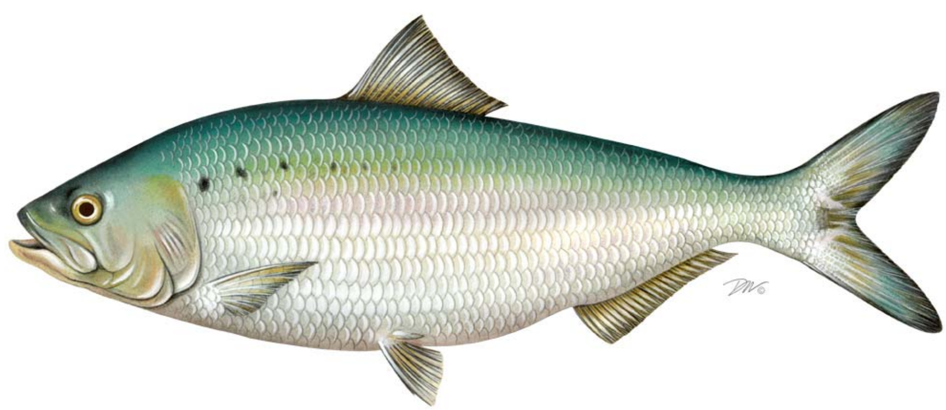
Stock Assessment Report No. 07-01 (Supplement)
of the

Atlantic States Marine Fisheries Commission

American Shad Stock Assessment Report for Peer Review

Volume III



August 2007

Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

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Volume III

Conducted on
July 16 – 20, 2007

And

Accepted by
The Shad and River Herring Management Board
August 16, 2007

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA05NMF4741025.

PREFACE

The American Shad Stock Assessment Report analyzes the status of 31 stocks of American shad along the Atlantic coast. Due to the large volume of material contained within the report (1200+ pages), it is organized into three volumes. Volume I contains a comprehensive look at all of the stocks, including an introduction to the science and management of the species, summaries of coastwide indices, summaries of the state or river system assessments, conclusions and recommendations, and a look at hypothesized causes of decline. Volumes II and III provide an in-depth exploration of American shad stock status by state or river system. These volumes provide stand-alone assessments of stocks and serve as a reference for material contained in Volume I. The contents of the three volumes follow:

- Volume I: Introduction
  Coastwide Summaries
  State and River Stock Assessment Summaries
  Conclusions and Recommendations
  Causes of Decline
- Volume II: Maine
  New Hampshire
  Merrimack River
  Rhode Island
  Connecticut River
  Hudson River
  Delaware Bay and River
  Minority Report for Connecticut River
- Volume III: Maryland
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  Potomac River
  Virginia
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  South Carolina
  Georgia
  Florida

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ACKNOWLEDGEMENTS

The Atlantic States Marine Fisheries Commission thanks all of the individuals who contributed to the development of the American shad stock assessment and its terms of reference. The Commission also thanks the ASMFC Shad and River Herring Technical Committee (TC) and American Shad Stock Assessment Subcommittee (SASC) members who developed the consensus stock assessment report, especially Andrew Kahnle (NY State Department of Environmental Conservation) for his exceptional work as the Chair of the SASC. Members of the SASC include: Andrew Kahnle (Chair), Russ Allen (NJ Division of Fish and Wildlife), Christine Burgess (NC Division of Marine Fisheries), Kathryn Hattala (NY State Department of Environmental Conservation), Mike Hendricks (PA Fish and Boat Commission), Joe Hightower (U.S. Geological Survey/North Carolina State University), Laura Lee (ASMFC/RI Department of Environmental Management), John Olney (Virginia Institute of Marine Science), and Bob Sadzinski (MD Department of Natural Resources). Members of the Shad and River Herring TC include: Mike Hendricks, Chair (PA Fish and Boat Commission), Russ Allen (NJ Division of Fish and Wildlife), Phillips Brady (MA Division of Marine Fisheries), Michael Brown (Department of Marine Resources), Ellen Cosby (Potomac River Fisheries Commission), Phillip Edwards (RI Department of Environmental Management), Ruth Haas-Castro (NMFS), Don Harrison (GA Department of Natural Resources), Kathryn Hattala (NY State Department of Environmental Conservation), Reid Hyle (FL Fish and Wildlife Conservation Commission), Wilson Laney (USFWS), Rich McBride (FL Fish and Wildlife Conservation Commission), Larry Miller (USFWS), John Olney (Virginia Institute of Marine Science), Cheri Patterson (NH Fish and Game Department), Bill Post (SC Department of Natural Resources), Bob Sadzinski (MD Department of Natural Resources), Tom Savoy (CT Department of Environmental Protection), Jon Siemien (D.C. Fisheries and Wildlife), Michael Stangl (DE Department of Natural Resources and Environmental Control), and Sara Winslow (NC Division of Marine Fisheries). The Commission would also like to thank everyone individuals from outside of the SASC and TC who contributed to the American shad stock assessment, including Kristen Delano, A.C. Carpenter, and many other federal employees, state employees, and academics.

The Commission appreciates the efforts of the Commission staff that assisted in the development and review of the American shad stock assessment. A very special thanks goes to Erika Robbins and Patrick Kilduff for their outstanding efforts in coordinating the stock assessment process, writing and editing substantial parts of the assessment, and ensuring the delivery of a complete and thorough assessment for peer review.

TERMS OF REFERENCE

1. Compile and determine adequacy of available life history data for each stock.
2. Compile and determine adequacy of available fishery-dependent and/or independent data as indices of relative abundance for each stock.
3. Determine most appropriate method of estimating natural mortality.
4. Determine which assessment analyses are most appropriate to available data for each stock.
5. Assessment methods will range from simple trend analysis to more complex models.
6. Estimate biological reference points for each stock where possible.
7. Determine current status of each stock where possible.
8. Develop recommendations for needed monitoring data and future research.
9. Describe the locations and amounts of shad and river herring bycatch in commercial fisheries for mackerel, sea herring, and other pelagic species and estimate the contribution of that bycatch to fishing mortality.

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LIST OF TERMS

Stock Assessment:	An evaluation of a stock, including age and size composition, reproductive capacity, mortality rates, stock size, and recruitment.
Benchmarks:	A particular value of stock size, catch, fishing effort, fishing mortality, and total mortality that may be used as a measurement of stock status or management plan effectiveness. Sometimes these may be referred to as biological reference points.
Bycatch:	That portion of a catch taken in addition to the targeted species because of non-selectivity of gear to either species or size differences; may include non-directed, threatened, endangered or protected species.
Catch Curve:	An age-based analysis of the catch in a fishery that is used to estimate total mortality of a fish stock. Total mortality is calculated by taking the negative slope of the logarithm of the number of fish caught at successive ages (or with 0, 1, 2... annual spawning marks).
Catch-Per-Unit-Effort (CPUE):	The number or weight of fish caught with a given amount of fishing effort.
Cohort:	See "Year Class."
De minimis:	Status obtained by states with minimal fisheries for a certain species and that meet specific provisions described in fishery management plans allowing them to be exempted from specific management requirements of the fishery management plan to the extent that action by the particular States to implement and enforce the plan is not necessary for attainment of the fishery management plan's objectives and the conservation of the fishery.
Discard:	A portion of what is caught and returned to the sea unused. Discards may be either alive or dead.
Exploitation:	The annual percentage of the stock removed by fishing either recreationally or commercially.
F_{30}:	The fishing mortality rate that will preserve 30% of the unexploited spawning biomass per recruit.
Fish Passage:	The movement of fish above or below an river obstruction, usually by fish-lifts or fishways.
Fish Passage Efficiency:	The percent of the fish stock captured or passed through an obstruction (i.e., dam) to migration.
Fishing Mortality (F):	The instantaneous rate at which fish in a stock die because of fishing.

Habitat:	All of the living and non-living components in a localized area necessary for the survival and reproduction of a particular organism.
Historic Potential:	Historic population size prior to habitat losses due to dam construction and reductions in habitat quality
Iteroparous:	Life history strategy characterized by the ability to spawn in multiple seasons.
Mortality:	The rate at which fish die. It can be expressed as annual percentages or instantaneous rates (the fraction of the stock that dies within each small amount of time).
Natural Mortality (M):	The instantaneous rate at which fish die from all causes other than harvest or other anthropogenic cause (i.e., turbine mortality). Some sources of natural mortality include predation, spawning mortality, and senescence (old age).
Ocean-Intercept Fishery:	A fishery for American shad conducted in state or federal ocean waters targeting the coastal migratory mixed-stock of American shad.
Oxytetracycline (OTC):	An antibiotic used to internally mark otoliths of hatchery produced fish.
Recovery:	Describes the condition of when a once depleted fish stock reaches a self-sustaining or other stated target level of abundances.
Recruitment:	A measure of the weight or number of fish that enter a defined portion of the stock, such as the fishable stock or spawning stock.
Relative Exploitation:	An approach used when catch is known or estimated, but no estimates of abundance are available. For example, it may be calculated as the catch divided by a relative index of abundance. Long-term trends in relative exploitation are can be useful in evaluating the impact of fishing versus other sources of mortality.
Restoration:	In this assessment, this describes the stocking of hatchery produced young-of-year American shad to augment wild cohorts and the transfer of adult American shad to rivers with depleted spawning stocks. Restoration also includes efforts to improve fish passage or remove barriers to migration.
Run Size:	The magnitude of the upriver spawning migration of American shad.
Semelparous:	Life history strategy in which an organism only spawns once before dying.
Spawning Stock Biomass:	The total weight of mature fish (often females) in a stock.
Stock:	A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery.

Stock Status: The agreed perspective of the SASC of the relative level of fish abundance

Sub-adult: Juvenile American shad which are part of the ocean migratory mixed-stock fish.

Total Mortality (Z): The instantaneous rate of removal of fish from a population from both fishing and natural causes.

Turbine Mortality: American shad mortalities that are caused by fish passing through the turbines of hydroelectric dams during return migrations to the sea.

Year Class: Fish of a particular species born during the same year.

Yield-per-Recruit: The expected lifetime yield per fish of a specific cohort.

Z_{30}: The total mortality rate that will preserve 30% of the unexploited spawning biomass per recruit.

Section 9
Status of American Shad Stocks in Maryland

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9.1 INTRODUCTION

The Chesapeake Bay is the largest estuary in the United States. It is approximately 200 miles long with a surface area of 4,480 square miles. The Chesapeake Bay watershed includes six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia, encompasses 64,000 square miles, and includes about 150 river systems (www.chesapeakebay.net, accessed 9 July 2005).

The mouth of the Chesapeake Bay is in Virginia and salinity decreases as you travel northward. The Chesapeake Bay divides Maryland into eastern and western shores; both halves have major tributaries with historical American shad landings (Walburg and Nichols 1967). Distinct geographical areas divide the Chesapeake Bay into two or three zones but the divisions are not consistent in the literature.

9.2 MANAGEMENT UNIT DEFINITION

The Maryland portion of the Chesapeake Bay (Figure 9.1) begins at the Virginia line and runs north, ending on the Susquehanna Flats. Major Chesapeake Bay tributaries analyzed include the Nanticoke, Choptank, Patuxent, and Pocomoke rivers and, in addition, the coastal commercial fishery (Figures 9.2-9.5). The Susquehanna River, although in this management unit, is assessed in a self-contained report.

9.3 REGULATORY HISTORY

Data on the American shad fishery in Maryland prior to 1800 are sporadic, giving only a portion of the total shad landings. It is evident from the literature that there was an extensive American shad fishery throughout the Bay and tributaries in the nineteenth century, employing thousands of people and worth millions (in present day dollars; Sadzinski, in prep).

In 1929, Maryland’s General Assembly adopted laws limiting the season for American shad. After the law was amended, American shad commercial fishing was allowed from January 1 to June 5 and had no effect on limiting the fishery. A 1944 newspaper article (“Susquehanna Shad Run Held Best in 20 Years,” April 20 1944, *Baltimore Sun*) states that there was a limit of ten American shad for anglers. In May of the same year, the *Sun* also reported that the Commercial Fisheries Advisory Committee (CFAC) concluded that the reason for the American shad fishery decline was overfishing; pollution was not considered a significant threat.

In 1941, based on the CFAC’s recommendation, Maryland’s General Assembly passed a bill allowing Tidewater Fisheries (presently the Department of Natural Resources, Fisheries Service) to reduce fishing effort by not issuing new licenses and not allowing more gear to be set than in the previous year. This bill allowed commercial fishermen to still make a living from American shad while attempting to cap fishing effort. According to the *Sun* article, in 1942 there were 800 licenses but in 1943 there were only 664 licenses. During WWII, fish prices rose and the demand for fish increased, causing bitter debates over this bill. The result was a cap on the number of Maryland commercial fishing licenses at 800 in 1944.

In 1944, commercial watermen were required by the Maryland Management Plan to submit catch and effort data by gear; however early records were either incomplete or not submitted. Annual submission of commercial data has been required since this date and this dataset is the most reliable estimate of annual landings for American shad although landings are likely underestimated. Over time, the reporting form has evolved into a more efficient means of daily catch reporting since its inception.

Walburg (1955) provided data from a legal unlicensed fishery using gill nets in each of the major tributaries. These watermen were generally local, opportunistic fishermen and not required to report their landings. In 1952, commercial watermen reported landing 166,616 pounds of American shad while the unlicensed fishery landed 114,195 pounds (Walburg 1955). In contrast to the government regulated effort cap, Walburg (1955) notes that effort had doubled in the shad fishery since 1944.

There were no real limits on the recreational and commercial fisheries and although there is reference to a ten American shad per person recreational creel limit, we could not find documentation of this regulation. There were laws banning American shad harvest from June 30 to Dec 1, but since the fish return to the ocean by June, this law was merely cosmetic. In short, the fishery was generally unregulated until commercial landings declined to such a low that in 1980 the Maryland Department of Natural Resources (MD DNR) closed both the commercial and recreational fisheries for American shad.

9.4 ASSESSMENT HISTORY

The previous ASMFC (1998) peer reviewed stock assessment for American shad only analyzed Maryland's data from the upper Chesapeake Bay and the ocean-intercept fishery. Fishing mortality rates for the upper Chesapeake Bay stocks were well below the overfishing definition (F_{30}=0.43) but it was because it was only calculated for the ocean-intercept fishery (ASMFC 1998). The total mortality rate for this stock was 2.0. Their report also concluded that upper Chesapeake Bay stocks have increased significantly for the time series (1980-1996).

9.5 STOCK-SPECIFIC LIFE HISTORY

The American shad (*Alosa sapidissima*) is an anadromous clupeid and is the largest member of the herring family. American shad enter the lower Chesapeake Bay in February and migrate into the Bay's freshwater tributaries to spawn (Olney and Hoenig 2001). In these systems, peak American shad catch-at-age is at four and five years old. American shad mature between two and seven years old in the Chesapeake Bay (Jarzynski *et al*. 2000). Some may return to spawn up to four consecutive years (repeat spawning). Hatching occurs one week after fertilization. Young-of-year (YOY) begin leaving the Chesapeake Bay in late fall but a few American shad juveniles will winter there. Juveniles remain in the ocean until sexually mature, with most returning to their natal rivers to spawn (Melvin *et al*. 1986).

9.5.1 Age -Length

Only limited historic age and length data for Chesapeake Bay American shad stocks were in the published literature. Fairbanks and Hamill (1932) state that an average female shad was 23 inches long and weighed 4.5 to 5 pounds while a male shad was 20 inches long and weighed 2.5 to 4 pounds but no characterization data were presented for individual fish. Walburg and Sykes (1957) studied American shad for the Potomac and determined age and repeat spawning from 772 fish captured in 1952. They noted the predominant ages for both sexes were four and five.

Cating's (1953) method has been used for ageing Maryland's Chesapeake Bay stocks of American shad. Walburg and Nichols (1967) stated that most American shad in the Chesapeake Bay were four or five years old during a period of stock declines and intense commercial fishing. LaPointe (1958) published mean length-at-age by sex for American shad in the Susquehanna River.

The freshwater spawning marks on American shad scales provide a unique analysis if a time series is present. The earliest data for Chesapeake Bay stocks of American shad are from Cable (1944). After years of intense commercial fishing, only 8 percent of the captured shad in 1939 were repeat spawners, in 1943 when effort had dropped due to the war, the number increased to 25 percent repeats in bay-wide samples (Cable 1944).

In summary, commercial fishing appeared to remove the larger fish and lower the repeat spawning percentages. Maturity schedules have not changed significantly since the 1930s although it is likely that female American shad were targeted by the fisheries because of their roe. There was a consistent demand for American shad for flesh and roe until the 1960s when demand dropped as consumers sought other, more readily available fish species.

9.5.2 Growth

Efforts to estimate growth rates for American shad in the Chesapeake Bay have concentrated on YOY. Carter (1973) presented extensive data on weekly lengths of YOY American shad caught using various gear types in the Susquehanna River and Flats area in 1969. He showed high variation in growth rates between sites and gear types that was likely associated with a change in preferred habitat. There have been no growth studies on adult American shad in the Chesapeake Bay that would contribute to this document.

9.6 HABITAT DESCRIPTION

Historically, suitable American shad habitat was available in every major river system in Maryland and Virginia and their tributaries up to points of natural impasse. Even during the nineteenth century when American shad stocks were heavily exploited, habitat degradation was only cited as a secondary cause of stock decline. During the eighteenth and early nineteenth centuries, siltation from poor farm practices increased the sediment load in the upper region of streams, covering spawning habitat (Mansueti and Kolb 1953). Even though habitat degradation had occurred, the decrease in fishing effort during WWII led to an increase in American shad landings after the war due to improved recruitment during war years and stocking (Cable 1944). Walburg and Nichols (1967) stated bay-wide effort increased from 1935 to 1951 because of economic depression and food shortages.

Pollution has been recognized as a threat to American shad stocks in Maryland. Anadromous species fish kills caused by pollution from sewage treatment plants was documented in the Susquehanna, Wicomico, and Potomac rivers. A comprehensive habitat report for east coast states showed Maryland to have suitable habitat for American shad in its major tributaries (ASMFC in prep).

Mowrer (2002) published comprehensive American shad spawning maps based on historical datasets; he documented spawning in the Susquehanna, Patuxent, Nanticoke, Chester, Pocomoke, and Potomac rivers. Unpublished data from American shad juvenile abundance and egg presence-absence studies by Mowrer (pers. comm.) have recently suggested that there is spawning in the Gunpowder, Choptank, Elk, and Wicomico Rivers but directed sampling in these systems has not been done and densities are likely minimal.

9.7 RESTORATION PROGRAMS

9.7.1 Introduction

The earliest restoration data for the Chesapeake Bay are from the late 1800s and they show extensive stocking of all major river systems and the upper Chesapeake Bay with an annual stocking of millions of eggs and fry (Sadzinski in prep). The purpose of these earliest stockings was to supplement existing stocks by replacing American shad landed by the commercial fishery and it appeared to be successful.

9.7.2 Restoration Objective

The purpose of stocking American shad into rivers where there were once historic runs is to restore self-sustaining populations. In short, stocking will continue in select tributaries until the adult and juvenile hatchery-origin contribution is negligible (Richardson *et al.* 2006).

9.7.3 Hatchery Evaluations

The effects of the earliest stockings are difficult to quantify because hatchery fish were not marked. Still, with the millions of American shad stocked annually, it is likely that stocking of American shad deferred the steep declines in abundance caused by overfishing, loss of habitat, and degradation of water quality. Stocking of American shad occurred annually until 1960 when adult stocks declined and brood fish were difficult to capture.

Maryland DNR began culturing American shad and experimental stocking of oxytetracycline (OTC) marked fish into the Nanticoke River in 1985, with annual stocking in select tributaries since 1994 (Table 9.1). The Patuxent River, Choptank River, Marshyhope Creek, and the Nanticoke River were initially stocked in 1994 with American shad and have since been stocked annually (Table 9.2). American shad hatchery evaluation in Maryland began with analysis of YOY from the Patuxent River in 1994 (Table 9.3), followed by the Choptank River in 1996 (Table 9.4) and Marshyhope Creek in 2002 (Table 9.5); because of the difficulty in obtaining juvenile American shad samples from the Nanticoke River, analyses has not been done.

In general, the Choptank and Patuxent rivers showed a low prevalence of hatchery fish; however, Marshyhope Creek showed a high percentage of wild fish. It appears that there is successful natural reproduction occurring in the Choptank and Patuxent rivers but empirical data (unquantified electrofishing) and relative abundance indicators (hook and line and bycatch data, not published) showed that abundance of adults was low.

9.7.4 Fish Passage

With the exception of the Susquehanna River, there are no significant obstructions or dams that would impede spawning. Surveys at and below some of these dams have not captured American shad. There are no dams or blockages in the lower portion of any assessed tributary that significantly affects reproduction.

9.8 AGE

For ageing of fish, scales from American shad were removed from below the insertion of the dorsal fin. A minimum of four scales per fish were cleaned, mounted between two glass slides, and read for age and spawning history using a Bell and Howell MT-609 microfiche reader. The scale edge was counted as a year-mark since it was assumed that each fish had completed a full year’s growth at the time of capture. It is important to note that the same reader has aged American shad in Maryland since 1980. This reader uses Cating's (1953) method. Repeat spawning defined as the freshwater spawning mark on the American shad scale and the number of these is also noted for each fish.

9.9 FISHERY DESCRIPTIONS

9.9.1 Commercial Fishery

Reported total annual commercial landings of American shad represent only a minimum number of fish landed because they are likely underestimated due to poor record keeping and the unlicensed gill-net fishery. The unlicensed fishery was generally made up of waterfront landowners who initially had easy access to the prosperous American shad fishery. When demand increased for American shad, gear types changed, allowing fishing in deeper water of the main Bay, which is before the spawning area. It is evident from the literature that there once was an extensive American shad fishery throughout the Bay and tributaries, employing thousands of people, and worth millions of dollars (in present day dollars).

Ferguson and Downes (1876) provided initial, limited effort data on the commercial American shad fishery from the upper Chesapeake Bay. In 1824, one commercial crew caught 52,617 American shad; a longer seine caught 17,800 American shad in 1871, followed by an increase to 28,409 in 1875 using the same gear.

In 1835 gill nets were introduced into the Chesapeake Bay (Walburg and Nichols 1960), followed by pound nets in 1865 (Stevenson 1899). These gears allowed local fishermen to extend their operations into the main Bay and deep rivers where hauls seines were not effective (Mansueti and Kolb 1953).

Stevenson (1899) noted a gear switch from seines to drift, stake, and pound nets from the early 1800s to 1880. He also suggested that the new gear was much more efficient, allowing relatively more gear fished per person. Pound nets, which quickly became the preferred gear in the Chesapeake Bay, caught over 90 percent of the harvested shad ten years after the gear's introduction. Because of the gear switch, fishermen could target shad before they entered freshwater and therefore the open Bay became the popular area to fish and not the tributaries. In addition, pound and stake gill nets were likely more efficient because they fished continuously. By 1904, most of the upper river gill-net fisheries had been eliminated because of poor catches and poor market prices (U.S. Bureau of Fisheries 1909). Fairbanks and Hamill (1932) stated that the industry of shad fishing was dependent on artificial propagation and was the most important fishery in the Maryland.

Truitt (1936) summarized many early authors' reasons for the shad decline: harvesting American shad prior to spawning and poor water quality. The decline in the American shad fishery was estimated to have caused a loss of one million dollars annually.

Mansueti and Kolb (1953) stated many commercial shad fishermen no longer fished by 1940 because of several factors including poor catches and low prices. During WWII, fishing effort decreased causing an apparent increase in natural production and significant increases in American shad catches from 1948 to 1950, averaging 1.2 million pounds a year.

Economic benefit (Table 9.6) was inversely correlated with total annual landings, demonstrating the continued strong market for American shad, which encouraged high levels of effort throughout the early 1900s, and maintaining the higher price per pound. Due to the vigorous stocking of millions of American shad throughout the Chesapeake Bay and tributaries, abundance and therefore landings were not affected significantly.

Market value apparently remained good until the 1960s when consumers demanded only the roe or boned shad. Wholesalers generally did not process fish, therefore demand fell but restaurant sales apparently increased during that time as consumers demanded prepared shad (Walburg and Nichols 1967).

Although the American shad fishery in Maryland has been closed since 1980, other fisheries have caught shad. Two American shad per commercial license is presently permitted in Maryland but there is no data of this bycatch because onboard biologists have rarely observed this harvest. Species targeted during the spring include catfish, white perch, gizzard shad, and river herring.

9.9.2 Fishery-Dependent Surveys

In 1896, the U.S. Commission of Fish and Fisheries reported 2,250,000 American shad were landed from the Chesapeake Bay (Stevenson 1899). The series of U.S. Commission of Fish and Fisheries' reports from 1882 to 1919 are the best source of historical American shad data available for the Bay.

Annual, total American shad commercial landings for Maryland are presented in Table 9.7. Associated effort is presented in tables by area, when available. American shad commercial landings data from the National Marine Fisheries Service (NMFS) are also presented (Table 9.8). Because of Maryland's mandatory commercial reporting system, emphasis is placed on state landings.

Nanticoke River

The Nanticoke River is the only river system in Maryland that originates in Delaware, empties into the Chesapeake Bay, and has a significant, historical American shad fishery (Walburg and Nichols 1967). Based on Stevenson's (1899) data from 1896, American shad landings from the Nanticoke River were almost one million pounds (812,417 pounds landed in Maryland and 182,250 pounds landed in Delaware); there were over 400 gill nets, 38 pound nets, and 143 fyke nets fished in the river and it ranked third in landings for the state in that year.

Commercial landings data from the Nanticoke River, 1930 through 1980, are presented in Table 9.9. In 1960, the Nanticoke River ranked first in American shad landings in Maryland with 85,302 pounds (Walburg *et al*. 1967) and an additional 2,000 pounds were landed in Delaware. It was primarily a gill-net fishery with only 15 pound nets fished from Vienna to the mouth, which landed only 10,023 pounds of American shad (Walburg *et al*. 1967).

Although there is no effort associated with this data, they show a significant drop in reported landings during the time series. MD DNR initiated a fishery-dependent survey in this river in 1988 to evaluate the American shad stock, collect characterization data, and estimate relative abundance (Weinrich *et al.* 1989). It appears that the extensive American shad commercial fishery in the Maryland portion of the Nanticoke River limited the catch in Delaware and inhibited a sufficient number of fish from reaching the spawning grounds causing the decline of this fishery.

The Nanticoke River has the longest time series of fishery-dependent catch-per-unit-effort (CPUE) data in Maryland for American shad. The same family of commercial watermen has cooperated with MD DNR since the inception of this project in 1988. American shad in the Nanticoke River were collected in 6 to 10 fyke nets and 0 to 4 pound nets once per week below Vienna, Maryland between mid February and late April at the discretion of the commercial watermen. The nets were located between river kilometer (rkm) 30.4 and 35.7 (Figure 9.2). Fish were sorted according to species and transferred to the survey boat for processing. In general, sampling occurred each time the commercial watermen checked their nets and target species including American shad were removed from their catch and brought on the MD DNR boat for processing.

Effort from pound and fyke nets was calculated as the number of days the net was fished. Relative abundance, measured as annual catch-per-unit-effort (CPUE) for American shad collected from pound or fyke nets in the Nanticoke River, was calculated as the geometric mean (based on a $\log_e$-transformation; Sokal and Rohlf 1981) of fish caught per net-day. It should be noted that pound nets were not set in the study area in the Nanticoke River in 2004.

Choptank River

The Choptank River American shad landings in 1896 were over 1.2 million pounds (Stevenson 1899) for this very extensive targeted fishery. Choptank River American shad commercial landings from 1930 to 1978 are presented in Table 9.10. Mean landings in the Choptank River from 1930 to 1959 averaged 37,287 pounds but from 1960 to 1978 averaged just over 3,700 pounds.

In 1960, Walburg and Nichols (1967) reported 11,130 pounds were landed in the Choptank River, of which pound nets caught an estimated 3,116 pounds of American shad. They also reported that unlicensed gill netters landed 7,380 pounds of shad in the upper reaches of the system (Walburg and Nichols 1967). The dramatic decline of American shad stocks in the Choptank River is attributed to overfishing. There have been no significant habitat alterations or water quality degradation and the watershed remains rural.

Patuxent River

The Patuxent River is a major western shore tributary of the Chesapeake Bay and historically had a significant American shad fishery with 188,262 pounds landed in 1896 (Stevenson 1899). Walburg and Nichols (1967) defined the spawning area in the Patuxent River to be between Drury and Lower Marlboro in 1960. Landings in 1967 were 807 pounds from a directed gill-net fishery (Walburg and Nichols 1967). It was also reported that a recreational fishery existed in this system prior to 1960 below Hardesty (Mansueti and Kolb 1953). An additional unlicensed gill-net fishery operated in the spawning area and data from 1960 estimated 2,000 pounds landed (Walburg and Nichols 1967).

Commercial landings data from the Patuxent River during 1944 to 1978 are presented in Table 9.11. Although there is no effort associated with this dataset, it clearly demonstrates a precipitous decline during the later years and is attributed to overfishing.

Pocomoke River

The Pocomoke River is a major eastern shore tributary of the Chesapeake Bay. Stevenson (1898) stated that landings from this river in 1896 were 106,986 pounds and bow nets were used almost exclusively to catch shad; bow nets were used because the river is deep channeled with steep banks. In 1960, the commercial shad fishery landed 1,674 pounds and Walburg and Nichols (1967) stated that two pound nets caught 1,100 pounds and the remaining 574 pounds were caught by staked gill nets. They also stated that from 1957 to 1960, unlicensed gill netters landed 300 pounds annually (Walburg and Nichols 1967). A time series dataset for commercial landings within this system could not be located and may not exist. This system remains very rural and the river system appears to be relatively unchanged for the last one hundred years.

Chesapeake Bay

Because of the depth of the Chesapeake Bay main stem, the commercial American shad fishery was a limited haul seine fishery until the mid-1800s. Gill nets were introduced in the early 1800s followed by pound nets in the late 1800s. Stevenson (1898) presented data from the commercial American shad fishery in 1896 that was dominated by staked gill nets and pound nets in the mid and lower Bay, and significant fisheries in the main Bay above Swan Point. He showed that 32 percent of American shad landings in the upper Chesapeake Bay system were caught in the main stem Bay and of this, 66 percent were caught in the fishery above Swan Point (Table 9.12). Effort data from baywide American shad commercial fishing and associated effort are summarized in Fairbanks *et al*. (1932) and Walburg (1955; Tables 9.13 and 9.14).

Figure 9.6 summarizes pound net CPUEs for American shad from the late 1800s to the moratorium on American shad (1980). This trend shows very high CPUEs in the late 1800s followed by years of stable landings supplemented by statewide hatchery production, and then during the 1960s hatchery contributions ended and fishing rates remained high resulting in the collapse of the fishery. Effort, measured as the number of pound nets set, decreased in 1960 while CPUE increased, potentially demonstrating that catchability may have increased and without the supplemental stocking, caused the collapse of this fishery. CPUEs after the moratorium show that it took two generations of American shad (12-14 years; assuming an average lifespan of six or seven) of hatchery stocking to see a significant increase in relative abundance.

The earliest abundance estimates for Chesapeake Bay stocks of American shad is presented in Table 9.15 (Walburg and Sykes 1957). Walburg (1955) estimated the biomass of American shad and conditional fishing mortality rate (F; Ricker 1975) from 418 shad tagged during 1952; these tag-based estimates were combined with commercial fishing effort data from 1944 through 1951 to estimate annual population biomass and F. Forty-eight recaptures from Virginia and the Potomac River were subtracted from the total number of tagged fish. Ninety-six percent of returned tags from Maryland's commercial fishery (189 of 197) in 1952 were from upper Chesapeake Bay and that abundance estimates for Maryland likely represented the upper Bay population. The mean estimate of the American shad population in this portion of Maryland in 1952 was 2,800,000 pounds (95% CI = 2,500,000 to 3,300,000 pounds; Walburg 1955). American shad in the historic fishery typically averaged 4.0 pounds (Richkus *et al*. 1995), so biomass estimates for 1952 would translate approximately into a mean of 710,000 fish (95% CI 620,000-820,000) in the upper Bay. During 1944 through 1951, American shad abundance estimates in the upper Bay ranged from 450,000 to 750,000 fish.

Ocean Fishery

Mansueti and Kolb (1953) presented data from the American shad ocean-intercept fishery in 1945, primarily a pound net fishery with only a small percentage of landings caught in trawls. During that year, 10,577 pounds of American shad were landed.

Maryland ocean commercial landings are presented in Table 9.16. In addition, Maryland commercial fishermen were required to report harvest and effort data for American shad on landing forms provided by MD DNR. Landings from the ocean-intercept fishery peaked in 1989 and declined afterwards (ASMFC 1998). Dockside sub-sampling (length, weight, sex, and scale samples) of American shad caught in the ocean-intercept fishery was initiated in 2002.

9.9.3 Bycatch Losses

Prior to 1980, baywide and tributary commercial fishery discards were thought to be minimal and only consisted of those fish too decomposed for fresh market. After the closure in 1980, bycatch mortality, although not estimated, is likely minimal because pound nets used in the main Bay have good survival rates for American shad. The drift gill-net fishery in the Chesapeake Bay that targets striped bass has unquantifiable bycatch of American shad; however, due to its seasonality and area restrictions, the striped bass fishery would not likely encounter a significant number of American shad.

9.9.4 Recreational Fisheries

There have been no creel surveys on these systems. There are two rivers in the management unit with small recreational fisheries targeting American shad: the Patuxent and Choptank. The Patuxent River has a small, directed catch-and-release fishery during the spring that has not been quantified. On the Choptank River, fishing is concentrated at one location below a low-head dam. The recreational fishery is very limited on the other systems because of the low abundance of American shad and the lack of access. It is likely few American shad are angled from these rivers annually and it would be catch and release.

9.10 FISHERY-INDEPENDENT SURVEYS

The alosine project initiated in 1980 by MD DNR, has concentrated on two areas of the Bay where there were remnant stocks of either American shad or river herring: the upper Chesapeake Bay (defined as the Susquehanna Flats and Susquehanna River) and the Nanticoke River. Other rivers in Maryland have not been assessed.

In the Nanticoke River captured American shad were measured for fork length (FL) and scales were removed just below the insertion of the dorsal fin on the fish’s right side for age determination. The length data were recorded on a standard coin envelope and the scale sample placed inside, if otoliths were removed, they were placed inside a 5-ml vial and this was also deposited into the envelope.

Data are stored in Excel with an independent spreadsheet for each year and area. Merging these spreadsheets would be difficult because different variables have been used and added as technology has advanced (e.g., latitude and longitude).

9.10.1 Nanticoke River

Fishery-independent data generated by MD DNR are limited in the Nanticoke River to the striped bass seine survey (SBSS; 1959-present) and a mid-water trawl survey (1985-1996) but both of these surveys sample American shad YOY. These surveys collected few American shad in the Nanticoke River because the salinity in the sampling areas were higher than the preferred maximum of 5 ppt for YOY shad and therefore should not be used as a reliable YOY index (Figure 9.7).

In 2000, the Delaware Division of Fish and Wildlife (DDFW) initiated American shad restoration in the Delaware portion of the Nanticoke River that included gill netting and electrofishing for adult broodstock, tank-spawning, and subsequent release of shad fry. They also beach seined and electrofished for YOY. This has generated an index of relative abundance for adults and juveniles and a hatchery evaluation (Stangl 2006). The data collected from these juvenile American shad have shown a high percentage of non-hatchery fish. Results from this survey have shown that there is natural spawning, sufficient nursery habitat, and food is not limited in the upper reaches of the river.

Delaware DFW adult American shad relative abundance indices, expressed as fish captured per hour of electrofishing, show no distinct trend (2002-2005; Table 9.17; Figure 9.8). This is likely due to the short time series. The juvenile American shad seine data (Table 9.18) demonstrate an increase compared to the first two years and the juvenile electrofishing data also showed an increase in relative abundance (Figure 9.9); however, this may be attributed to the increase in hatchery contribution and a change in the 2005 protocol that targeted YOY American shad and therefore estimates of YOY abundance in 2005 are likely inflated (Table 9.19).

Adult American shad stocks in the Nanticoke River have not recovered since the 1980 closure of the directed American shad fisheries. The high percentage of repeat spawning shad and the poor recruitment of virgin fish may indicate that YOY survival is poor or that there is increased predation of pre-adult American shad. The juvenile abundance indices in the main stem Nanticoke River by DDFW demonstrate successful reproduction and survival of natural fish.

Since American shad were stocked in the uppermost reaches of the river (Marshyhope Creek in Maryland and Seaford, Delaware), there may be a behavioral shift that results in the lower river being quickly bypassed due to homing to the upper reaches of the river. Adult indices by DDFW did show a slight decline for the time series.

9.10.2 Patuxent River

MD DNR aquaculture personnel annually electrofished the Patuxent River for adults but CPUEs generated by this survey were inappropriate because the area is not enclosed and there is repeated electrofishing if fish are observed and missed. American shad collected during this survey are used for hatchery determination (Table 9.3). The SBSS seine survey has generated a CPUE of juvenile American shad in the Patuxent River (Figure 9.10). In general, American shad stocks in the Patuxent River are hatchery driven and are at very low abundance levels.

9.10.3 Choptank River

MD DNR personnel have set springtime fyke nets targeting spawning fish since 1989 in the Choptank River. No American shad have been captured by this survey in these nets, which indicates abundance on this system is very low (Piavis, pers. comm.).

9.11 ASSESSMENT APPROACHES AND RESULTS

The Nanticoke River is the only system in Maryland, besides the Susquehanna River, that has sufficient data to allow an index-based assessment of adult American shad stocks. Fishery-dependent data from pound nets are the most reliable source of trend data because they are set in deeper water than fyke nets and are generally unaffected by low flows or high wind, resulting in American shad catches that are relative to the abundance of fish in the river.

9.11.1 Total and Natural Mortality

Walburg and Sykes (1957) reported fishing mortality rates of 73 percent in the Chesapeake Bay based on tagging data. Whitney (1961) stated that natural mortality rates for Chesapeake Bay stocks are poorly defined because age at first spawn ranges from 2-7 and modal age is four or five.

Repeat spawning may provide the only reliable estimate of total mortality because repeat spawning marks do not require an age structure that may include aging errors (McBride *et al*. 2005). Repeat spawning marks can be used to estimate mortality if used as a cohort (0, 1, 2, 3…marks) since these fish are fully recruited, age-based analysis is not required, and catch curves or cohort analysis is used. Since full recruitment of American shad is assumed using the freshwater spawning marks and fish with one spawning mark are in their second year of spawning, mortality estimates do not rely on age-structured analysis. These repeat spawning cohorts can also be weighted by effort defined as pound-net-days. It should be noted that CPUE was summed within gear types.

Table 9.20 presents the various methods used to estimate mortality rates for Nanticoke River American shad stocks. Since fully recruited year-classes are not present until age-7 and few fish are observed of age-8 or more, traditional methods such as age-structured catch curves and cohort analysis gave erroneous total instantaneous mortality (Z) estimates of less than 0.43 to 2.37. Instead, repeat spawning marks are used in a catch curve or cohort analysis and the results are significantly improved.

Using repeat spawning marks, Z was estimated by the $\log_e$-transformed spawning group frequency plotted against the natural log transformed corresponding number of times spawned, assuming that consecutive spawning occurred (catch curve using repeat spawning; Gibson *et al*. 1988):

$$\log_e (S_{fx} + 1) = a + Z * W_{fx}$$

where S_{fx}= number of fish with 1,2,...f spawning marks in year x;
a = y-intercept;
W_{fx} = frequency of spawning marks (1,2,...f) in year x.

The second method used repeat spawning marks as above but followed a specific cohort (Table 9.20) and represents mortality associated with spawning.

Since American shad do not fully recruit until age-7 in the Maryland portion of the Chesapeake Bay, as detected by virgin fish, several methods were investigated to estimate total mortality: two age-based and two repeat spawning mark methods. The traditional catch curve was compared to a spawning mark catch curve and the same comparison was made for the cohort analysis. Nanticoke River American shad mortality estimates for the four methods ranged from 0.53 to 1.89 but average Z-estimates were similar, 1.16 and 1.17, respectfully (Table 9.21). Using the two similar methods (comparing age-based catch curve to spawning mark catch curve, etc), neither catch curves nor cohort estimates were correlated (r^2 = 0.62 P = 0.19; r^2 = 0.42 P = 0.41, respectively). Using Hoenig's (1983) estimation of natural mortality:

$$\ln (M_x) = 1.46 - 1.01[\ln (t_{max})]$$

Natural mortality was estimated to be 0.42 based on a maximum age of 10 for Nanticoke River stocks of American shad.

In general, the cohort-specific mortality rates based on repeat spawning were likely the most reliable and appeared to decrease for fully recruited year classes over the time series. These rates are generally higher than the non-spawning stock that has not recruited because of the increased mortality associated with spawning and the increased susceptibility of spawning fish to predation. Since American shad are not fully recruited until age seven in the Nanticoke River, traditional catch curves and cohort analyses give mortality estimates that are inaccurate.

Since relative abundance of American shad is decreasing in the Nanticoke River based on pound net CPUEs, age structure has not changed significantly and stocks are supplemented by hatchery fish, it appears there is poor recruitment because of the lack of natural reproduction or the increased mortality of young-of-year.

9.11.2 Age and Sex Composition

Annual age structure is presented in Table 9.22. In general, annual peak catch-at-age was at ages four and five. The 2005 male-female ratio for adult American shad captured in the Nanticoke River was 0.96:1 and over the time series was near 1:1. American shad are not fully recruited as adults into the spawning population in the Nanticoke River until age seven, based on the presence of the freshwater spawning mark.

Since age structure was obtained from archived data with variables (e.g., individually assigned ages, spawning marks) missing prior to 2000 and effort from this fishery-dependent data has changed, further analysis is not possible.

9.11.3 Repeat Spawning

The percentage of repeat spawning by American shad from fyke nets in the Nanticoke River in 2005 was 26.3% for males and 65.0% for females. For data reconstructed since 2000, the percent of repeats from one pound net equaled 38 percent (standard deviation equaled 0.180). The arcsine-transformed proportions of repeat spawners (1988-2005, sexes combined) have increased since 1988 (r^2=0.48, P=0.05; Figure 9.11). This demonstrates the poor virgin recruitment to the population.

9.11.4 Relative Abundance

Nanticoke River pound net geometric mean CPUE for American shad has increased linearly since 1988 (r^2=0.50, P=0.04; Figure 9.12) while fyke net geometric mean CPUE for American shad has been very low most years and shows no trend (r^2<0.01, P=0.92; Figure 9.13). Fyke net CPUE is an unreliable estimate of relative abundance because the catchability of this gear is highly influenced by environmental conditions such as very low tide, while pound net catchability remains more stable because it is set in deeper water. The trend in relative abundance of adult American shad has dropped in 2005 with a more significant drop in 2006 (Sadzinski *et al*. 2006).

9.11.5 Hatchery Evaluation

Maryland DNR collected adult American shad otoliths from the Nanticoke River. Because of the limited numbers of fish observed per year (N<100), only dead American shad had otoliths removed for OTC analysis. Analyses from these fish have shown Susquehanna River hatchery fish to be present in the Nanticoke only during one very high flow year.

In general, less than two YOY American shad are caught annually from this system by MDNR and therefore no OTC analysis has been performed from these samples.

9.12 BENCHMARKS

A benchmark value of Z_{30}= 0.62 was calculated for Chesapeake Bay region American shad stocks (See Section 1.1.5 for York River, Virginia).

9.13 CONCLUSIONS AND RECOMMENDATIONS

Adult relative abundance trends on the lower Nanticoke River have trended up during the last few years but this may be hatchery driven (analysis on adult otoliths is incomplete). The trend in repeat spawners, which is an inverse recruitment indicator, shows a very high number compared to the number of virgin fish, indicating overfishing or predation may be occurring on sub-adult fish. The low juvenile American shad indices over the time series do not indicate recruitment failure. Juvenile abundance indices in the upper river have trended up and are not recruitment driven although they are also supplemented by hatchery fish. In general, stocks have been at very low levels compared to historic landings, the number of virgin recruits has been low, and overall catches have been low.

Although repeat spawning marks indicate that mortality rates have not changed, there may be either increased mortality of YOY or of sub-adult ocean stocks as indicated by the sharp decline in relative abundance. It indicates increased mortality across ages (proportional mortality), that is not reflected in our age or spawning mark mortality estimates since mortality estimates are based on catch-at-age matrices. Increased mortality across all ages would not increase our Z estimates.

In the Nanticoke River, the supplemental stocking may have caused a behavioral shift resulting in the lower river being quickly bypassed, especially during low spring flows when there are higher salinities, because of homing to the upper reaches of the river.

Trends in relative abundance of adults and juveniles have declined in recent years even though the ocean-intercept fishery has been closed. Supplemental hatchery introductions have helped stabilize low abundances but American shad stocks in Maryland remain at historically low levels. This may be because of mortality undefined in this report.

The percent of repeat spawning American shad trended up in most systems and may be indicative of poor ocean survival. There are also indications that there may be increased predation of adult fish on their spawning run (Crecco *et al*. 2006) and in Maryland waters adult American shad may be preyed upon by striped bass or flathead catfish. These factors need to be investigated in Maryland to better manage stocks under restoration. Adult indices in the Choptank, Patuxent, and Pocomoke rivers were at historically low levels based on landings data and more recent empirical data indicates stocks are still depressed.

Since the closure of the American shad fisheries in 1980, the introduction of significant numbers of hatchery fish and reopening over one thousand of miles of streams in the last ten years have yet to produce a significant indication of recovery in American shad stocks. The significant decreases observed in most datasets over the last few years has continued into 2006, indicating that recovery of these rivers to self-sustaining levels is not practical under current hatchery production and mortality rates.

To improve future analysis of the upper Chesapeake and Maryland American shad stocks, the following should be completed:

1. Re-key lost data on the Nanticoke River
2. Continue to collect fishery-independent data fro the Nanticoke River
3. Define the predator-prey relationship that may exist between piscivorous fish (e.g., striped bass, flathead catfish) and American shad by analyzing stomach contents of potential predators
4. Partition the hatchery and non-hatchery components of the samples in the Nanticoke River and then calculate CPUE for each

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Table 9.1 Annual stocking in the Choptank, Nanticoke, Chester, and Patuxent rivers and Marshyhope Creek, 1994-2005.

Year	Larvae	Juvenile
1994	1,240,000	14,240
1995	1,311,300	121,124
1996	2,367,600	289,104
1997	2,784,100	96,435
1998	227,200	33,611
1999	968,000	125,333
2000	731,000	128,414
2001	364,200	146,886
2002	1,592,000	316,660
2003	2,606,000	430,000
2004	1,550,000	382,000
2005	3,167,500	445,356

Table 9.2 Annual stocking summaries for larval and juvenile American shad in target tributaries, 1994-2005.

Patuxent River

Year	Larvae	Early Juveniles	Late Juveniles
1994			104,000
1995	346,000		121,124
1996	655,000		173,994
1997	1,345,000		60,040
1998	61,000		16,726
1999	526,000		60,377
2000	349,000	37,250	26,765
2001	364,000	77,500	21,903
2002	472,000	124,750	24,968
2003	717,000	108,000	31,061
2004	537,000	93,000	36,571
2005	707,500	93,000	40,873
Total	**6,079,500**	**488,500**	**718,402**

Choptank River

Year	Larvae	Early Juveniles	Late Juveniles
1994			
1995			
1996	626,000		115,110
1997	1,245,000		32,612
1998	136,000		16,885
1999	442,000		64,956
2000	357,000		64,369
2001		15,000	32,483
2002	1,020,000	100,000	23,118
2003	1,322,000	167,500	
2004	675,000	125,000	28,898
2005	1,930,000	170,000	41,483
Total	**7,753,000**	**577,500**	**419,584**

Marshyhope Creek

Year	Larvae	Early Juveniles	Late Juveniles
1994			
1995			
1996			
1997			
1998			
1999			
2000			
2001			
2002	100,000	39,000	9,074
2003	203,000	50,000	
2004	238,000	33,000	
2005	205,000	40,000	
Total	**746,000**	**162,000**	**9,074**

Nanticoke River

Year	Larvae	Early Juveniles	Late Juveniles
1994			
1995	34,000		8,400
1996			
1997	152,000		
1998			
1999			
2000			
2001	40,000		
2002	90,000	20,000	13,347
2003	364,000	73,500	
2004	127,000	60,000	
2005	325,000	60,000	
Total	**1,132,000**	**213,500**	**21,747**

Table 9.3 Juvenile American shad recaptures in Patuxent River from summer seine survey since inception of the restoration effort, 1994-2005. Data are presented as percentage of origin composition of all juveniles collected by the survey. Sample size equals the number of captured juvenile American shad that were successfully analyzed for origin.

Year	**Sample Size**	**Larval Stocked Origin**	**Juvenile Stocked Origin**	**Wild Fish**
1994‡	NA	0%	100%	0%
1995	330	54%	46%	0%
1996	285	60%	40%	0%
1997	362	79%	21%	0%
1998	90	0%	83%	17%
1999	260	25%	74%	1%
2000	340	1%	91%	8%
2001	376	13%	73%	14%
2002	163	51%	39%	10%
2003	268	47%	37%	17%
2004	256	19%	74%	7%
2005	314	43%	39%	18%

‡Data collected from a related trawl survey. Seine survey began in 1995.

Table 9.4 Juvenile American shad recaptures in Choptank River from summer seine survey, 1994-2005. Data are presented as percentage of origin composition of all juveniles collected by the survey. Sample size equals the number of captured juvenile American shad that were successfully analyzed for origin.

Year	**N**	**Larval Stocked Origin**	**Juvenile Stocked Origin**	**Wild Fish**
1996	99	37%	63%	0%
1997‡	**NA**	**NA**	**NA**	**NA**
1998	1	100%	0%	0%
1999	13	36%	62%	0%
2000	8	0%	100%	0%
2001	41	0%	83%	17%
2002	200	58%	34%	9%
2003	188	36%	48%	17%
2004	145	52%	43%	5%
2005	213	77%	14%	9%

‡There is no data available for 1997.

Table 9.5 Juvenile American shad captures in Marshyhope Creek from summer seine survey since the inception of the restoration effort, 2002-2005. Data are presented as percentage of origin composition of all juveniles collected by the survey. Sample size equals the number of captured juvenile American shad that were successfully analyzed for origin.

Year	N	Larval Stocked Origin	Juvenile Stocked Origin	Wild Fish
2002	163	25%	34%	41%
2003	230	16%	29%	56%
2004	130	27%	35%	38%
2005	86	29%	24%	47%

Table 9.6 Economic data for the American shad commercial fishery, 1880-1979.

Year	Total Value of Landings ($)	Price per Pound	Price per Pound (2004 Dollars)	Source	Year	Total Value of Landings ($)	Price per Pound	Price per Pound (2004 Dollars)	Source
1880	140,326	$0.04	$0.65	Fairbanks and Hamill 1932	1951	1,553,134	$0.17	$1.23	Hensel and Tiller 1954
1887	146,951	$0.04	$0.69	Fairbanks and Hamill 1932	1952	1,634,476	$0.14	$1.01	Hensel and Tiller 1954
1888	176,655	$0.04	$0.69	Fairbanks and Hamill 1932	1962	202,996	$0.13	$0.81	
1890	242,909	$0.03	$0.68	Fairbanks and Hamill 1932	1963	132,197	$0.16	$0.99	
1891	211,575	$0.03	$0.68	Fairbanks and Hamill 1932	1964	115,639	$0.13	$0.79	
1897	159,365	$0.03	$0.57	Fairbanks and Hamill 1932	1965	146,184	$0.11	$0.66	
1901	120,602	$0.04	$0.83	Fairbanks and Hamill 1932	1966	131,868	$0.12	$0.70	
1904	159,772	$0.06	$1.12	Fairbanks and Hamill 1932	1967	129,905	$0.15	$0.85	
1908	247,000	$0.06	$1.24	Fairbanks and Hamill 1932	1968	101,263	$0.11	$0.60	
1920	355,217	$0.19	$1.79	Fairbanks and Hamill 1932	1969	100,122	$0.09	$0.46	
1925	264,388	$0.21	$2.26	Fairbanks and Hamill 1932	1970	107,250	$0.10	$0.49	
1929	223,380	$0.14	$1.58	Fairbanks and Hamill 1932	1971	123,000	$0.13	$0.61	
1935	83,777	$0.11	$1.44	Johnson 1938	1972	118,351	$0.14	$0.63	
1944	709,070	$0.12	$1.31	Hensel and Tiller 1954	1973	105,673	$0.18	$0.77	
1945	606,494	$0.21	$2.23	Hensel and Tiller 1954	1974	45,669	$0.21	$0.81	
1946	716,384	$0.19	$1.80	Hensel and Tiller 1954	1975	44,805	$0.24	$0.84	
1947	867,403	$0.17	$1.43	Hensel and Tiller 1954	1976	40,619	$0.37	$1.23	
1948	1,001,293	$0.15	$1.17	Hensel and Tiller 1954	1977	26,647	$0.36	$1.12	
1949	1,082,900	$0.16	$1.28	Hensel and Tiller 1954	1978	17,473	$0.33	$0.96	
1950	1,440,115	$0.16	$1.22	Hensel and Tiller 1954	1979	8,024	$0.39	$1.02	

Table 9.7 Maryland commercial landings of American shad, 1880-1980. These data include the main bay, ocean, and tributaries, years missing indicate no available data.

Year	Metric Tons Landed	Year	Metric Tons Landed
1880	1712	1950	491
1887	1833	1951	655
1888	2209	1952	705
1890	3234	1953	742
1891	2824	1954	657
1896	2514	1955	681
1897	2632	1956	664
1901	1412	1957	949
1904	1321	1958	1069
1908	1786	1959	862
1909	1476	1960	672
1915	660	1961	606
1920	847	1962	824
1921	820	1963	715
1925	572	1964	375
1929	703	1965	404
1930	453	1966	609
1931	543	1967	514
1932	756	1968	393
1933	623	1969	435
1934	402	1970	586
1935	363	1971	471
1936	259	1972	432
1937	184	1973	434
		1974	271
1944	0	1975	100
1945	323	1976	83
1946	280	1977	50
1947	326	1978	35
1948	394	1979	42
1949	456	1980	8

Table 9.8 NMFS American shad commercial landings for Maryland, 1950-2003.

Year	Metric Tons	Pounds	Value of Landings ($)	Year	Metric Tons	Pounds	Value of Landings ($)
1950	654.5	1,442,900	225,666	1976	49.7	109,500	41,086
1951	705	1,554,300	264,512	1977	35.2	77,600	26,886
1952	741.9	1,635,700	232,383	1978	42	92,600	25,532
1953	657	1,448,400	222,410	1979	21	46,200	11,997
1954	680.8	1,500,800	186,718	1980	10.8	23,800	9,317
1955	664.2	1,464,300	211,592	1981	0.3	600	222
1956	948.9	2,092,000	259,823	1982	7.3	16,100	3,616
1957	1,068.60	2,355,900	298,947	1983	28.1	62,000	18,551
1958	862	1,900,400	301,393	1984	31.9	70,300	17,991
1959	671.7	1,480,800	182,851	1985	85.9	189,400	41,936
1960	604.7	1,333,100	206,480	1986	61.1	134,600	31,687
1961	823.1	1,814,600	288,522	1987	85.9	189,300	53,124
1962	714.6	1,575,400	202,996	1988	191.4	421,900	132,594
1963	374.9	826,600	132,243	1989	271.3	598,200	194,691
1964	403.7	890,100	115,786	1990	188.6	415,721	140,114
1965	609.4	1,343,400	149,804	1991	131.5	289,895	151,782
1966	514.2	1,133,600	132,028	1992	119.9	264,337	120,944
1967	393.3	867,000	129,925	1993	45	99,117	49,430
1968	434.6	958,100	105,447	1994	9.9	21,933	18,035
1969	586.1	1,292,200	124,612	1997	75.4	166,131	59,929
1970	471.1	1,038,600	107,261	1998	54.1	119,236	42,439
1971	432.1	952,500	123,746	1999	27.7	61,074	26,492
1972	434.3	957,400	118,213	2000	16.3	36,044	9,880
1973	270.8	596,900	105,481	2001	26	57,381	15,113
1974	99.7	219,800	45,414	2002	12.4	27,230	8,326
1975	83.3	183,600	44,551	2003	4.9	10,734	6,733
				Total	**16,537.80**	**36,459,333**	**5,777,251**

Table 9.9 Nanticoke River American shad commercial landings, 1930- 1978.

Year	Landings (lbs)	Source
1930	14000	Sadzinski *in prep*
1931	40000	Sadzinski *in prep*
1932	24000	Sadzinski *in prep*
1933	63000	Sadzinski *in prep*
1934	58000	Sadzinski *in prep*
1935	48000	Sadzinski *in prep*
1936	28000	Sadzinski *in prep*
1937	16000	Sadzinski *in prep*
1938	14000	Sadzinski *in prep*
1939	20000	Sadzinski *in prep*
1940	6000	Sadzinski *in prep*
1941	16000	Sadzinski *in prep*
1944	33123	Hensel et al 1954
1945	16606	Hensel et al 1954
1946	17912	Hensel et al 1954
1947	26598	Hensel et al 1954
1948	20711	Hensel et al 1954
1949	29154	Hensel et al 1954
1950	28517	Hensel et al 1954
1951	29110	Hensel et al 1954
1952	56370	Sadzinski *in prep*
1953	58856	Sadzinski *in prep*
1954	51130	Sadzinski *in prep*
1955	161632	Sadzinski *in prep*
1956	131867	Sadzinski *in prep*

Year	Landings (lbs)	Source
1957	168850	Sadzinski *in prep*
1958	132194	Sadzinski *in prep*
1959	99795	Sadzinski *in prep*
1960	85302	Sadzinski *in prep*
1961	82166	Sadzinski *in prep*
1962	66652	Weinrich *et al.* 1981
1963	47205	Weinrich *et al.* 1981
1964	47562	Weinrich *et al.* 1981
1965	39978	Weinrich *et al.* 1981
1966	36324	Weinrich *et al.* 1981
1967	22983	Weinrich *et al.* 1981
1968	23253	Weinrich *et al.* 1981
1969	38282	Weinrich *et al.* 1981
1970	45198	Weinrich *et al.* 1981
1971	37888	Weinrich *et al.* 1981
1972	15756	Weinrich *et al.* 1981
1973	21648	Weinrich *et al.* 1981
1974	17102	Weinrich *et al.* 1981
1975	8181	Weinrich *et al.* 1981
1976	4654	Weinrich *et al.* 1981
1977	3071	Weinrich *et al.* 1981
1978	7317	Weinrich *et al.* 1981
1979	6000	Weinrich *et al.* 1981
1980	5201	Weinrich *et al.* 1981

Table 9.10 Choptank River American shad landings, 1930-1978.

Year	Landings (lbs)	Year	Landings (lbs)	Source
1930	5000	1955	74628	
1931	55000	1956	122236	
1932	51000	1957	94982	
1933	29000	1958	70796	
1934	19000	1959		
1935	28000	1960	11,130	
1936	32000	1961		
1937	19000	1962	2382	Carter and Weinrich 1980
1938	16000	1963	4339	Carter and Weinrich 1980
1939	22000	1964	14440	Carter and Weinrich 1980
1940	10000	1965	1096	Carter and Weinrich 1980
1941	25000	1966	1985	Carter and Weinrich 1980
1942		1967	13958	Carter and Weinrich 1980
1943		1968	392	Carter and Weinrich 1980
1944	26465	1969	119	Carter and Weinrich 1980
1945	30618	1970	3231	Carter and Weinrich 1980
1946	25159	1971	4209	Carter and Weinrich 1980
1947	45755	1972	5346	Carter and Weinrich 1980
1948	23719	1973	1702	Carter and Weinrich 1980
1949	27933	1974	999	Carter and Weinrich 1980
1950	30533	1975	494	Carter and Weinrich 1980
1951	16750	1976	813	Carter and Weinrich 1980
1952	41462	1977	167	Carter and Weinrich 1980
1953	31529	1978	79	Carter and Weinrich 1980
1954	33190			

Table 9.11 Patuxent River American shad landings, 1944-1978.

Year	Landings (lbs)	Comment	Source
1944	1,312		Hensel and Tiller 1948
1945	849		Hensel and Tiller 1948
1946	70		Hensel and Tiller 1952
1947	1,668		Hensel and Tiller 1952
1948	806		Hensel and Tiller 1952
1949	409		Hensel and Tiller 1952
1950	2,700	Provides catch by gear	Hensel and Tiller 1952
1951	1,441	Provides catch by gear	Hensel and Tiller 1954
1952	3,427		Hensel and Tiller 1954
1955	8035		Sadzinski *in prep*
1956	3840		Sadzinski *in prep*
1957	16230		Sadzinski *in prep*
1958	9594		Sadzinski *in prep*
1959	425		Sadzinski *in prep*
1960	297		Sadzinski *in prep*
1961	1097		Sadzinski *in prep*
1962	609		Carter and Weinrich 1980
1963	498		Carter and Weinrich 1980
1964	595		Carter and Weinrich 1980
1965	272		Carter and Weinrich 1980
1966	726		Carter and Weinrich 1980
1967	484		Carter and Weinrich 1980
1968	22		Carter and Weinrich 1980
1969	113		Carter and Weinrich 1980
1970	511		Carter and Weinrich 1980
1971	1262		Carter and Weinrich 1980
1972	2156		Carter and Weinrich 1980
1973	7701		Carter and Weinrich 1980
1974	887		Carter and Weinrich 1980
1975	4091		Carter and Weinrich 1980
1976	426		Carter and Weinrich 1980
1977	702		Carter and Weinrich 1980
1978	340		Carter and Weinrich 1980

Table 9.12 1898 American shad data reproduced from Stevenson (1899) and his estimated CPUE by gear type.

Area	Number of Nets Fished by Area				Number of American Shad Caught by Gear				CPUE of American shad by Gear Type			
	Gill Net	Seine	Pound Net	Fyke Net	Gill Net	Seine	Pound Net	Fyke Net	Gill Net	Seine	Pound Net	Fyke Net
Chesapeake Bay (main stem)	2,563	7	177	0	284,302	33,622	169,118	0	110.9	4803.1	955.5	
Potomac River	118	5	131	0	136,880	44,000	7,595	0	1160	8800	58	
Patuxent River	18	10	33	0	19,700	24,375	8,279	0	1094.4	2437.5	250.9	
Pocomoke River	40	6	0	16	3,198	2,537	0	205	80	422.8		12.8
Wicomico River	377	3	290	36	50,033	4,054	12,536	1,302	132.7	1351.3	43.2	36.2
Nanticoke River	433	0	26	143	80,561	0	85,303	9,337	186.1		3280.9	65.3
Choptank River	1923	14	185	23	89,132	45,050	114,758	402	46.4	3217.9	620.3	17.5
St Michaels River (Miles River)	92	0	0	0	2,215	0	0	0	24.1			
Chester River	180	17	81	83	19,865	9,933	21,319	2,390	110.4	584.3	263.2	28.8
Sassafras River		0	31	0	0	0	1,290	0			41.6	
Elk River		0	139	0	0	0	5,244	0			37.7	
Susquehanna River	223	12	0	15	39,489	30,345	0	2,003	177.1	2528.8		133.5
Total Catch/Avg. CPUE	5967	65	1123	316	725,375	193,916	425,442	15639	121.6	2983.3	378.8	49.5

Table 9.13 Maryland's American shad landings, pound net effort, and CPUE.

Year	Landings (lbs)	Number of Net Days	Catch Per Net-Day	Source
1929	768,648	780 nets total		Fairbanks, W.L. and W.S. Hamill. 1932.
1944	420,622	11929* (470 pound nets)	35.26	Walburg 1955
1945	337,455	10740 (452 pound nets)	31.42	Walburg 1955
1946	280,594	11495	24.41	Walburg 1955
1947	306,773	12395	24.75	Walburg 1955
1948	363,021	13556	26.78	Walburg 1955
1949	524,926	14691	35.73	Walburg 1955
1950	820,605	13764	59.62	Walburg 1955
1951	518,391	13364 (446 nets)	38.79	Walburg 1955
1952	453,688	14462 (477 nets)	31.37	Walburg 1955
1960	325,230	226 pound nets		Walburg and Nichols 1967
Upper Chesapeake Bay Pound Net Data				
1988	NA	NA	1.96	
1989	NA	NA	5.06	
1990	NA	NA	3.21	
1991	NA	NA	12.53	
1992	NA	NA	2.99	
1993	NA	NA	6.76	
1994	NA	NA	7.28	
1995	NA	NA	7.89	
1996	NA	NA	5.22	
1997	NA	NA	13.47	
1998	NA	NA	4.3	
1999	NA	NA	4.67	
2000	NA	NA	30.86	

* The number of pound nets in the Chesapeake Bay came from Hammer et al. 1948.

Table 9.14 Maryland's catch (lbs) and effort statistics for the American shad fishery reproduced from Walburg 1955.

Year	Pound Nets			Drift Gill Nets			Anchor Gill Nets			Stake and Anchor Gill Nets			Total Landings
	Catch	Effort	CPUE	Catch	Effort*	CPUE	Catch	Effort	CPUE	Catch	Effort*	CPUE	
1944	420,622	11,929	35.26	68,329	1,373	49.77	55,291	1,544	35.81	116,763	10,538	11.08	661,005
1945	337,455	10,740	31.42	51,440	3,237	15.89	63,883	3,362	19	103,363	9,624	10.74	556,141
1946	280,594	11,495	24.41	81,335	7,288	11.16	161,917	6,832	23.7	130,022	9,918	13.11	653,868
1947	306,773	12,395	24.75	123,324	6,331	19.48	128,441	8,982	14.3	210,292	23,708	8.87	768,830
1948	363,021	13,556	26.78	106,412	5,321	20	212,548	16,225	13.1	210,871	17,427	12.1	892,273
1949	524,926	14,691	35.73	119,328	8,252	14.46	125,633	7,019	17.9	179,803	19,715	9.12	949,690
1950	820,605	13,764	59.62	135,046	5,954	22.68	146,634	11,280	13	240,116	12,840	18.7	1,342,401
1951	518,391	13,364	38.79	382,894	11,219	34.13	163,606	9,089	18	421,725	28,304	14.9	1,486,616
1952	453,688	14,462	31.37	270,855	8,225	32.93	208,463	10,960	19.02	554,079	37,951	14.6	1,487,085
1960	325,230	226 nets		322,927	64,908					677,745	181,896		

Table 9.15 Walburg's (1955) population estimates for Chesapeake Bay.

Year	Landings (lbs)	Estimated Population	Estimated Fishing Rate
1944	580,465	2,029,749	41.9
1945	545,718	824,347	66.2
1946	524,716	893,894	58.7
1947	1,336,173	2,364,908	56.5
1948	796,141	1,137,344	70
1949	904,010	1,189,487	76
1950	931,614	1,288,539	72.3
1951	877,018	1,403,229	62.5
1952	853,066	1,471,035	58

Table 9.16 American shad commercial landings and fishing effort in Maryland's ocean waters, 1935-2004.

Year	Total Pounds Landed	Number of Watermen	Number of Days Fished	Total Yards of Gill Net Fished	CPUE (lbs/1000 netyards)	Source
1935	14,000					Johnson 1938
1944	1,591					Hensel and Tiller 1948
1945	10,577					Hensel and Tiller 1949
1946	2,995					Hensel and Tiller 1950
1947	3,730					Hensel and Tiller 1951
1948	3,121					Hensel and Tiller 1952
1949	1,679					Hensel and Tiller 1953
1950	2,439					Hensel and Tiller 1954
1951	1,080					Hensel and Tiller 1955
1952	1,195					Hensel and Tiller 1956
1975	113,697					ASMFC 1988
1976	43,080					ASMFC 1988
1977	20,565					ASMFC 1988
1978	53,424					ASMFC 1988
1979	32,338					ASMFC 1988
1980	17,344					ASMFC 1988
1981	34					ASMFC 1988
1982	7,263					ASMFC 1988
1983	20,043	6	151	10,800	1855.8	
1984	19,088	8	257	9,825	1942.8	
1985	150,030	6	420	26,173	5732.2	
1986	126,223	8	512	34,400	3669.3	
1987	119,304	6	443	33,067	3608	
1988	264,642	14	767	74,900	3533.3	
1989	487,812	15	539	56,150	8687.7	
1990	283,649	12	545	78,840	3597.8	
1991	233,968	17	894	107,950	2167.4	
1992	198,784	12	579	85,200	2333.1	
1993	77,883	7	242	42,634	1826.8	
1994	33,646	9	290	34,600	972.4	
1995	49,927	9	269	68,300	731	
1996	94,980	11	306	53,933	1761.1	
1997	99,435	17	479	65,300	1522.7	
1998	74,105	10	285	36,400	2035.9	
1999	54,491	13	241	44,795	1216.5	
2000	19,337	11	117	21,150	914.3	
2001	9,386	5	34	14,350	654.1	
2002	7,529	2	21	15,000	501.9	
2003	2,485	4	19	5,500	451.8	
2004	876	9	53	9,942	88.1	

Table 9.17 Summary statistics of adult American shad (sexes combined) sampled by DDFW from the Nanticoke River electrofishing survey, 2002-2005.

Year	N	Mean TL	% Repeat Spawners	% Females
2002	24	449	48	14
2003	156	441	53	16
2004	194	447	55	30
2005	183	466	69	33

Table 9.18 The geometric mean and confidence intervals of YOY American shad caught by DDFW's haul seine survey in the Nanticoke River, 1999-2005.

Year	GM	95% CI	CPUE	SE
1999	0.5	0 - 1.3	0.9	0.5
2000	0.3	0.1 - 0.6	0.6	0.3
2001	0.8	0.0 -1.3	1.5	0.5
2002	1.6	0.7- 2.9	5.8	3
2003	1.3	0.7 - 2.1	2.2	0.5
2004	3.5	2.1 - 5.4	7.6	2.5
2005	2.6	1.4 - 4.3	5.7	1.5

Table 9.19 The percentage of hatchery-reared juvenile American shad determined from random samples collected in the Nanticoke River by DDFW, 2000-2005.

Year	N	% Hatchery	% Wild
2000	31	29%	71%
2001	66	0%	100%
2002	133	17%	83%
2003	55	9%	91%
2004	120	30%	70%
2005	132	37%	63%

Table 9.20 Methods for calculating mortality rates for Nanticoke River American shad stocks (Hoenig 1983).

Method	Description	Formula	Comments	Results
Hoenig's Method 1	Uses the maximum observed age (10)	3/ tmax		0.3
Hoenig's Method 2	Uses the maximum observed age (10)	Ln (Mx) = 1.46 - 1.01{ln (tmax)		0.42
Estimating Z using Catch Curves	Assumes constant recruitment and M		Because of the maturity schedule, American shad are fully recruited until age 5, therefore this represent only three age classes.	Average Z using data smoothing is 1.02
Estimating Z using Cohort Analysis				Average Z using data smoothing is 0.95
Estimating Z using Repeat Spawning Marks Method 1 (catch curve type)	Averaged the difference between the natural logs of the spawning group frequencies	A-B B-C C-D Averages the differences between these	Results in higher mortality rates because it includes mortality associated with spawning.	Z =0.93-1.44 (average Z = 1.16)
Estimating Z using Repeat Spawning Marks Method 2 (cohort type)	Loge-transformed spawning group frequency plotted against the corresponding number of times spawned	loge (Sfx + 1) = a + Z * Wfx		Z =0.88-1.33 (average Z = 1.17)

Table 9.21 Age-based and freshwater spawning mark catch curve and cohort mortality estimates for American shad in the Nanticoke River, 1997-2005.

Year	Age Based Catch Curve	Spawning Mark Catch Curve	Year-Class	Age-Based Cohort Analysis	Spawning Mark Cohort Analysis
1997	0.8	0.93	1992	0.8	1.08
1998	1.2	1.2	1993	1.04	1.89
1999	0.55	0.97	1994	0.67	0.88
2000	0.92	1.38	1995	1.13	1.33
2001	1.55	1.44	1996	1.13	0.95
2002	1.5	1	1997	0.94	0.9
2003	1.07	0.95	1998	NA	NA
2004	0.9	1.35	1999	NA	NA
2005	0.53	1.26	2000	NA	NA
AVERAGES	**1**	**1.16**	**--**	**0.95**	**1.17**

Table 9.22 American Shad captured from the Nanticoke River (all gears) by year and age 1988-2005. (a) Males; (b) females; and (c) sexes combined.

(a) Males

Year	Age								
	2	3	4	5	6	7	8	9	10
1988	5	86	163	101	22	0	0	0	0
1989	0	45	158	25	5	0	1	0	0
1990	0	5	64	72	4	4	1	0	0
1991	0	20	73	81	22	2	1	0	0
1992	1	3	18	21	18	4	0	0	0
1993	1	2	22	50	22	12	4	1	0
1994	1	24	41	23	5	1	0	0	0
1995	1	8	34	26	3	0	0	0	0
1996	0	8	31	24	7	0	0	0	0
1997	0	6	27	13	4	0	0	0	0
1998	0	3	14	14	3	2	0	0	0
1999	0	1	6	7	1	0	0	0	0
2000	0	8	58	43	5	0	0	0	0
2001	0	12	17	24	6	0	0	0	0
2002	0	9	26	28	18	2	0	0	0
2003	0	2	21	34	17	0	0	0	0
2004	0	3	8	14	1	1	0	0	0
2005	0	2	7	6	2	1	1	0	0

Table 9.22 cont. American Shad captured from the Nanticoke River (all gears) by year and age 1988-2005. (a) Males; (b) females; and (c) sexes combined.

(b) Females

Year	Age								
	2	3	4	5	6	7	8	9	10
1988	0	7	76	128	92	11	0	0	0
1989	0	0	18	47	13	8	6	0	0
1990	0	0	18	81	30	9	2	0	0
1991	0	1	24	75	48	22	2	0	0
1992	0	1	4	22	24	19	0	0	0
1993	0	0	5	28	22	17	9	2	2
1994	0	1	16	22	8	3	1	0	0
1995	0	1	7	23	21	2	0	0	0
1996	0	2	12	15	13	10	0	0	0
1997	0	1	7	12	5	5	1	0	0
1998	0	0	8	13	7	0	0	0	0
1999	0	0	5	2	1	0	0	0	0
2000	0	0	21	27	19	1	3	0	0
2001	0	0	11	9	15	3	0	0	0
2002	0	0	12	5	21	9	1	0	0
2003	0	0	10	15	15	19	1	1	0
2004	0	0	7	15	4	2	0	0	0
2005	0	0	2	6	7	3	1	1	0

Table 9.22 cont. American Shad captured from the Nanticoke River (all gears) by year and age 1988-2005. (a) Males; (b) females; and (c) sexes combined.

(c) Sexes combined

Year	**Age**								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1988	5	93	239	229	114	11	0	0	0
1989	0	45	176	72	18	8	7	0	0
1990	0	5	82	153	34	13	3	0	0
1991	0	21	97	156	70	24	3	0	0
1992	1	4	22	43	42	23	0	0	0
1993	1	2	27	78	44	29	13	3	2
1994	1	25	57	45	13	4	1	0	0
1995	1	9	41	49	24	2	0	0	0
1996	0	10	43	39	20	10	0	0	0
1997	0	7	34	25	9	5	1	0	0
1998	0	3	22	27	10	2	0	0	0
1999	0	1	11	9	2	0	0	0	0
2000	0	8	79	70	24	1	3	0	0
2001	0	12	28	33	21	3	0	0	0
2002	0	9	38	33	39	11	1	0	0
2003	0	2	31	49	32	19	1	1	0
2004	0	3	15	29	5	3	0	0	0
2005	0	2	9	12	9	4	2	1	0

Figure 9.1 Map of the upper Chesapeake Bay. Lines indicate first barrier to upstream migration.

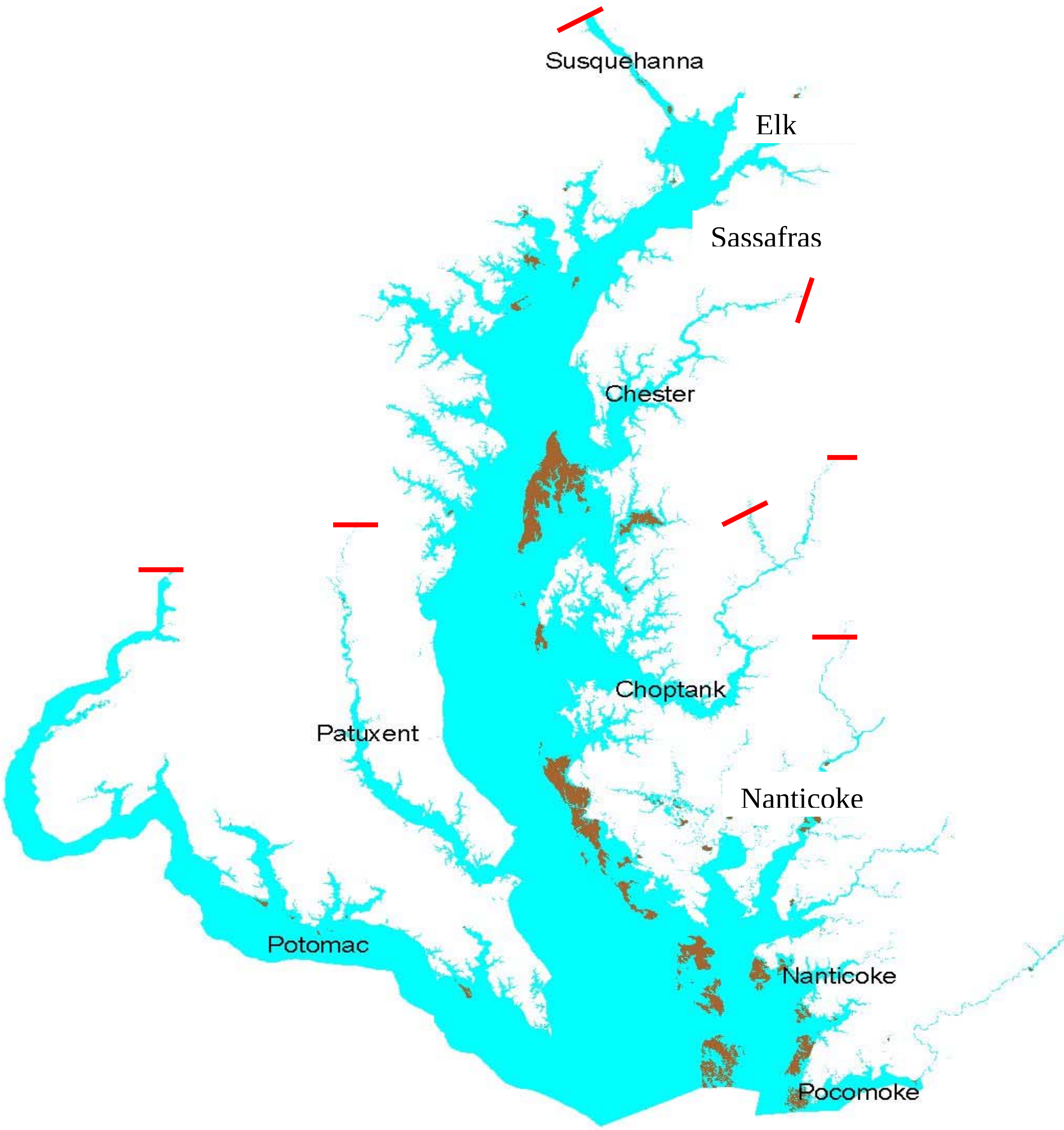


Figure 9.2 Distribution of fyke and pound nets sampled on the Nanticoke River.

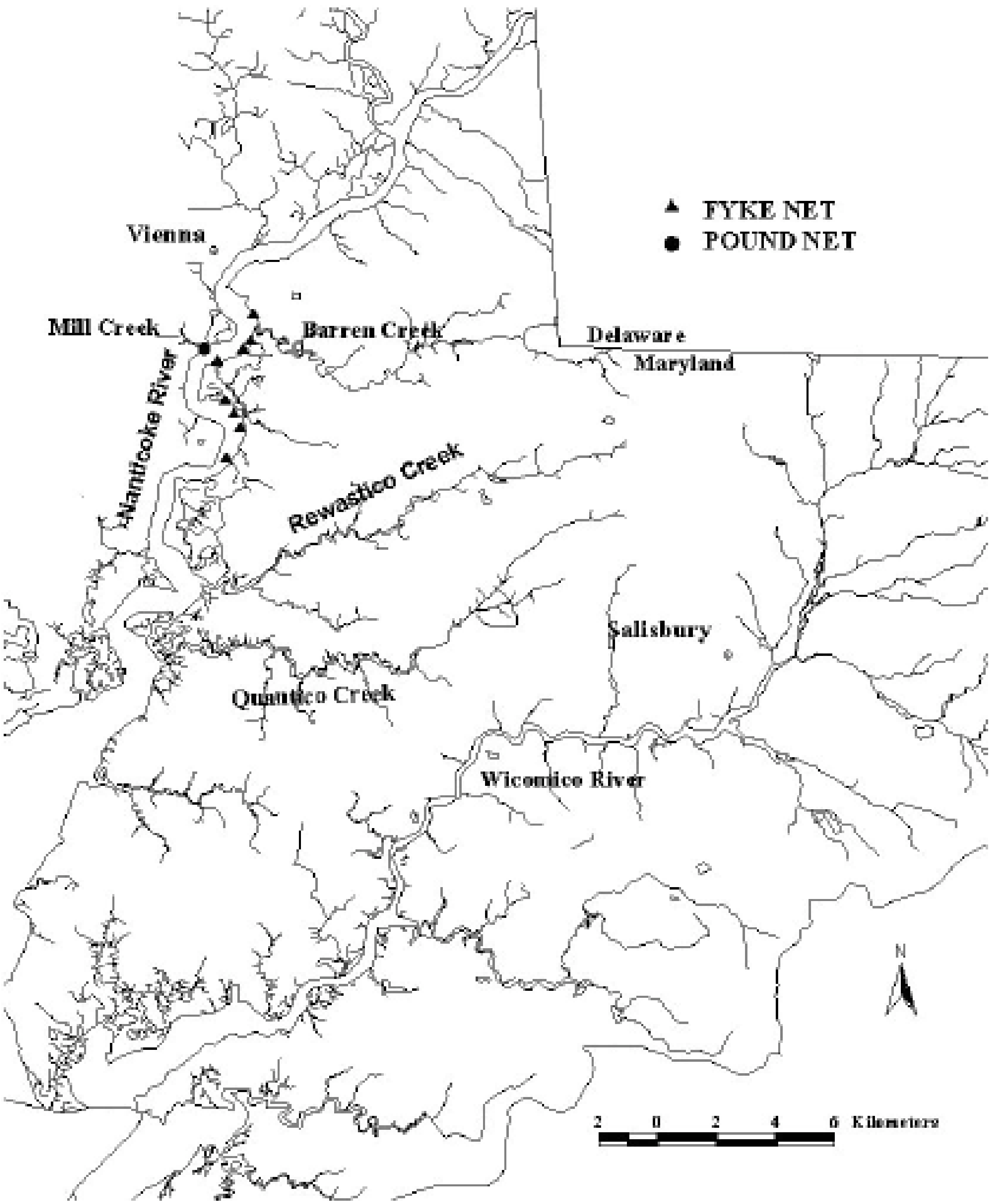


Figure 9.3 Choptank River watershed and the 2005 juvenile American shad haul seine sites.

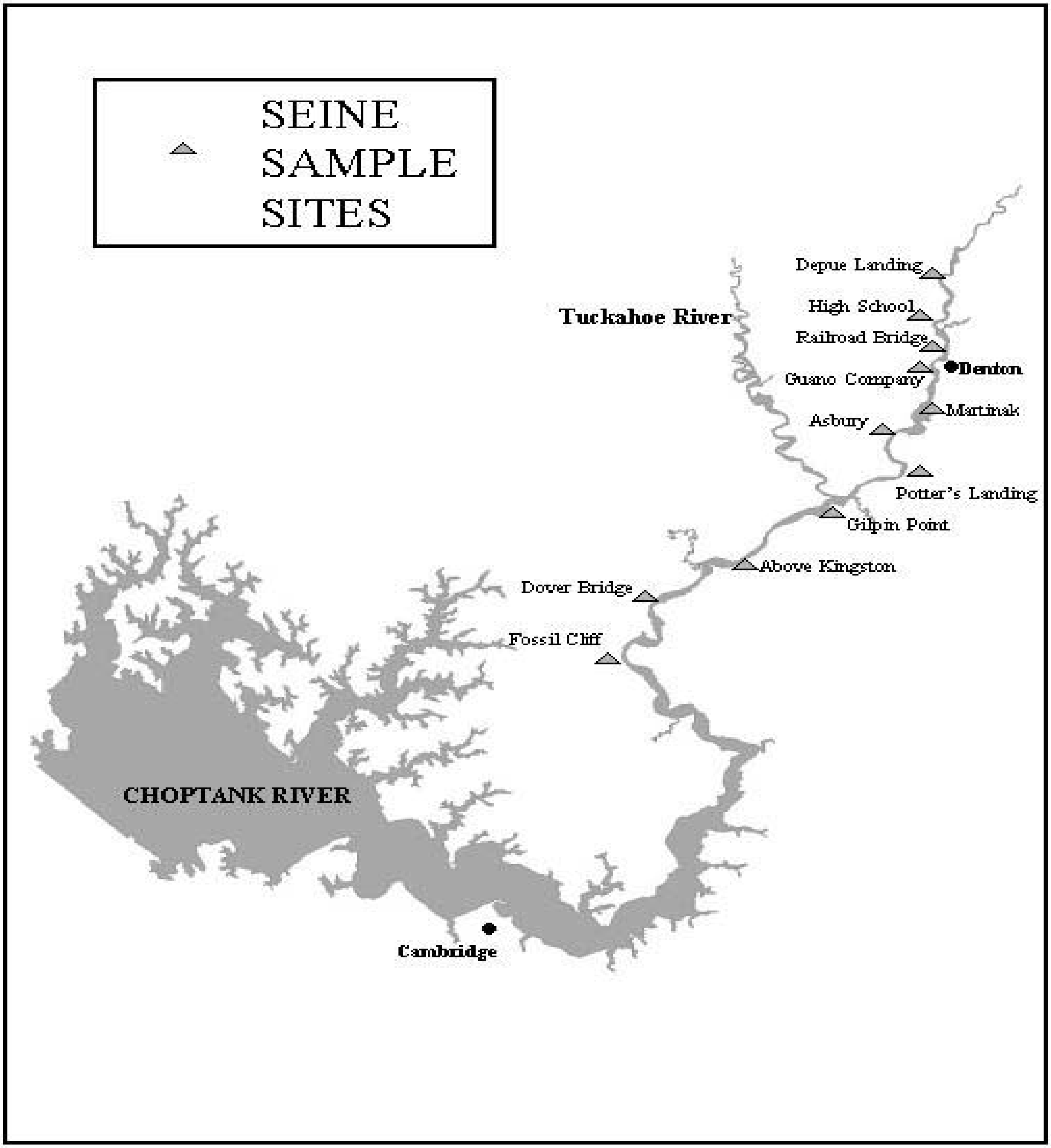


Figure 9.4 Patuxent River watershed and the 2005 juvenile American shad haul seine sites.

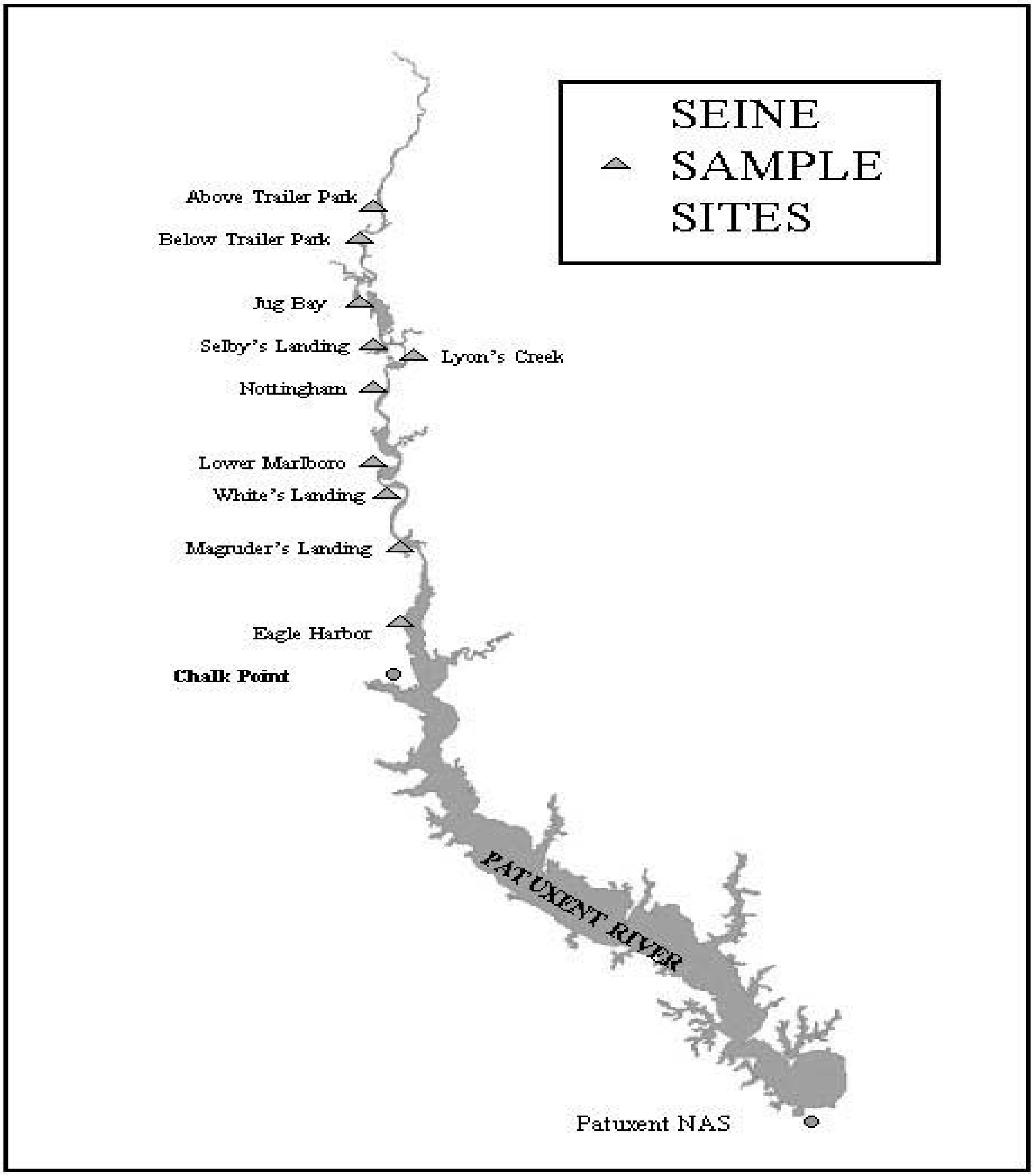


Figure 9.5 Pocomoke River watershed and 2005 seine sites (black dots).

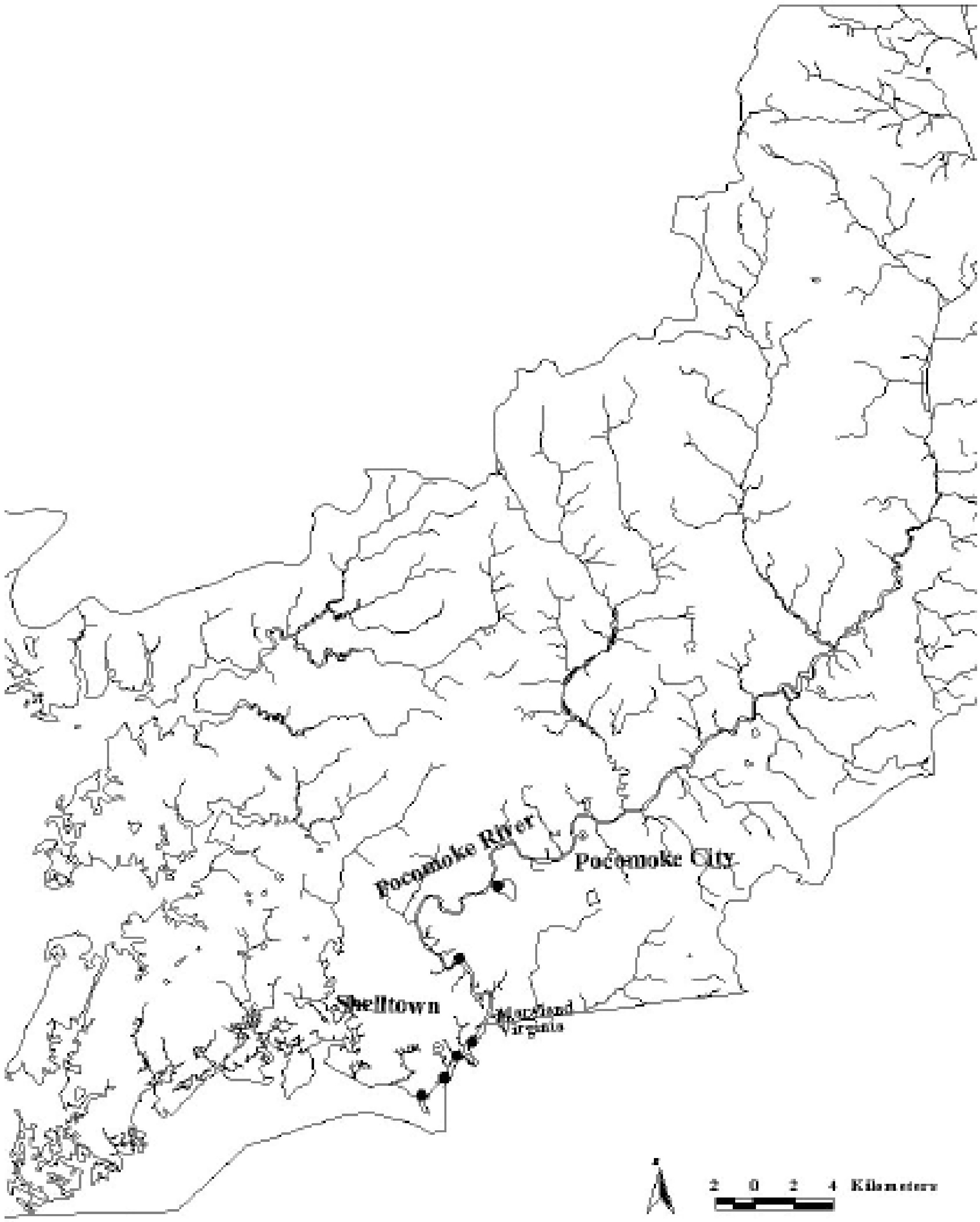


Figure 9.6 American shad CPUE defined as catch in numbers divided by the total number of pound nets in the Chesapeake Bay for select years.

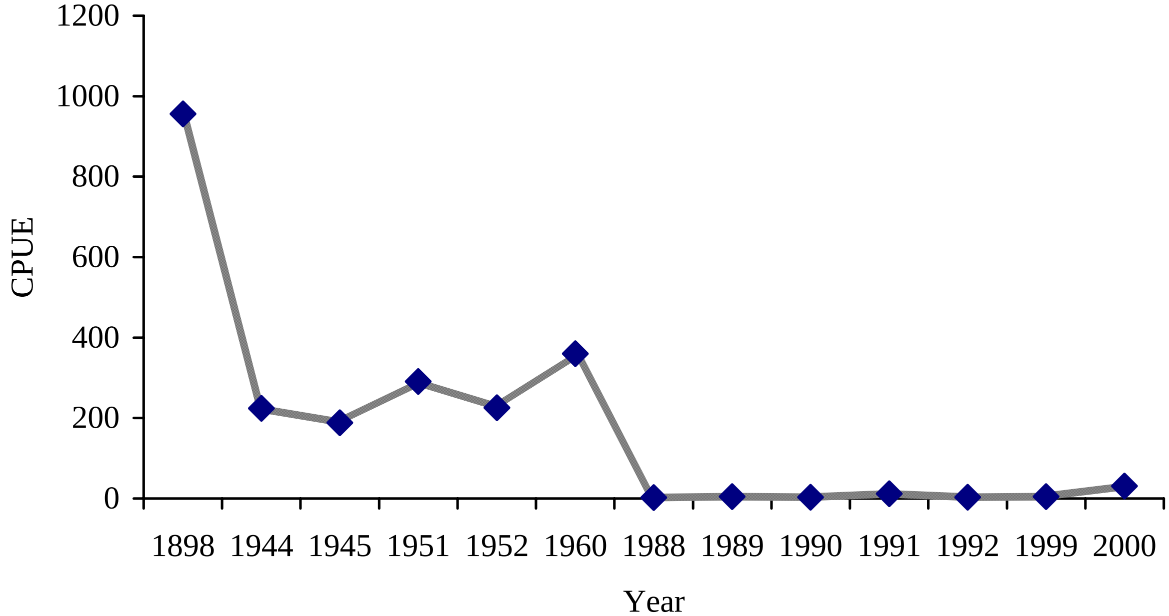


Figure 9.7 Nanticoke River juvenile American shad indices (geometric mean) from the SBSS survey, 1959-2005.

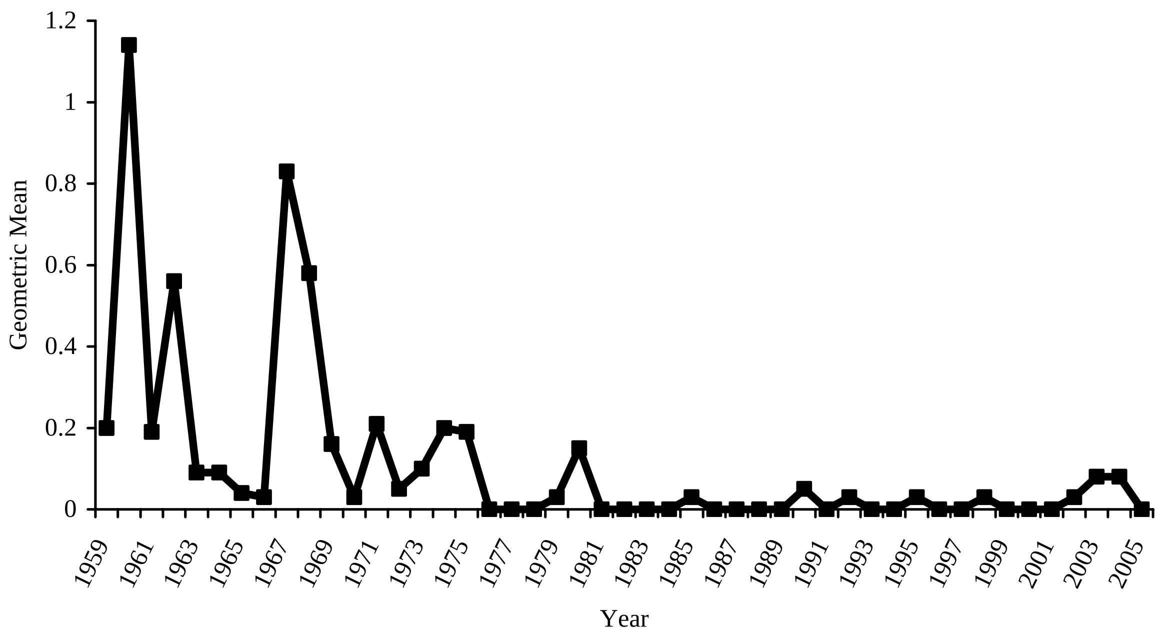


Figure 9.8 CPUE (fish/hr) from adult American shad collected on the upper Nanticoke River and Deep Creek by DDFW, 2002-2005 (Stangl 2006).

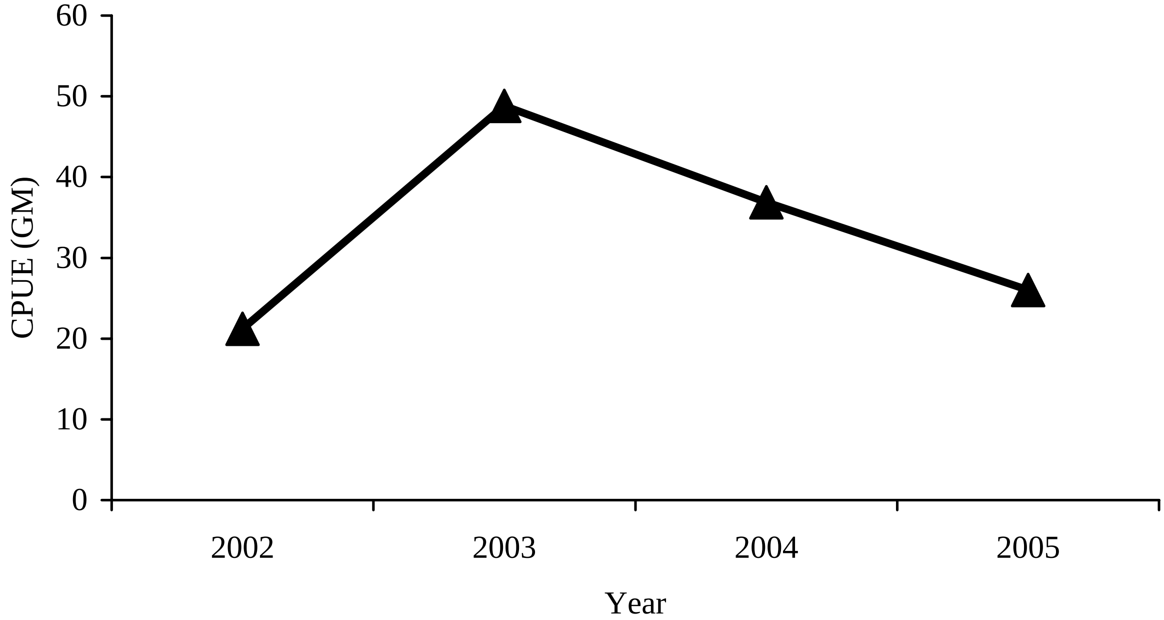


Figure 9.9 Juvenile American shad CPUE (fish/electrofishing hour) in the upper Nanticoke River by DDFW, 1999-2005.

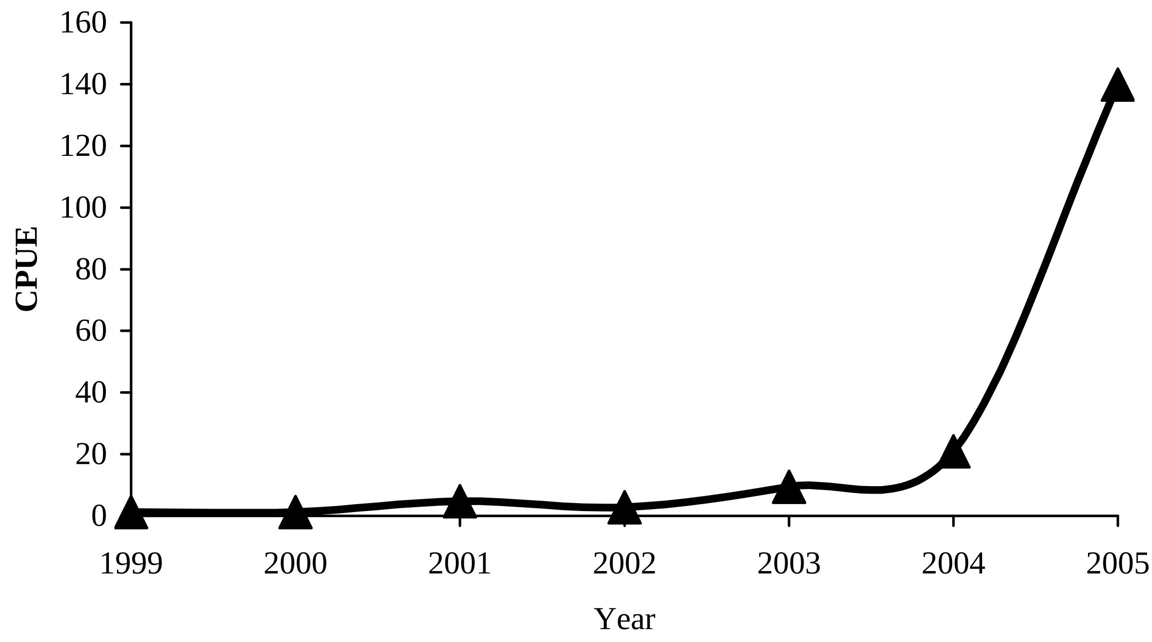


Figure 9.10 Patuxent River juvenile American shad indices (geometric mean), 1983-2005.

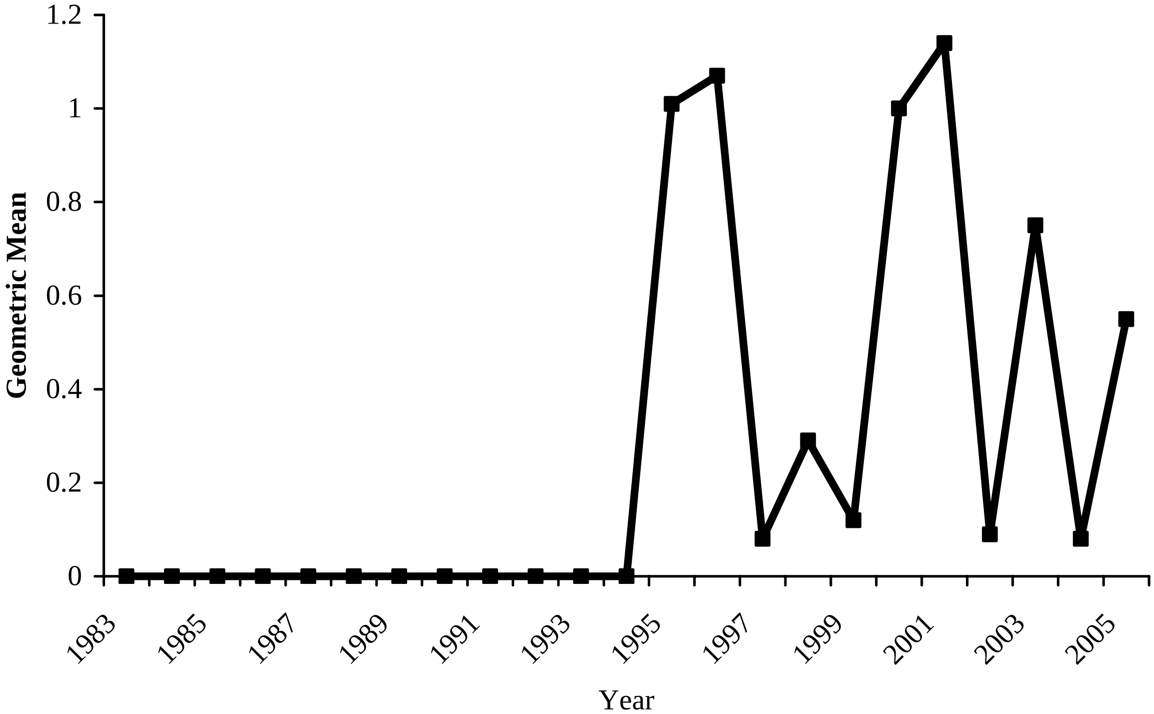


Figure 9.11 Trends in arcsine-transformed percentages of repeat spawning American shad (sexes combined) collected from the Nanticoke River (1988-2005).

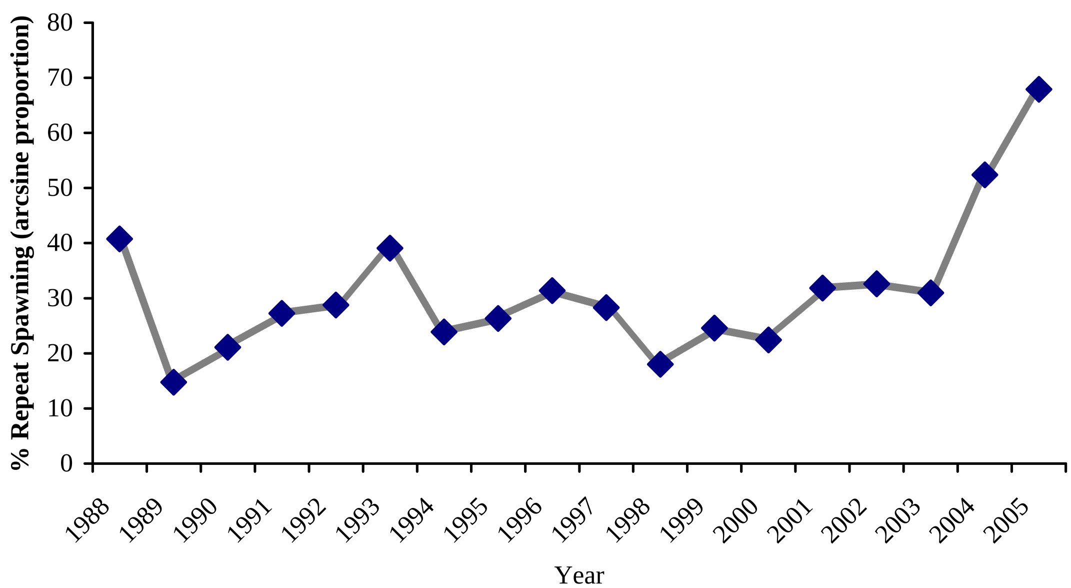


Figure 9.12 Pound net geometric mean (GM) CPUE and exponential trend line for American shad from the Nanticoke River, 1988-2005. No pound nets were fished in 2004.

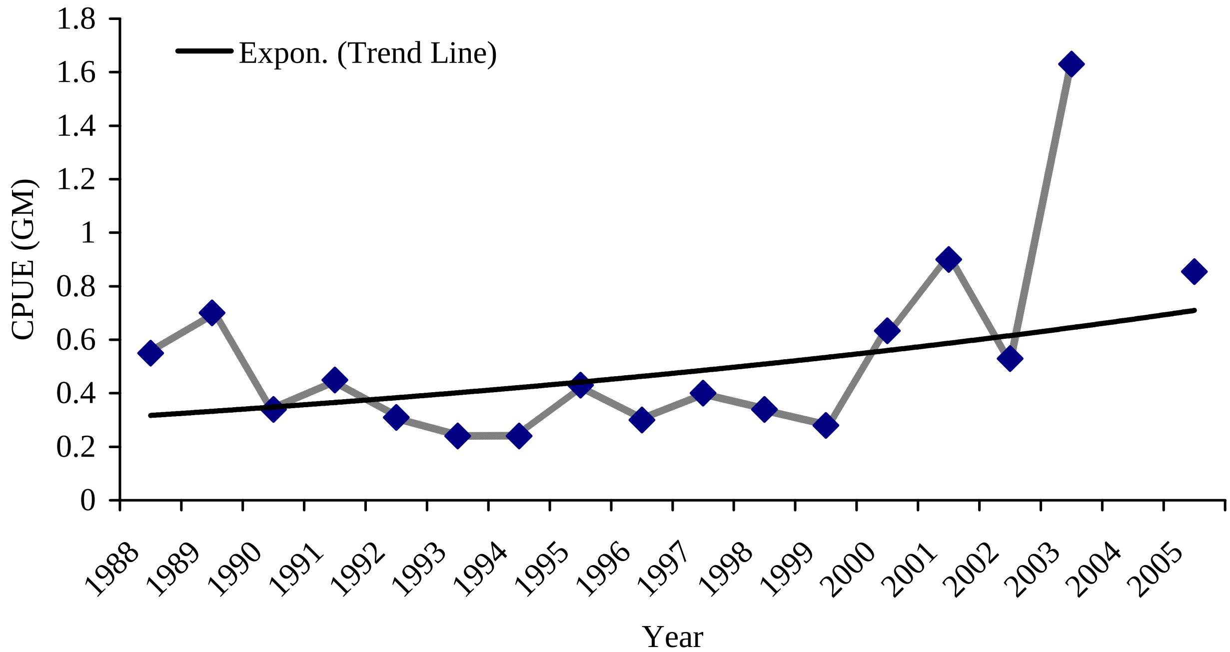
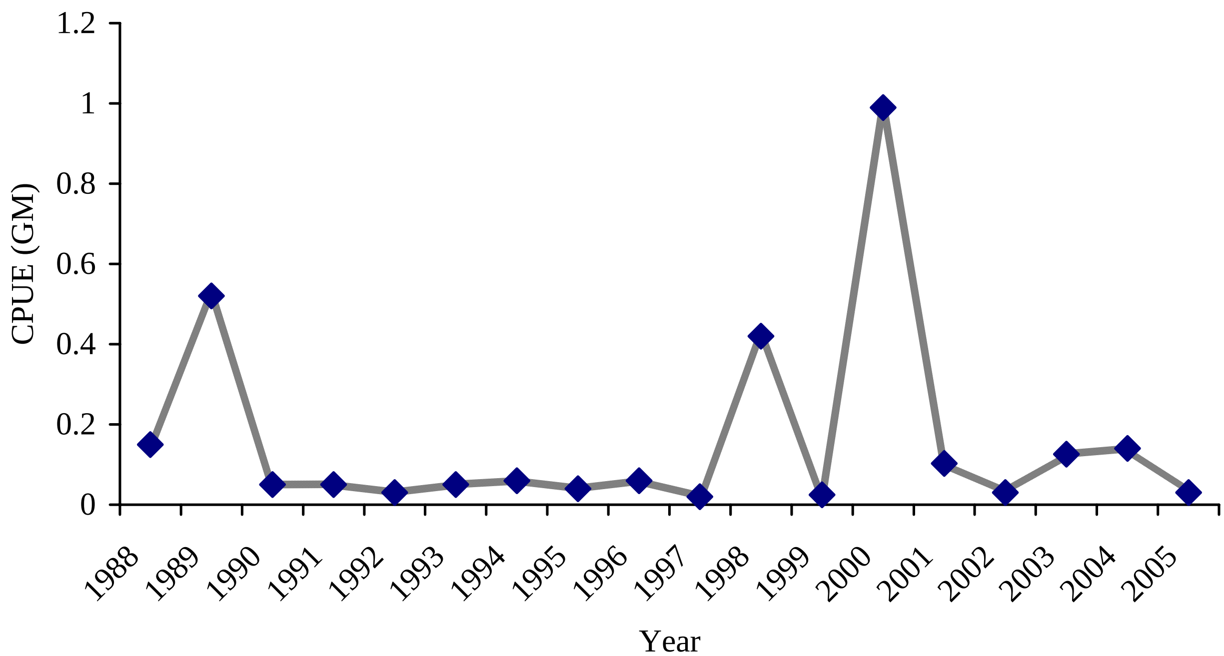


Figure 9.13 American shad geometric mean (GM) CPUE from fyke nets on the Nanticoke River, 1988-2005.



Section 10
Status of the Susquehanna River and Susquehanna Flats American Shad Stock

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10.1 INTRODUCTION

The Susquehanna River (Figure 10.1) is the second largest river in eastern North America, draining over 71,225 square kilometers, including parts of New York and Maryland and nearly one-half of Pennsylvania. The main stem originates in Lake Otsego, New York and travels 714 km to its mouth at Havre-de-Grace Maryland. Major river tributaries include the West Branch (367 km) and the Juniata River (161 km). The Susquehanna River provides more than one-half of the freshwater flow to the Chesapeake Bay, an average of 900 cubic meters of water per second (Carlson 1968).

The Susquehanna Flats encompasses the upper Chesapeake Bay from Turkey Point north to the mouth of the Susquehanna River and is characterized by shallow, sandy areas with a deep channel running along the shore (Figure 10.2).

American shad (*Alosa sapidissima*) were abundant in the Susquehanna River until the early 1900s. Native Americans and early colonists utilized shad as an important source of food. The use of various types of brush nets, dip nets, and traps eventually gave way to large seines as local economies relied heavily on this abundant source of protein. Gerstell (1998) documented 453 separate shore and island shad fisheries in the Susquehanna River from 1735 to 1928. The Pennsylvania portion of the river alone supported a commercial fishery of nearly 400,000 pounds in 1901 (Mansueti and Kolb 1953). In Maryland, there was an extensive American shad fishery throughout the Bay and tributaries, employing thousands of people and worth millions in present day dollars.

The first major hydroelectric plant on the river was constructed in 1904 at York Haven, Pennsylvania (river km 90). In 1910, Holtwood Dam (river km 39) was built with two fishways that were later shown to be ineffective. Commercial fishing continued below Holtwood until 1924 but soon disappeared because of the absence of American shad. Conowingo Dam (river km 16) was constructed in 1928 and Safe Harbor Dam (river km 52) was completed in 1931. These dams permanently block American shad from their historical spawning areas in the Susquehanna River.

Remnant populations of Susquehanna River and Upper Chesapeake Bay American shad have existed in the upper Bay and lower Susquehanna River since construction of the hydroelectric dams in the early 1900s. This stock likely expanded after Maryland enacted a fishing moratorium in 1980. Susquehanna River shad restoration was initiated in the early 1970s; eggs from many rivers (i.e., Hudson, Delaware, Connecticut, James, Pamunkey, Mattaponi, Potomac, Savannah, and Columbia rivers) have been transplanted to the Susquehanna or incubated, reared, and stocked as larvae or fingerlings. Recent genetic analyses have confirmed that Hudson River and Delaware River stocks have contributed to the current Susquehanna and Upper Bay population through natural reproduction (M. Bartron, USFWS, pers. comm.). Contribution of other stocks was not evaluated.

10.2 MANAGEMENT UNIT DEFINITION

The management unit is defined as the Susquehanna Flats, which encompasses an area on the Chesapeake Bay from Turkey Point in Kent County, Maryland north to the mouth of the Susquehanna River and the main stem Susquehanna River and watershed.

In general, since most American shad in the Chesapeake Bay will return to their natal rivers to spawn, each river is considered a separate stock. The upper Chesapeake Bay, which is generally fresh water in the spring, appears to have two stocks, one destined for the upper part of the Susquehanna River (mostly hatchery fish) and one that spawns below Conowingo Dam (exhibiting a higher prevalence of wild fish). This is supported by otolith tagging analysis, which shows increased hatchery contribution at Conowingo Dam, compared to the upper bay. For example, in each year from 1993 to 1998, hatchery contribution in samples collected at Conowingo Dam (29 to 90%) exceeded that of samples from the pound nets in the upper bay (14 to 58%; SRAFRC reports, 1994 to 1999).

10.3 REGULATORY HISTORY

Commercial fishing in the Susquehanna River was largely unregulated during the 1800s. Construction of Conowingo Dam in 1928 restricted runs to the Maryland portion of the river, below the Dam. Recreational harvest was prohibited in the Maryland portion of the river, below Conowingo Dam in 1980.

The earliest regulation for the Bay was a prohibition on pound nets “in the Chesapeake Bay, north of a line 1 mile south of Poole Island, except the bay shore of Kent County up to Howell Point at the mouth of the Sassafras River” (Stevenson 1899). In 1929, Maryland’s General Assembly established a season for American shad from January 1 to June 5. A 1944 newspaper article (“Susquehanna Shad Run Held Best in 20 Years,” April 20 1944, *Baltimore Sun*) states that there was a limit of ten American shad for anglers. In May, the Sun also reported that the Commercial Fisheries Advisory Committee concluded that the reason for the decline of the American shad fishery was overfishing. Pollution was not considered a significant threat. In 1941, based on this recommendation, a bill passed that allowed Tidewater Fisheries (presently the Department of Natural Resources (DNR), Fisheries Service) to reduce fishing effort through a moratorium on new licenses and additional gear. This bill permitted the commercial fishery for shad to persist while attempting to cap fishing effort. The article noted that licenses declined from 800 to 664 between 1942 and 1943. Because of the war, the demand for fish rose, as did prices. With bitter debates over this bill, the number of Maryland commercial fishing licenses was capped at 800 in 1944.

In 1944, commercial watermen were also required to submit catch and effort data by gear, although records were either incomplete or not submitted. Walburg (1955) provided data from a legal, unlicensed fishery using gill nets in each of the major tributaries. In 1952, commercial watermen reported landing 166,616 pounds of American shad while the unlicensed fishery landed 114,195 pounds (Walburg 1955). Walburg (1955) also concluded that effort had doubled in the shad fishery since 1944.

In general, there were no size or creel limits for American shad commercial fisheries while there was a recreational creel limit of ten American shad per person. More importantly, gear was regulated by area and season and American shad could not be kept from June 30 to Dec 1. Since fish returned to the ocean by June, this law was merely cosmetic. In short, the fishery was generally unregulated until commercial landings data substantially declined and the DNR closed both the commercial and recreational fisheries for American shad in 1980.

10.4 ASSESSMENT HISTORY

Gibson *et al*. (1988) conducted a stock assessment on the Susquehanna River stock of American shad using the Shepherd stock-recruitment (S-R) model. S-R points for the Susquehanna River were widely scattered and poorly described by the model. They attributed this to either significant measurement errors in the stock or recruitment estimates or recruitment variability resulting from density independent (climatic) factors. They calculated a maximum sustainable yield of 1.3 million pounds, a historical MSY of 2.5 million pounds, and a fishing rate (F) of 0.942 (1970s), suggesting that over-harvest was the major cause of the stock collapse in the late 1970s.

The most recent stock assessment was conducted in 1998 (ASMFC 1998) and concluded that shad population abundance (in-river stock size plus coastal landings from Upper Bay) increased steadily from 1980 to 1995 but decreased in 1996. 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, 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 generally increased from 1984 through 1995.

In-river fishing mortality rates (F_r) on Upper Bay shad were zero from 1980 to 1996 due to a complete moratorium on harvest instituted in 1980. Coastal fishing mortality rates (F_c) declined since 1980 from a high of 0.77 in 1984 to a low of 0.02 in 1995. Since coastal landings were the only directed commercial landings from the Upper Bay since 1980, the trend in total fishing mortality (F_t) was the same as the trend in coastal fishing mortality (F_c). The recent (1992-1996) average F_t rate on Upper Bay shad of 0.11 was considerably below the overfishing definition (F_{30} = 0.43) for the Upper Bay stock. Natural mortality (M) of adult shad was estimated by subtracting F_t from the total mortality (Z) estimates from 1986 to 1995. 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.

10.5 STOCK-SPECIFIC LIFE HISTORY

The American shad is an anadromous clupeid and is the largest member of the herring family (Walburg 1955). American shad enter the lower Chesapeake Bay in February and migrate into the Bay's freshwater tributaries to spawn (Olney and Hoenig 2001). They mature between two and seven years of age in the Chesapeake Bay (Jarzynski *et al*. 2000). Peak American shad catch-at-age is at ages four and five. Some may return to spawn four consecutive years (repeat spawning). Hatching occurs one week after fertilization. Young-of-year begin leaving the Chesapeake Bay in late fall but a few American shad juveniles will winter there. Juveniles remain in the ocean until sexually mature, with most returning to their natal rivers (Melvin *et al*. 1985).

10.5.1 Growth

Growth rate studies for American shad in the Chesapeake Bay have concentrated on young-of-year (YOY) and probably reflect the difficulty of ageing. Carter (1973) presented extensive data on weekly lengths of YOY American shad caught using various gear types in the Susquehanna River and Flats area in 1969. He reported high variation between sites and gear types that were likely associated with a change in preferred habitat as the fish grew; therefore he was likely not measuring growth but rather movement and an extended hatching period.

Growth rates of YOY shad in the Susquehanna River are high, presumably due to ample prey and lack of competition in the lotic areas above Conowingo Dam. The largest YOY specimen recorded was a 210 mm shad taken at Peach Bottom Atomic Power Station on December 1, 1986. St. Pierre (1997) reported that YOY shad were larger in the Susquehanna River than in the upper Chesapeake Bay with specimens reaching 144 mm by the end of October 1996. During October and November, length frequency distributions are skewed toward smaller fish as one moves upstream, suggesting that larger fish out-migrate sooner or faster (Young 1987). There have been no adult American shad growth studies in the Chesapeake Bay that would contribute to this document.

10.5.2 Natural Reproduction

Natural reproduction of American shad in the Susquehanna River above dams has been documented by the collection of un-marked juvenile shad at Holtwood Dam (lift net) and near the town of Columbia in Lancaster County, Pennsylvania (haul seine). Natural reproduction has also been documented by seine and/or electrofishing collections of juvenile non-hatchery shad in the Juniata River and Susquehanna River below Sunbury, Pennsylvania. No natural reproduction has been documented between Conowingo and Holtwood Dams or between Holtwood and Safe Harbor Dams. These river sections do not contain lotic habitats since both Safe Harbor and Holtwood Dams discharge into the headwaters of the next downstream reservoir. Push-net sampling for juvenile alosines was conducted in these areas during 1997-2003, but few juvenile American shad were collected. In Pennsylvania, the location of specific river reaches where natural reproduction occurs has not been documented, but natural reproduction is likely restricted to the free-flowing river sections above Safe Harbor and York Haven Dams. Approximately 24 km of lotic habitat exists between the upper limit of Safe Harbor Reservoir and York Haven Dam. American shad currently have access to another 265 km of lotic habitat upstream from York Haven Dam, including the main stem and Juniata Rivers up to the next blockage.

Maryland DNR personnel have sampled juvenile American shad using a 100-foot seine in the Susquehanna Flats since 1959. This was in conjunction with the striped bass seine survey. Sub-samples have shown these fish to be mostly of hatchery origin during the few years that MD DNR stocked the Susquehanna Flats with American shad (1993-1997) and only wild fish during those years when stocking did not occur

10.6 HABITAT DESCRIPTIONS

The Susquehanna River is a wide, shallow river characterized by erosion resistant sandstone ledges, alternating with long, gravel-bottom pools. Historically, American shad migrated long distances and extended into the headwaters of the Susquehanna River Basin. Major seine fisheries were documented upstream to Huntingdon on the Juniata River, Lock Haven on the West Branch and well into New York on the North Branch (Gerstell 1998). The first dams to block shad migrations were the milldams on tributaries, beginning in the 1700s. During the early 1800s canal dams (most notably the Columbia Dam) were built to supply various barge canals with water. These dams effectively blocked shad migrations in some years, but were subject to breaching by floodwaters in high water years. Canal dams were abandoned as the railroad replaced the canal system for transport of goods across country. Construction of four hydroelectric dams in the lower river from 1904 to 1931 effectively blocked shad runs and inundated 73 km of riverine spawning habitat.

Conowingo Dam was constructed in 1929 at river km 16 on the Susquehanna River. Constructed with seven generating units, Conowingo Dam generally had at least one turbine operating consistently and did not experience dissolved oxygen problems. In 1964, four large units were added, doubling hydraulic capacity and increasing flow fluctuations. The increased capacity permitted Conowingo to be operated in a peaking mode, resulting in higher flows during periods of energy demand and permitting complete shutdown during periods of low demand. This resulted in low oxygen concentrations and caused fish kills of anadromous species in 1965 and 1971 (Carter 1973). Minimum flow requirements were established in 1971, but low flow requirements were only required during the spring.

10.7 RESTORATION PROGRAMS

Declines in the shad fisheries of the upper Chesapeake Bay and the Susquehanna River can be attributed largely to overfishing and elimination of spawning habitat due to construction of dams. Pollution has the potential to impact shad, however, Mansueti and Kolb (1953) concluded that pollution was not a significant problem in the Susquehanna River. Another problem facing American shad in the Susquehanna River is flow alteration. Truitt (1936 cited in Mansueti and Kolb 1953) observed that although there is successful reproduction, dewatering of the river due to peaking operations at Conowingo Dam might delay spawning and harm eggs. Peaking may also produce hydraulic conditions unfavorable to shad reproduction.

In the 1960s, State and Federal agencies sought cooperation from hydropower developers to restore American shad and other diadromous fish to their historical range above dams. Power companies requested solid evidence that restoration was feasible before agreeing to spend millions of dollars on fish passage facilities. Feasibility of a full-scale restoration could only be established by demonstrating success with a modest-scale restoration.

Remnant populations of wild shad continued to spawn in the lower ten miles of the Susquehanna River and upper Chesapeake Bay, but commercial catches had declined severely since 1890 (Foerster and Reagan 1977). Since few wild Susquehanna stock American shad remained, a “demonstration project” was initiated with out-of-basin stocks.

The Susquehanna River Anadromous Fish Restoration Committee (SRAFRC) was formed in 1976 to oversee restoration of migratory fish. Membership of SRAFRC has included the states of New York, Pennsylvania and Maryland, the U.S. Fish and Wildlife Service (USFWS), the National Oceanographic and Atmospheric Administration, and the Susquehanna River Basin Commission. From 1971 to 1976, over 216 million shad eggs were stocked in the Susquehanna River from sources in the Columbia River and many East coast rivers (Table 10.1). Between 1980 and 1987, over 25,000 pre-spawn adult shad from the Hudson and Connecticut Rivers were released in the Susquehanna River (Table 10.2). These efforts produced few out-migrating juvenile shad, and were ultimately discontinued.

In 1972, Philadelphia Electric Company built the west fish-lift at Conowingo Dam to collect pre-spawn adult American shad for transplant in upstream spawning areas. Few adult shad were collected until 1982 when actual transplant of shad began. In 1976, the Pennsylvania Fish and Boat Commission (PFBC) established the Van Dyke Research Station for Anadromous Fish to develop techniques for American shad culture for use in the Susquehanna River restoration effort. In 1991, the east fish-lift was built at Conowingo, capable of releasing fish directly into Conowingo Reservoir. In 1997, fish-lifts were constructed at Holtwood and Safe Harbor Dams. In 2000, a vertical slot fishway was built at York Haven Dam. This passage opened the Susquehanna River as far upstream as the inflatable dam at Sunbury, Pennsylvania and the Juniata River to Warrior Ridge and Raystown Dams, a total of about 265 km. Fish passage is scheduled for the Fabri-Dam in Sunbury for 2008. Hepburn St. Dam on the West Branch Susquehanna River in Williamsport has a fishway, which will be updated by 2008.

The restoration effort has consisted of: (1) trapping of adults at Conowingo Dam and transplanting them to upstream spawning areas (1982-1997); (2) upstream adult fish passage (1997-present); and (3) production of hatchery-reared larvae and fingerlings. The objective of the restoration plan is to produce a self-sustaining population of two million adult shad upstream of York Haven Dam. The role of the hatchery is to produce adequate numbers of juvenile shad imprinted to return to upstream spawning areas, thereby initiating spawning runs, which will be maintained by self-sustaining natural reproduction.

American shad for use in stocking the Susquehanna River are cultured by methods developed at the PFBC's Van Dyke Hatchery, and are similar to those reported by Howey (1985). Eggs have been obtained from adult American shad collected by gill net in the Susquehanna, Hudson, Delaware, Connecticut, James, Pamunkey, Mattaponi, Potomac, Savannah and Columbia rivers (Table 10.1). Ripe adults are strip-spawned and the eggs are fertilized and water-hardened at the collection site. Eggs have also been obtained from tank-spawn efforts at Conowingo Dam and at the USFWS Northeast Fishery Center at Lamar, Pennsylvania. Adult shad for tank-spawn efforts are obtained from the West Fish-lift at Conowingo Dam, injected with hormones (LHRHa, or GNRHa) to induce maturation and allowed to spawn in tanks. Maximum egg production occurs in 48 hours. Eggs are delivered to the Van Dyke Hatchery (Juniata River, Susquehanna River basin) for incubation at 15-17 ºC, and hatching occurs in about seven days. Larvae are reared at 18-21°C in circular, 1,200-L tanks at densities of 100,000 to 500,000 larvae per tank, and are fed *Artemia* spp. and Zeigler AP-100 larval fish food, beginning on day three or four (Wiggins *et al*. 1986).

Stocking of hatchery-reared American shad larvae in the Susquehanna River began in 1976 (Table 10.2). Releases have occurred at many sites in the Juniata River, main stem Susquehanna River, West Branch Susquehanna River, North Branch Susquehanna River, Conodoguinet Creek, West Conewago Creek, Swatara Creek, and Conestoga River (Figure 10.1). In addition, MD DNR stocked over 33 million American shad in the Susquehanna River below Conowingo Dam from 1985 to 1996 (B. Richardson, MD DNR, pers. comm.).

Larvae are stocked annually, during May, June, and July at 7 to 35 days of age. Fingerlings are stocked between September and October, although fingerling culture has been substantially curtailed since 1994.

Since 1985, all hatchery-reared American shad larvae have been immersed in tetracycline antibiotics to mark their otoliths to distinguish hatchery-reared shad from wild, naturally produced shad (Hendricks *et al*. 1991). Since 1987, larvae have been marked by 4 to 6-hour immersion in 200-256 mg L-1 oxytetracycline or tetracycline hydrochloride. Marks produced by this protocol usually exhibit 100 percent mark retention. Multiple marks are produced by subsequent immersions at three or four day intervals and have been used primarily to mark fish according to release site.

10.7.1 Restoration Objective and Target

The Policy Committee of the Susquehanna River Anadromous Fish Restoration Cooperative approved an "Alosid Management and Restoration Plan for the Susquehanna River Basin" in 2002. The goal of the restoration is:

> By 2025, produce self-sustaining annual populations of 2 million American shad and 5 million river herring, reproducing in the free-flowing Susquehanna River above York Haven Dam, and in suitable tributaries, and provide 500,000 angling days annually throughout the Basin for these species.

Approved objectives within the plan include:

- Open 300 miles of the main stem Susquehanna River above Sunbury, Pennsylvania including the lower West Branch and Chemung rivers to anadromous fish by 2004.
- Inventory tributaries, set priorities, and reopen 100-200 additional miles of blocked habitat to anadromous fish (mostly herring) through dam removals and fish passage development by 2006.
- Work with the CBP Fishery Management Planning and Coordination Workgroup to develop appropriate criteria for anadromous fishery exploitation in the Chesapeake Bay and its tributaries that meet all ASMFC requirements and do not compromise river restoration activities and timetables. Until such criteria are formalized, regulate harvest of American shad to maximize return of spawners to the Susquehanna River.
- Maximize passage of shad and river herring at lower river hydroelectric projects.
- Establish spawning populations of alewife and blueback herring in select lower river tributaries by 2010.
- Establish American shad stocks oriented to all suitable and available habitat within the basin at least to Binghamton, New York.
- Maximize survival of adult and juvenile alosines during downstream passage at lower river hydroelectric projects.
- Monitor abundance, stock characteristics and source (hatchery vs. wild) of adult American shad returning to the Susquehanna River and upper Bay.
- Monitor distribution of adult and juvenile alosines and characterize stock composition of juveniles within the Susquehanna River Basin.
- Ensure fishery agency, CBP and utility coordination, cooperation and communication, and generate and maintain public support for anadromous fish restoration in the Susquehanna Basin.

The management plan is currently under revision (February 2003) and a revised plan is expected by spring 2008.

10.7.2 Hatchery Evaluations

In an effort to restore American shad stocks in the Susquehanna River, fry stocking was initiated in 1875, but the report concluded that without a curb of the commercial fishing efforts, American shad stocks could not recuperate (Ferguson and Downes 1876). Despite this report, stocking resumed and even expanded to include other rivers such as the Chester, Choptank, and Bush rivers (Mansueti and Kolb 1953). Stocking of the Susquehanna River continued annually with sporadic numbers through the late 1940s and 1950s, including over 2 million American shad stocked in the Susquehanna River in 1948 (Mansueti and Kolb 1953).

Despite billions of juvenile shad stocked coastwide during the latter part of the 1800s and the first half of the 1900s, shad populations continued to decline. Mansueti and Kolb (1953) concluded that shad hatcheries were not effective in restoring American shad stocks, although they noted that no objective studies had been done to evaluate the success of shad hatcheries or the survival of stocked fry. They heralded the end of over a half-century of coastwide shad culture when they stated that: "In recent years no competent fishery biologist has advocated the stocking of shad fry as a successful rehabilitory measure."

It is important to note that the goals of the early shad hatcheries were to sustain commercial fisheries in the face of loss of habitat due to dam construction, water quality degradation, and largely un-regulated fishing mortality. Early hatcheries were not capable of counteracting these severe assaults on the fisheries, but modern hatcheries have more modest goals. The goals of modern hatchery programs are to restore severely depleted populations to a level where natural reproduction will replace hatchery production. Today, hatchery efforts are accompanied by regulations that limit fishing mortality and efforts to enhance or restore habitat and protect water quality. Enhancement of shad stocks by release of hatchery fish has been clearly demonstrated to be a useful tool, when used as part of a comprehensive restoration program (Hendricks 1995, 2003).

The development of tetracycline otolith tagging has permitted critical evaluation of hatchery effectiveness. The first successful application of tetracycline (OTC) marking of American shad larvae occurred at the Van Dyke Hatchery in 1984. Marking on a production basis began in 1985 but was only marginally successful due to the low concentration of OTC used (25-50 ppm, Hendricks *et al*. 1986). In 1986, OTC concentration was increased to 200 ppm and 97.8 percent tag retention was achieved (Hendricks *et al*. 1987). Monitoring of juveniles for hatchery contribution began in 1986. Hatchery juveniles dominated the catch in most years with the exception of 1991, 1993, 1996 and 2001(Table 10.3; Figure 10.3). Maximum wild contribution was in 1993 when 61% of the lift net and 80% of the haul seine juveniles were wild. Monitoring of pre-spawn adults for hatchery contribution at Conowingo Dam began in 1989. Adult shad returning to Conowingo Dam have been predominately hatchery (Table 10.4; Figure 10.4). Hatchery contribution averaged approximately 80% for 1989 to 1995, decreased to 29% in 1998, and then increased to an average of 68% for 2001 to 2005. The increase in wild adult returns during 1996 to 2000 was encouraging although short-lived.

Pennsylvania FBC stocked American shad below Conowingo Dam from 1985 to 1993. Maryland DNR stocked American shad into the Susquehanna River and Susquehanna Flats from 1990 to 1996 and ceased doing this once abundance reached a level that was thought to be self-sustaining. During these years, hatchery fish averaged 32 percent of the juvenile shad captured in haul seines on the Susquehanna Flats (Table 10.4). Since 1998, the percent of hatchery origin juvenile American shad has been less than one percent from the Susquehanna Flats.

10.7.4 Upstream Fish Passage Efficiency

Fishway counts are provided in Tables 10.2 and 10.5. The number of shad captured in the Conowingo Dam fish-lifts increased exponentially from 1972, peaked in 2001, and has declined since 2001 (Figure 10.5). Hatchery-origin and wild shad followed the same trend, with hatchery shad outnumbering wild shad by 1.6 to one during 1989 through 2004.

Mean apparent fishway efficiency (the number passed divided by the number passed at the next fishway downstream) is 30% for Holtwood Dam, 74% for Safe Harbor Dam and 14% for York Haven Dam (Table 10.5; Figure 10.6). Combined fishway efficiency is 3 percent and does not include Conowingo Dam. Clearly, too few shad are reaching the spawning grounds above York Haven Dam for successful restoration (Table 10.6). Fishway efficiency must be improved to achieve a self-sustaining population.

A hypothetical stock-recruitment analysis is presented in Table 10.6. Assuming fecundity of 200,000, 50% ripening of eggs, 90% fertilization, 70% hatch of fertilized eggs (long-term average of hatchery data), 25% survival from hatching to 10 mm, 26% survival from 10 to 13 mm (Crecco *et al*. 1983), and return of one of every 320 larvae stocked (see discussion below) we can vary fishway efficiency to determine what efficiencies are required to exceed replacement and grow the population. Note that increasing efficiency at Holtwood to 100%, without addressing York Haven efficiency does not achieve replacement. Increasing efficiency at York Haven to 79 percent, without addressing Holtwood efficiency will just achieve replacement. Based on this analysis, we recommend a goal of 80 percent efficiency at both Holtwood and York Haven Dams. This will return 6.1 adults for each male and female, permitting population growth and a cushion for years with high flow and poor fish passage.

Fish passage efficiency appears to be inversely related to river flow. At higher flows, the volume of attraction water exiting the fishway constitutes a smaller portion of total river flow and shad appear to have difficulty in finding the fishway. There appears to be a curvilinear relationship between efficiency at Holtwood and mean flow during May, the month during which most shad pass (Figure 10.7). Increased fish passage at Holtwood Dam during lower flows is also depicted in Figure 10.8.

Safe Harbor Dam not only exhibits good fishway efficiency, but also passes fish with little delay. In 1999, peaks in fish passage for Safe Harbor Dam followed one day after peaks in passage at Holtwood Dam (Figure 10.9). Thus, shad passed Holtwood Dam, traveled seven miles through Holtwood Reservoir and passed Safe Harbor Dam the next day.

10.7.5 Downstream Turbine Passage

The earliest known turbine mortality study done at Conowingo Dam was by Whitney (1961) who tagged shad above and below Conowingo Dam during three consecutive years (1958-1960) and compared recapture rates. Recaptures came from the commercial fishery and were corrected for turbine mortality based on American shad tagged below Conowingo Dam. He found turbine mortality (includes shad passed over the spillway) to be 90.3 percent in 1958. No mortality estimates were done in 1959 because of poor recapture rates for fish tagged above and below Conowingo Dam. It should be noted that his mortality rates were based on recapture rates one-year later and estimated rates of survival. These results are suspect because they contrast with more recent results (see below) and because many of the fish planted above the dam may have exhausted their energy reserves in the reservoir prior to exiting the system and may have suffered mortality regardless of turbine survival.

Susquehanna River turbine passage survival studies for adult American shad have been performed only at Safe Harbor Dam. One-hour survival of adult American passing through turbines at Safe Harbor Dam was 87.0% for a mixed-flow turbine and 89.7% for a Kaplan turbine (Normandeau Associates 1998). This was not significantly different, so the data were pooled resulting in an estimated 88.3 percent survival (90% CI = 84.2% - 91.7%). Twenty-four to forty-eight hour survival was 86.2 percent. We assume survival at Conowingo Dam would be similar to Safe Harbor because the new turbines are similar. Telemetered adult shad moving downstream from other studies in the 1980s exhibited about 50 to 60 percent survival at York Haven (though most fish likely spilled) and much less for Holtwood. The numbers of telemetered fish at Holtwood were too few to draw many conclusions but it is assumed that adult American shad cannot successfully pass through the turbines at Holtwood Dam.

One-hour survival of juvenile American shad passing through a Kaplan turbine, operated at 55 to 56-wicket gate opening, at Conowingo Dam was 94.9% (RMC Environmental Services, Inc. 1993). Forty-eight hour survival was 92.9 percent.

One-hour survival of juvenile American shad passing through Francis turbines at Holtwood Dam was 89 percent (Mathur and Heisey 1993). Twenty-four hour survival was 78 percent.

One-hour survival of juvenile American shad passing through turbines at Safe Harbor Dam was 98%, 97.8% and 98.9% for Kaplan, mixed flow (unvented) and mixed flow (vented) turbines, respectively (Heisey *et al*. 1992). Forty-eight hour survival was 98%, 100%, and 67% (adjusted for controls) for Kaplan, mixed flow (un-vented) and mixed flow (vented) turbines, respectively.

One-hour survival of juvenile American shad passing through turbines at York Haven Dam was 92.7% and 77.1% for a vertical shaft Kaplan (Unit 3) and a dual vertical shaft Francis turbine, respectively (Normandeau Associates 2002). Adjusted forty-eight hour survival exceeded the one-hour survival and was not utilized.

Operational strategies for maximizing turbine survival of out-migrating juvenile American shad are in place at all four Susquehanna River hydroelectric projects. At Conowingo, the downstream juvenile plan calls for preferential use of low mortality Kaplan or mixed flow turbines during the hours of 1700 to 2300 during October and November (RMC Environmental Services, Inc. 1994). When river flows exceed 40,000 cubic feet per second, higher mortality Francis turbines may be operated. This plan ensures that turbine passage survival is greater than 94 percent at Conowingo Dam.

The downstream juvenile protocol at Holtwood requires selective evening use of single-runner Francis units closest to the eastern end of the powerhouse where fish historically gather and spilling at the trash sluice to draw fish from outside the skimmer wall or along the face of the dam.

The juvenile downstream passage protocol at Safe Harbor requires that the project selectively utilize one or more of the large new units (9-12) at full capacity during evening hours in October and November.

The juvenile downstream passage protocol at York Haven Dam provides for monitoring the forebay to determine when out-migrating juveniles arrive at the project and starting "Downstream Operation" when juveniles arrive. Downstream Operation begins each evening at sunset and continues until about 2330 hours. Downstream Operation includes: turning on temporary lighting at the trash sluiceway and opening the sluiceway, preferentially operating only Units 1-6 when river flow is insufficient for operation of any of the remaining units, operating Units 7-20 only when river flow exceeds the hydraulic capacity of available Units 1-6, and ceasing downstream operation at the end of the run, based on monitoring and sampling in the forebay to determine when the juvenile shad emigration has ended for the season.

10.7.6 Trap and Transport

Transport of out-of-basin adult shad into the Susquehanna River occurred between 1980 and 1987 (Table 10.2). Radio telemetry studies of adult shad transported from the Hudson River to the Susquehanna River demonstrated that the transported fish moved rapidly downstream 260 to 300 km to the York Haven and Safe Harbor Dam forebays where they exhibited reluctance to move through the trash racks (RMC Environmental Services 1986). In addition, this program produced few juvenile shad and was discontinued.

Transport of pre-spawn adult American shad from the Conowingo Dam fish-lifts occurred from 1982 to 1996 for the West Fish-lift and from 1991 to 1996 for the East Fish-lift (Table 10.2). Over 210,000 pre-spawn American shad were transported upstream but was discontinued in 1997 when fish passage facilities at Holtwood and Safe Harbor Dams became operational.

10.8 AGE

Maryland DNR has collected scale samples from American shad through fishery-independent sampling in the Conowingo Dam tailrace since 1980. Scales were removed below the insertion of the dorsal fin. A minimum of four scales per fish were cleaned, mounted between two glass slides, and read for age and spawning history using a Bell and Howell MT-609 microfiche reader. The scale edge was counted as a year-mark since it was assumed that each fish had completed a full year's growth at the time of capture. Annuli were identified using Cating's (1953) method and the same reader has aged American shad in Maryland since 1980. Repeat spawning, defined as the freshwater spawning mark on the American shad scale, was recorded for each fish.

Pennsylvania collected scales and otoliths from adult American shad randomly sampled from the fish-lifts at Conowingo Dam. Three to five scales from each fish were cleaned and pressed sculptured side down on acetate sheets (1.27 mm thick) by using pressure (5000 psi) and heat (100° C) for five minutes. A single reader read the scales using Cating's method and traditional annuli counts.

Sagittal otolith pairs were extracted with the first otolith mounted whole in rod-building epoxy or mineral oil and aged by a single reader using a dissecting microscope equipped with a video camera and monitor. The second otolith was mounted on a microscope slide and ground on both sides to produce a thin sagittal section (Hendricks *et al*. 1991). A single reader then examined it with an epi-fluorescent microscope with a 100W mercury vapor lamp and an FITC (fluorescein isothiocyanate) fluorcluster under UV light for the presence and pattern of tetracycline marks.

Length frequency of male and female American shad captured in the Conowingo Dam fish-lifts is presented in Tables 10.7 and 10.8. For 1995 to 2000, total length was estimated from fork length according to TL = FL*1.117 + 6.674. This relationship was derived from some 554 specimens captured in the Conowingo Dam fish-lifts during 2001 to 2003 (R^2 = 0.989). Age frequency for hatchery and wild male and female shad captured in the Conowingo Dam fish-lifts is presented in Table 10.9.

Mean length and weight of American shad males, females, and sexes combined are presented in Table 10.10. Mean weight appeared to increase from 1999 to 2002 (Figure 10.10) though this is less apparent when looking at mean length (Figure 10.11). Mean total length-at-otolith-age and scale-age for males and females is presented in Tables 10.11 and 10.12. Mean total weight-at-otolith-age and scale-age for males and females is presented in Tables 10.13 and 10.14.

Age structure and repeat spawning for otolith and scale ages are presented in Tables 10.15 through 10.20. Maximum age was eleven for both otoliths and scales. The maximum number of repeats was four. Repeat spawning was highest in 2002 and 2005. Ageing methods have not been validated for either otoliths or scales for the Susquehanna River.

10.9 FISHERY DESCRIPTIONS

10.9.1 Commercial Fisheries

Evidence suggests that Native Americans depended partially on fish for food and caught shad in large quantities long before European colonists arrived in North America (Meehan 1897; Gay 1892). The Indians used many methods including "weirs and traps; seines, gill and scoop nets; spears, bows and arrows and gigs; hand, pole and set lines" (Meehan 1897). In the latter half of the 18^{th} century, colonists from Connecticut settled near what is now Wilkes-Barre and established commercial and subsistence seine fisheries for shad. The Pennsylvania government disputed rights to these fisheries. These disputes lasted 30 years and were given the term Yankee-Pennamite War (or "shad" wars), which were characterized by the burning of buildings, plundering of produce, and destruction of the seines (Meehan, 1897). Eventually, Connecticut gave up its claim to the northern tier of Pennsylvania. Yankee settlers were allowed to stay and about forty permanent seine fisheries were established between Northumberland and Towanda (Gay 1892).

Shad were a staple and an integral part of the local economy. Gilbert Fowler of Berwick wrote in 1881: "The Susquehanna shad constituted the principal food for all the inhabitants. No farmer, a man with a family, was without his barrel of shad the whole year round" (Gay 1892). The fisheries in the North Branch were extremely economically valuable and the fish were fantastically abundant. The annual commercial value of the North Branch shad fisheries was estimated at $12,000 with an estimated catch of 150,000 fish.

While North Branch fisheries were more famous, it should be noted that many shad seine fisheries simultaneously operated in the West Branch, the Juniata River, and on the lower river in Pennsylvania and Maryland during the early decades of the 1800s. Maryland watermen also began using gill nets prior to 1830 (Gerstell 1998), and their harvest was of great concern to Pennsylvania fishermen.

The early settlers relied on American shad for subsistence but, as haul seines became popular, the fishery evolved from a subsistence fishery to a commercial fishery. Large haul seines, up to 2,500 yards in length, pulled by many men, horses, or even steam engines (Mansueti and Kolb 1953) were the most effective gear until the early 1800s when gill nets were introduced.

The importance of the shad fisheries of the Chesapeake Bay cannot be minimized. From the earliest colonists to the Revolutionary War, American shad were a significant part of the local diet. Initially a subsistence fishery, American shad stocks were quickly exploited for profit during the Revolutionary War, especially if salt was available for preservation. It is thought that American shad stocks were generally stable during the early 1800s because of haul seine limitations. Where haul seines could not be used because of stream morphology, gill nets became the gear of choice. American shad could be targeted on the spawning grounds and eventually shad landings decreased because of overfishing, dam construction, pollution, and capture of YOY (Walburg and Nichols 1967).

Uhler and Lugger (1876; cited in Mansueti and Kolb 1953) noted a decline in shad catches in relation to the previous 50 to 60 years and expressed concern that overfishing was occurring. The upper Bay region (from Swan Point to the mouth of the Susquehanna River) became not only the primary shad fishery for the upper Chesapeake Bay, but also the most valuable drift-net fishery for shad south of the Delaware Bay (Stevenson 1899).

The American shad fishery was driven by availability and price even in the late 1880s and once the market became saturated and prices fell, (average price was 25 cents per fish), fishermen no longer targeted shad (Stevenson 1899).

In 1835, gill nets were introduced into the Chesapeake Bay (Walburg and Nichols 1960), followed by pound nets in 1865 (Stevenson 1899). These gears allowed fishers to extend their operations into the Bay, where their haul seines were not effective (Mansueti and Kolb 1953). Pound nets were much more efficient, there was relatively more gear fished per person, and within ten years over 90 percent of landed shad came from these nets (Stevenson 1899). With pound nets, fishers could target shad before they entered freshwater and the open bay became the preferred area to fish, not the tributaries. By 1940, most of the upper river gill-net fisheries had been eliminated because of poor catches and poor market prices (Mansueti and Kolb 1953).

No commercial fishing for American shad has occurred in the Susquehanna River above Conowingo Dam since dam construction in the early 1900s. Commercial landings data for the Susquehanna River are presented in Table 10.21. Landings followed a decreasing trend until the commercial and recreational fisheries were closed in 1980.

Susquehanna Flats - Pound Nets

From 1980 to 2001, Susquehanna Flats pound nets were fished at the discretion of the commercial waterman (Table 10.22). In general, one to three nets were sampled two to four times per week from mid March to early May. When fished, pound net cribs were pursed; fish were dipped with a hydraulic lift onto a culling board and American shad removed. American shad in good physical condition were marked with T-bar anchor tags and released, but all fish caught were used in the catch estimation. In addition, heads of dead adult American shad were frozen for later otolith extraction and analysis. Hatchery raised American shad were differentiated from wild fish based either on the presence of oxytetracycline marks on the otoliths or otolith microstructure (Hendricks *et al*. 1994).

Annual relative abundance was estimated by calculating the geometric mean (based on a $\log_e$-transformation; Sokal and Rohlf 1981) CPUE of upper bay American shad collected in the "Rocky Point pound net." This net was used because of its longer time series and an observed variation in catchability between pound net sites. CPUEs from this net are presented in Figure 10.12.

Age Composition

American shad age structure from pound nets is presented in Table 10.23. In comparison to other gears used for adult sampling in the upper Chesapeake Bay by MD DNR, pound nets have continuously caught the largest and oldest fish.

10.9.2 Bycatch Losses

Bycatch of Susquehanna River American shad occurs in the Chesapeake Bay and ocean fisheries. The extent of this bycatch is unknown, but has been documented in the Virginia portion of the Chesapeake Bay. Otolith samples of adult American shad taken from pound nets in 2004 and 2005 were analyzed for tetracycline marks. Susquehanna River source hatchery fish represented 2% (N = 19) in 2004 and 3% (N = 113) in 2005. Other tagged fish (8% in both years) exhibited a hatchery mark that could have been from the Susquehanna River or Virginia Rivers.

Maryland DNR has tagged adult American shad from two locations in the upper Chesapeake Bay: the Conowingo Dam tailrace from hook and line (1980-present) and Susquehanna Flats from pound nets (1980-2001). Tag returns from pre-spawned tailrace tagged fish have always been from tailrace anglers and the lifts; however, pre-spawned adult American shad tagged from pound nets on the Susquehanna Flats have been reported in the Delaware River and Bay. Few post-spawned fish have been reported as captured as down-runners from Maryland's commercial fishery but it is likely that commercial watermen do not report tagged American shad. Since 1980, there have also been several (post-spawned) tagged American shad reported captured in other East Coast Fisheries but because of low sample size, no analysis of these data have been preformed.

10.9.3 Recreational Fisheries

The earliest law concerning anglers in Maryland appears in a 1944 newspaper article (April 20 1944, *Baltimore Sun*) stating a limit of ten American shad. In the late 1950s, when creel surveys were initiated in Maryland, most rivers had few American shad available to sport anglers. Therefore, creel surveys in Maryland for American shad have concentrated on the Susquehanna River because of the remnant population of fish available to anglers and accessibility.

Mansueti and Kolb (1953) provided data on recreational shad anglers in the 1950s, noting that the first American shad caught by hook and line was in 1930. Sport fishing for shad quickly grew in popularity and within twenty years it was the craze. Although no records exist to reconstruct CPUE, historically popular areas for shad fishing included Conowingo Dam tailrace and areas on the Potomac and Patuxent rivers. Whitney (1961) conducted a three-year recreational fishery study in the 10 miles below Conowingo Dam and noted over 500,000 man-hours were spent fishing annually. Most of the effort was from boat anglers. During April through June, the peak of the American shad run in the river, an average of 13,000 American shad was harvested from 1958 to 1960 by surveyed anglers. From this survey, Whitney (1961) concluded that less than 0.2 American shad were kept per hour, but these included all anglers, not just those targeting American shad. If these data are extrapolated for the number of American shad harvested per angler for May, 8.2 American shad were harvested per angler per day or 0.7 per hour. This is a conservative estimate since most anglers in the tailrace were targeting catfish and not shad (Whitney 1961).

Carter (1973) conducted a spring creel survey in the Susquehanna River below Conowingo Dam in 1970. It was a non-uniform probability survey at thirteen locations and involved 34 dates. This survey interviewed 1,607 anglers who fished 8,314 hours. These anglers caught 694 American shad or 0.43 shad per angler (Table 10.24). No associated effort from anglers targeting American shad could be found from Whitney's (1961) survey to Carter's (1973) creel survey and no significant changes in the American shad stock occurred when looking at total spring fishing pressure. Carter (1973) estimated that 110,000 man-hours were spent fishing in the tailrace annually during the early 1970s and that American shad catch was low.

From 1980 to 1985, an annual spring creel survey was conducted in the Conowingo Dam tailrace (Weinrich *et al*. 1986). In general, few catches of American shad were reported, reflecting both the low abundance of shad and the harvest restriction recently passed. Over 1,100 anglers were surveyed annually, fishing 4,500 hours, with an estimated annual total catch of 175 American shad (Table 10.24). Many of these anglers targeted other species, so comparisons to other studies warrant caution. In general, the catch-and-release fishery for American shad remained poor during these six years, resulting in CPUEs averaging 0.39 shad per hour.

RMC Environmental Services (Drumore, Pennsylvania) conducted a creel survey in 1979 (cited in Carter 1983). These studies showed a dramatic decrease in the American shad catch-per-hour from 1970 to 1979, suggesting a decline in the American shad population.

In 1999, MD DNR initiated a logbook survey to estimate CPUE of American shad in the Conowingo Dam tailrace and has continued this survey annually. Anglers voluntarily provided MD DNR with daily catch records of American shad including location, hours fished, and species composition. In addition, MD DNR has conducted a roving creel survey below Conowingo Dam on the Susquehanna River since 2001. Table 10.24 presents a summary of these creel surveys showing significant increases in catch rates from 1958 to 2003 with slightly decreased catch rates since 2003. Angler catch rates reflected the relative abundance index in the tailrace and the Conowingo Dam lift catches. These data show an increase in adult American shad catch rates from Susquehanna River anglers and is attributed to the significant restoration efforts and the harvest moratorium. The declines in catch-per-angler-hour since 2003 reflect the decrease in abundance in the tailrace.

At present, no harvest of American shad is permitted in Pennsylvania waters of the Susquehanna River. There is a very limited recreational catch-and-release fishery, concentrated below York Haven Dam and Dock Street Dam (a low head, partially breached dam at Harrisburg). This fishery operates only when sufficient numbers of fish pass Safe Harbor Dam. No data have been collected from this fishery.

10.10 FISHERY-INDEPENDENT SURVEYS

10.10.1 Adult Catch Data

There are two sources used to collect American shad for biological data from fishery-independent surveys in the Susquehanna River: the West Fish-lift at Conowingo Dam and Conowingo Dam tailrace (sampling by hook and line).

The west fish-lift at Conowingo Dam has been used to monitor adult abundance and collect adult shad for biological information since 1972. This lift operates in the traditional manner except that fish collected are dumped into a large steel trough where the catch is hand-sorted by biologists. Target species are enumerated, sampled, and then either released back into the Conowingo Dam tailrace, used for tank-spawning, or transported upstream, as dictated by restoration plan requirements. The Conowingo East Fish-lift, the fish-lifts at Holtwood and Safe Harbor Dam, and the vertical slot fishway at York Haven Dam are fish passage facilities. Each was constructed with a viewing window where a trained biologist counts target species as they exit the fishway and enter the upstream reservoir. Floy-tagged fish collected in the Conowingo Dam West Fish-lift can be examined for the tag number. Floy-tagged fish observed in the other fishways can only be identified by the color of the tag.

Adult American shad were collected for biological information in the West (1972-present) or East fish-lifts (1991-1996) at Conowingo Dam (river km 16.1). Every 50th or 100th shad to enter the lifts was sacrificed to ensure a representative sample, although mortalities and fish in poor condition have sometimes been substituted for the random sample. Scales were collected from the area below the dorsal fin and above the lateral line, and stored dry in labeled envelopes. Specimens were decapitated and the heads were frozen prior to otolith extraction and mark detection.

Fish-lift catches at Conowingo Dam (Table 10.2) were extremely low, averaging 180 shad during the first ten years of operation (1972-1982). During the 1980s and 1990s fish-lift catches increased geometrically, reaching 200,000 American shad in 2001. Since 2001, fish-lift catches have declined to a low of 73,000 in 2005. Hatchery and wild shad exhibited these trends (based on otolith tagging; Figure 10.5). Annual estimates of fish-lift geometric mean CPUEs have decreased significantly since 2001 (R^2=0.75, P=0.026; Figure 10.13).

In 1980, MD DNR targeted the Susquehanna River American shad stock for research and restoration. The purpose of this research was to determine American shad abundance in the Susquehanna River and Susquehanna Flats and to characterize the existing stock. This area was chosen because of the remnant stock, catch-and-release fishery, historical records, restoration efforts by Pennsylvania, and the recent addition of a fish-lift at Conowingo Dam. MD DNR initiated five projects in the Upper Chesapeake Bay in 1980:

1. Conowingo Dam tailrace tagging in 1984
2. Collecting characterization data from American shad
3. Extensive creel survey in the Susquehanna River and Susquehanna Flats
4. American shad juvenile survey and
5. Literature review

American shad were collected by angling from the Conowingo Dam tailrace two to five times per week from late April through late May during 1984 to 2005. Landed fish were sexed and measured for fork length. Scales were removed to determine age and spawning history. American shad in good physical condition were tagged with a numbered T-bar anchor tag in the dorsal musculature posterior to the dorsal fin and released. Annual color-coding by area and gear and unique numbering allowed individual fish to be identified if the fish was handled.

Recaptures were obtained from shoreline anglers and from the Conowingo Dam fish-lifts. A MD DNR Fisheries Service hat was given to anglers as a reward for returned tags. Most returns came from the fish-lifts at Conowingo Dam. Estimates of hook and line geometric mean CPUEs increased significantly from 1.07 in 1984 to 15.94 in 2002 (R^2=0.78, P< 0.001; Figure 10.13), but have since decreased.

10.10.2 Age Composition and Repeat Spawning Marks

Mean weight (Figure 10.10), mean length (Figure 10.11), and mean age (Figure 10.14) of adult shad captured at Conowingo Dam all exhibit an increasing trend over time. In addition, hatchery males and females (Figure 10.14) are often older than wild fish, perhaps due to genetic differences associated with the egg sources for hatchery fish.

Age composition for Conowingo Dam tailrace hook and line sampled American shad is presented in Table 10.25. In general, ages four and five are the most prevalent fish in the samples but American shad are not fully recruited to the spawning population until age seven, as shown with the freshwater spawning mark not present on all seven year-old fish.

Since there may be errors in ageing American shad (McBride *et al*. 2005), freshwater spawning marks were used as an indicator of previous spawning. If the number of virgin fish in one year is regressed against the number of repeat spawners the following year, there was a strong correlation (R^2=0.60, P= 0.003).

10.10.3 Juvenile Catch Data

In Pennsylvania, juvenile American shad were collected by haul seine and lift net to develop an index of abundance. Haul seining in the lower Susquehanna River was scheduled once each week beginning mid-July and continuing through October. Sampling was conducted in the Columbia-Marietta area, in the riverine area just above Lake Clarke (Safe Harbor Reservoir) because this location has been very productive for both wild and hatchery origin juvenile shad. Sampling consisted of six hauls per day beginning at sunset and continuing into the evening with a net measuring 400 ft x 6 ft with 3/8 inch stretch mesh.

Lift-net sampling was conducted at the Holtwood Dam inner forebay using a fixed 8-ft square lift-net beginning in mid-September and continuing every three days through early December. Sampling began at sunset and consisted of 10 lifts with a 10-minute interval between lift cycles. The lift net was placed on the north side of the coffer cell in the inner forebay. A lighting system was used to illuminate the water directly over the lift net.

Sub-samples of up to 30 juveniles per day were retained for otolith analysis from haul seine and lift-net collections. Samples were returned to the PFBC's Benner Spring Fish Research Station for analysis of otoliths for tetracycline marks.

Long-term CPUE for juvenile American shad is available for lift-net (Table 10.26) and haul seine collections (Table 10.27). Unfortunately, data for individual lifts and hauls are not available prior to 1995 for lift netting and prior to 1997 for haul seining. As a result, geometric means (GM) cannot be computed for those years. Combined daily catch for each gear is available and was used as a surrogate to compute GM means (Tables 10.26 and 10.27). Because the Holtwood dam lift net collects juvenile shad during the directed out-migration, area under the curve (AUC) measures of juvenile abundance were used instead of GM mean catches.

A plot of GM combined daily CPUE versus GM individual lift CPUE is shown in Figure 10.15. A significant correlation exists (R^2 = 0.72, P= 0.004) between the two measures of abundance. Upon inspection of the raw data, it is clear that the discrepancy between the two measures of CPUE for lift net is due to extreme variation between individual lifts on several collection dates. For example, individual lift catches varied from six to 200 fish on November 11 and from one to 155 fish on November 14. GM combined daily CPUE has the advantage of more than doubling the span of the index. The AUC measure of juvenile abundance for lift net sampling is plotted against GM combined daily CPUE in Figure 10.16. There is a significant correlation between the two measures of juvenile abundance (R^2 = 0.81, *P*= 5.7E -08). Henceforth, AUC will be used as the sole index of juvenile abundance for lift-net sampling.

A plot of GM combined daily CPUE versus GM individual haul CPUE is shown in Figure 10.17. For haul seining, there is an extremely strong correlation (R^2 = 0.99, P= 1.9^{-13}) between the two measures of CPUE. GM combined daily CPUE will be used as an index of juvenile abundance for haul seine sampling.

For analysis, juvenile abundance indices (JAI) are partitioned into hatchery and wild based on otolith tagging (Tables 10.26 and 10.27). If JAIs for lift net and haul seine are representative of juvenile abundance we might expect correlations between:

1. Abundance of hatchery juveniles and the number of larvae stocked,
2. Abundance of wild juveniles and the number of adult shad transported or lifted above Safe Harbor Dam or both Safe Harbor and York Haven dams,
3. Total adult recruitment of a cohort to Conowingo Dam and the American shad JAI for that cohort,
4. Recruitment of a cohort of adult hatchery shad to Conowingo Dam and the abundance of hatchery juvenile shad for that cohort,
5. Recruitment of a cohort of adult hatchery shad to Conowingo Dam and the number of larvae stocked for that cohort, and
6. Adult returns in year Y at age t and the JAI in year Y-t for each age t.

The relationship between the number of hatchery larvae stocked and relative abundance of hatchery juveniles is depicted for lift-net AUC and haul seine CPUE in Figures 10.18 and 10.19, respectively. No relationship exists for either lift net or haul seine.

The relationship between the number of adult shad transported or passed above Safe Harbor Dam and abundance of wild juveniles is depicted for lift net AUC and haul seine CPUE in Figures 10.20 and 10.21, respectively. A relationship is not apparent for lift net AUC (R^2 = 0.06, *P*= 0.37). A significant relationship is present for haul seines (R^2 = 0.28, *P*= 0.03).

The relationship between the number of adult shad transported or passed above York Haven Dam (where most of the historical spawning habitat exists) and abundance of wild juveniles is depicted for lift-net AUC and haul seine CPUE in Figures 10.22 and 10.23, respectively. Significant relationships exist for both lift net and haul seine. Haul seine CPUE correlates better to the number passed than does the lift-net AUC.

The relationship between the abundance of juvenile American shad (hatchery and wild fish included), as represented by lift-net AUC and haul seine CPUE, and total recruitment of that cohort to the Conowingo fish-lifts is depicted in Figures 10.24 and 10.25, respectively. No significant relationship was detected for both lift net and haul seines.

The relationship between abundance of juvenile hatchery American shad, as represented by hatchery lift-net AUC and hatchery haul seine CPUE, and recruitment of hatchery fish for that cohort to the Conowingo fish-lifts is depicted in Figures 10.26 and 10.27, respectively. No relationship is apparent for lift net or for haul seines (R^2 = 0.13, *P*= 0.30).

The relationship between the number of American shad larvae stocked and adult cohort recruitment of hatchery shad to the Conowingo fish-lifts is depicted in Figure 10.28. No relationship is apparent ($R^2 = 0.01$, $P= 0.73$). The year 1997 appears to be an outlier.

The relationship between adult recruitment in year Y at age t and the JAI in year Y-t for each age t is plotted in Figures 10.29 to 10.38. Positive relationships for these variables would indicate correlation between juvenile abundance and adult recruitment resulting from those juveniles t years later. Lift-net AUC and recruitment at ages three and four were negative, but not significant. Relationships between lift-net AUC and recruitment at ages five, six, and seven were positive, but not significant. There was a positive relationship between haul seine CPUE and recruitment-at-age for each age, three through seven, but only the relationships for ages six and seven were significant. There were other variables which were expected to be related, but which did not exhibit significant correlations: larvae stocked vs. JAI for hatchery fish, JAI vs. total recruitment by cohort, JAI (hatchery) vs. hatchery recruitment by cohort, and larvae stocked vs. hatchery recruitment by cohort. The lack of a correlation between the JAIs and various measures of recruitment for both lift net and haul seine suggest that:

1. Our JAIs may not be good measures of juvenile abundance
2. Something is happening in the ocean to over-ride the relationship between juvenile and adult abundance
3. Ageing errors in adults mask the relationship
4. Inter-annual variation in Conowingo fish-lift efficiency is sufficient to mask the relationship

The lack of a relationship between the number of larvae stocked and the JAI (both lift net and haul seine) for hatchery fish could result from ecological factors (predation, competition, prey availability, disease, etc.) or it could be additional evidence that the JAI may not, in fact, be representative of juvenile abundance.

The significant relationship between the number of adult shad transported or passed above Safe Harbor Dam and the JAI for haul seine suggests that the haul seine JAI may be a better index of juvenile abundance than the lift-net JAI, which did not exhibit a significant relationship. Haul seine JAI was also better than the lift net JAI, in the strength of the relationship (R^2) with number of adults transported above York Haven Dam, total recruitment by cohort, and hatchery recruitment by cohort.

The data suggest that better juvenile production is achieved by fish that pass York Haven Dam than by those which pass Safe Harbor Dam only. Relationships between the number of adults passed and the JAI were stronger (higher R^2, lower P) for fish passing York Haven than for those passing Safe Harbor only.

In summary, three significant regressions were generated by lift-net or haul seine indices of abundance: the relationship between number of adult shad transported or passed above Safe Harbor Dam and haul seine CPUE for wild juvenile fish, the relationship between number of adult shad transported or passed above York Haven Dam and lift-net juvenile AUC for wild fish, and the relationship between number of adult shad transported or passed above York Haven Dam and haul seine CPUE for juvenile wild fish. There was no correlation between number of hatchery fish stocked and the two hatchery juvenile indices.

On the Susquehanna Flats, seven permanent sites and six auxiliary sites have been sampled annually since 1959 by Maryland's juvenile striped bass recruitment assessment. Juvenile American shad indices for these locations (1959-2005; Figure 10.39) have increased exponentially since 1980 ($R^2 = 0.32$ $P<0.001$).

10.11 ASSESSMENT APPROACHES AND RESULTS

10.11.1 Index-Based

Conowingo Dam fish-lift catch, age composition, and origin (hatchery vs. wild), by year, are presented in Table 10.28. Percent virgin fish captured in the Conowingo Dam fish-lifts is presented in Table 10.29. Yearly fish-lift catch at Conowingo Dam is partitioned by age and percent virgin to estimate recruitment of virgin shad by year and cohort (Table 10.30). Only virgins are used to avoid double counting. The catch is further partitioned by origin to estimate recruitment, by cohort, of hatchery larvae to the Conowingo Dam fish-lifts (Table 10.31). Since we know the number of hatchery larvae stocked each year, we can estimate survival. Survival from stocking to maturity ranged from 1.47% for the 1996 cohort to 0.14% for the 1986 cohort. Inverting survival gives the number of larvae required to return one adult to the Conowingo Dam fish-lifts. For the 1996 cohort, 68 larvae were required to return one adult, while 724 larvae were required to return one adult for the 1986 cohort. The mean number of larvae required to return one adult virgin shad to the Conowingo Dam fish-lifts was 339.

Table 10.32 is an example of an iterative method to estimate survival from stocking to maturity at whatever age maturity occurs. Estimation of annual survival (and thus mortality) can be accomplished by assuming constant survival, some value of fish-lift efficiency to account for surviving fish that were not captured by the lifts, and working backward from the known recruitment. We start by taking the known recruitment-at-age and dividing it by the assumed lift efficiency (e.g., cell G11, Table 10.32). Dividing by annual survival (cell B15) gives us the number of these fish alive at maturity minus one year. We continue working backward, applying the annual survival on a yearly basis, to estimate the number of shad alive at age-0 that would have been required to give us the known recruitment-at-maturity, for each age at which shad matured. The sum of age-0 shad (cells B4 to G4) represents the total shad alive at age-0 for that cohort and must equal the number stocked. Using the "goal seek" function of EXCEL to set cell B13 equal to cell B14 by changing cell B15, we can iteratively choose the value of annual survival that will result in the known recruitment, starting with the known number of shad stocked (see Table 10.33 for an example). Results of mortality estimates using the hatchery method at various assumed lift efficiencies are given in Table 10.34.

Because all American shad moving upriver in the Susquehanna River must use the East fish-lift at Conowingo Dam, the counts at that fishway are the best tool available for stock assessment. Fish passage at Conowingo increased geometrically from 1980 to 2001, when 193,000 shad passed upstream (Tables 10.2 and 10.28; Figure 10.5). Since 2001, fishway counts have declined below 70,000 shad. Both hatchery origin shad and wild shad have exhibited the same trends, although hatchery shad have generally dominated the catch since 1990. Clearly, hatchery enhancement has had a positive impact on the population. The increase in abundance of wild fish can be attributed to lower fishing mortality resulting from Maryland's moratorium on harvest enacted in 1980. Natural reproduction above dams has been limited, but reproduction of hatchery fish below Conowingo Dam may have contributed to the population increases below Conowingo Dam. The cause of the decline in fish passage since 2001 is not known. The lack of predictive relationships between larvae stocked and cohort recruitment and between JAIs and cohort recruitment provide no help in understanding these trends.

10.11.2 Benchmarks, Total Mortality

Estimates of total mortality (Z) using the hatchery method are compared to estimates using catch curve analysis for repeat spawners using otolith and scale age in Table 10.35. A lift efficiency of 80 percent was chosen for comparison because Conowingo Dam is most like Safe Harbor Dam (long-term lift efficiency 76%) in terms of its height, its hydraulic capacity, and the fact that spill occurs only rarely. The catch curve method uses repeat spawners only, resulting in high mortality estimates as a result of spawning stress. Mortality estimates for the hatchery method are lower than those for the catch curve method despite the fact that the hatchery method assumes constant mortality over the life of the fish including the high mortality period during the first year. Note that the catch curve method results in highly variable mortality estimates compared to the hatchery method. This is likely a result of the relatively low frequency of repeat spawning, reducing the effective sample size and increasing the impact of each individual repeat spawner.

Since American shad do not fully recruit until age seven in the Maryland portion of the Chesapeake Bay, as detected by virgin fish, repeat spawning marks were used in place of age-structured analysis. Two methods were utilized to estimate total instantaneous mortality of American shad. Both methods were based on the number of repeat spawning marks and both were weighted by the annual CPUE. For the first method, total instantaneous mortalities (Z) were estimated by the $\log_e$-transformed spawning group frequency plotted against the corresponding number of times spawned, assuming that consecutive spawning occurred (ASMFC 1988):

$$\log_e (S_{fx} + 1) = a + Z * W_{fx},$$

where S_{fx} is the number of fish with 1,2,...f spawning marks in year x, a is the y-intercept, and W_{fx} is the frequency of spawning marks (1,2,...f) in year x.

The second method followed the natural logs of the spawning group frequencies over time (Repeat Spawning–Cohort Analysis). The Z-estimates calculated for these fish represents mortality associated with repeat spawning.

In the Conowingo Dam tailrace, mortality estimates from repeat spawning age groups is presented in Table 10.36. Age-based mortality estimates vary significantly and were highly influenced by recruitment and ranged from less than zero to greater than 2.0. Repeat spawning age-analysis had much lower total mortality estimates, in general, with less variance. This is explained by the minimizing the effect of recruitment and maturity and the increased number of points to determine slope of the line.

10.11.3 Models

Total number of tagged fish, total catch, and number of tagged American shad from Conowingo Dam fish-lifts were used to calculate annual relative abundance of spawning American shad (sexes combined) from 1984 to 2005 by using Chapman's modification of the Petersen estimate (MDDNR 1998; Table 10.37; Figure 10.40):

$$N_t = [(C_t+1)\,(M_t+1)] / (R_t+1),$$

where N_t was the relative population estimate, C_t was the total catch examined for marks in year t, M_t was the number of marked fish in year t, and R_t was the number of recaptured marked fish in year t. Confidence intervals (95%) for population index were derived using a Poisson distribution

(Ricker 1975). These estimates were divided by 1000. We assumed 3 percent tag loss based on Leggett (1976) and no hook and line mortality because of our selection criteria (Lukacovic 1998).

10.11.4 Results

Conowingo Dam tailrace tag-based indices of American shad rose steadily from 4 to 86 between 1984 and 1992, dipped to 33 in 1993, and then steadily increased to 962 by 2000 (Table 10.37). Estimates stabilized at about 570 in 2001 and 2002.

Using the constant survival and reporting Brownie model (based on Akaike's Information Criterion scores), survival was estimated to be 0.117 and therefore the resulting mortality rate would equal 2.14. This was considerably higher than mortality rates calculated by other methods (Tables 10.36).

10.11.5 Discussion

Our estimates of relative abundance in the Conowingo tailrace during 2001 through 2005 (≈ 690,000 American shad) fell within the range of the 1944 to 1952 population estimates for Maryland waters, excluding the Potomac River (Walburg 1955). Walburg (1955) estimated the biomass of American shad and m (conditional fishing mortality rate; Ricker 1975) from 418 shad tagged during 1952 (less 48 recaptures from Virginia and the Potomac River); these tag-based estimates were combined with commercial fishing effort data during 1944 to 1951 to estimate annual population biomass and m. We estimated that 96 percent of tags returned from Maryland's commercial fishery (189 of 197) in 1952 were from upper Chesapeake Bay and that biomass estimates for Maryland likely represented the upper Bay population. The mean estimate of American shad biomass in this portion of Maryland in 1952 was 1270 mt (95% CI = 1134-1497 mt; Walburg 1955). Biomass estimates ranged from 816-1043 mt during 1944 through 1949 to 1270-1361 mt during 1950 through 1952. American shad in the historic fishery typically averaged 1.9 kg (Richkus *et al*. 1995), so biomass estimates in the upper Bay, translated into abundance, would have ranged between 450,000 and 580,000 fish during 1944 to 1949 and 700,000-750,000 fish during 1950 to 1952.

Adult indices have increased during 1984 through 2001 and may be reflecting a large stocking effort (3,000,000-14,000,000 fry per year; Hendricks 2006). Hatchery fish returned in large numbers as adults and have typically been the majority in the fish-lifts operating in the tailrace since 1984, although at lesser frequency after 1996 (60-90% during 1985-1995 and 29-66% after 1995; Hendricks 2006). Rapid growth of the tailrace population between 1994 and 1999 coincided with the nadir of the coastal fishery (ASMFC 1998). The coastal American shad fishery has been closed since December 2004.

A substantial catch-and-release fishery for American shad has developed below Conowingo Dam (Lukacovic 1998), but the effect of this catch-and-release fishery should be minor. Short-term catch-and-release mortality in thirteen experiments at Conowingo Dam during 1998 was less than 1% (Lukacovic 1998); however, the impact on behavior and potential fish passage delay caused by catch-and-release was not studied.

10.12 BENCHMARKS

A benchmark value of Z_{30}= 0.62 was calculated for Chesapeake Bay region American shad stocks (See Section 1.1.5 for York River, Virginia).

10.13 CONCLUSIONS AND RECOMMENDATIONS

Susquehanna River American shad have made a remarkable recovery in the last 30 years. Annual Conowingo Dam fish-lift catches, tailrace population estimates, and hook and line CPUEs have increased exponentially. Fishways have now been installed at each of the four lower river hydro-dams. Natural reproduction has been documented in the Juniata River and in the main stem below Sunbury. Techniques for obtaining broodstock, spawning, hatching, feeding, tagging, and stocking larvae have been developed. Cohort analysis on hatchery-tagged fish has shown that survival of hatchery-reared larvae is as high as one percent. Hatchery-reared adult shad have been documented in the Conestoga River and West Conewago Creek. A popular catch-and-release fishery has developed below Conowingo Dam with anglers boasting of 100-fish days. The Susquehanna American shad stock appears well on its way to restoration, despite troubling recent (2002-2005) declines in run size.

Despite these major accomplishments, shad restoration on the Susquehanna River is not assured. Fish passage efficiency at Holtwood and York Haven Dams (30% and 14%, respectively) must be substantially improved (80%) for successful restoration. In addition, downstream fish passage mortality must be minimized to permit repeat spawning.

While the Holtwood Dam lift net provides ample specimens for otolith analysis, it may not be a suitable index of juvenile abundance. In addition, the operators of Holtwood Dam are considering re-developing Holtwood to double the hydraulic capacity, increase generating capacity, and reconfigure the forebay where the lift net is now deployed. If this happens, the lift-net site will be lost or at least modified, making inter-annual catch comparisons difficult. The lift-net index should be replaced with additional seine sites or with hoop nets fished in the boils below Holtwood Dam.

Recommendations:

1. Establish required performance measures for upstream passage efficiency and downstream passage survival at each of the four FERC licensed hydroelectric dams and require studies to document compliance. Current downstream passage efficiency should be determined.
2. Replace the Holtwood lift-net index with additional seine sites or with hoop net fished in the boils below Holtwood Dam.
3. Expand tank-spawning operation at Conowingo Dam to provide more Susquehanna River source eggs for the restoration program.
4. Initiate otolith analysis of American shad from the Conowingo Dam tailrace.
5. Utilize PIT tags to evaluate shad passage through existing fishways.
6. Determine the effects of peaking flow on reproductive success and survival of eggs and larval American shad below Conowingo Dam.
7. Conduct a tag mortality study for adult American shad using floy and PIT tags and a combination of these tags.
8. Conduct a high-reward tagging program to determine reporting rate, accurate recreational exploitation rates, and commercial bycatch.
9. Collect characterization data from all American shad captured from the West Fish-lift while continuing to sacrifice every 50^{th} or 100^{th} fish.

10. Determine the percent of hatchery marked American shad in Conowingo Dam's tailrace to determine if there is differential catchability from non-hatchery fish.
11. Verify the accuracy of scale and otolith ages and the freshwater spawning marks.

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Table 10.1 American shad eggs (millions) used in the Susquehanna River shad restoration program, by egg source.

	Location (collection source)													
Year	Hudson (Gill Net)	Delaware (Gill Net)	Susq. Conowingo (Tank Spawn)	Susq. Lapidum (Gill Net)	Susq. Muddy Run (Gill Net)	Susq. Lamar (Tank Spawn)	Connecticut (Gill Net)	Pamunkey (Gill Net)	Mattaponi (Gill Net)	James (Gill Net)	Savannah (Gill Net)	Columbia (Gill Net)	Potomac (Gill Net)	Total
1971				8.42										**8.42**
1972				7.10										**7.10**
1973				4.74			4.30	8.45	6.48				34.64	**58.61**
1974							0.53	9.75	6.80	19.20		8.18	5.56	**50.02**
1975								1.88		7.15		18.42	5.70	**33.15**
1976		4.10										54.80		**58.90**
1977							0.35	4.40	0.57	3.42		8.90		**17.64**
1978								6.90		10.11		0.00		**17.01**
1979								3.17		4.99		0.00		**8.16**
1980								6.73		6.83		0.00		**13.56**
1981								4.58		1.26		5.78		**11.62**
1982								2.03		1.25		22.57		**25.85**
1983	1.17	2.40						5.49		5.91		19.51		**34.48**
1984		2.64						9.83		0.74		27.88		**41.09**
1985		6.16						5.28		2.05		12.06		**25.55**
1986		5.86						5.62		1.07		39.97		**52.52**
1987		5.01						4.35		0.11		23.53		**33.00**
1988		2.91						1.92		0.05		26.92		**31.79**
1989	11.18	5.96						1.91		0.53		23.10		**42.68**
1990	14.53	13.15				0.33		0.48			0.12			**28.61**
1991	17.66	10.75				0.30	1.10							**29.80**
1992	3.00	9.60					5.71			0.17				**18.49**
1993	2.97	9.30					7.45	1.78						**21.50**
1994	6.29	10.27					4.09	0.53	0.03					**21.22**
1995	11.85	10.75												**22.61**
1996	5.69	8.31				0.41								**14.41**
1997	11.08	11.76												**22.84**
1998	15.68	10.38				1.66								**27.72**
1999	21.10	5.49												**26.59**
2000	14.88	3.83												**18.71**
2001	3.92	6.35	5.81			5.05								**21.13**
2002	18.51	2.04	7.08			7.99								**35.62**
2003	17.12	3.61	11.72	0.56	0.02									**33.04**
2004	9.39	2.41	4.74	0.75										**17.29**
2005	2.92	6.21	8.00											**17.14**
Total	**188.95**	**159.26**	**37.35**	**21.57**	**0.02**	**15.74**	**23.53**	**85.08**	**13.88**	**64.84**	**0.12**	**291.62**	**45.90**	**947.86**

Table 10.2 Summary of American shad collection and stocking activities in the Susquehanna River Basin above dams. Fish passage was documented with visual counts.

Year	Eggs Planted (millions)	Hatchery Stocking: Fry (thousands)	Hatchery Stocking: Fingerlings (thousands)	Live Pre-Spawn Adults: Out-of-Basin Transfers	Conowingo Fish Lifts (rm 10): Catch*	Conowingo Fish Lifts (rm 10): Transfers/Passage**	Fish Passage: Holtwood (rkm 39.6)	Fish Passage: Safe Harbor (rkm 51.7)	Fish Passage: York Haven (rkm 90.3)
1971	8.4	-	-	-	-	-			
1972	7.1	-	-	-	182	-			
1973	58.6	-	-	-	65	-			
1974	50.0	-	-	-	121	-			
1975	33.2	-	-	-	87	-			
1976	54+	518	266	-	82	-			
1977	11+	969	35	-	165	-			
1978	-	2,124	6	-	54	-			
1979	-	629	34	-	50	-			
1980	-	3,526	5	114	139	-			
1981	-	2,030	24	1,165	328	-			
1982	-	5,019	41	2,565	2,039	800			
1983	-	4,048	98	4,310	413	64			
1984	-	11,996	31	3,777	167	0			
1985	-	6,228	115	2,834	1,546	967			
1986	-	9,899	73	4,965	5,195	4,172			
1987	-	5,180	81	6,051	7,667	7,202			
1988	-	6,451	74	-	5,146	4,736			
1989	-	13,465	65	-	8,218	6,469			
1990	-	5,619	90	-	15,719	15,075			
1991	-	7,218	54	-	27,227	24,662			
1992	-	3,039	22	-	25,721	15,674			
1993	-	6,542	79	-	13,546	11,717			
1994	-	6,420	140	-	32,330	28,681			
1995	-	10,001	-	-	61,650	56,370			
1996	-	7,466	-	-	37,512	33,825			
1997	-	8,019	25	-	103,945	101,684	28,063	20,828	
1998	-	11,757	2.2	-	46,481	44,497	8,235	6,054	
1999	-	13,501	-	-	79,370	75,220	34,702	34,210	
2000	-	9,461	-	-	163,331	158,249	29,421	21,079	4,687
2001	-	6,524	6.5	-	203,776	193,574	109,976	89,816	16,200
2002	-	2,589	-	-	117,348	108,001	17,522	11,705	1,555
2003	-	12,742	-	-	134,937	125,135	25,254	16,646	2,536
2004	-	4,730	-	-	112,786	109,360	3,428	2,109	219
2005	-	3,571	-	-	72,822	68,926	34,189	25,425	1,771
Totals	**157**	**191,280**	**1,367**	**25,781**	**1,280,165**	**1,195,060**	**290,790**	**227,872**	**26,968**

* West lift only 1971-1990, East and West Lifts, 1991-2006.

** Includes transfers from the West Lift, 1982 to 2004 and fish passage at the East lift, 1997 to 2006.

Table 10.3 Origin of juvenile American shad collected by lift net at Holtwood Dam and haul seine at Columbia, based on otolith analysis. All values are numbers of fish.

Year	Lift net					Haul seine					Larvae Stocked	Shad Transported or Passed Above Safe Harbor
	Lifts	Total Fish	Wild Fish	Hatchery Fish	% Hatchery	Hauls	Total Fish	Wild Fish	Hatchery Fish	% Hatchery		
1990	290	3988	70	3984	100%	87	285	0	272	96%	5619000	15075
1991	370	208	19	189	91%	144	170	80	90	53%	7218000	24662
1992	250	39	14	25	64%	92	269	146	172	64%	3039400	15031
1993	250	1095	669	426	39%	111	218	174	44	20%	6541500	11171
1994	250	206	35	171	83%	110	390	254	322	82%	6420100	28269
1995	115	1048	83	965	92%	48	409	58	351	86%	10001000	55766
1996	No lift net collections					105	283	157	126	44%	7465500	33825
1997	300	1372	100	1272	93%	90	879	136	743	85%	8019000	31356
1998	300	180	9	171	95%	94	230	5	225	98%	11757000	10647
1999	300	490	19	471	96%	90	322	13	309	96%	13501000	39658
2000	300	406	4	402	99%	90	31	0	31	100%	9460728	21876
2001	299	1245	538	707	57%	90	377	119	258	69%	5510184	89816
2002	220	68	15	53	78%	84	0	0	0	0%	2588796.9	11705
2003	300	61	3	58	95%	48	17	2	15	88%	10685252	16646
2004	240	0	0	0		66	25	0	25	100%	4729967	2109

Table 10.4 Origin of adult American shad collected at Conowingo Dam Fish Lifts, based on otolith analysis.

Year	Sample: one in every x	Hatchery							Naturally Reproduced		Total Sample Size
		Larvae				Fingerling		Unmarked**			
		Susquehanna		Below Conowingo Dam							
		N	%*	N	%*	N	%*	N	N	%	
1989	50	36	82	-		-		94	29	18	159
1990	100	49	73	1	1	-		42	32	26	124
1991	100	111	67	8	5	3	2	63	68	27	253
1992	100	154	73	8	4	2	1	19	54	23	237
1993	100	76	64	21	18	2	2	4	21	17	124
1994	100	217	81	22	8	3	1	17	28	10	287
1995	100	255	77	19	6	4	1	1	52	16	331
1996	100	180	48	22	6	4	1	1	172	45	379
1997	50	84	34	12	5	4	2	0	150	60	250
1998	50	29	22	7	5	2	2	0	92	71	130
1999	50	90	48	9	5	1	1	0	88	47	188
2000	50	78	40	11	6	0	0	0	104	54	193
2001	50	120	58	9	4	0	0	0	79	38	208
2002	50	118	65	2	1	0	0	0	62	34	182
2003	50	146	74	0	0	0	0	0	50	26	196
2004	50	113	72	0	0	0	0	0	45	28	158
2005	50	176	64	2	1	0	0	0	96	35	274
Totals		**1856**	**61**	**151**	**5**	**25**	**1**	**241**	**1126**	**3399**	**3399**

*Unmarked hatchery fish distributed among groups based on annual percentage.

**Distinguished from naturally-reproduced fish by otolith microstructure.

Table 10.5 American shad passage at Susquehanna River Dams, 1997-2005.

	Fish Passage (number)				Fish Passage Efficiency			
Year	**Conowingo** (rkm 16.1)	**Holtwood** (rkm 39.6)	**Safe Harbor** (rkm 51.7)	**York Haven** (rkm 90.3)	**Holtwood %**	**Safe Harbor %**	**York Haven %**	**Combined %**
1997	90,971	28,063	20,828		31%	74%		
1998	39,904	8,235	6,054		21%	74%		
1999	69,712	34,702	34,210		50%	99%		
2000	153,546	29,421	21,079	4,687	19%	72%	22%	3%
2001	193,574	109,976	89,816	16,200	57%	82%	18%	8%
2002	108,001	17,522	11,705	1,555	16%	67%	13%	1%
2003	125,135	25,254	16,646	2,536	20%	66%	15%	2%
2004	109,360	3,428	2,109	219	3%	62%	10%	0%
2005	68,926	34,189	25,425	1,772	50%	74%	7%	3%
Total	**959,129**	**290,790**	**227,872**	**26,969**	**30%**	**74%**	**14%**	**3%**

Number required to reach goal of 2 million shad above York Haven at present efficiencies:

Conowingo	Holtwood	Safe Harbor	York Haven
63,386,855	18,761,189	13,929,893	2,000,000

Table 10.6 Hypothetical stock-recruitment analysis for wild American shad in the Susquehanna River. The basis for this analysis is to track the recruitment by a single female and male. S = survival.

Fecundity	% ripening	% fertilization	% hatch*	% S hatch to 10mm	% S hatch 10-13mm**	Return to Conowingo (1 of ?)***	Apparent Fish Passage Efficiency (%)			# of Adult Spawners Produced by 1 female and 1 male****
							Holtwood	Safe Harbor	York Haven	
200,000	50%	90%	70%	25%	26%	320	27%	74%	16%	0.4
200,000	50%	90%	70%	25%	26%	320	50%	74%	50%	2.4
200,000	50%	90%	70%	25%	26%	320	**60%**	74%	**60%**	**3.4**
200,000	50%	90%	70%	25%	26%	320	50%	74%	16%	0.8
200,000	50%	90%	70%	25%	26%	320	60%	74%	16%	0.9
200,000	50%	90%	70%	25%	26%	320	70%	74%	16%	1.1
200,000	50%	90%	70%	25%	26%	320	80%	74%	16%	1.2
200,000	50%	90%	70%	25%	26%	320	90%	74%	16%	1.4
200,000	50%	90%	70%	25%	26%	320	100%	74%	16%	1.5
200,000	50%	90%	70%	25%	26%	320	27%	74%	16%	0.4
200,000	50%	90%	70%	25%	26%	320	27%	74%	50%	1.3
200,000	50%	90%	70%	25%	26%	320	27%	74%	60%	1.5
200,000	50%	90%	70%	25%	26%	320	27%	74%	70%	1.8
200,000	50%	90%	70%	25%	26%	320	27%	74%	79%	2.0

* Data from Van Dyke Anadromous Fish Research Station, 1985-2005.
** Data from Crecco, V., T. Savoy and L. Gunn. 1983. Daily mortality rates of larval and juvenile American shad (Alosa sapidissima) in the Connecticut River with changes in year-class strength. Canadian Journal of Fisheries and Aquatic sciences, 40:1719-1728.

*** Data from Hendricks Pennsylvania Fish and Boat Commission, 1998-2005. See Table 10.31.

****Need > 2.0 (replacement) to achieve a self-sustaining population.

Conclusions: Improving efficiency at Holtwood alone does not yield replacement.

Improving efficiency to 79% at York Haven alone yields replacement but provides no population growth or cushion for poor years.

Recommendation: Establish goal of 60% at both Holtwood and York Haven (provides for population growth and a cushion for years with high river flows)

Table 10.7 Length frequency of pre-spawn adult male American shad collected at the Conowingo West Fish Lift, 1993-2005.

Total Length (mm)	1993	1994	1995*	1996*	1997*	1998*	1999*	2000*	2001	2002	2003	2004	2005
250												1	
275													
300	2												
325	3		1										
350	17		1	2			1					2	2
375	17		18	11	12	1	8		1	2		5	2
400	18		31	45	48	6	13	7	4	11	8	2	18
425	27		80	56	47	13	40	32	5	5	12	14	26
450	6		107	44	34	26	22	55	20	9	27	15	33
475			71	32	24	19	15	27	34	14	24	19	31
500			18	13	6	2	4	12	20	24	12	12	11
525			4	9	1	1	1	3	1	8		3	4
550			2	2						2		1	
575											2		
600													
625				1									
650													
675													
Total	**90**	**no data**	**333**	**215**	**172**	**68**	**104**	**136**	**85**	**75**	**85**	**74**	**127**

*TL estimated from FL according to: TL= FL * 1.117 + 6.674

Table 10.8 Length frequency of pre-spawn adult female American shad collected at the Conowingo West Fish Lift, 1993-2005.

Total Length (mm)	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
250													
275													
300													
325													
350			1										
375	3		1	2			1						
400	9			2	2								2
425	7		2	1	3		3					1	1
450	7		6	11	4	4	12	3	3	1	5	4	6
475	14		64	28	28	11	20	14	16	4	11	10	19
500	4		91	36	20	27	26	12	36	14	14	24	44
525	1		47	49	12	24	14	21	39	32	19	26	34
550			14	17	10	6	8	5	18	42	21	12	29
575			8	7	3		4	4	2	15	23	11	11
600			2							4	7		2
625			1				1				1		
650													
675											1		
Total	**45**	**no data**	**237**	**153**	**82**	**72**	**89**	**59**	**114**	**112**	**101**	**88**	**148**

Table 10.9 Age frequency of adult American shad collected at the Conowingo Dam West Fish Lift, 1995-2005. (a) Wild males; (b) hatchery males; (C) wild females; and (d) hatchery females.

(a) Wild males

Otolith Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2		3									
3	2	54	33	1	11	12	2	6	2	8	4
4	25	41	58	27	22	48	12	3	8	5	30
5	8	15	5	17	8	8	11	7	7	6	10
6	2		3			2	2	3	5	2	4
7									1	3	
8										1	
9											
unknown	2	8									1
Total	**37**	**121**	**99**	**45**	**41**	**70**	**27**	**19**	**23**	**25**	**49**
Mean Age	**4.3**	**3.4**	**3.8**	**4.4**	**3.9**	**4.0**	**4.5**	**4.4**	**4.8**	**4.6**	**4.2**

(b) Hatchery males

Otolith Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2		1									
3	9	25	28	3	8	7	2	10	2	5	3
4	50	29	24	9	40.0	37	17	12	41	7	32
5	74	32	12	10	8	17	31	24	10	27	18
6	12	1	2		2	3	5	6	12	6	18
7	2	2						2	1	2	3
8					1				1		1
9								1			
unknown	5	2	2		1			1	2		
Total	**147**	**92**	**68**	**22**	**60**	**64**	**55**	**56**	**69**	**47**	**75**
Mean Age	**4.6**	**4.1**	**3.7**	**4.3**	**4.1**	**4.3**	**4.7**	**4.4**	**4.4**	**4.9**	**4.9**

Table 10.9 cont. Age frequency of adult American shad collected at the Conowingo Dam West Fish Lift, 1995-2005. (a) Wild males; (b) hatchery males; (C) wild females; and (d) hatchery females.

(c) Wild females

Otolith Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2											
3		3	2			1					1
4	4	20	23	8	14	11	11	5	4	1	9
5	7	14	16	28	22	13	27	14	7	9	11
6	2	6	9	9	8	6	10	18	11	3	18
7				1	1			4	4	5	3
8								1		1	3
9											1
unknown		6			2			1			1
Total	**13**	**49**	**50**	**46**	**47**	**31**	**48**	**43**	**26**	**19**	**47**
Mean Age	**4.8**	**4.0**	**4.6**	**5.1**	**4.7**	**4.8**	**5.0**	**5.4**	**5.6**	**5.8**	**5.4**

(d) Hatchery females

Otolith Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2			1								
3									1		1
4	10	24	5	4	10	2	7	8	8	4	9
5	79	60	11	6	24	14	29	29	23	34	22
6	26	10	12	5	5	8	24	24	33	13	53
7	7	5	2		1	2	4	5	9	13	13
8								2	1	1	1
9											
10											
11											1
unknown	5	6	1		2			1			1
Total	**122**	**105**	**32**	**15**	**42**	**26**	**64**	**69**	**75**	**65**	**101**
Mean Age	**5.2**	**4.7**	**5.1**	**5.1**	**4.7**	**5.4**	**5.4**	**5.4**	**5.6**	**5.6**	**5.6**

Table 10.10 Mean length (TL, mm) and weight (g) of pre-spawn adult American shad collected at the Conowingo Dam West Fish List, 1993-2005.

Year	1993	1995*	1996*	1997*	1998*	1999*	2000*	2001	2002	2003	2004	2005
Males												
N	90	333	215	172	68	104	136	85	75	95	74	127
Total Length (mm)	404	456	452	441	461	445	465	479	481	474	463	458
SD	36	33	41	32	26	32	26	28	44	36	48	35
N		333	208	172	68	104	136	86	75	95	75	127
Weight (g)		889	808	797	783	739	862	912	1041	1032	947	907
SD		205	227	187	149	145	169	180	303	293	255	228
Females												
N	45	237	156	82	62	89	59	114	112	102	88	148
Total Length (mm)	457	513	507	509	519	478	493	524	550	547	528	526
SD	37	32	79	38	27	40	32	25	27	44	34	35
N		237	150	82	62	89	59	114	112	101	88	148
Weight (g)		1371	1413	1441	1295	1201	1346	1372	1618	1735	1474	1508
SD		284	292	349	261	251	292	215	347	443	315	333
Both Sexes Combined												
N	135	624	371	254	130	193	195	199	187	197	163	277
Total Length (mm)	422	479	475	463	489	474	483	505	523	512	498	495
SD	44	43	66	47	39	47	39	34	49	54	52	49
N		624	358	254	130	193	195	200	187	196	164	277
Weight (g)		1090	1062	1005	1027	966	1026	1174	1387	1394	1232	1229
SD		342	394	392	331	318	327	304	434	516	390	416

*TL estimated from FL according to: TL= FL * 1.117 + 6.674

Table 10.11 Mean total length (mm) at otolith age for pre-spawn American shad collected at the Conowingo Dam West Fish Lift, 1995-2005.

Age	1995*	1996*	1997*	1998*	1999*	2000*	2001	2002	2003	2004	2005
Male											
2		392									
3	410	424	416	431	420	454	478	419	429	366	411
4	445	463	447	454	443	460	465	471	458	387	441
5	466	484	488	473	472	488	486	502	488	430	474
6	477	526	481		482	515	494	527	512	444	496
7	529	492					480	509	510	477	492
8					509				512	410	510
9								536			
Female											
2			426								
3			442						450		405
4	492	504	486	491	499	500	506	528	489	445	488
5	511	526	515	521	508	526	521	547	540	461	521
6	515	473	538	539	521	541	537.5	554	560	486	531
7	566	533	560	495	540	549	537	580	579	495	549
8								579	570	498	571
9											620
10											
11											575

*TL estimated from FL according to: TL= FL * 1.117 + 6.674

Table 10.12 Mean total length at scale age for pre-spawn American shad collected at the Conowingo Dam West Fish Lift, 1999-2005. Scales were not read from 1995 to 1999.

Age	2000*	2001	2002	2003	2004	2005
Male						
2						
3	453	447	418	440	366	424
4	463	481	470	467	397	443
5	488	488	502	495	434	472
6	516	500	522	518	448	495
7			509		477	493
8					410	
9						
Female						
2						
3	461	510		470		405
4	512	511	528	508	450	490
5	518	527	545	545	461	522
6	550	548	554	577	490	531
7	587	551	580	600	494	550
8			568	570	498	571
9				620		620
10						
11						575

*TL estimated from FL according to: TL= FL * 1.117 + 6.674

Table 10.13 Mean total weight at otolith age for pre-spawn American shad collected at the Conowingo Dam West Fish Lift, 1995-2005.

Age	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
						Male					
2		546									
3	610	662	667	614	642	838	949	669	740	590	608
4	840	869	834	750	717	828	831	986	919	834	797
5	936	967	1022	861	855	983	956	1126	1090	1025	982
6	1022	1220	1018		885	1195	1009	1413	1336	1094	1160
7	1293	970					795	1280	1335	1402	1237
8					1130				1180	1020	1270
9								1380			
						Female					
2			1400								
3			950						1000		673
4	1162	1344	1233	1012	1154	1227	1247	1383	1216	1250	1242
5	1343	1440	1524	1311	1234	1425	1340	1619	1726	1345	1437
6	1418	1513	1647	1474	1382	1495	1496	1657	1817	1572	1555
7	1826	1321	1695	1210	1500	1885	1460	1841	1989	1739	1740
8								1675	2080	1715	1613
9											2470
10											
11											1900

Table 10.14 Mean total weight at scale age for pre-spawn American shad collected at the Conowingo Dam West Fish Lift, 2000-2005.

Age	2000	2001	2002	2003	2004	2005
			Male			
2						
3	809	728	670	810	600	703
4	840	923	960	967	869	814
5	1018	983	1155	1196	1047	976
6	1128	1060	1333	1365	1106	1161
7			1280		1402	1170
8					1020	
9						
			Female			
2						
3	915	1355		1103		673
4	1322	1284	1391	1406	1297	1276
5	1369	1399	1590	1732	1347.02	1442
6	1562	1638	1690	1946	1610	1552
7	2230	1080	1726	2218	1722	1721
8			1703	2080	1715	1613
9				2550		2470
10						
11						1900

Table 10.15 Otolith age and repeat spawning for pre-spawn male American shad collected at the Conowingo Dam West Fish Lift, 2000-2005.

Year	Repeat Spawning Marks	Age										Total	%
		2	3	4	5	6	7	8	9	10	11		
2000	0		18	77	17	2						114	89%
	1			3	4	3						10	8%
	2				4							4	3%
	Total		**18**	**80**	**25**	**5**						**128**	
2001	0		3	30	38	7	1					79	99%
	1				1							1	1%
	Total		**3**	**30**	**39**	**7**	**1**					**80**	
2002	0		16	9	12	4						41	58%
	1			5	13	3						21	30%
	2				4	2	2		1			9	13%
	Total		**16**	**14**	**29**	**9**	**2**	**0**	**1**			**71**	
2003	0		4	44	17	17	2					84	95%
	1			3				1				4	44%
	Total		**4**	**47**	**17**	**17**	**2**	**1**				**88**	
2004	0		13	13	27	7	3	1				64	86%
	1				7	1	1					9	12%
	2						1					1	1%
	Total		**13**	**13**	**34**	**8**	**5**	**1**				**74**	
2005	0		7	44	21	6	1					79	64%
	1			18	4	9	1	1				33	27%
	2			2	2	5						9	7%
	3					2	1					3	2%
	Total		**7**	**64**	**27**	**22**	**3**	**1**				**124**	

Table 10.16 Otolith age and repeat spawning for pre-spawn female American shad collected at the Conowingo Dam West Fish Lift, 2000-2005.

Year	**Repeat Spawning Marks**	**Age**										**Total**	**%**
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
2000	0		1	13	19	11	1					45	79%
	1				4							4	7%
	2				3	3						6	11%
	3						1					1	
	4				1							1	
	Total		**1**	**13**	**27**	**14**	**2**					**57**	
2001	0			16	51	30	4					101	100%
	Total			16	51	30	4					101	
2002	0			11	19	21	5	1				57	53%
	1			2	19	15	4	2				42	39%
	2				4	5						9	8%
	Total			**13**	**42**	**41**	**9**	**3**				**108**	
2003	0		1	12	24	40	9	1				87	86%
	1				3	2	2					7	7%
	2				3	2	2					7	7%
	Total		**1**	**12**	**30**	**44**	**13**	**1**				**101**	
2004	0			5	37	14	12					68	79%
	1				5	2	4					11	13%
	2				1	1		1				3	3%
	3						3					3	3%
	4							1				1	1%
	Total			**5**	**43**	**17**	**19**	**2**				**86**	
2005	0		2	11	19	37	4	1				74	51%
	1			7	7	21	4	2				41	28%
	2				7	5	3	1	1		1	18	12%
	3					7	3					10	7%
	4						2					2	1%
	Total		**2**	**18**	**33**	**70**	**16**	**4**	**1**	**0**	**1**	**145**	

Table 10.17 Otolith age and repeat spawning for pre-spawn American shad (sexes combined) collected at the Conowingo Dam West Fish Lift, 2000-2005.

Year	Repeat Spawning Marks	Age										Total	%
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
2000	0		19	90	36	13	1					159	86%
	1			3	8	3						14	8%
	2				7	3						10	5%
	3						1					1	1%
	4				1							1	1%
	Total		**19**	**93**	**52**	**19**	**2**					**185**	
2001	0		3	46	89	37	5					180	99%
	1				1							1	1%
	2											0	0%
	Total		**3**	**46**	**90**	**37**	**5**					**181**	
2002	0		16	20	31	25	5	1				98	55%
	1			7	32	18	4	2				63	35%
	2				8	7	2		1			18	10%
	Total		**16**	**27**	**71**	**50**	**11**	**3**	**1**			**179**	
2003	0		5	56	41	57	11	1				171	90%
	1			3	3	2	2	1				11	6%
	2				3	2	2					7	4%
	Total		**5**	**59**	**47**	**61**	**15**	**2**				**189**	
2004	0		13	18	64	21	15	1				132	83%
	1				12	3	5					20	13%
	2				1	1	1	1				4	3%
	3						3					3	2%
	4							1				1	1%
	Total		**13**	**18**	**77**	**25**	**24**	**3**				**160**	
2005	0		9	55	40	43	5	1				153	57%
	1			25	11	30	5	3				74	28%
	2				9	10	3	1	1		1	25	9%
	3					9	4					13	5%
	4						2					2	1%
	Total		**9**	**80**	**60**	**92**	**19**	**5**	**1**	**0**	**1**	**267**	

Table 10.18 Scale age and repeat spawning for pre-spawn male American shad collected at Conowingo Dam West Fish Lift, 2000-2005.

Year	**Repeat Spawning Marks**	**Age**										**Total**	**%**
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
2000	0		37	65	14	1						117	89%
	1			5	4	1						10	8%
	2				4							4	3%
	Total		**37**	**70**	**22**	**2**						**131**	
2001	0		10	45	23	1						79	99%
	1				1							1	1%
	2											0	0%
	Total		**10**	**45**	**24**	**1**						**80**	
2002	0		15	12	10	5						42	58%
	1			5	12	4						21	29%
	2				3	4	2					9	13%
	Total		**15**	**17**	**25**	**13**	**2**					**72**	
2003	0		17	41	20	9						87	96%
	1			3		1						4	4%
	2											0	0%
	Total		**17**	**44**	**20**	**10**						**91**	
2004	0		13	18	23	6	3	1				64	86%
	1			2	5	1	1					9	12%
	2						1					1	1%
	Total		**13**	**20**	**28**	**7**	**5**	**1**				**74**	
2005	0		9	45	20	7						81	66%
	1			19	7	7						33	27%
	2				4	5						9	7%
	3					2	1					3	2%
	4											0	0%
	Total		**9**	**64**	**31**	**19**	**0**	**0**	**0**	**0**	**0**	**123**	

Table 10.19 Scale age and repeat spawning for pre-spawn female American shad collected at the Conowingo Dam West Fish Lift, 2000-2005.

Year	Repeat Spawning Marks	Age										Total	%
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
2000	0		2	14	17	11						44	76%
	1			2	3	1						6	10%
	2				4	2						6	10%
	3					1						1	2%
	4						1					1	2%
	Total		**2**	**16**	**24**	**15**	**1**					**58**	
2001	0		1	35	54	11	1					102	100%
	1											0	0%
	2											0	0%
	Total		**1**	**35**	**54**	**11**	**1**					**102**	
2002	0			12	22	18	4	1				57	52%
	1			3	19	16	5					43	39%
	2				4	5		1				10	9%
	Total			**15**	**45**	**39**	**9**	**2**				**110**	
2003	0		5	17	36	23	5	1				87	86%
	1			1	4	1			1			7	7%
	2				3	4						7	7%
	Total		**5**	**18**	**43**	**28**	**5**	**1**	**1**			**101**	
2004	0			39	77	139	39	10				304	94%
	1			1	4	2	4					11	3%
	2				1	1		1				3	1%
	3						3					3	1%
	4							1				1	0%
	Total			**40**	**82**	**142**	**46**	**12**				**322**	
2005	0		2	12	21	36	4	1				76	52%
	1			7	8	21	3	2				41	28%
	2				7	5	3	1	1		1	18	12%
	3					6	4					10	7%
	4						2					2	1%
	Total		**2**	**19**	**36**	**68**	**16**	**4**	**1**	**0**	**1**	**147**	

Table 10.20 Scale age data and repeat spawning for pre-spawn American shad (sexes combined) collected at the Conowingo Dam West Fish Lift, 2000-2005.

Year	**Repeat Spawning Marks**	**Age**										**Total**	**%**
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**		
2000	0		39	79	31	12						161	85%
	1			7	7	2						16	8%
	2				8	2						10	5%
	3					1						1	1%
	4						1					1	1%
	Total		**39**	**86**	**46**	**17**	**1**					**189**	
2001	0		11	80	77	12	1					181	99%
	1				1							1	1%
	2											0	0%
	Total		**11**	**80**	**78**	**12**	**1**					**182**	
2002	0		15	24	32	23	4	1				99	54%
	1			8	31	20	5					64	35%
	2				7	9	2	1				19	10%
	Total		**15**	**32**	**70**	**52**	**11**	**2**				**182**	
2003	0		22	58	56	32	5	1				174	91%
	1			4	4	2			1			11	6%
	2				3	4						7	4%
	Total		**22**	**62**	**63**	**38**	**5**	**1**	**1**			**192**	
2004	0		13	57	100	145	42	11				368	93%
	1			3	9	3	5					20	5%
	2				1	1	1	1				4	1%
	3						3					3	1%
	4							1				1	0%
	Total		**13**	**60**	**110**	**149**	**51**	**13**				**396**	
2005	0		11	57	41	43	4	1				157	58%
	1			26	15	28	3	2				74	27%
	2				11	10	3	1	1		1	27	10%
	3					8	5					13	5%
	4						2					2	1%
	Total		**11**	**83**	**67**	**89**	**17**	**4**	**1**		**1**	**273**	

Table 10.21 Upper Chesapeake Bay and Susquehanna River commercial American shad landings (pounds), 1944-1979.

Year	Upper Chesapeake Bay	Susquehanna Flats	Susquehanna River	Total
1944	153,597	----------	----------	153,597
1945	157,371	----------	----------	157,371
1946	250,584	----------	----------	250,584
1947	264,339	----------	----------	264,339
1948	312,649	----------	----------	312,649
1949	302,273	----------	----------	302,273
1950	352,870	----------	----------	352,870
1951	609,118	----------	----------	609,118
1952	589,405	----------	----------	589,405
1953	474,837	----------	----------	474,837
1954	571,321	----------	----------	571,321
1955	440,544	----------	----------	440,544
1956	412,052	----------	----------	412,052
1957	719,993	----------	----------	719,993
1958	444,667	----------	----------	444,667
1959	430,471	----------	----------	430,471
1960	380,647	----------	----------	380,647
1961	449,954	----------	----------	449,954
1962	245,713	196,682	54,946	497,341
1963	192,102	100,706	71,093	363,901
1964	124,725	51,714	43,626	220,065
1965	164,456	86,327	25,653	276,436
1966	132,380	74,691	36,566	243,637
1967	191,589	83,950	36,247	311,786
1968	139,898	84,784	33,587	258,269
1969	114,590	111,639	44,108	270,337
1970	89,369	63,943	11,909	165,221
1971	147,580	100,857	83,364	331,801
1972	139,800	101,400	34,900	276,100
1973	81,500	87,200	56,800	225,500
1974	12,400	19,000	26,100	57,500
1975	13,200	10,400	5,000	28,600
1976	4,800	5,700	2,400	12,900
1977	2,700	3,400	2,700	8,800
1978	1,600	6,900	13,200	21,700
1979	1,700	13,000	900	15,600

Table 10.22 Conowingo Dam tailrace hook and line data, 1982-2005, and Susquehanna Flats pound net data, 1982-2001. Catch-per-angler-hour (CPAH) and pound net (PN).

Year	Hook and Line	Hours Fished	CPAH	PN Catch	PN Effort
1982	88	NA	NA	50	26
1983	11	NA	NA	50	38
1984	126	52	2.42	62	27
1985	182	85	2.14	30	10
1986	437	147.5	2.96	na	na
1987	399	108.8	3.67	na	na
1988	256	43	5.95	170	115
1989	276	42.3	6.52	400	105
1990	309	61.8	5	399	109
1991	437	77	5.68	1054	148
1992	383	62.75	6.1	190	103
1993	264	47.5	5.56	281	93
1994	498	88.5	5.63	346	94
1995	625	84.5	7.4	1159	128
1996	446	44.25	10.08	956	158
1997	607	57.75	10.51	1168	111
1998	337	23.75	14.19	215	48
1999	823	52	15.83	401	103
2000	730	35.75	20.42	1137	75
2001	972	65.75	14.78	2020	43
2002	812	60	13.53	N/A	N/A
2003	774	69.3	11.17	N/A	N/A
2004	474	38.75	12.23	N/A	N/A
2005	412	57.92	7.11	N/A	N/A

Table 10.23 American shad age structure from Susquehanna Flats pound net fishery, 1988-2001.

Year	**Age**								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1988	1	16	57	69	18	0	0	0	0
1989	0	27	119	140	53	4	0	0	0
1990	0	18	90	182	66	26	0	0	0
1991	2	14	111	280	255	52	7	0	0
1992	0	1	24	61	46	29	1	0	0
1993	0	7	39	71	66	22	9	0	0
1994	0	22	84	134	49	13	1	0	0
1995	0	28	94	104	55	16	1	0	0
1996	2	128	266	561	411	131	0	0	0
1997	0	3	226	353	205	17	12	0	0
1998	0	7	102	122	70	5	0	0	0
1999	0	25	105	149	75	14	4	0	0
2000	0	21	622	491	91	14	2	0	2
2001	0	32	204	335	137	13	1	0	0

Table 10.24 Spring creel surveys in the Susquehanna River and Susquehanna Flats, 1958-2960, 1970, 1979-1985, and 2001-2005.

Year	Number of Interviews	Total Fishing Hours	Total Catch of American Shad	Catch-Per-Angler-Hour	Catch-Per-Interviewed-Angler	Source
1958	1013	1041.5	94	0.09	9.151	Whitney 1961
1959	3119	3874.5	620	0.16	5.704	"
1960	2699	2168	282	0.13	4.896	"
1970	1607	8315	694	0.083	0.432	Carter 1973
1979	937	3462	15	0.004	0.016	Carter 1980
1980	749	3668	8	0.002	0.011	Weinrich 1985
1981	1320	5436	118	0.022	0.089	"
1982	1103	4275	266	0.062	0.241	"
1983	1250	5245	132	0.025	0.106	"
1984	1223	4466	358	0.08	0.293	"
1985	1123	4066	170	0.042	0.151	"
2001	90	202.9	991	4.88	11.011	Sadzinski 2006
2002	52	85.3	291	3.41	5.596	"
2003	65	148.2	818	5.52	12.585	"
2004	97	193.3	233	1.21	2.4	"
2005	29	128.8	63	0.49	2.17	"

Table 10.25 American shad age structure from Conowingo Dam tailrace on the Susquehanna River, 1984-2005.

Year	Age								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1984	0	30	45	32	14	3	0	0	0
1985	0	22	83	48	18	2	0	0	0
1986	0	103	233	93	3	0	0	0	0
1987	1	63	188	124	4	0	0	0	0
1988	3	64	123	54	8	0	0	0	0
1989	0	46	117	86	19	0	0	0	0
1990	0	16	138	119	28	4	0	0	0
1991	0	3	64	166	95	8	0	0	0
1992	1	18	61	178	82	30	1	0	0
1993	0	8	83	83	49	10	0	0	0
1994	0	15	142	205	54	8	0	0	0
1995	0	10	61	79	49	4	0	0	0
1996	0	27	173	131	94	11	0	0	0
1997	2	71	511	644	337	74	9	0	0
1998	1	9	146	128	42	9	1	1	0
1999	2	84	403	316	104	6	0	3	1
2000	0	12	464	446	98	11	2	0	0
2001	0	36	294	556	209	18	0	0	0
2002	0	14	150	295	241	94	6	0	0
2003	0	14	294	366	195	80	20	0	0
2004	3	7	80	199	83	12	1	1	0
2005	2	9	110	129	129	32	2	0	0

Table 10.26 Juvenile abundance index for American shad collected by lift net in the forebay of Holtwood Hydroelectric Station, Susquehanna River, 1985-2005.

		Total					Wild				Hatchery			
Year	**Number of Lifts**	**Number of Fish**	**Mean Combined Daily CPUE**	**GM Combined Daily CPUE**	**GM Individual Lift CPUE***	**Area Under the Curve CPUE**	**Number of Fish**	**Mean Combined Daily CPUE**	**GM Combined Daily CPUE**	**Area Under the Curve CPUE**	**Number of Fish**	**Mean Combined Daily CPUE**	**GM Combined Daily CPUE**	**Area Under the Curve CPUE**
1985	378	3626	20.31	7.55		1422	**	**						
1986	404	2926	10.30	5.71		888	**	**						
1987	428	832	3.17	1.90		178	**	**						
1988	230	929	3.87	1.28		254	**	**						
1989	286	556	0.86	0.43		53	**	**						
1990	290	3988	13.75	3.67		1059	70	0.24	0.18	16	3984	13.74	3.66	1042
1991	370	208	0.56	0.39		72	19	0.05	0.05	7	189	0.51	0.36	65
1992	250	39	0.16	0.12		13	14	0.06	0.05	5	25	0.10	0.08	9
1993	250	1095	4.38	1.20		383	669	2.79	0.86	233	426	1.70	0.72	149
1994	250	206	0.82	0.48		71	35	0.15	0.13	12	171	0.68	0.42	59
1995	115	1048	9.11	1.26	1.07	801	83	0.72	0.32	53	965	8.39	1.01	742
1997	300	1372	4.57	0.88	0.61	411	100	0.33	0.23	30	1272	4.24	0.85	381
1998	300	180	0.60	0.37	0.22	53	9	0.03	0.03	2	171	0.57	0.35	49
1999	300	490	1.63	0.78	0.50	145	19	0.06	0.07	5	471	1.57	0.76	140
2000	300	406	1.35	0.61	0.18	121	4	0.01	0.01	1	402	1.34	0.60	120
2001	299	1245	4.18	1.37	0.43	273	538	1.81	0.45	112	707	2.38	0.99	161
2002	220	68	0.31	0.15	0.09	20	15	0.07	0.05	3	53	0.24	0.13	16
2003	300	61	0.20	0.13	0.07	17	3	0.01	0.01	1	58	0.23	0.15	17
2004	240	0	0.00	0.00	0.00	0	0	0.00	0.00	0	0	0	0	0
2005	300	200	0.67	0.15	0.10	59	47	0.16	0.11	13	153	0	0	46

* Required by ASMFC

**Most of the Holtwood samples processed were from cast net collections.

Table 10.27 Juvenile abundance index for American shad collected by haul seine in the Susquehanna River at Marietta, Columbia, and Wrightsville, 1990-2005.

Year	Number of Hauls	Total: Number of Fish	Total: Mean Combined Daily CPUE	Total: GM Combined Daily CPUE	Total: GM Individual Haul CPUE*	Wild: Number of Fish	Wild: Mean Combined Daily CPUE	Wild: GM Combined Daily CPUE	Hatchery: Number of Fish	Hatchery: Mean Combined Daily CPUE	Hatchery: GM Combined Daily CPUE	Larvae Stocked	Cohort Recruitment to Lifts	Shad Transported or Passed Above Safe Harbor
1990	87	285	4.40	1.23		0	0.15	0.11	272	4.251	1.181	5619000	44415	15075
1991	144	170	1.01	0.54		80	0.48	0.35	90	0.526	0.211	7218000	44820	24662
1992	92	269	4.24	1.45		146	2.49	0.78	172	2.630	0.913	3039400	39852	15031
1993	111	218	1.90	1.22		174	1.61	1.01	44	0.291	0.194	6541500	80499	11171
1994	110	390	4.74	2.29		254	3.19	1.38	322	3.639	2.039	6420100	93746	28269
1995	48	409	8.92	7.89		58	1.29	1.06	351	7.630	6.848	10001000	135916	55766
1996	105	283	2.89	2.05		157	1.61	1.20	126	1.280	0.994	7465500	214718	33825
1997	90	879	9.77	6.77	3.36	136	1.51	1.24	743	8.259	5.648	8019000	238811	31356
1998	94	230	2.51	1.03	0.50	5	0.05	0.05	225	2.457	0.972	11757000	172314	10647
1999	90	322	3.58	1.16	0.67	13	0.15	0.13	309	3.431	1.058	13501000		39658
2000	90	31	0.34	0.26	0.14	0	0.00	0.00	31	0.344	0.264	9460728		21876
2001	90	377	4.19	3.04	1.52	119	1.32	1.25	258	2.870	2.139	5510184		89816
2002	84	0	0.00	0.00	0.00	0	0.00	0.00	0	0.000	0.000	2588797		11705
2003	48	17	0.35	0.28	0.20	2	0.04	0.04	15	0.313	0.254	10685252		16646
2004	66	25	0.38	0.25	0.17	0	0.00	0.00	25	0.379	0.246	25		0
2005	90	23	0.26	0.24	0.16	21	0.23	0.24	2	0.022	0.019	3570675		25425

* Required by ASMFC

Table 10.28 Age composition and origin of Susquehanna River American shad collected at the Conowingo Dam Fish Lifts, 1988-2005.

Year	Total Fish-lift Catch	% Age composition										% Composition by Hatchery Release Site			
												Above Dams		Below Dams	Wild
		11	10	9	8	7	6	5	4	3	2	Larvae	Fingerlings		
1988	5146			0.0	0.0	4.0	31.7	38.1	21.2	4.7	0.36	71%*		6%*	23%*
1989	8218			0.0	0.0	4.3	18.1	41.5	30.2	5.6	0.24	82%			18%
1990	15719			0.0	0.1	5.5	32.7	45.2	15.0	1.5	0.00	73%		1%	26%
1991	27227			0.0	0.0	10.7	36.7	38.4	12.4	1.7	0.00	67%	2%	5%	27%
1992	25721			0.0	0.6	12.3	35.7	36.8	11.7	2.9	0.00	73%	1%	4%	23%
1993	13546			0.0	0.0	3.2	21.6	52.8	21.6	0.8	0.00	64%	2%	18%	17%
1994	32330			0.0	0.0	3.3	22.6	54.7	19.3	0.0	0.00	81%	1%	8%	10%
1995	61650			0.0	0.0	3.2	12.4	51.9	28.5	4.0	0.00	77%	1%	6%	16%
1996	37513			0.0	0.0	0.8	16.1	41.5	33.6	7.6	0.28	48%	1%	6%	45%
1997	103945			0.0	0.0	0.0	10.5	18.1	44.8	26.2	0.40	34%	2%	5%	60%
1998	46481			0.0	0.0	0.8	10.9	48.1	37.2	3.1	0.0	22%	2%	5%	71%
1999	79370			0.0	0.5	1.1	8.1	33.5	46.5	10.3	0.0	48%	1%	5%	47%
2000	163331			0.0	0.0	1.0	9.9	27.6	51.0	10.4	0.0	40%	0%	6%	54%
2001	203776			0.0	0.0	2.0	21.4	50.5	24.0	2.0	0.0	56%	0%	4%	38%
2002	117348			0.5	1.6	6.0	27.7	40.2	15.2	8.7	0.0	65%	0%	1%	34%
2003	134937			0.0	1.0	7.2	31.4	25.8	32.0	2.6	0.0	74%	0%	0%	26%
2004	112786			0.0	1.9	14.9	15.5	48.4	11.2	8.1	0.0	72%	0%	0%	28%
2005	72822	0.4	0.0	0.4	1.8	6.6	34.4	22.3	30.8	3.3	0.0	64%	0%	1%	35%

Table 10.29 Percent virgin American shad collected in the Conowingo Dam fish-lifts, Susquehanna River, 1998-2005.

Year	**% Virgin-at-Age***									
	11	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
1988	0%	0%	0%	0%	91%	99%	96%	97%	100%	100%
1989	0%	0%	0%	0%	83%	92%	91%	97%	100%	100%
1990	0%	0%	0%	0%	87%	91%	93%	99%	100%	100%
1991	0%	0%	0%	50%	78%	88%	85%	93%	100%	100%
1992	0%	0%	0%	75%	78%	81%	87%	98%	100%	100%
1993	0%	0%	0%	0%	0%	82%	88%	100%	100%	100%
1994	0%	0%	0%	0%	0%	94%	94%	93%	100%	100%
1995	0%	0%	0%	0%	0%	86%	95%	100%	100%	100%
1996	0%	0%	0%	0%	13%	62%	89%	97%	100%	100%
1997	0%	0%	0%	0%	13%	62%	89%	97%	100%	100%
1998	0%	0%	0%	0%	13%	62%	89%	97%	100%	100%
1999	0%	0%	0%	0%	13%	62%	89%	97%	100%	100%
2000	0%	0%	0%	0%	50%	68%	69%	97%	100%	100%
2001	0%	0%	0%	0%	0%	0%	99%	100%	100%	100%
2002	0%	0%	0%	33%	45%	50%	44%	74%	100%	100%
2003	0%	0%	0%	50%	73%	93%	87%	95%	100%	100%
2004	0%	0%	0%	33%	63%	84%	83%	100%	100%	100%
2005	0%	0%	0%	0%	33%	27%	78%	69%	100%	100%

* 1996-1999- used the average of 1994,1995, 2000 and 2001

Table 10.30 Recruitment of virgin adult American shad, by cohort, to the Conowingo fish-lifts, Susquehanna River, 1988-2005.

Year	Cohort																		
	1986	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1988	19																		
1989	457	20																	
1990	2330	228	0																
1991	8885	3155	461	0															
1992	7474	8229	2950	752	0														
1993	433	2398	6291	2926	108	0													
1994	0	1062	6841	16557	5787	0	0												
1995		0	1962	6557	30304	17555	2478	0											
1996			0	278	5251	13877	12273	2861	106										
1997				0	0	9474	16802	45281	27244	419									
1998					0	315	4385	19901	16833	1441	0								
1999						429	751	5595	23696	35910	8152	0							
2000							0	851	11059	31213	80678	17014	0						
2001							0	0	4159	43666	101784	48865	4159	0					
2002								638	638	3189	16263	20606	13228	10204	0				
2003									0	696	7141	39646	30338	40931	3478	0			
2004										0	701	10508	14711	45416	12610	9107	0		
2005											0	267	1264	11593	10670	15205	2401	0	
Total recruits to lifts:	**19598**	**15093**	**18506**	**27071**	**41450**	**41650**	**36690**	**75126**	**83734**	**116535**	**214718**	**136905**	**63699**	**108146**	**26757**	**24312**	**2401**	**0**	**0**

Table 10.31 Recruitment of virgin hatchery larvae, stocked above dams, to the Conowingo Fish Lifts, Susquehanna River.

Year	Cohort																		
	1986	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1988	13																		
1989	373	16																	
1990	1690	166	0																
1991	5909	2098	307	0															
1992	5419	5966	2139	545	0														
1993	277	1530	4014	1867	69	0													
1994	0	859	5534	13395	4682	0	0												
1995		0	1517	5069	23425	13570	1916	0											
1996			0	133	2505	6619	5854	1365	51										
1997				0	0	3196	5668	15275	9191	141									
1998					0	70	978	4439	3755	322	0								
1999						205	359	2678	11344	17191	3902	0							
2000							0	344	4469	12615	32605	6876	0						
2001								0	2339	24562	57254	27486	2339	0					
2002								0	413	2067	10544	13360	8576	6616	0				
2003									0	515	5283	29330	22444	30281	2573	0			
2004										0	501	7515	10521	32481	9018	6513	0		
2005											0	171	812	7447	6854	9766	1542	0	
Total Recruits to Lifts	**13680**	**10635**	**13510**	**21008**	**30681**	**23661**	**14776**	**24102**	**31562**	**57413**	**110089**	**84739**	**44692**	**76825**	**18445**	**16280**	**1542**	**0**	**0**
Larvae Released (millions)	**9.90**	**5.18**	**6.45**	**13.46**	**5.62**	**7.22**	**3.04**	**6.54**	**6.42**	**10.00**	**7.47**	**8.02**	**11.70**	**13.50**	**9.46**	**5.51**	**2.59**	**10.69**	**4.73**
# of Larvae to Return 1 Adult	**724**	**487**	**477**	**641**	**183**	**305**	**206**	**271**	**203**	**174**	**68**	**95**	**262**	**176**	**513**	**338**	**1679**	**-**	**-**
Survival	**0.0014**	**0.0021**	**0.0021**	**0.0016**	**0.0055**	**0.0033**	**0.0049**	**0.0037**	**0.0049**	**0.0057**	**0.0147**	**0.0106**	**0.0038**	**0.0057**	**0.0019**	**0.0030**	**0.0006**	**-**	**-**

Mean Number of larvae to return 1 adult (1986-2000): 318.9928411

Table 10.32 Formulas for calculation of survival (S) using the hatchery method.

1	A	B	C	D	E	F	G
2	1986 cohort			Age at return for virgins			
3	Year	II	III	IV	V	VI	VII
4	0	=B5/B15	=C5/B15	=D5/B15	=E5/B15	=F5/B15	=G5/B15
5	1	=B6/B15	=C6/B15	=D6/B15	=E6/B15	=F6/B15	=G6/B15
6	2	Recr at age/B16	=C7/B15	=D7/B15	=E7/B15	=F7/B15	=G7/B15
7	3		Recr at age/B16	=D8/B15	=E8/B15	=F8/B15	=G8/B15
8	4			Recr at age/B16	=E9/B15	=F9/B15	=G9/B15
9	5				Recr at age/B16	=F10/B15	=G10/B15
10	6					Recr at age/B16	=G11/B15
11	7						Recr at age/B16
12	8						
13		=sum(B4:G4)	Sum at age 0				
14		9,899,430	Number stocked				
15		**0.360**	**Survival**				
16		**0.40**	**Lift efficiency**				

Recr = Recruitment

Use "Goal Seek" to set cell B13 equal to cell B14 by changing cell B15

Table 10.33 Results of calculation of survival (S) using the hatchery method and the 1986 cohort as an example, Susquehanna River.

Year	Age at Return					
	II	**III**	**IV**	**V**	**VI**	**VII**
0	252	20095	252878	2459921	6275412	890872
1	91	7224	90910	884346	2256021	320270
2	33	2597	32682	317924	811043	115138
3		934	11749	114294	291571	41392
4			4224	41089	104820	14881
5				14772	37683	5350
6					13547	1923
7						691
8						

Sum at Age-0	**9899430**
Number Stocked	**9899430**
Survival	**0.3595**
Lift Efficiency	**0.4**

Table 10.34 Survival (S) and total mortality by cohort for a given lift efficiency, using hatchery method, 1986-1998.

Cohort	Survival at Lift Efficiency				Z at Lift Efficiency			
	40%	**60%**	**80%**	**100%**	**40%**	**60%**	**80%**	**100%**
1986	0.36	0.34	0.32	0.31	1.02	1.09	1.14	1.18
1987	0.38	0.36	0.34	0.33	0.96	1.03	1.08	1.12
1988	0.40	0.38	0.36	0.35	0.91	0.97	1.02	1.05
1989	0.35	0.33	0.31	0.30	1.04	1.11	1.16	1.21
1990	0.43	0.39	0.37	0.36	0.86	0.93	0.99	1.03
1991	0.39	0.36	0.35	0.33	0.93	1.01	1.06	1.11
1992	0.40	0.37	0.35	0.34	0.91	0.98	1.04	1.08
1993	0.38	0.35	0.33	0.32	0.98	1.05	1.11	1.15
1994	0.44	0.41	0.39	0.38	0.82	0.89	0.94	0.97
1995	0.47	0.44	0.42	0.40	0.76	0.83	0.88	0.92
1996	0.52	0.49	0.46	0.44	0.65	0.72	0.77	0.81
1997	0.52	0.48	0.46	0.44	0.66	0.73	0.78	0.82
1998	0.41	0.38	0.37	0.35	0.88	0.96	1.01	1.05
Mean	**0.42**	**0.39**	**0.37**	**0.36**	**0.88**	**0.95**	**1.00**	**1.04**

Table 10.35 Comparison of total mortality estimates (Z) for American shad on the Susquehanna River, using two methods: hatchery method and otolith and scale method. Hatchery method iteratively calculates the survival required to produce the known recruitment of hatchery fish from the known number of fish stocked, assuming annual survival is constant. Otolith and scale methods use catch curve analysis (slope of descending limb) based on repeat spawners only.

Cohort	Hatchery*	Virgin Age	Otoliths	Scales
1986	1.14			
1987	1.08			
1988	1.02			
1989	1.16			
1990	0.99			
1991	1.06			
1992	1.04			
1993	1.11	7	0.15	
1994	0.94	7	1.46	
1995	0.88	5	1.59	1.52
		6	2.77	1.43
		7	1.52	0.00
1996	0.77	4		0.80
		5	2.13	1.90
		6	1.57	1.34
1997	0.78	3	0.58	1.01
		4	1.23	1.21
		5	1.68	1.50
		6	2.45	1.49
1998		3	0.23	0.88
		4	1.46	1.36
		5	2.63	2.55
1999		3	1.35	1.12
		4	1.55	1.49
Mean	**1.00**		**1.52**	**1.31**

*Z at lift efficiency = 80%

Table 10.36 Catch curve and cohort mortality estimates based on both age structure and freshwater spawning marks for American shad from the Susquehanna River in Conowingo Dam's tailrace, 1996-2005.

Age structured				Spawning Mark			
Year	**Catch Curve**	**Year Class**	**Cohort Analysis**	**Year**	**Catch Curve**	**Year Class**	**Cohort Analysis**
1996	2.16	0.03	1990	1996	0.58	1996	0.38
1997	0.87	3.03	1991	1997	0.18	1997	0.23
1998	0.69	0.9	1992	1998	0.6	1998	0.82
1999	0.98	1.1	1993	1999	0.35	1999	0.34
2000	0.18	0.06	1994	2000	0.4	2000	0.46
2001	1.19	0.49	1995	2001	0.59	2001	0.42
2002	0.67	0.84	1996	2002	0.38	2002	0.47
2003	0.58	1.34	1997	2003	0.36	2003	NA
2004	0.24	0.08	1998	2004	0.51	2004	NA
2005	0.21	0.39	1999	2005	0.38	2005	NA

Table 10.37 Relative population estimates, their 95% confidence intervals, losses associated with Susquehanna River fish passage, and mean spawning season (April-June) river flow. CI = confidence interval; cfs = cubic feet per second.

Year	Relative Population Index	Population Upper 95% CI	Population Lower 95% CI	Losses	Mean River Flow (cfs)
1984	3.52	7.40	1.83	167	60,800
1985	7.88	11.40	5.64	1,546	28,000
1986	18.13	22.62	14.53	5,195	29,100
1987	21.82	26.46	17.98	7,667	29,200
1988	28.71	41.02	20.72	5,169	30,300
1989	43.65	59.29	32.93	8,311	34,300
1990	59.42	77.32	45.64	15,964	44,900
1991	84.12	100.42	70.45	27,227	34,900
1992	86.42	97.01	76.66	25,721	47,700
1993	32.53	39.53	26.74	13,546	115,000
1994	94.77	111.49	80.54	32,330	76,800
1995	210.55	247.16	179.34	61,650	27,100
1996	112.22	123.05	100.42	37,513	67,700
1997	423.32	502.26	356.73	47,034	37,600
1998	314.90	458.04	223.93	17,797	69,200
1999	583.20	705.84	481.71	45,869	29,100
2000	961.54	1151.25	802.89	62,899	56,700
2001	560.91	629.35	501.73	133,611	22,700
2002	578.32	684.40	488.58	42,479	44,000
2003	487.07	561.21	422.69	52,675	39,733
2004	1005.80	1590.36	670.53	30,793	60,170
2005	322.92	407.74	259.41	43,847	27,350

Figure 10.1 Map of the Susquehanna River.

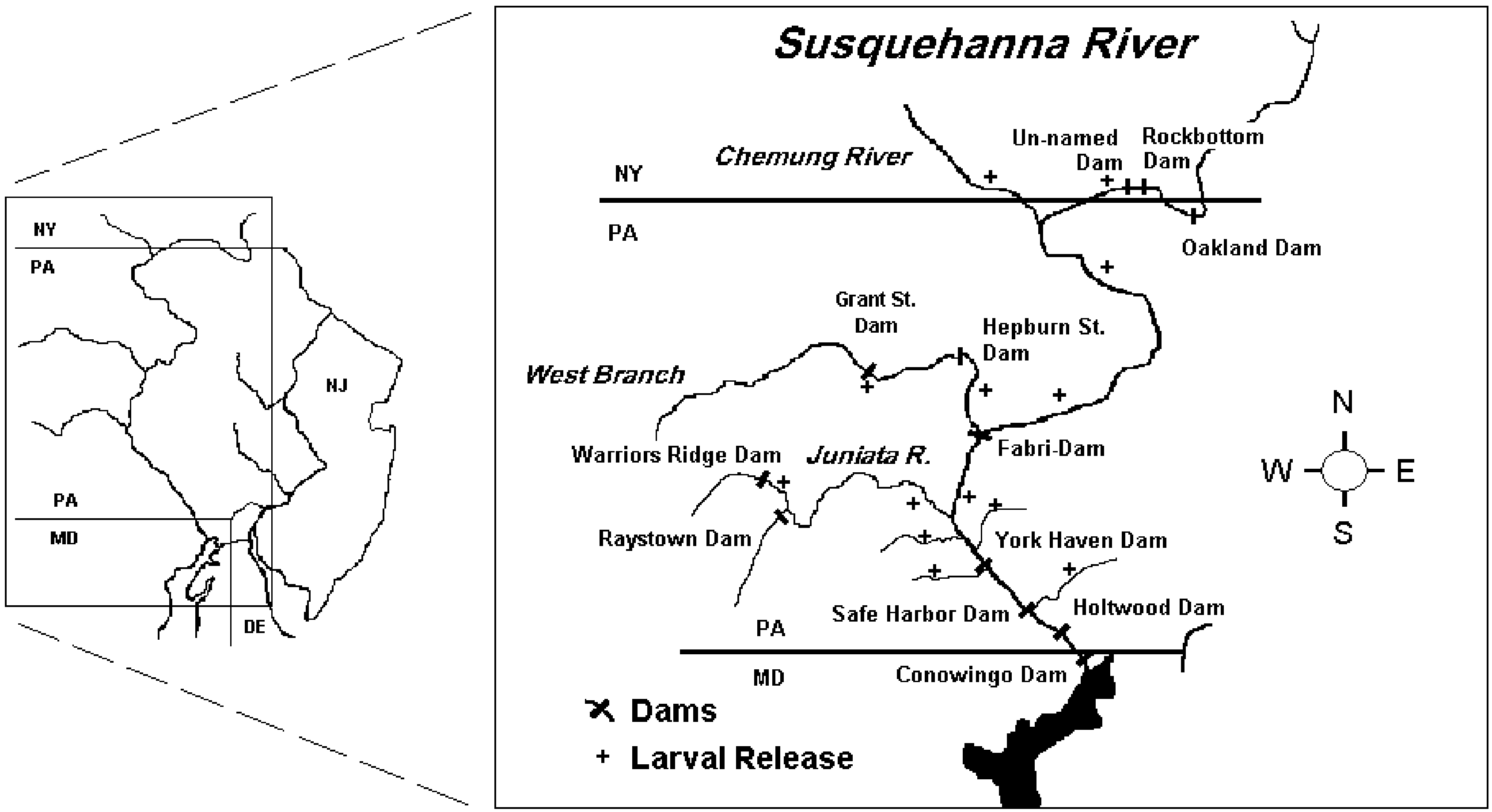


Figure 10.2 Map of the Susquehanna Flats.

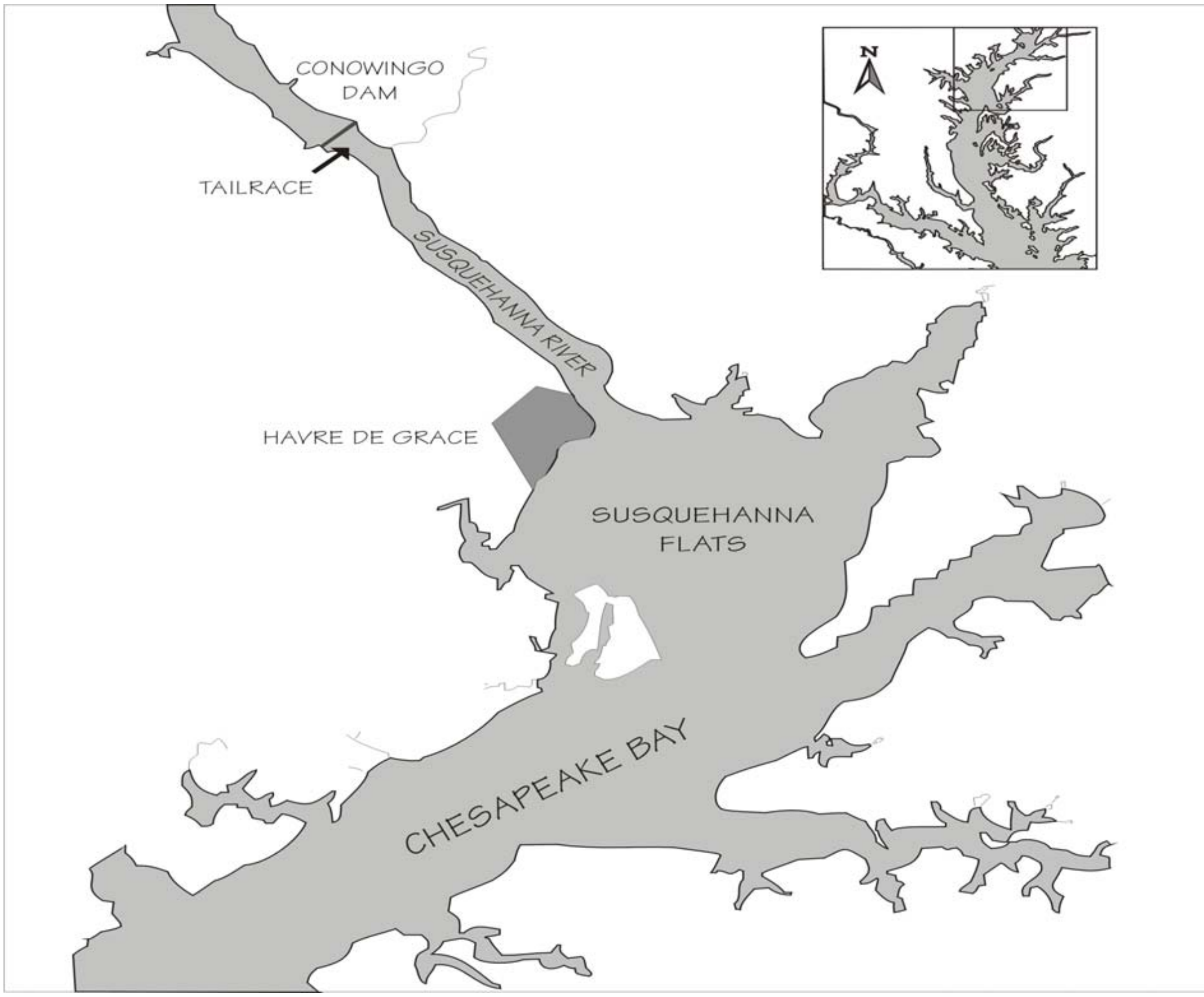


Figure 10.3 Percent hatchery for juvenile American shad collected by lift net at Holtwood Dam or haul seine at Columbia, Pennsylvania on the Susquehanna River.

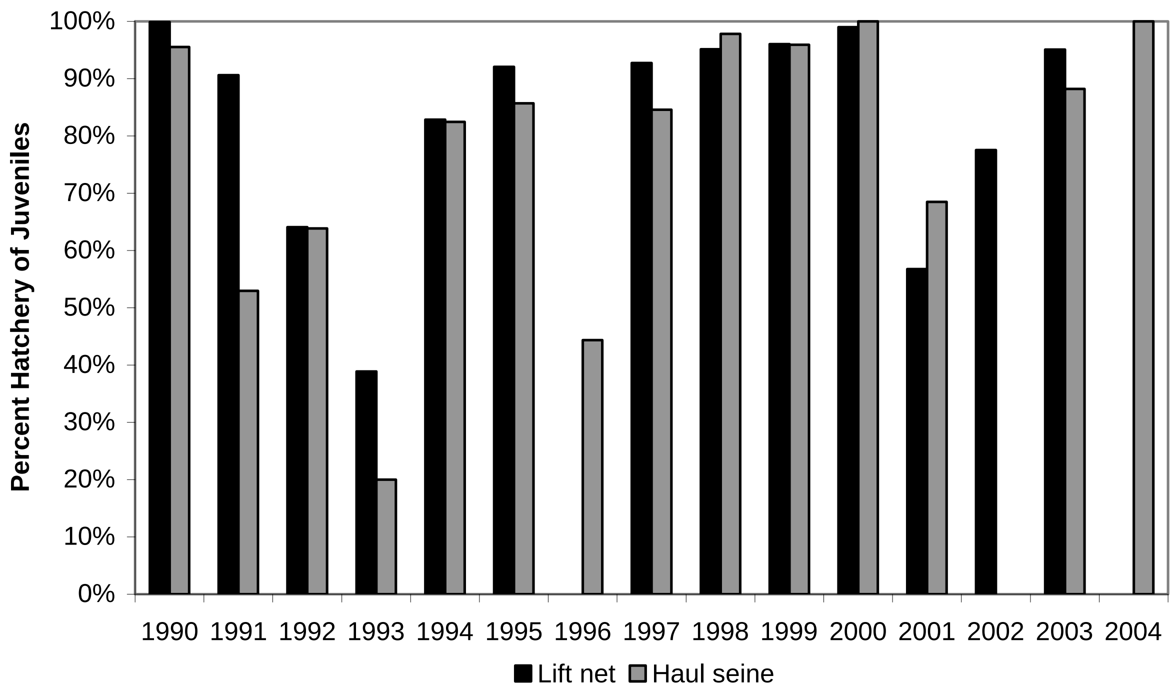


Figure 10.4 Estimated composition of adult American shad caught at Conowingo Dam, based on otolith microstructure and tetracycline marking.

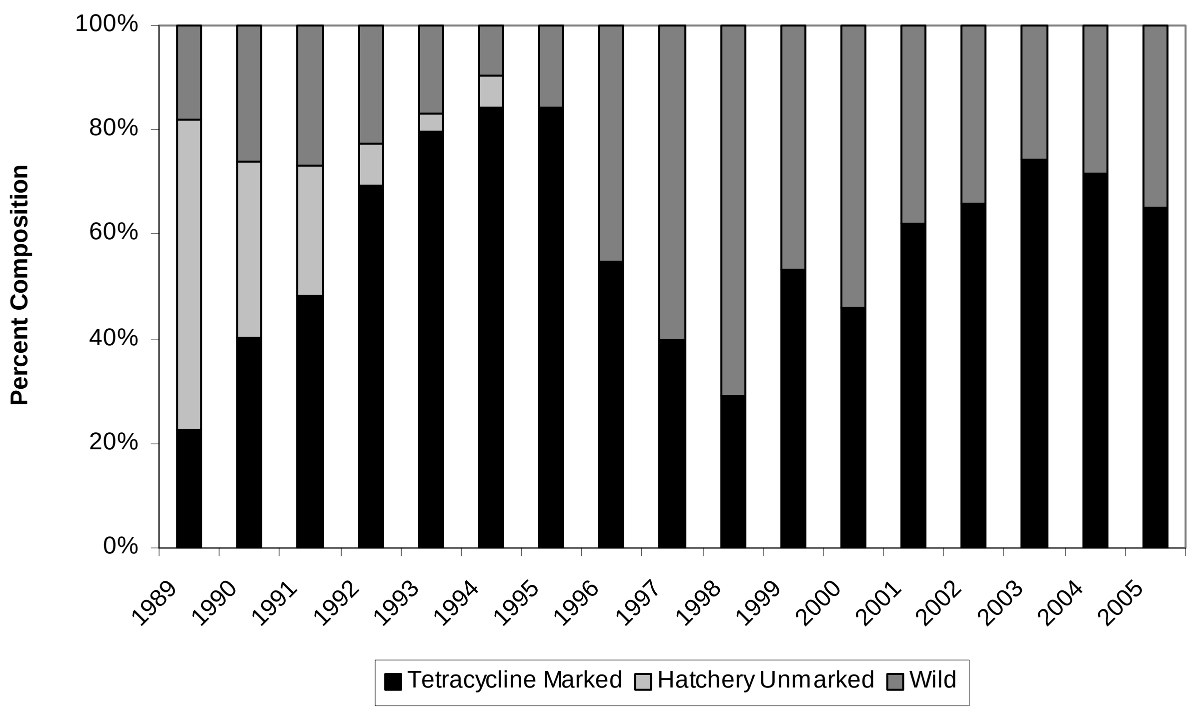


Figure 10.5 Number of American shad captured, by origin, at the Conowingo Dam fish-lifts, Susquehanna River, 1972-2005.

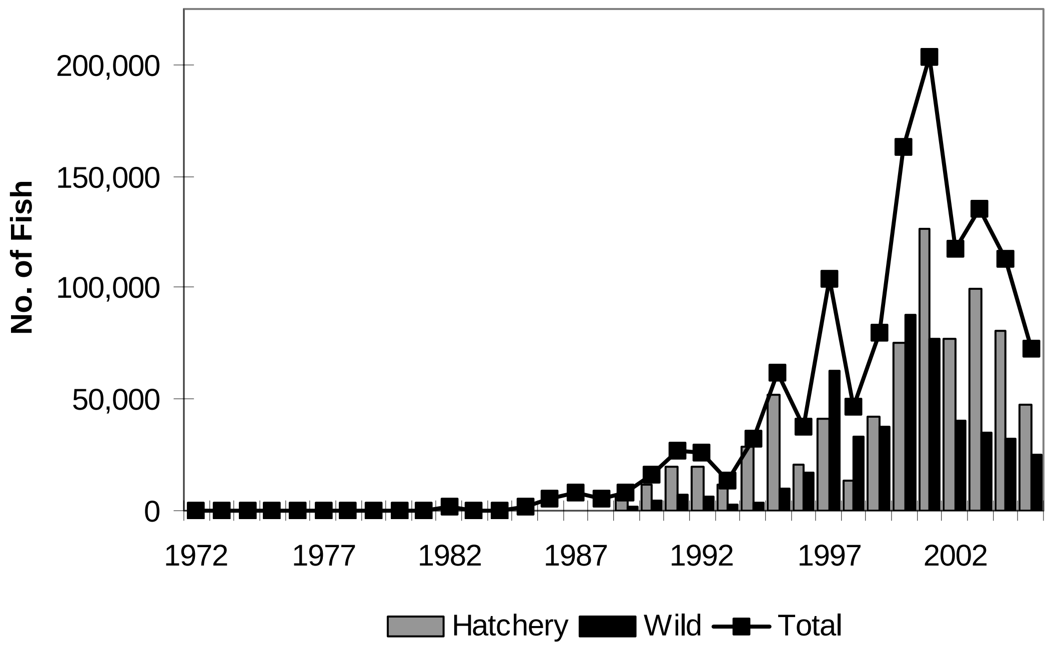


Figure 10.6 American shad passage at Susquehanna River Dams, 1997-2005.

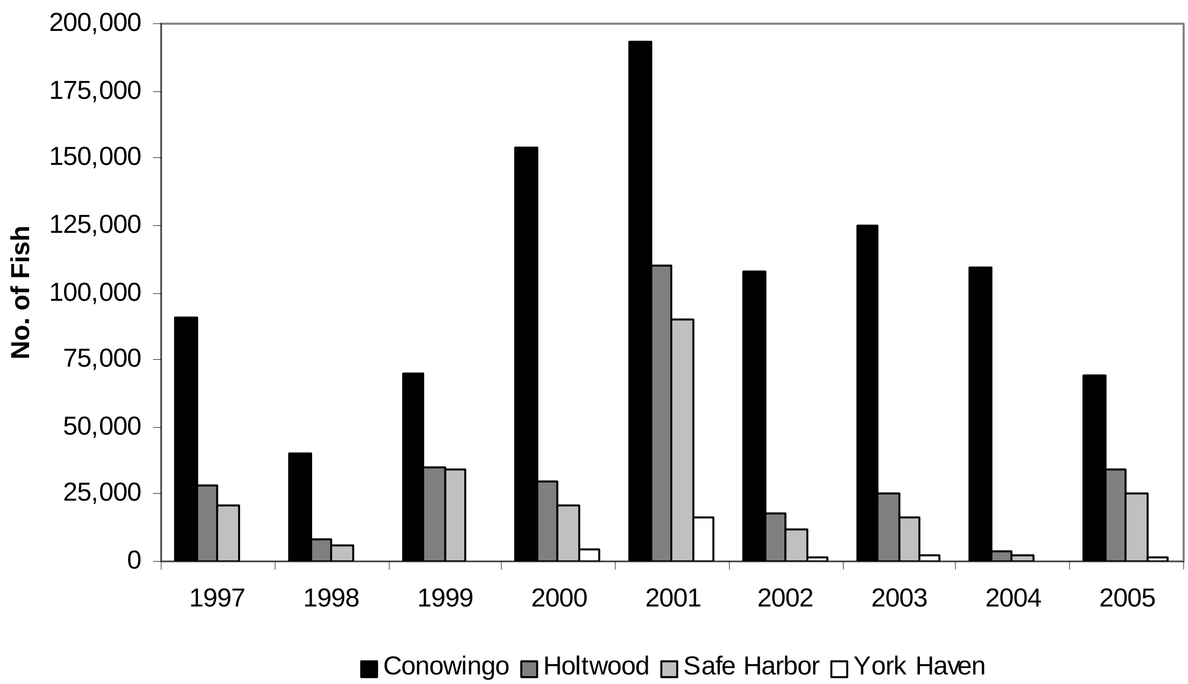


Figure 10.7 Apparent fish passage efficiency at Holtwood Dam versus mean river flow during May, 1997-2004.

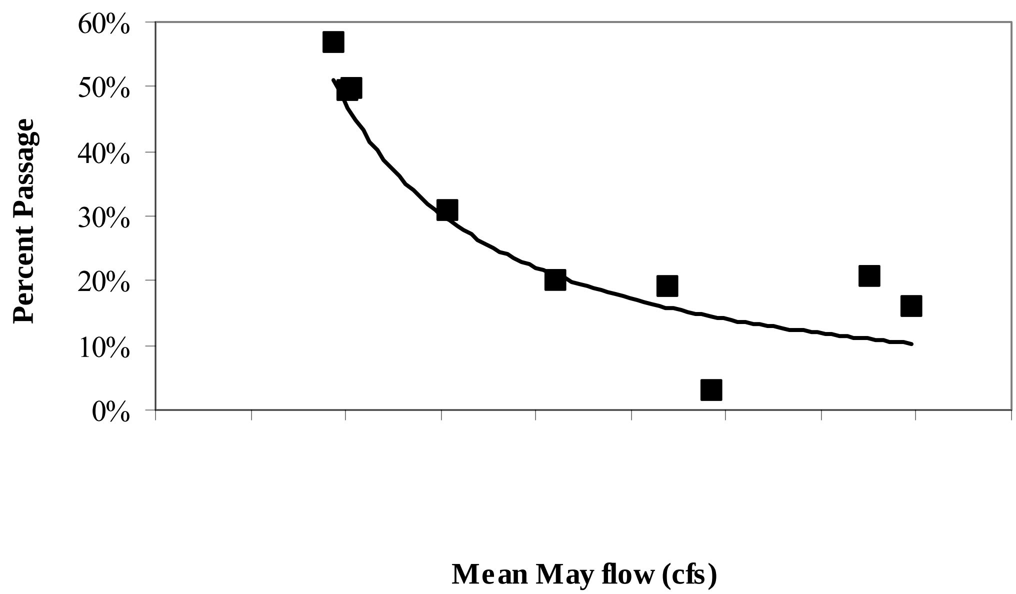


Figure 10.8 River flow (x 1000 cfs) and water temperature (˚F) in relation to the daily American shad catch at the Holtwood fish-lift, 2002. No operation April 19-20, May 2-5, and 14-26. Note that the peaks in shad passage correspond with periods when flow is less than 40,000 cfs.

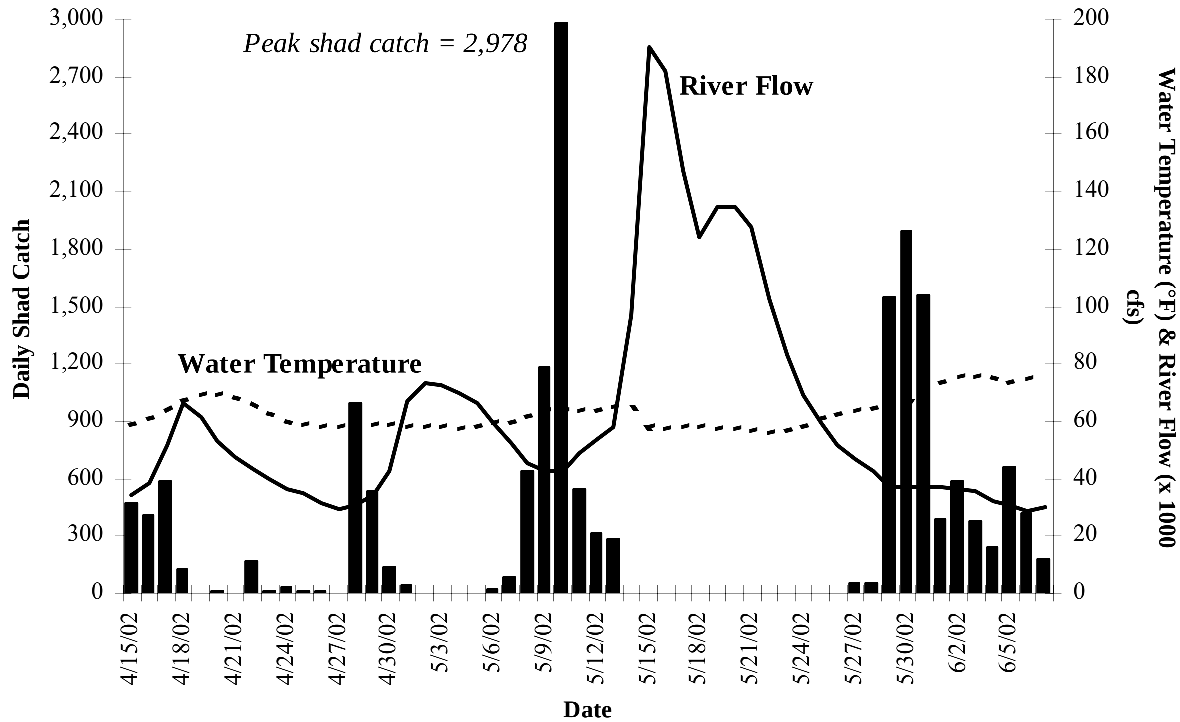


Figure 10.9 American shad passage by date at Holtwood and Safe Harbor dams, Susquehanna River, 1999. Note the single day lag between peaks.

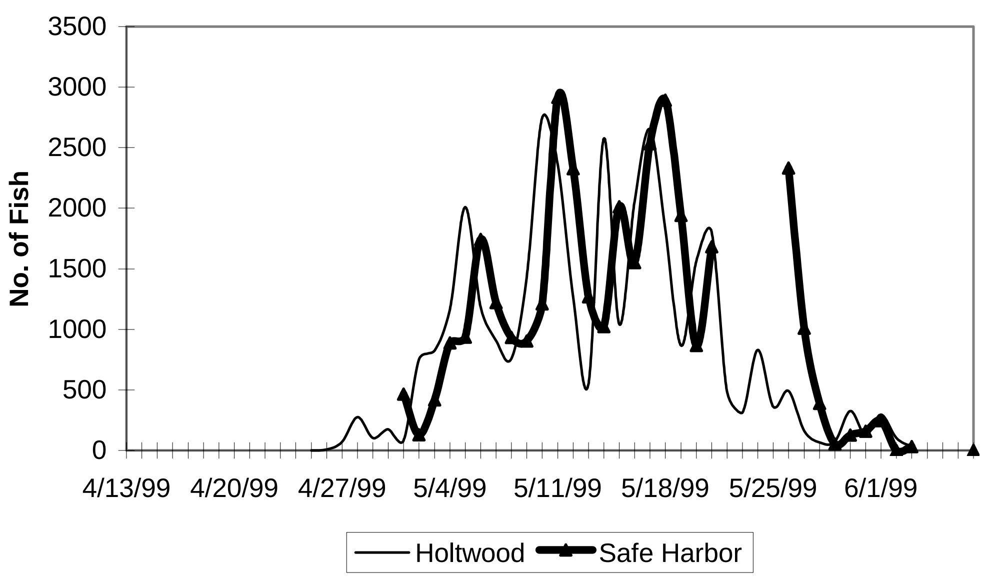


Figure 10.10 Mean weight of adult American shad, sexes combined, collected at Conowingo Dam fish-lifts, Susquehanna River.

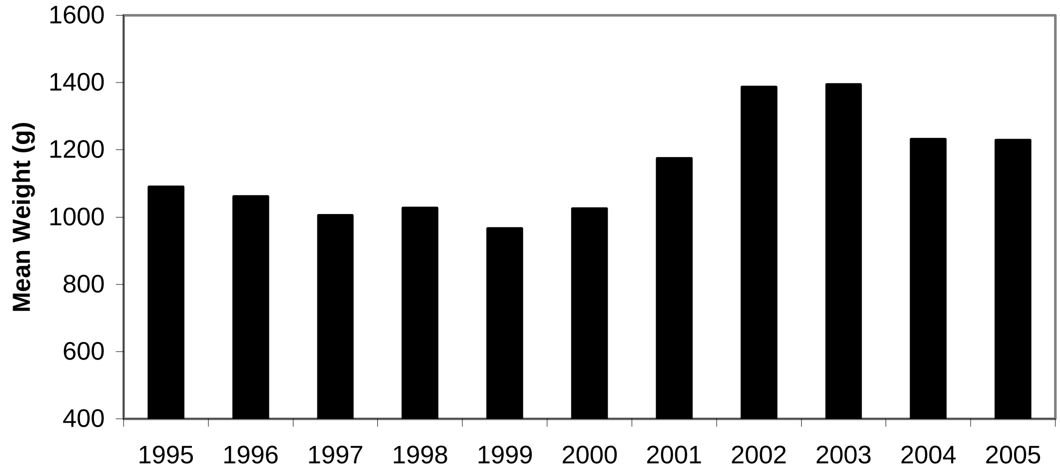


Figure 10.11 Mean length (TL) of adult American shad, sexes combined, collected at Conowingo Dam fish-lifts, Susquehanna River. (*) indicates that TL was estimated from FL according to: TL = FL * 1.117 + 6.674.

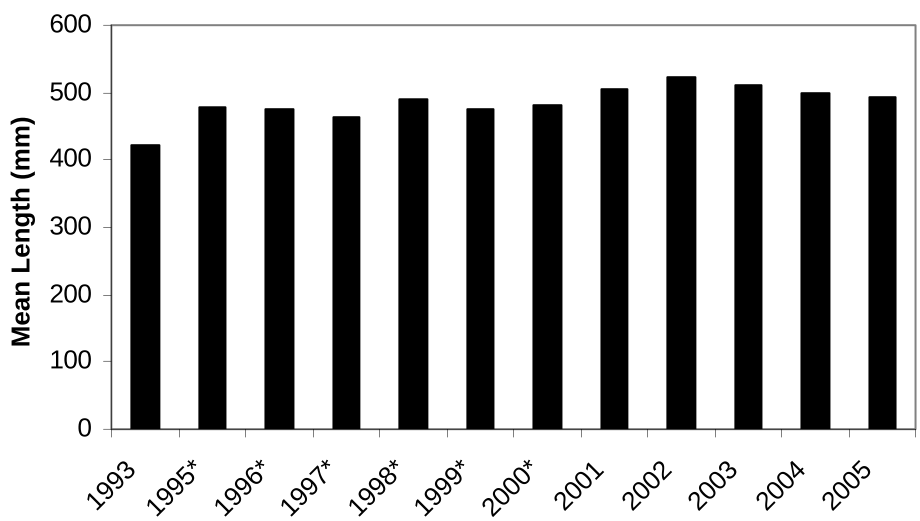


Figure 10.12 CPUE (geometric mean) of adult American shad from Susquehanna Flats pound nets.

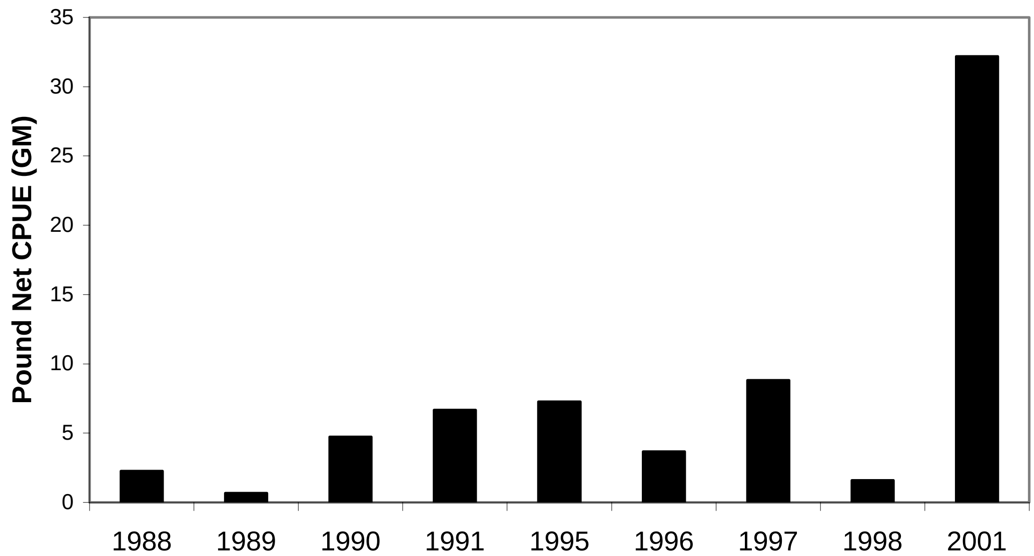


Figure 10.13 Conowingo Dam tailrace hook and line geometric mean CPUE, 1984-2005 and fish-lift geometric mean CPUE, 1984-2005.

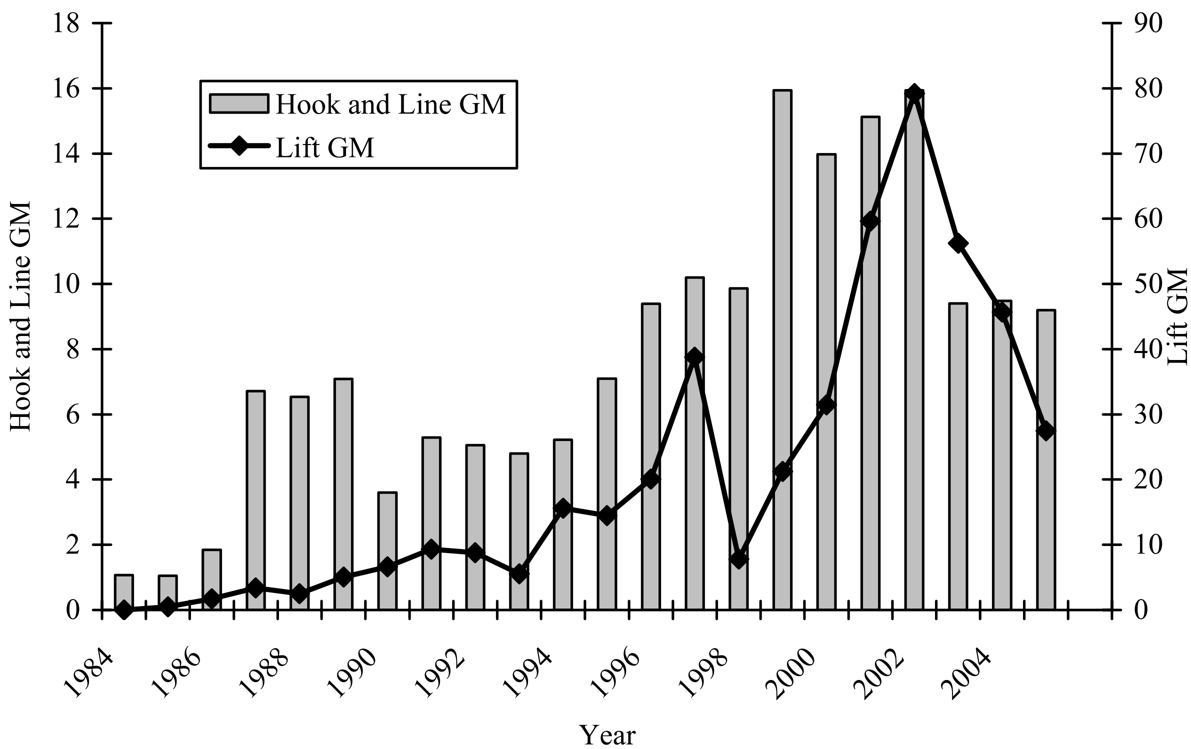


Figure 10.14 Mean age of adult American shad collected in the Conowingo Dam fish-lifts, 1995-2005.

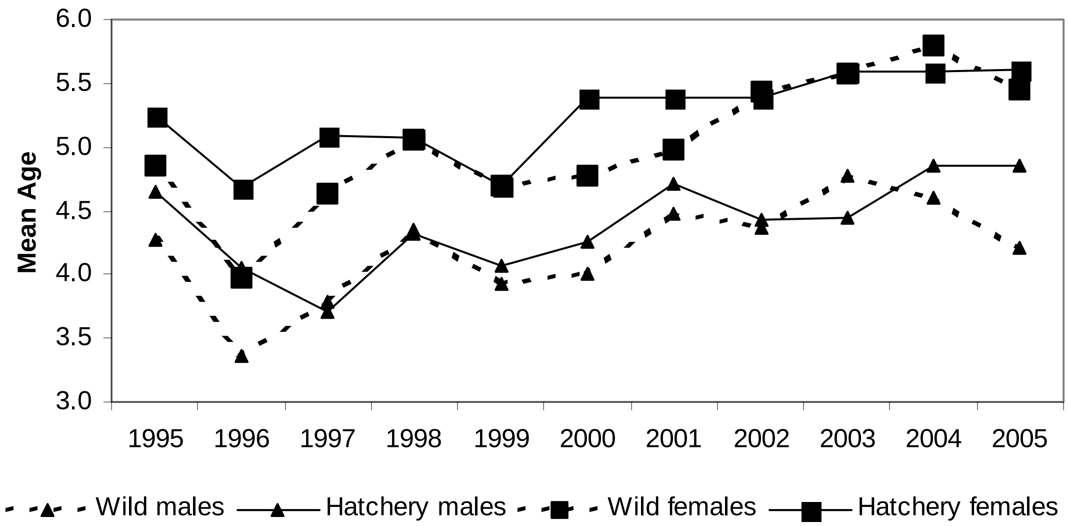


Figure 10.15 Geometric mean (GM) combined daily CPUE vs. GM individual lift CPUE for lift nets at the Holtwood Dam forebay. $Y = 0.40X + 0.04$; $R^2 = 0.72$; Significant $P = 0.004$.

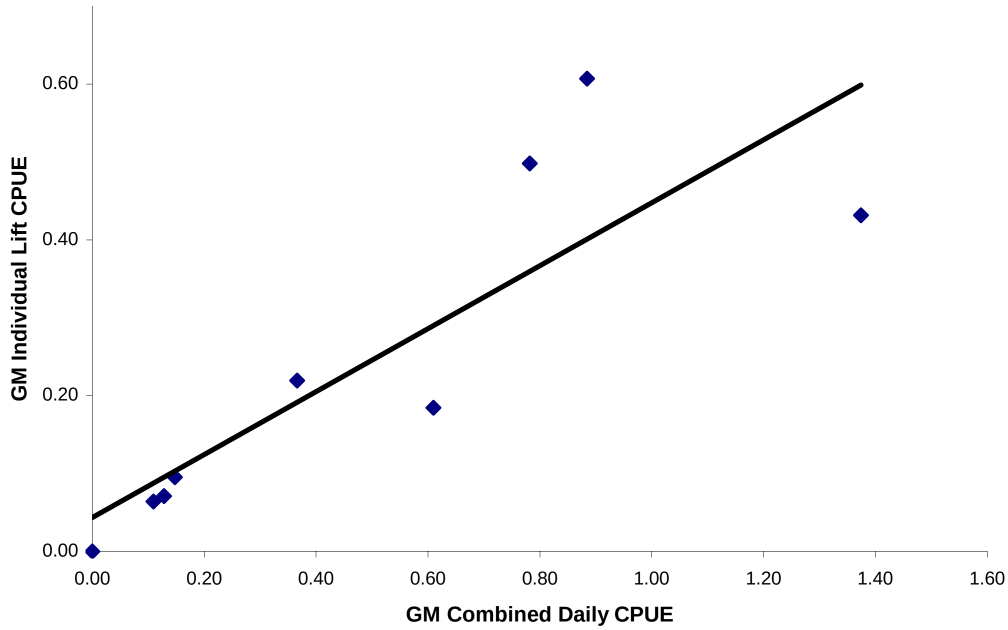


Figure 10.16 Geometric mean (GM) combined daily CPUE vs. area under the curve for lift net collections at Holtwood Dam forebay. $Y = 0.004X + 0.02$; $R^2 = 0.81$; Significant $P = 5.7 \times 10^{-8}$.

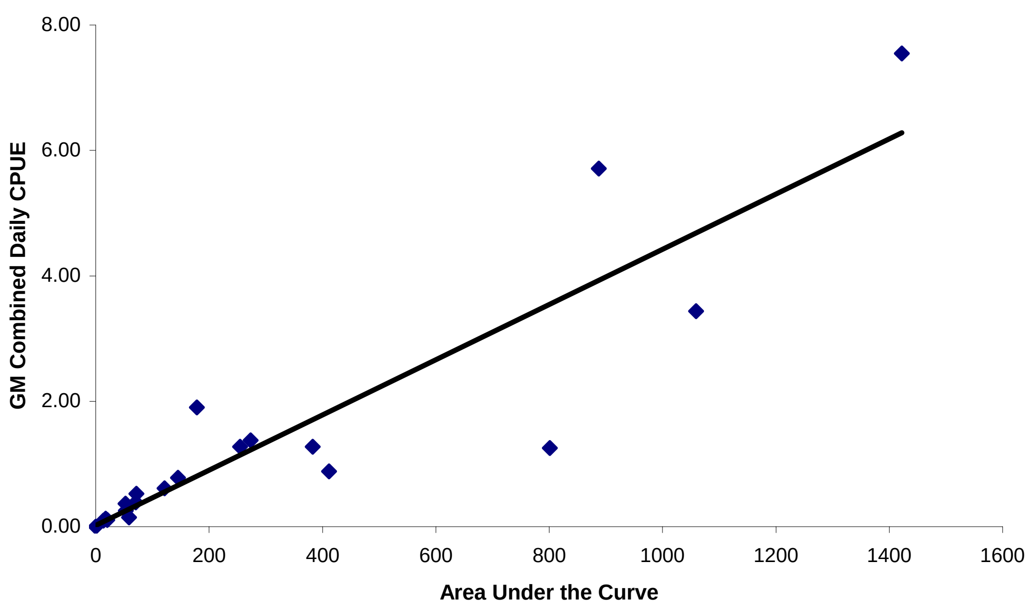


Figure 10.17 Geometric mean (GM) combined daily CPUE vs. GM individual haul CPUE for haul seine collections in the Susquehanna River at Columbia, Pennsylvania. Y = 0.49X + 0.03; R^2 = 0.99; Significant P = 1.9 x 10^{-13}.

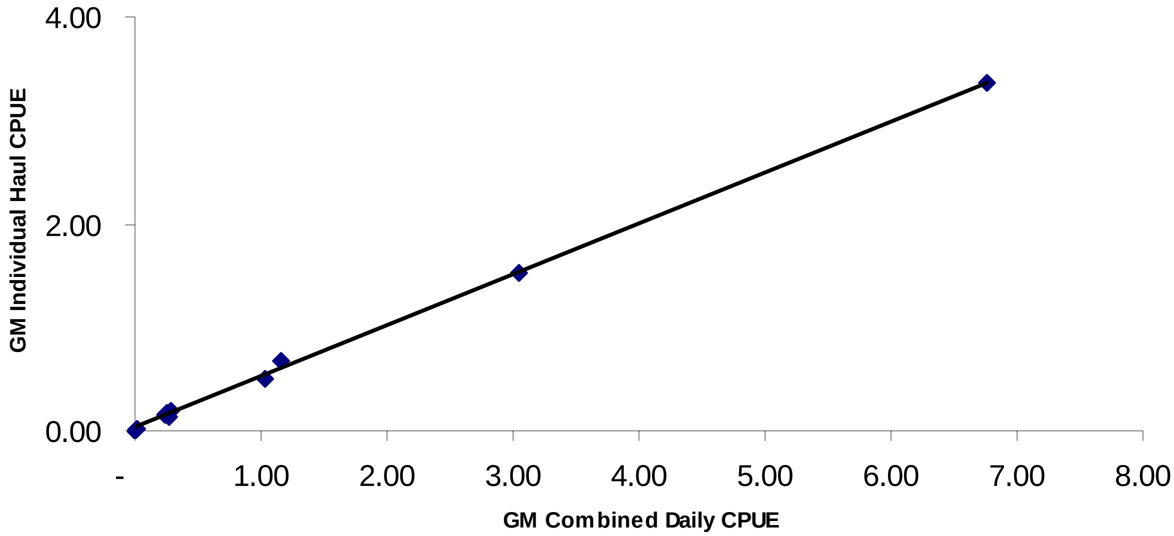


Figure 10.18 Number of shad larvae stocked vs. JAI (area under the curve for hatchery juvenile shad collected by lift net at Holtwood Dam). Y = (9 x 10^{-6})X + 134; R^2 = 0.01; Significant P = 0.73.

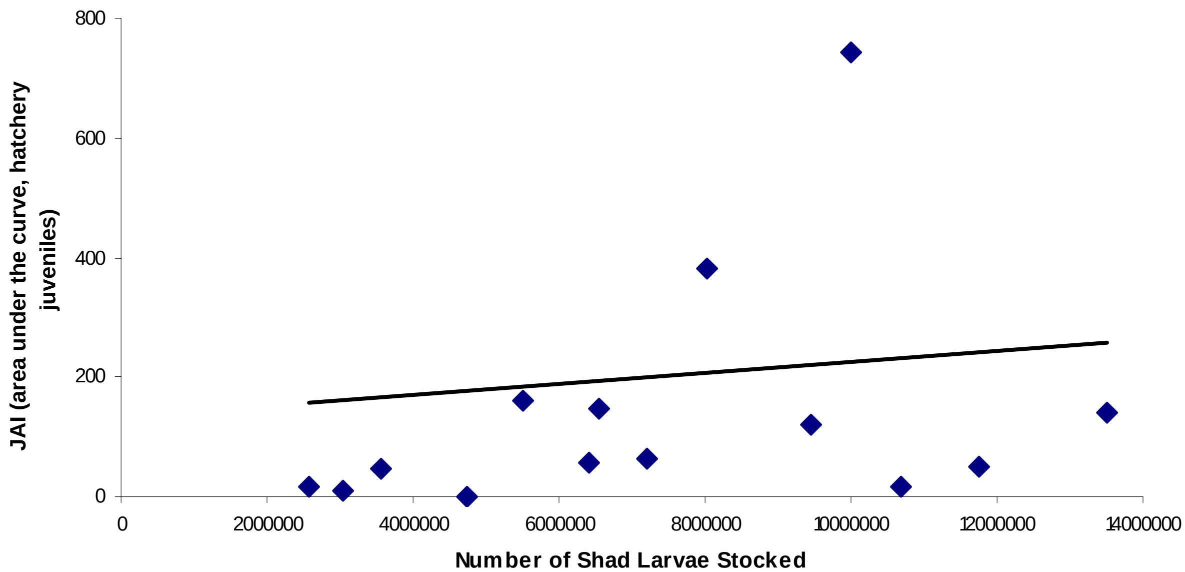


Figure 10.19 Haul seine geometric mean (GM) combined daily CPUE (hatchery) vs. larvae stocked. Y = $(1.8 \times 10^{-7})X + 0.06$; $R^2 = 0.08$; Significant $P = 0.27$.

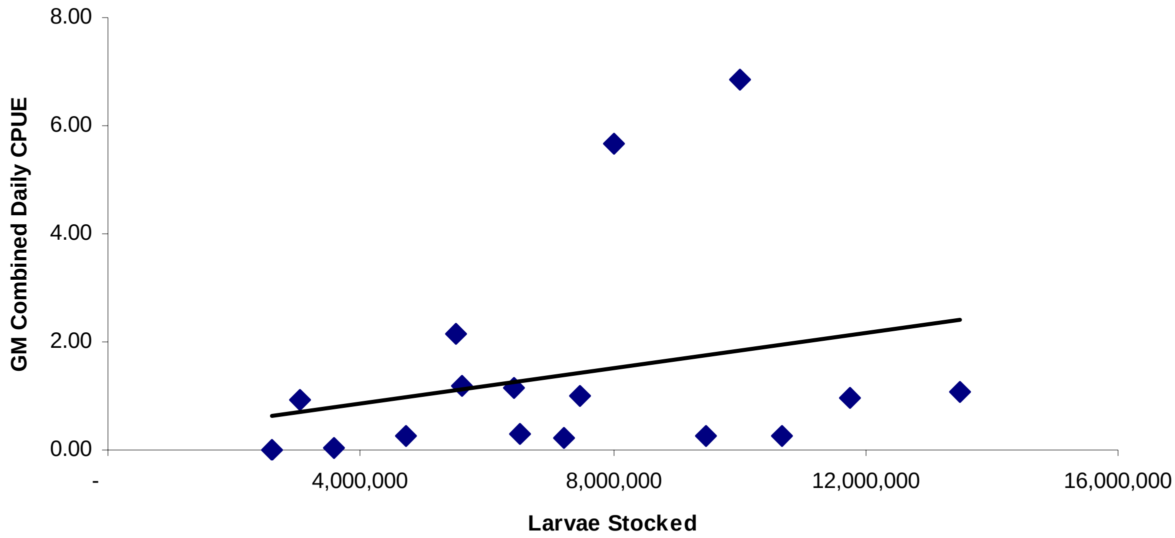


Figure 10.20 Number of adult American shad transported or passes above Safe Harbor Dam vs. JAI (area under the curve for wild juvenile shad collected by lift net at Holtwood Dam). Y = $0.0007X + 13.8$; $R^2 = 0.06$; Significant $P = 0.37$.

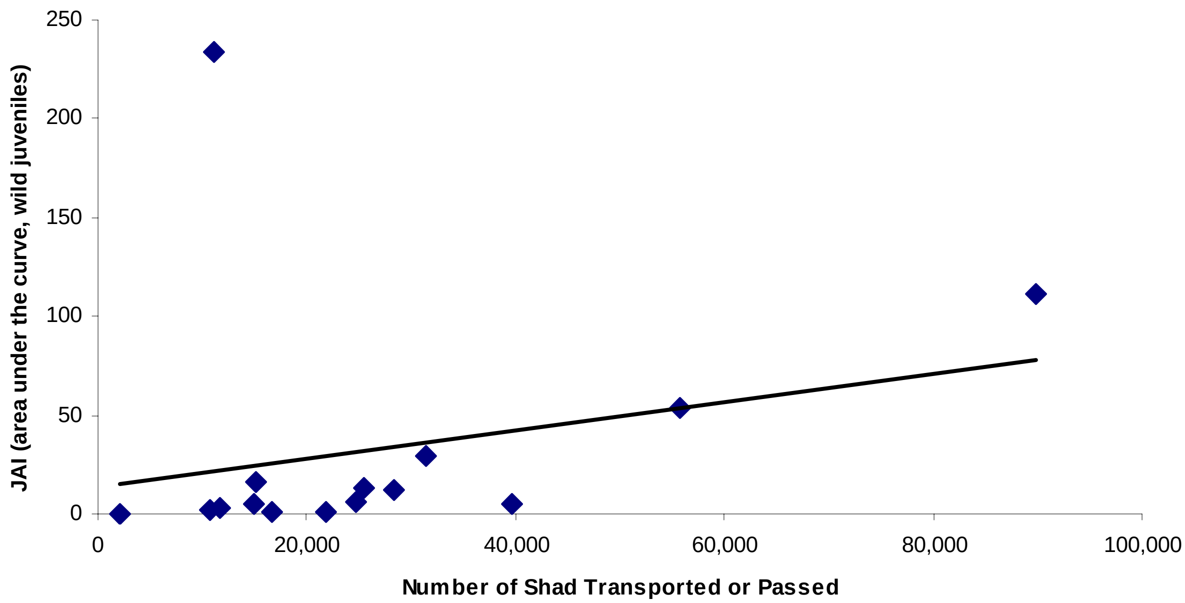


Figure 10.21 Number of adult American shad transported or passed above Safe Harbor Dam vs. geometric mean (GM) CPUE for wild juveniles collected by haul seine. Y = (1.4 x 10^{-5})X + 0.14; R^2 = 0.28; Significant P = 0.03.

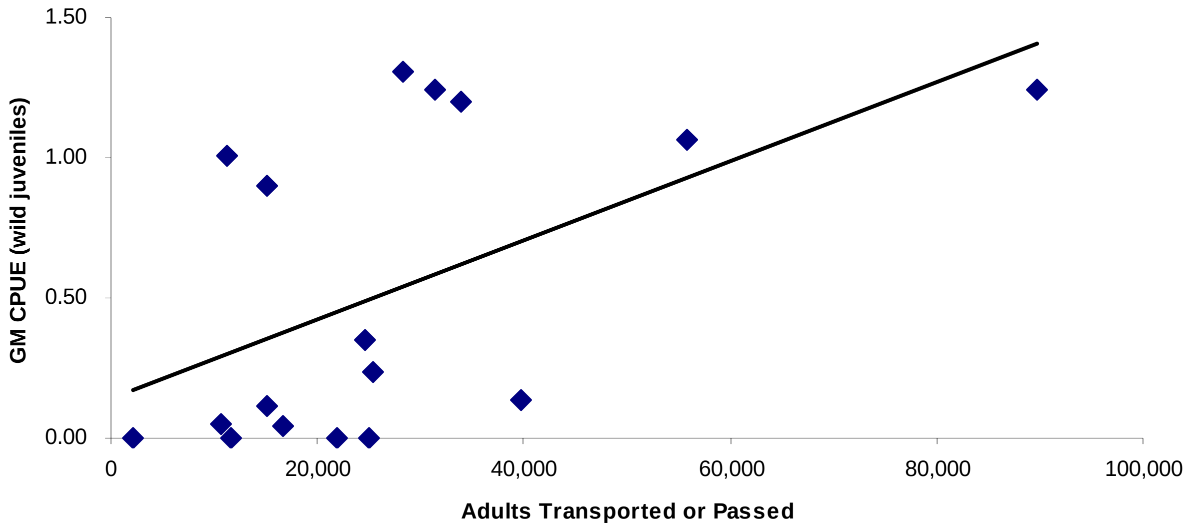


Figure 10.22 Number of adult American shad transported or passed above York Haven Dam vs. JAI (area under the curve for wild juvenile shad collected by lift net at Holtwood Dam). Y = 0.003X - 0.3; R^2 = 0.42; Significant P = 0.03.

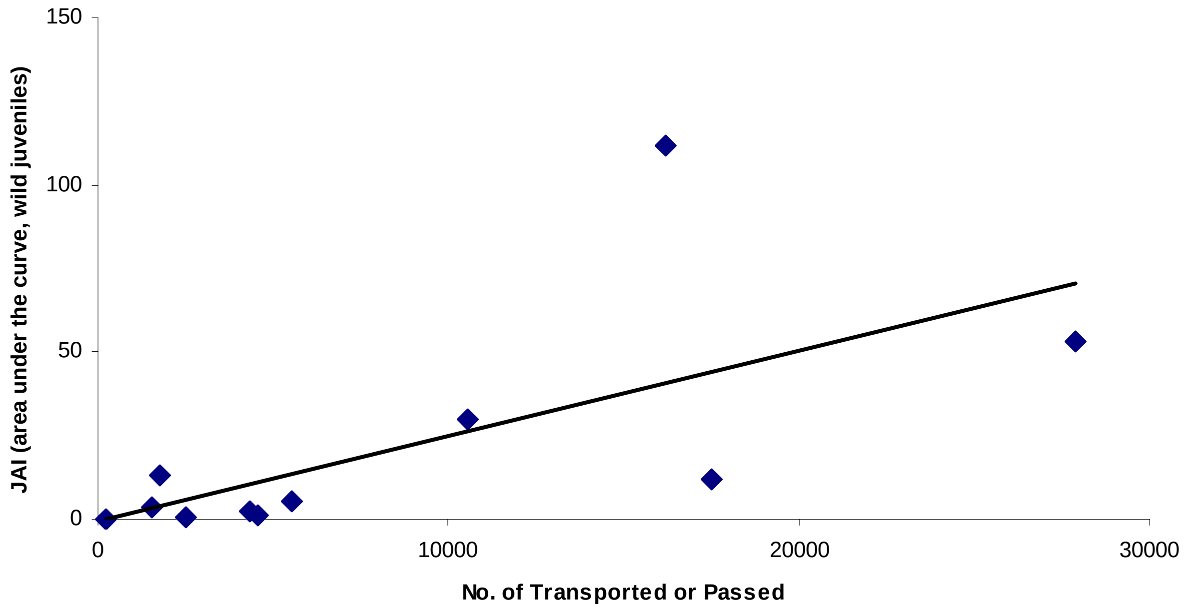


Figure 10.23 Number of adult American shad transported or passed above York Haven Dam vs. geometric mean (GM) CPUE for wild juveniles collected by haul seine. $Y = (4.6 \times 10^{-5})X + 0.04$; $R^2 = 0.50$; Significant $P = 0.002$.

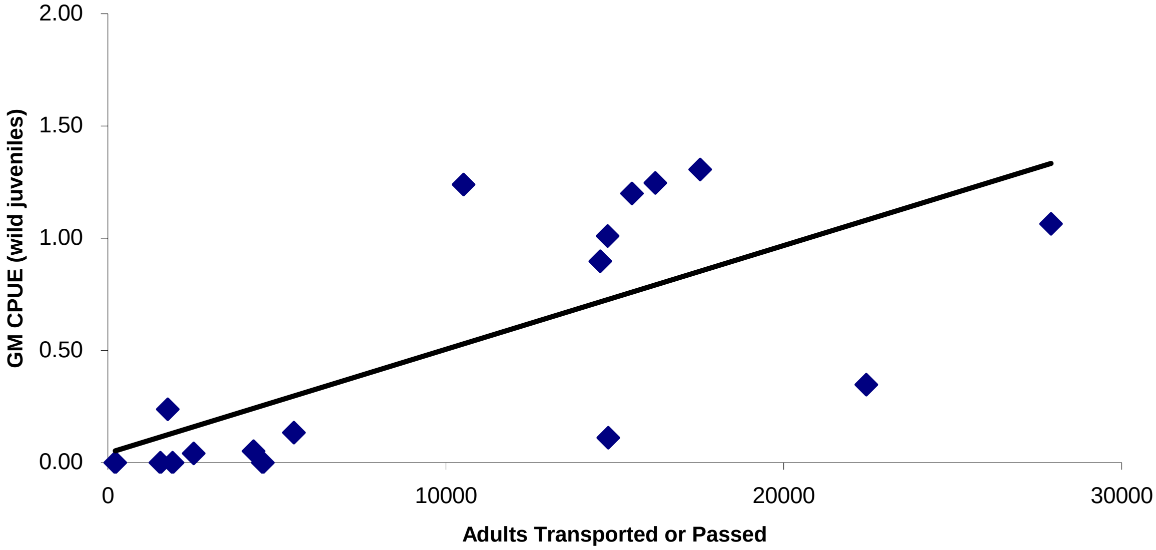


Figure 10.24 JAI (Area under the curve from Holtwood Dam lift net) vs. cohort recruitment to the Conowingo Dam fish-lifts. $Y = 1.84X + 77,652$; $R^2 = 9.3 \times 10^{-5}$; Significant $P = 0.98$.

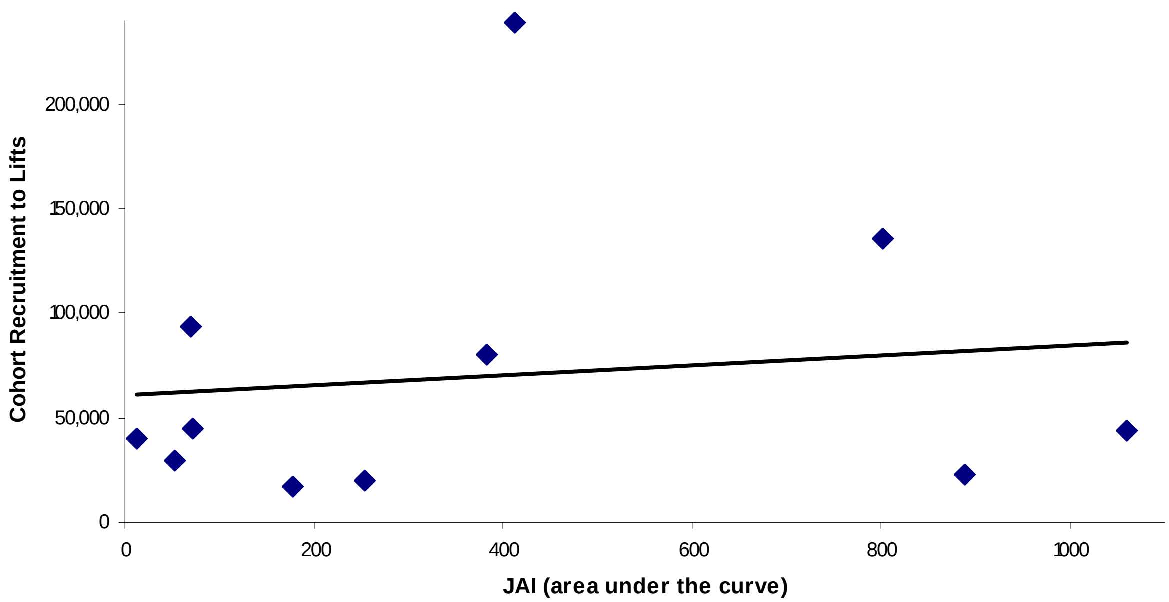


Figure 10.25 Geometric mean (GM) combined daily CPUE (haul seine) vs. recruitment to Conowingo Dam fish-lifts. Y = 8,772X + 69,236; R^2 = 0.17; Significant P = 0.24.

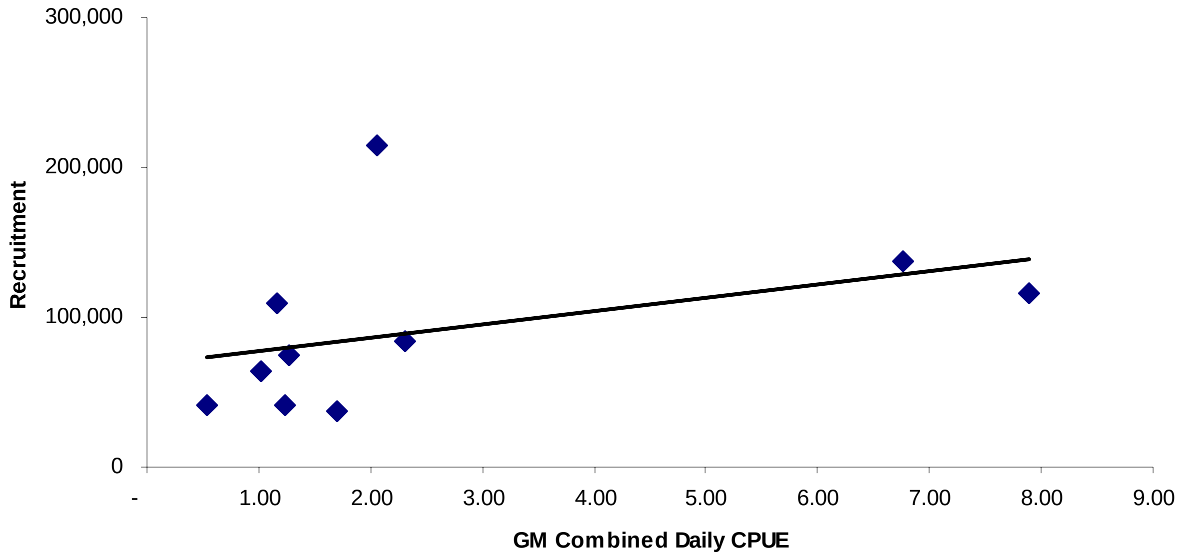


Figure 10.26 JAI (area under the curve, hatchery) from Holtwood Dam lift net vs. hatchery cohort recruitment to the Conowingo Dam fish-lifts. Y = 2.56X + 40,958; R^2 = 0.0006; Significant P = 0.94.

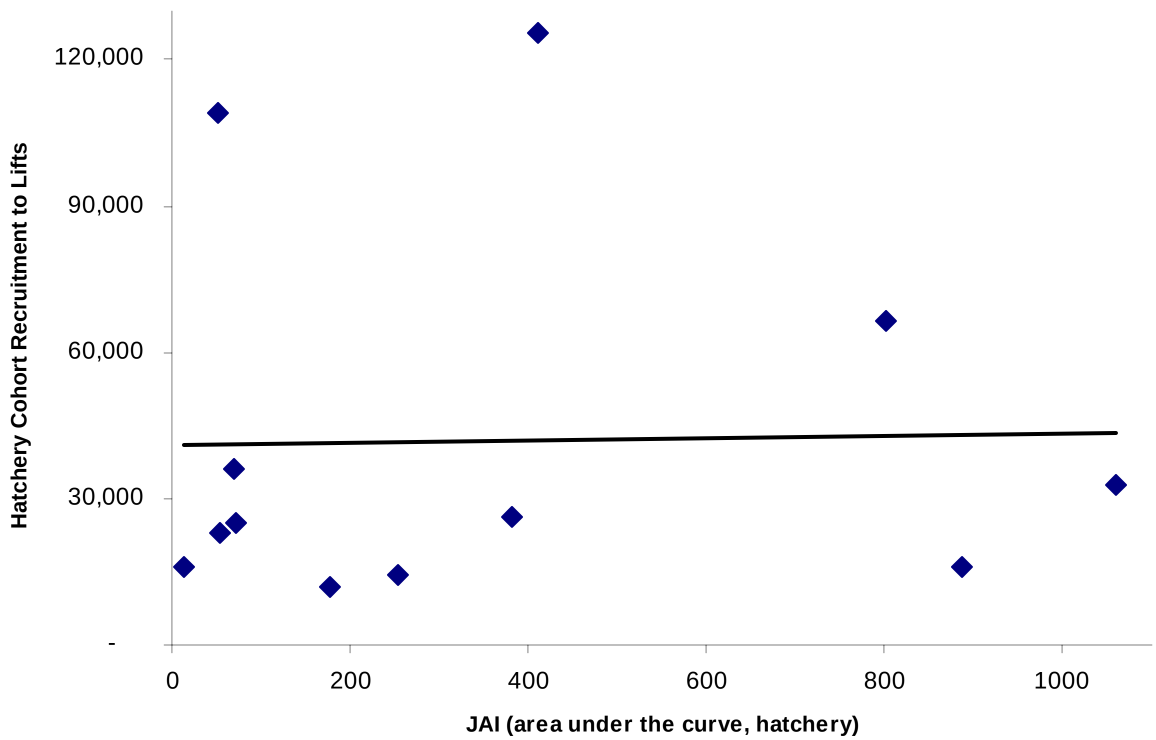


Figure 10.27 Haul seine geometric mean (GM) combined daily CPUE (hatchery) vs. hatchery recruitment to Conowingo Dam fish-lifts. Y = 4,999X + 40.294; R^2 = 0.13; Significant P = 0.30.

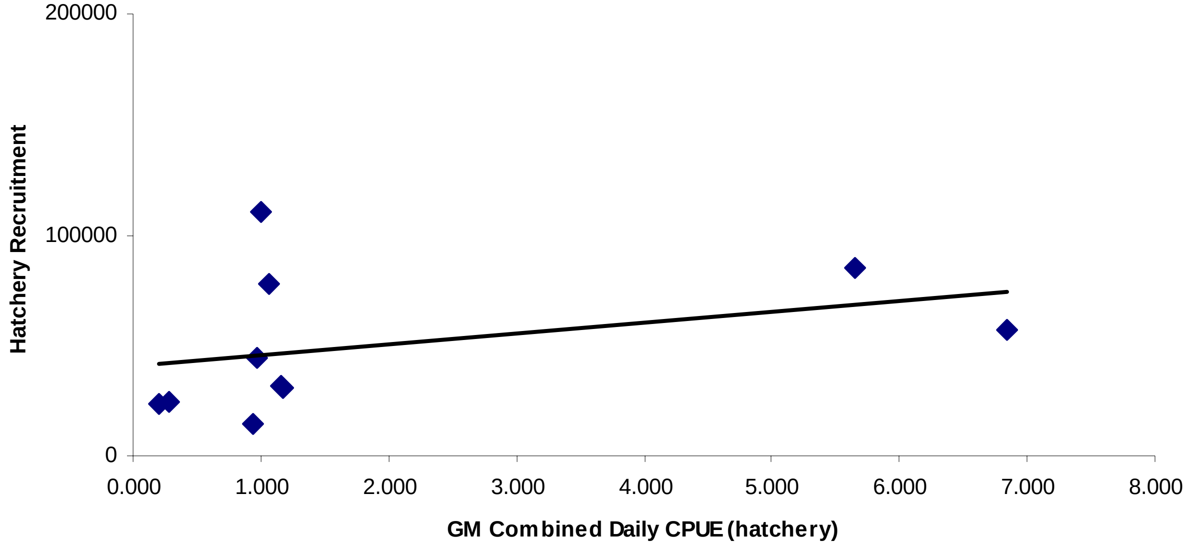


Figure 10.28 Number of shad larvae stocked vs. cohort recruitment of hatchery shad to fish-lifts at Conowingo Dam. Y = (9 x 10^{-6})X + 134; R^2 = 0.01; Significant P = 0.73.

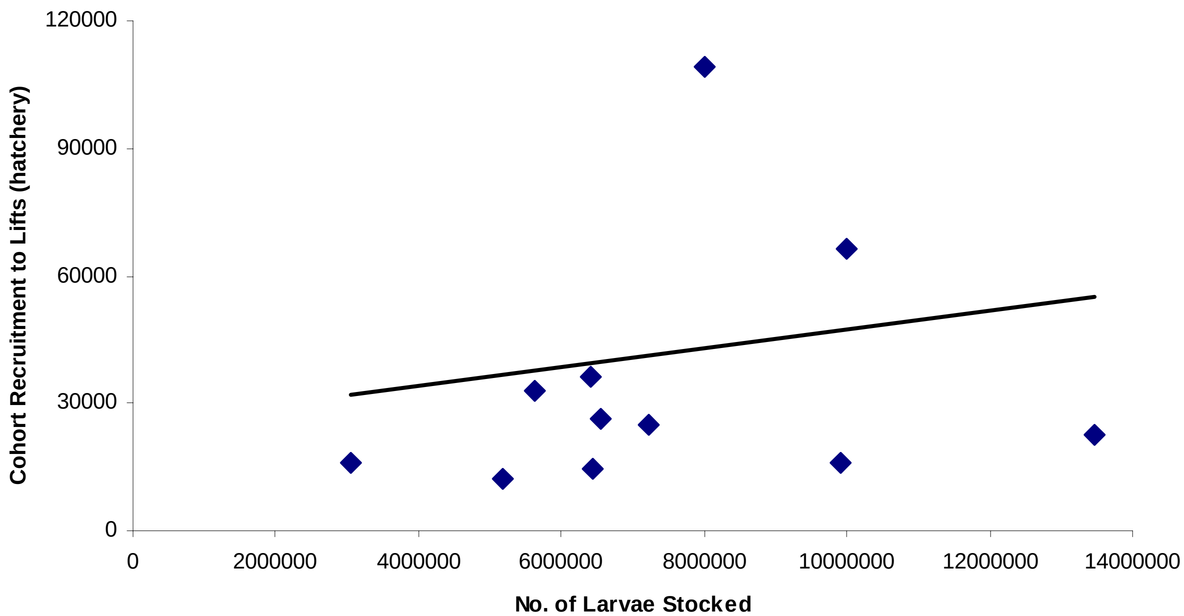


Figure 10.29 JAI (area under the curve) for lift net in year Y-3 vs. returns of 3 year olds to Conowingo Dam in year Y. Y = -6.8X + 7,016; $R^2 = 0.01$; Significant $P = 0.20$.

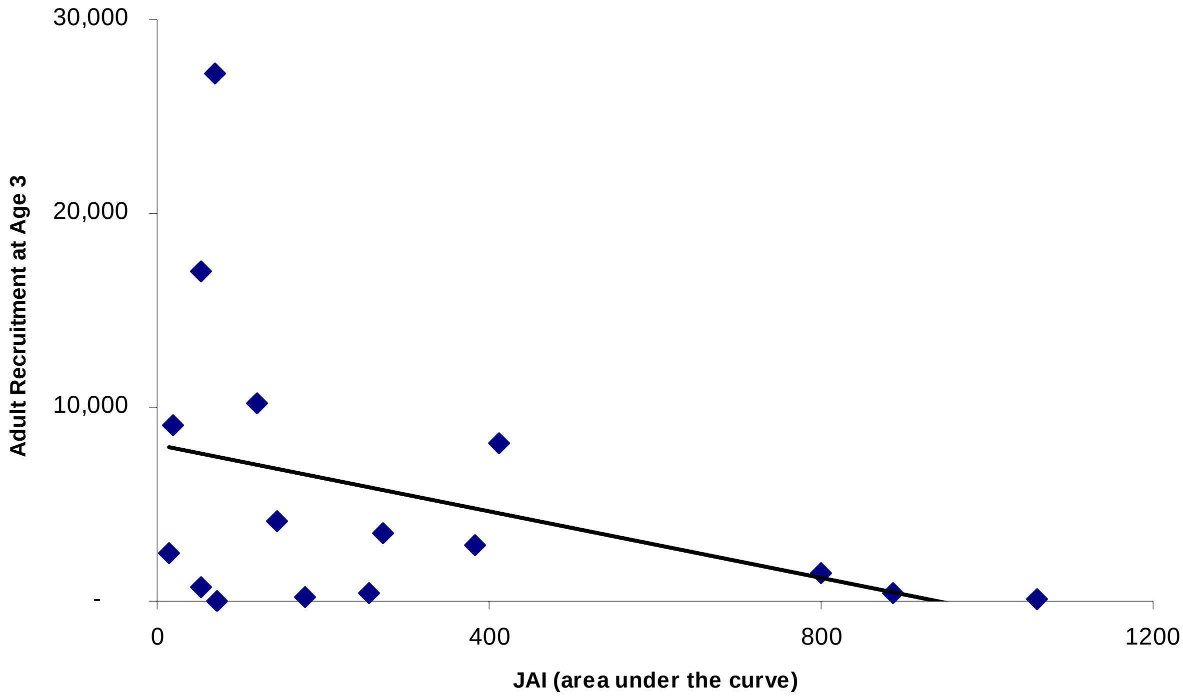


Figure 10.30 JAI (area under the curve) for lift net in year Y-4 vs. returns of 4 year olds to Conowingo Dam in year Y. Y = -0.81X + 22,101; $R^2 = 0.0002$; Significant $P = 0.96$.

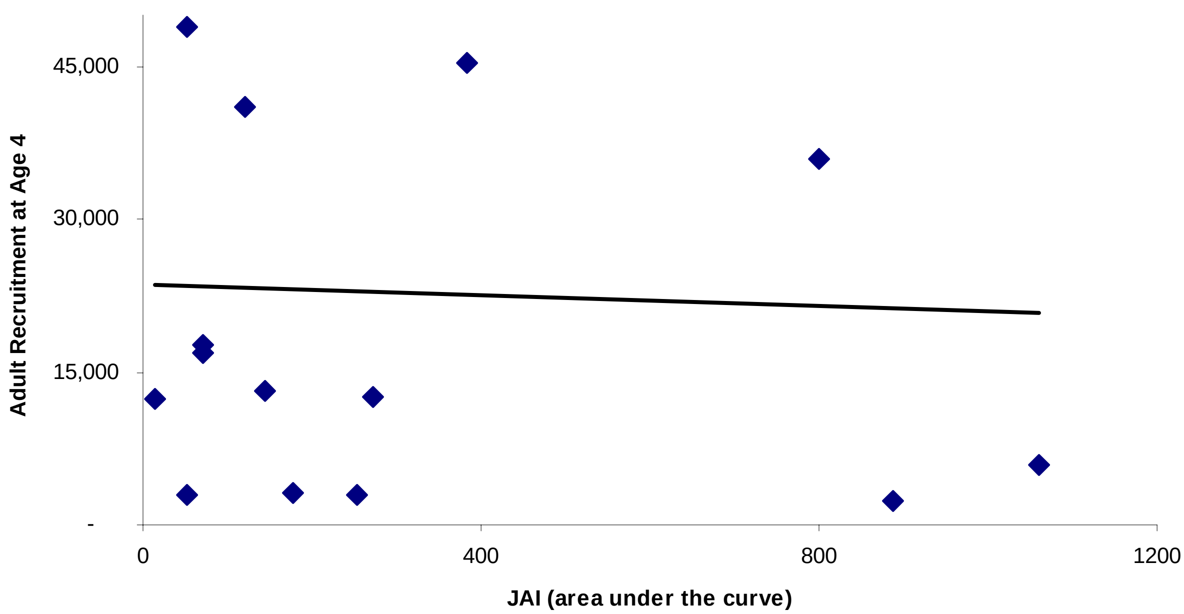


Figure 10.31 JAI (area under the curve) for lift net in year Y-5 vs. returns of 5 year olds to Conowingo Dam in year Y. Y = 7.05X + 23,392; R^2 = 0.01; Significant P = 0.70.

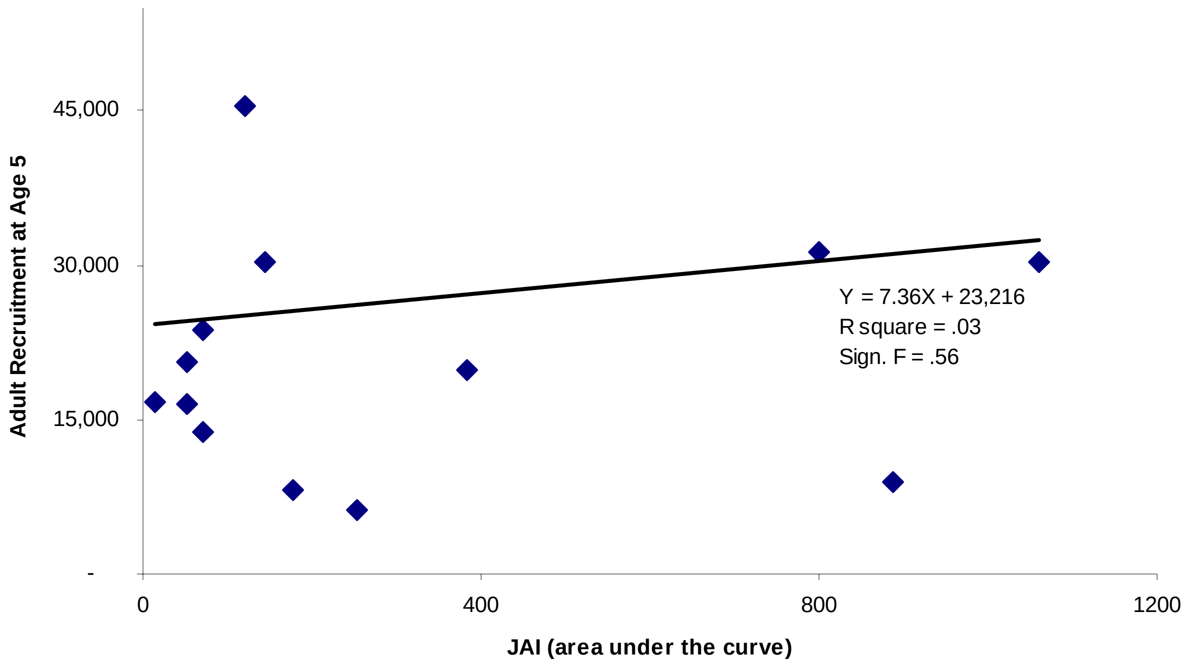


Figure 10.32 JAI (area under the curve) for lift net in year Y-6 vs. returns of 6 year olds to Conowingo Dam in year Y. Y = 3.76X + 11,475; R^2 = 0.01; Significant P = 0.72.

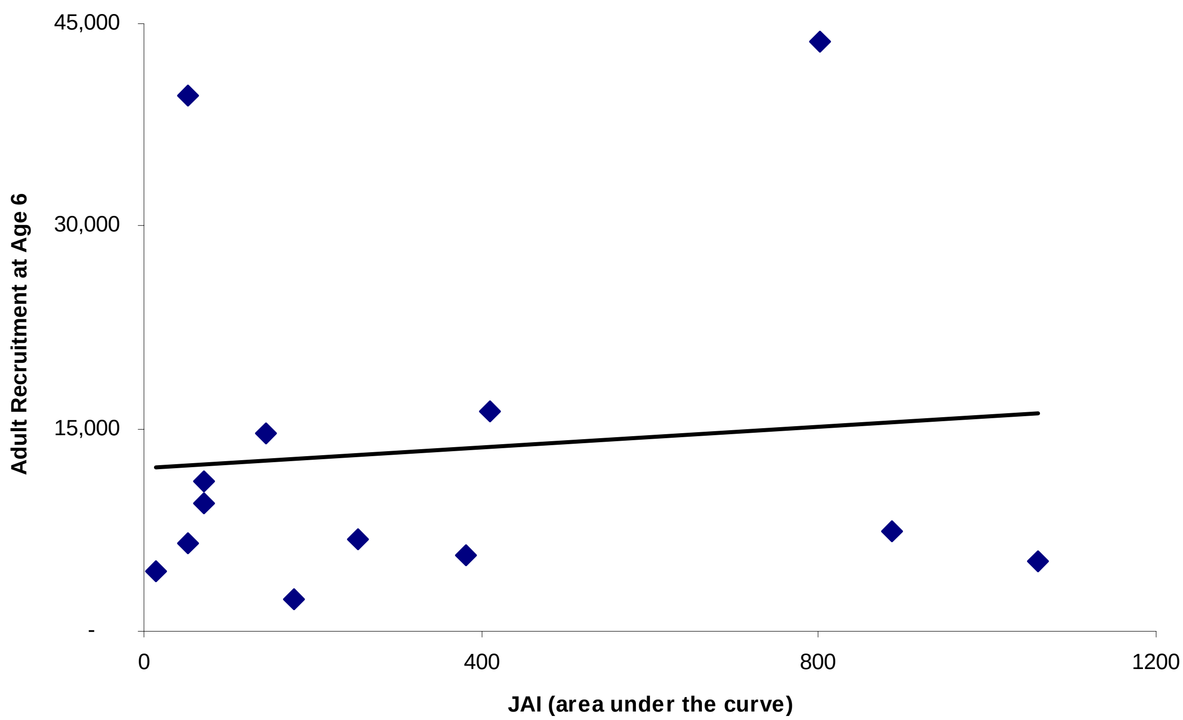


Figure 10.33 JAI (Area under the curve) for lift net in year Y-7 vs. returns of 7 year olds to Conowingo Dam in year Y. Y = -1.7X + 2,956; R^2 = 0.04; Significant *P* = 0.50.

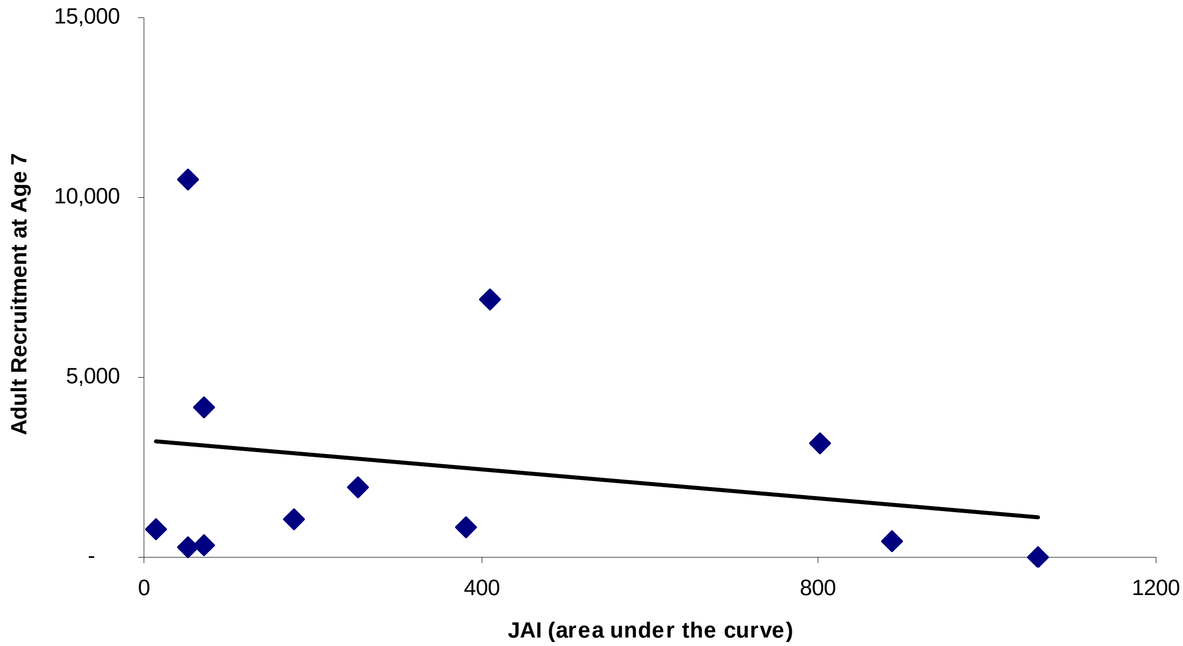


Figure 10.34 JAI (GM combined daily CPUE) for haul seine in year Y-3 vs. returns of 3 year olds to Conowingo Dam in year Y. Y = 933X + 4,488; R^2 = 0.08; Significant *P* = 0.31.

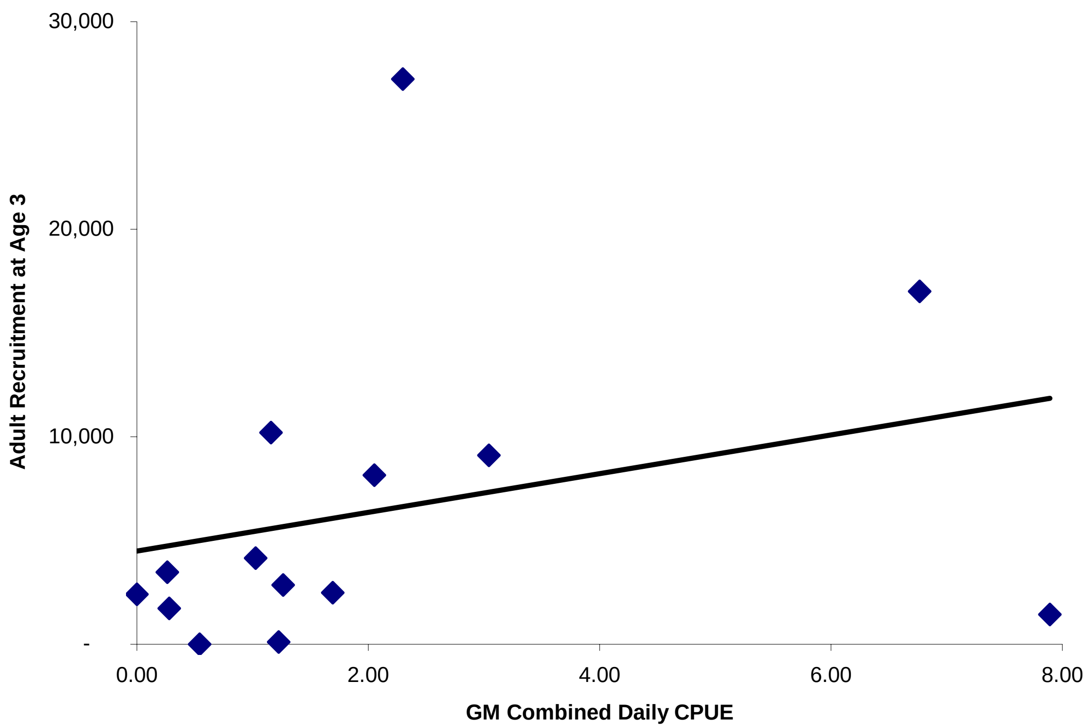


Figure 10.35 JAI (GM combined daily CPUE) for haul seine in year Y-4 vs. returns of 4 year olds to Conowingo Dam in year Y. Y = 3,56X + 20,848; R^2 = 0.12; Significant P = 0.25.

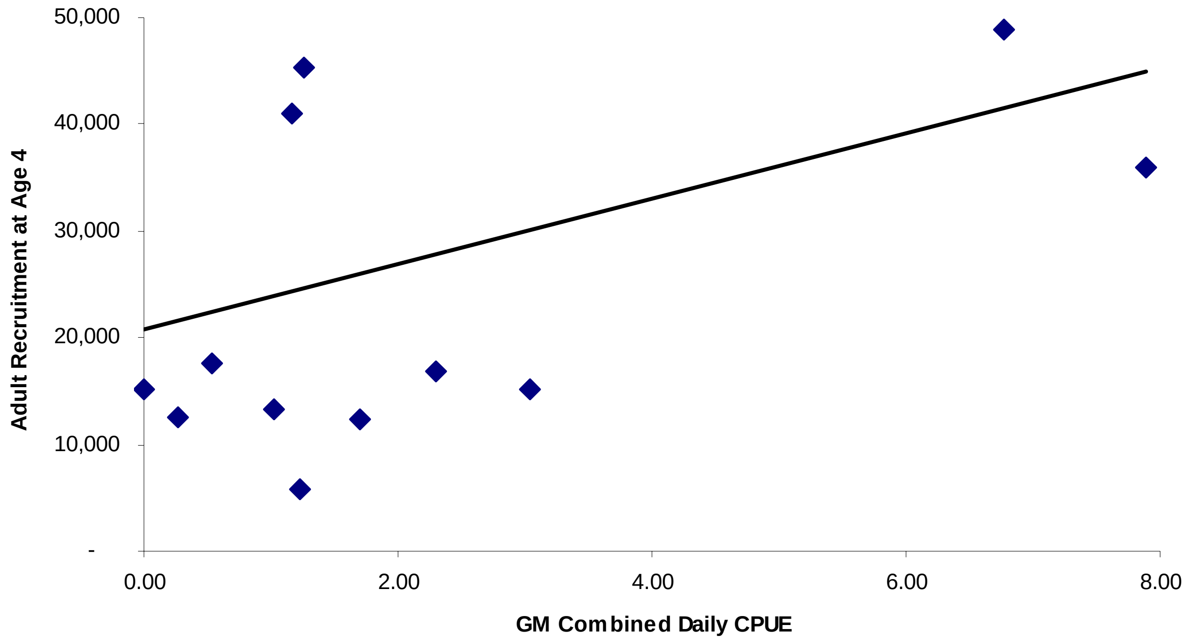


Figure 10.36 JAI (GM combined daily CPUE) for haul seine in year Y-5 vs. returns of 5 year olds to Conowingo Dam in year Y. Y = 147X + 30,377; R^2 = 0.0002; Significant P = 0.96.

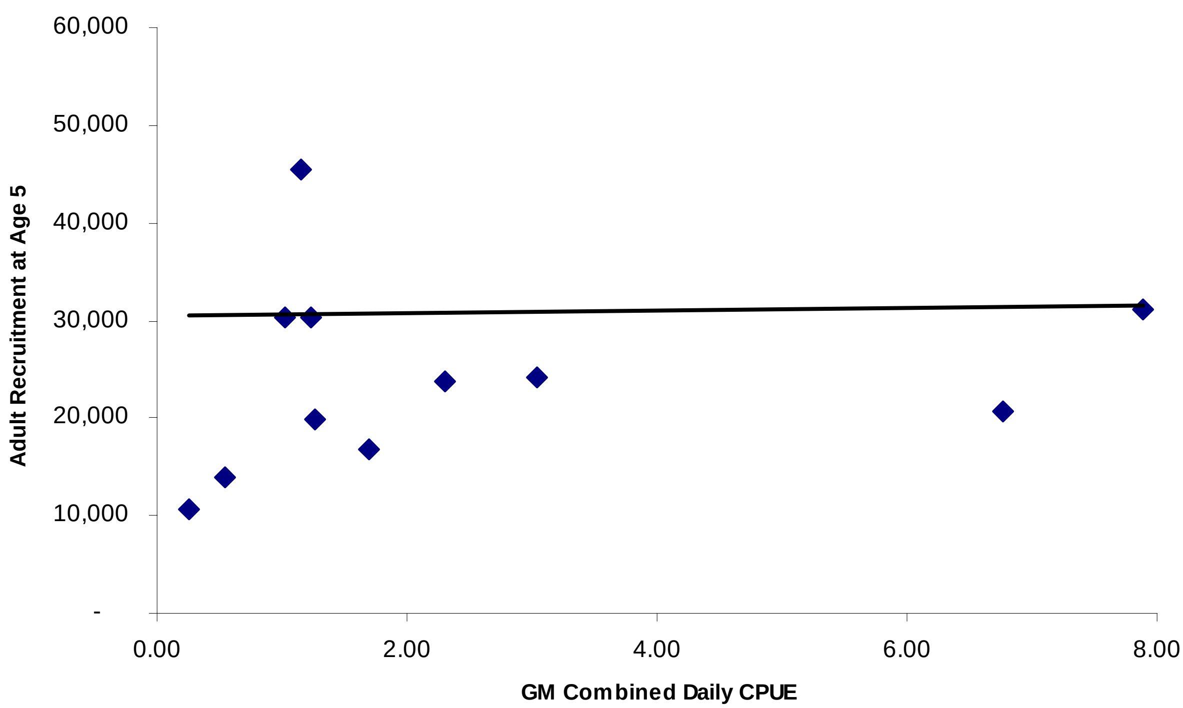


Figure 10.37 JAI (GM combined daily CPUE) for haul seine in year Y-6 vs. returns of 6 year olds to Conowingo Dam in year Y. Y = 5,157X + 2,921; R^2 = 0.91; Significant $P = 6.04 \times 10^{-6}$.

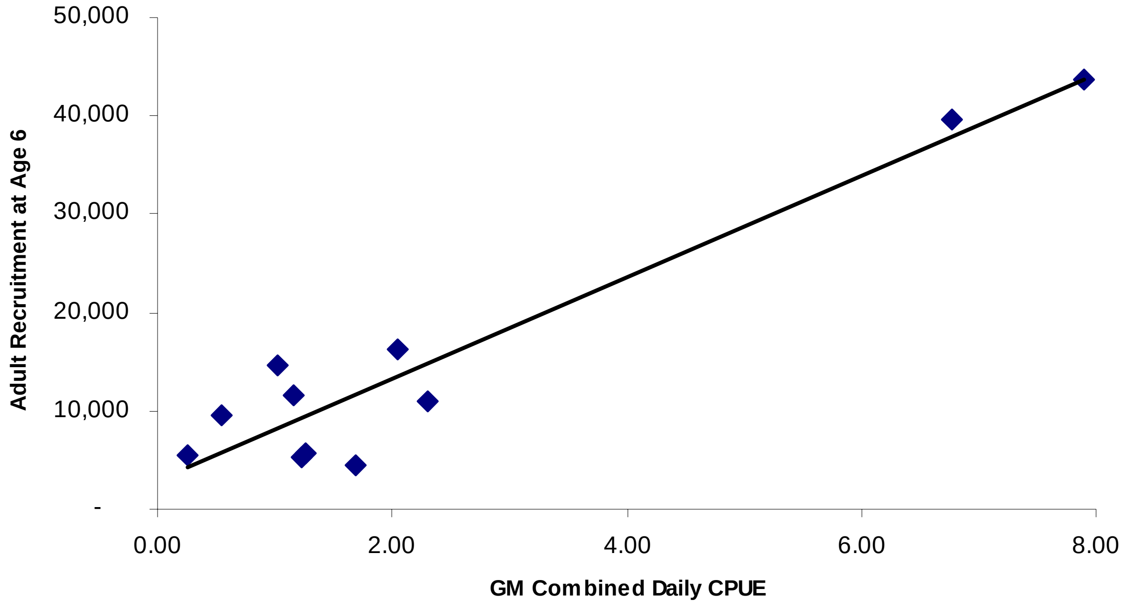


Figure 10.38 JAI (GM combined daily CPUE) for haul seine in year Y-7 vs. returns of 7 year olds to Conowingo Dam in year Y. Y = 826X + 848; R^2 = 0.38; Significant P = 0.06.

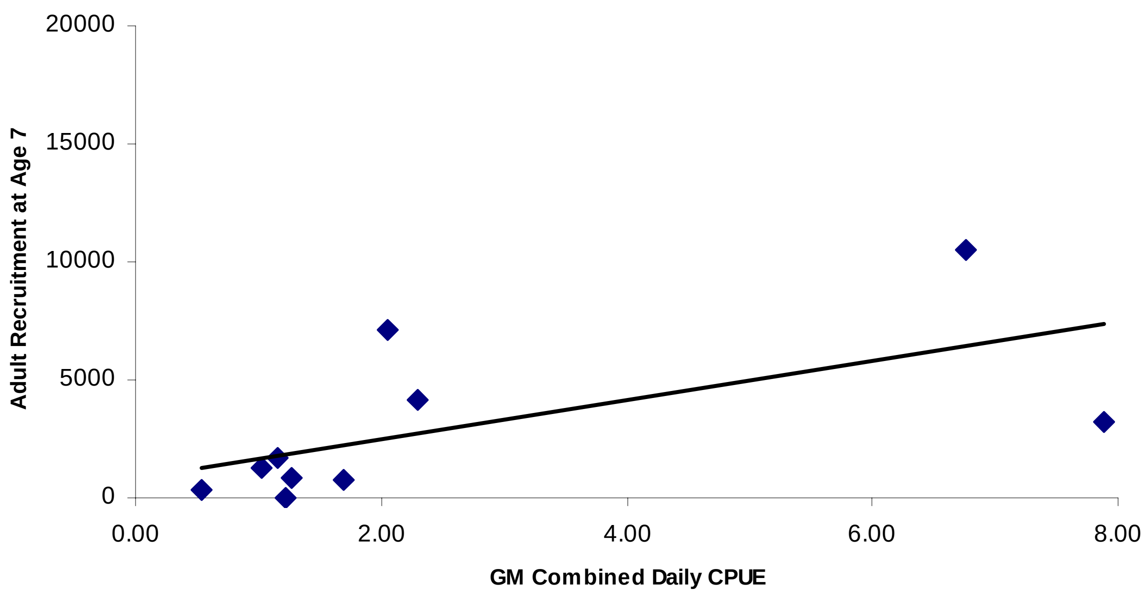


Figure 10.39 Upper Chesapeake Bay juvenile American shad geometric mean CPUE with 95% confidence intervals, 1959-2005.

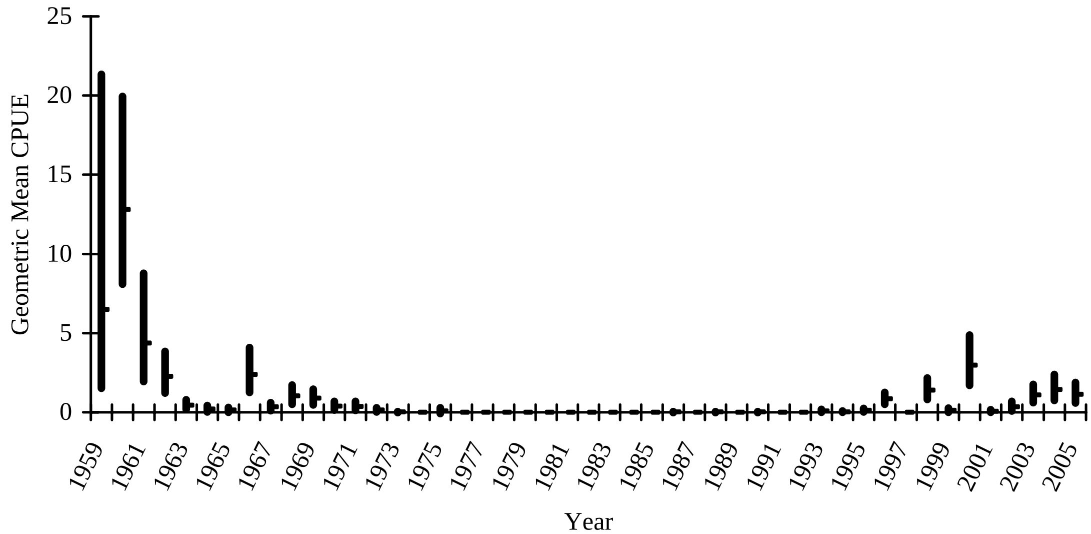
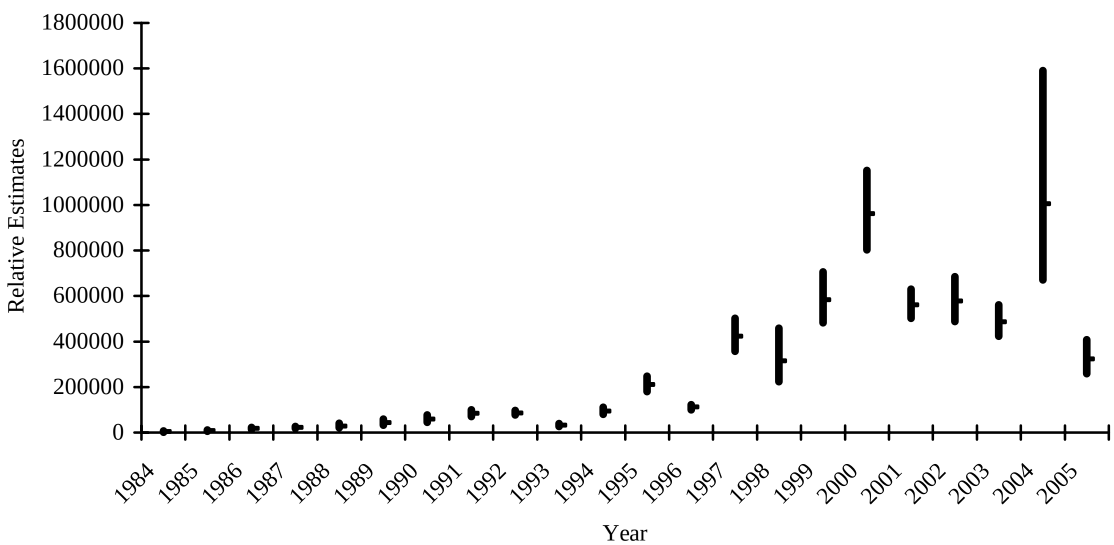


Figure 10.40 Conowingo Dam tailrace relative estimates of American shad abundance, 1984-2005, with 95% confidence intervals.



Section 11
Status of the Potomac River American Shad Stock

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11.1 INTRODUCTION

This Status of the Potomac River American Shad Stock Report was a collaborative effort on the parts of the several agencies, departments, organizations, and commissions with mutual interest in the fisheries of the tidal Potomac River. We wish to recognize and thank the many, many unnamed people, past and present, who knowingly and unknowingly, willingly and sometimes not so willingly, contributed of their time, talents and expertise in collecting, compiling, and analyzing the data needed and used in this report.

11.2 MANAGEMENT UNIT DEFINITION

The low water mark of the southern shore Potomac River, exclusive of the tributaries, is the boundary line between the states of Maryland and Virginia, with Maryland being the owner of the river. Maryland and Virginia first entered into a compact in 1785 to regulate, among other things, the fisheries of the Potomac. After the adoption of the U.S. Constitution and the formation of a federal government, Maryland ceded the area, including that part of the Potomac River, which is now the District of Columbia.

There are five fishery management authorities on the Potomac River. The Potomac River Fisheries Commission (PRFC) is the Maryland-Virginia bi-state Commission with fisheries management authority for the main stem, exclusive of the tributaries on either side, from the Chesapeake Bay to the southern Maryland-District of Columbia boundary line; the District of Columbia (D.C.) with authority for the Potomac to the Virginia shore and other waters within D.C.; the Maryland Department of Natural Resources (DNR) with authority for the tributaries of the Potomac on the Maryland side of the river and the fluvial portion of the river upstream of D.C.; the Virginia Marine Resources Commission (VMRC) with authority for commercial fisheries in all tidal Virginia tributaries and for recreational fisheries in the saltwater portions of the tidal Virginia tributaries below the Route 301 Bridge; and the Virginia Department of Game and Inland Fisheries (VDGIF) with authority for recreational fisheries in the freshwater portions on the Virginia tributaries. Additionally the Federal government controls much of the shoreline of, and therefore access to, the Potomac through several military bases and the National Park Service.

11.3 REGULATORY HISTORY

During Colonial times the fisheries were essentially unregulated. In 1785 Maryland and Virginia adopted a compact to regulate the fisheries by requiring all fishery laws for the Potomac to be enacted jointly by the legislatures of both states. The first fishing license requirement was imposed by the Union Army during the Civil War, a period when fishing all but ceased. By the middle of the 20th century there were restrictions on gill net mesh sizes, net lengths, and seasons when they could be set. The shad and herring season ran from March to the end of May.

In 1963 the PRFC was instituted and has regulated the fishery since. The portion of the Potomac River under the PRFC jurisdiction is not generally considered an area suitable for recreational shad fishing, so no regulations were enacted until 1982 when a two fish creel was imposed to “close” a perceived jurisdictional loophole.

Gill nets, pound nets, and haul seines were declared commercial gears and require licenses, and all commercial licensees are required to file catch reports. Table 11.1 contains a summary of the regulations for these gears as applied to the shad and herring fishery.

11.4 ASSESSMENT HISTORY

We are unaware of any previous assessments for the Potomac River American shad stock.

11.5 STOCK-SPECIFIC LIFE HISTORY

The only unique life history difference between the Potomac River shad and many other East Coast river stocks is the lack of a long fluvial spawning reach. The spawning grounds are an area only 10 to 12 miles long between Little Falls and Great Falls. The major spawning area is in the tidal freshwater part of the Potomac, extending about 30 miles downstream from the fall line at Little Falls. Growth models are presented in Appendix I.

11.6 HABITAT DESCRIPTIONS

The Potomac River, a major tributary of the Chesapeake Bay, is located on the western shore. Of all East Coast rivers, the Potomac’s watershed ranks fourth in area. The mouth of the river at the Chesapeake Bay is defined as a line from Point Lookout, Maryland to Smith Point, Virginia, and is about 12 miles wide. The estuary extends 113 miles from the Bay, up to just below Little Falls where it is but a few yards wide. At Little Falls, there exists a low head dam for water withdrawals that was built in the 19th century and traditionally had an ineffective fish passage way. That dam has a newly installed fish passage way that now allows shad to extend their range an additional 10 to 12 miles up stream to Great Falls, a natural barrier to all anadromous species. The fluvial portion of the River extends another 300 miles westward into the Appalachian Mountains. The total river basin drainage area is about 9.4 million acres, 1.6 million of which drain directly into the estuary. The yearly average freshwater flow is approximately 11,190 cubic feet per second at the head of the estuary (Lippson *et al.* 1980).

The shad spawning area extends from about Stump Neck, Maryland and Cockpit Point, Virginia upriver to Great Falls, a distance of about 40 miles (Lippson *et al*. 1980; Figure 11.1).

It is assumed that the tidal freshwater area of the river had relatively healthy stands of indigenous submerged aquatic vegetation throughout the 19th century. During the early part of the 20th century the water chestnut, a non-indigenous species, became a “nuisance” submerged aquatic vegetation needing periodical control. Submerged aquatic vegetation has all but disappeared during the middle of the century. The latter half of the century saw the introduction of another non-indigenous submerged aquatic vegetation species, hydrilla, but this species has functioned as a catalyst for the reemergence of some native submerged aquatic vegetation. Today the tidal fresh water Potomac supports large beds of submerged aquatic vegetation that provide numerous benefits.

11.7 RESTORATION PROGRAMS

The earliest restoration efforts date to about 1883 when the U.S. Fish Commission established a “Station” at Fort Washington, Maryland for the primary purpose of collecting American shad eggs for export to other river systems throughout the country. Some 10 percent of the eggs that were collected were released back into the Potomac. Several personal accounts refer to a shad hatchery operation during the 1940s and 1950s at Fort Belvoir, Virginia, but no specific documentation has been uncovered to date (Section 11.9).

An American shad stocking project for the Potomac River began in 1995 as part of an effort by a coalition of federal, state, regional, and local agencies, and non-profit groups, organized as a Task Force[1], to open historic spawning and nursery habitat for native and anadromous fishes. An important milestone for this project was reached in 2000 when the U.S. Army Corps of Engineers completed a fishway at the Little Falls (Brookmont) Dam. During the eight-year stocking phase of the project, which concluded in 2002, over 15.8 million shad fry were stocked into the Potomac River (Table 11.2).

Today the VDGIF, the MD DNR, and the U.S. Fish and Wildlife Service (USFWS) are all using the Potomac as a source of brood stock for their American shad recovery efforts in the Rappahannock River, Maryland rivers, and the Susquehanna River, respectfully (Table 11.3).

11.8 AGE

See Section 11.10.

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[1] The Little Falls Fish Passage Task Force members came from Virginia, Maryland, the District of Columbia, the Interstate Commission on the Potomac River Basin, the Potomac River Fisheries Commission, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the National Biological Survey, the U.S. Environmental Protection Agency, the National Park Service, the National Marine Fisheries Service, Montgomery County, Maryland, the Chesapeake Bay Foundation, and The Potomac Conservancy. The Task Force has been inactive since 2002.

11.9 FISHERY DESCRIPTION AND FISHERY DEPENDENT DATA

The historical record on shad and herring fisheries of the Potomac River date back to the Colonial period and most are anecdotal, but a few are fairly reliable. Listed here are a few examples:

1612: "Shad, great store, *of a yard long* and for sweetness and fatness a reasonable food fish." Observation of William Strachey (italics added for emphasis; Tilp 1978).

1759: "Sturgeon and shad are in such prodigious numbers [in the Potomac]…and of the latter five thousand have been caught at one single haul of the seine," observed Andrew Burnaby (Tilp 1978).

1814-1824: The very detailed records of George Chapman's haul seine fishery provide valuable information about the size and extent of at least one person's haul seine fishery located at the center of the prime spawning area. The records for each haul over an 11-year period are preserved in such detail that the numbers of shad and herring caught in ten-day periods are recorded, the timing of the runs is noted, the estimated mean shad catch per haul by ten-day period, and the estimated mean shad catch per haul for each year can be determined. During the 11-year period of record, 955,651 shad were landed. "Mr. Chapman's single fishery had catches estimated to equal about 1/3 of the catches of shad by all gears from the entire Potomac River from 1946 to 1956" (Massmann 1961).

1817: Thomas Fairfax of Alexandria, Virginia places an ad in the National Intelligencer of the National Capital calling for a meeting "to agree upon measures for preventing the destructive effects of tide or gill nets, which have been unlawfully set in the waters and have within the three last seasons so greatly lessened the number of Shad and Herrings taken out at the best landings" (Tilp 1978). It is uncertain if this is evidence of an early concern of overfishing in 1817, or just a squabble between gear types.

1832: "Some idea may be formed of the importance of these fisheries [in 1832] from the following statements:

Number of fisheries on the Potomac, about …158
Number of shad taken in a good season …22,500,000
Number of herrings under similar circumstances …750,000,000…

The Potomac can boast of the largest shad fisheries in the United States" (Tilp 1978).

Colonial 1880s: "Though the records of the average weight of shad in those days are lacking seven pounds is a fair estimate, and it may have been greater. The weights [in 1978] seldom exceed three or four pounds, because in the more recent years of intensive fishing, shad have been widely caught up as they returned from the ocean to spawn for the first time" (Tilp 1978).

1883: The Potomac River American shad population was apparently judged healthy enough by the U.S. Fish Commission to support their establishment of a station at Fort Washington, Maryland for the collection of eggs. Adult shad were captured with a shore haul seine that was approximately 810 feet long and 47 feet deep with most meshes of between 2.25 inches and 2.5 inches. Most eggs collected were sent to Central Station in Washington, D.C., although approximately 10 percent of the eggs harvested were hatched at the Fort Washington facility and released into the Potomac River in that vicinity. Central Station in Washington, D.C., was where the eggs from Fort Washington were processed for distribution. Eggs were distributed up and down the east coast, central U.S. and as far west as the Colorado River (Cummins, pers. comm.).

1898: "The 1898 total imports [in numbers of fish] to Alexandria, Washington, D.C., and Georgetown markets as taken by Charles Lundington, inspector of marine products for the Washington board of health: Shad 1,051,587; Herring 15,006,940; Hickory jacks 340,387; Sturgeon 1,650" (Tilp 1978).

1899: "Next to the oyster in value is the shad, of which 2,571,000 pounds were landed in 1899 ... the following year the aggregate catch was 2,356,759 pounds, or 621,911 fish [3.8 pounds average fish weight]" (Tilp 1978).

1940-1950s (approximated): Louis Harley remembers helping his father capture shad for a hatchery operation at Fort Belvoir and several Maryland fishermen remember their fathers working at the shad hatchery at Fort Belvoir, Virginia. "Fish-culturists at the old Fort Belvoir shad hatchery on the Potomac River" is mentioned several times in reports by Romeo Mansueti, but we could not find any further information (Cummins, pers. comm.).

1964-1981: From 1964 through 1981 the commercial fishery on the Potomac was operating relatively freely. Landings declined from about 466,000 pounds to 4,200 pounds but averaged about 222,000 pounds for the period.

1982-2005: The fishery was limited by regulations in 1982 such that it became a bycatch fishery only and landings have averaged about 2,300 pounds a year since then (Table 11.4; Figures 11.2 and 11.3).

The commercial American shad fishery and landings in the Potomac are today, by regulation, strictly bycatch of the pound nets and gill nets set for other fishes. Fishermen are limited to a one bushel (approximately 60 lbs.) per licensee, per day. Gill nets are fished from November through March 25 and pound nets can operate from February 15 to December 15 each year. Both gear types are "limited entry" fisheries such that no new licenses are sold.

The recreational fishery for American shad, although not a targeted fishery in the PRFC area, is currently closed. The District of Columbia conducts regular creel surveys, but has no creel data pointing to a recreational shad fishery in the District. A small group of fishermen at Fletchers Boathouse (just downstream of Little Falls) target American shad for catch and release; however, since D.C. has a closure on the recreational and commercial shad fishery, there is no legal harvest. This species appears to be on the rebound in D.C. and the District is considering requesting a limited recreational season.

The Potomac River Fisheries Commission instituted a mandatory harvester-based catch reporting system in the middle of 1963. Data from the first year is not considered reliable or consistent with later years because of problems with timing, participation, and collection. Therefore we rely on the data from 1964 to the present. Failure to submit the required information can and does result in license suspension or revocation.

11.9.1 Commercial Fisheries

Sampling Intensity

All licensed fishermen are required to submit reports of their daily harvest of all species by gear type on forms supplied by the PRFC. Originally fishermen recorded daily catch (in pounds) on separate forms for each gear they fished. The forms had columns for each species and one line for each day of the month, and space to record units of effort (number of nets, yards of net, etc.). From 1964 through 1980, the records submitted by the fishermen were tabulated by hand and summed for the month, and only the totals recorded. National Marine Fisheries Service (NMFS) port agents collected the actual paper records, which were used to publish the monthly Landings Bulletins for Maryland and Virginia.

Records of the harvest by area, by gear, and by month were hand tabulated and recorded from 1976 by the PRFC, and summary tables kept. Some of these records have been located and a few years have both effort information and pounds landed. In 1988 the daily records were still being hand tabulated, but the one line total was being entered into a computer program. In 1991 the reporting frequency was changed from monthly to weekly. Again the weekly reports were hand tabulated and a one-line entry made for the week. In 1999, computer programs were developed that permitted the daily information to be entered.

Commercial Landings

The PRFC has recorded shad landings by state since 1964 and by month, area, sex, and gear, including effort data for most years, since 1976. Regulations limited the fishery to bycatch starting in 1982.

Commercial Discards and Bycatch

The mandatory harvest reporting system on the Potomac was modified in 1999 to include information on bycatch and value. The fishermen are asked to estimate the number of pounds discarded and record it in one of three categories: no market, too small, or closed season. Prior to this change total catch was not reported.

Biases

The PRFC has enforced the mandatory catch reporting system for a full generation and believe the data is a reliable commercial database. Efforts have been made to improve the level of detail over the years while maintaining continuity throughout the time series. The Commission also has very accurate records on the number of licenses sold each year by gear type, and the commercial gears have remained relatively similar.

11.9.2 Recreational (For-Hire Included)

We know of no historical information on recreational fishing in the main stem of the Potomac under PRFC jurisdiction. The most likely areas for a recreational fishery are located within the District of Columbia. The PRFC does, however, supplement the Marine Recreational Fisheries Statistics Survey with additional phone calls to attempt to estimate the recreational fishing impact for all species, but the shore-side sampling stations are not located in areas where shad would likely be encountered. The District of Columbia conducts regular creel surveys, but has no creel data suggesting a recreational shad fishery exists in the District.

11.10 FISHERY-INDEPENDENT SURVEYS

The fishery-independent survey data for the Potomac River comes from several different sources: the Maryland Department of Natural Resources, the Interstate Commission on the Potomac River Basin (ICPRB), the Virginia Department of Inland Fisheries, and the District of Columbia (D.C.). Each source is listed separately by agency and type of survey.

11.10.1 Adult Fish

MD DNR Broodfish Collection

Introduction

MD DNR has collected American shad brood fish from the Potomac River since 2001.

Data Collection Methods

Survey Methods

Since 2001, MD DNR biologists have set gill nets in the Potomac River at Marshall Hall, near Fort Belvoir. American shad historically spawned from the middle of April to the middle of May in this section of the Potomac River. Different areas along the Potomac River were evaluated for their ability to concentrate American shad. The channel in front of Fort Belvoir tended to concentrate the greatest amount of American shad. Nets were set parallel to the channel edge in 6 to 15 m of water. The time of net set depended exclusively on tide. Nets were set at slack tide when possible since slack tide sets were most productive. American shad generally spawn near or just after sundown and we set nets from 1530 to 2130. Setting nets to collect shad before or after this six-hour window was deemed ineffective.

Biological Sampling

Biological data were not obtained for captured fish prior to 2005. Starting in 2005, sub-samples of American shad were taken and data obtained on sex, fork and total length, and weight; scales and otoliths were removed for ageing analysis.

Ageing Methods

The same reader has done age determination from American shad scales since 1980 and uses Cating's (1953) method. Repeat spawning is defined as the freshwater spawning mark on the American shad scale—the number of spawning marks is noted for each fish. Due to time constraints, otoliths from Potomac River American shad have not been aged.

Catch Data

Weather and temperature conditions in late March and early April greatly influence when American shad spawning begins. Gill netting started at the beginning of April to encompass the peak time for shad collection. Water temperature and location greatly affect the best time to initiate sampling. Early sampling should begin with temperatures between 13 and 15 °C. Significant numbers of ripe female shad were collected from 18 to 20 °C.

MD DNR Striped Bass Spawning Stock Survey

Introduction

Since 1985, the Maryland Department of Natural Resources has employed multi-panel drift gill nets to monitor the Chesapeake Bay component of the Atlantic coast striped bass population. The primary objective of this survey was to generate estimates of relative abundance-at-age for striped bass. American shad are caught as bycatch and since 1997 MD DNR personnel have collected data on this species.

Data Collection Methods

Survey Methods

Multi-panel experimental drift gill nets were deployed in the Potomac River and in the Upper Chesapeake Bay (Figure 11.4). The gill nets were fished six days per week from late March until mid-May. In the Potomac River, sampling was conducted from late March to mid May.

Individual mesh panels were 150 feet long, and ranged from 8.0 to 11.5 feet deep depending on mesh size. The panels were constructed of multifilament nylon webbing in 3.00, 3.75, 4.50, 5.25, 6.00, 6.50, 7.00, 8.00, 9.00, and 10.00-inch stretch mesh. Due to the design of the fishing boat, the nets were split in half in the Potomac River, and the two suites of panels (5 meshes tied together) were fished simultaneously end to end. All 10 meshes were fished twice daily unless the weather prohibited a second set. The order of meshes within the suite of nets was randomized with gaps of 3 to 10 feet between each mesh. Overall soak times for each mesh panel ranged from 7 to 162 minutes.

Sampling locations were assigned using a stratified random survey design. One randomly chosen site per day was fished in each spawning area. Sites were chosen from a grid superimposed on a map of each system. The Potomac River grid consisted of 40-0.5-square-mile quadrants. Once in the designated quadrant, air and surface water temperatures, surface salinity, and secchi depth were measured.

Biological Sampling

American shad length and sex data were written on a coin envelope and a scale sample enclosed for age and repeat spawning determination.

Ageing

The same reader has done age determination from American shad scales since 1980 and uses Cating's (1953) method. Repeat spawning is defined as the freshwater spawning mark on the American shad scale and the number of spawning marks is noted for each fish.

Abundance Indices

Relative abundance was measured as the catch of American shad per 1000 square yards (909 m^2) of experimental drift gill net per hour fished

ICPRB Shad Egg Collections

Introduction

The ICPRB has collect American shad for artificial spawning annually since 1995. Data collected provide some indication of abundance trends over time.

Survey Methods

From 1995 to 2002, the ICPRB and the USFWS jointly conducted this sampling. The ICPRB became the primary monitoring entity in 2003.

ICPRB gill-net collections are primarily performed for the collection of adult shad for brood stock. Two drifting gill nets, sequentially deployed, are fished together along the Virginia side of the channel at the mouth of Dogue Creek near Fort Belvoir. The nets are rigged in traditional manner for this section of the Potomac, approximately 91 meters (300 feet) long, 7 meters (23 feet) deep, 14 centimeter (5 ½ inch) stretch mesh, made of either #69 twine cotton or monofilament, with top line suspended below the surface approximately 1.5 meters (5 feet) from floating 16 centimeter (6 inch) diameter corks rigged about every 4.5 meters (15 feet). The bottom line was very lightly weighted, rigged with 16 centimeter (6 inch) diameter 9 gauge galvanized metal rings set about 4.8 meters (16 feet) apart. A ring is rigged below each cork; the difference in spacing between the corks and rings is done because the bottom line is longer than the top line to help provide the necessary slack in the nets. The nets were fished at evening slack water, at either the high or low tidal shift, for approximately two hours and continuously tended as described in the following paragraph. Nets were fished approximately between 1600 and 2400 hours, depending on the tide, with the best fishing tides being near dusk. It is imperative that collections are made during slack tides because otherwise the currents in the Potomac River would be too strong for the nets to fish properly, they would hang loosely and drift considerable distances (miles), subjecting them to snags, potential damage, and loss.

The nets were allowed to drift until the bobbing of corks indicated that fish had become entangled in the net. That section of the net was lifted, fish were removed from the net, and the section of net was dropped and allowed to keep fishing. At the end of the drift, the net was taken up and all fish were removed, culling out the ripe females and a roughly equal number of males. Care was taken to release bycatch alive. Captured shad were examined for sex and maturity. Male and female shad that appeared ripe or running were kept alive on board the boat in a 100-gallon oval stock tank with water circulation and aeration. Typically any female shad that did not have roe running (i.e., green shad) were released back into the river. Some of the green shad that were kept were also the result of false positive decisions (i.e., they appeared to be running ripe females when captured and were therefore kept but at stripping they only produced a few eggs). Unfortunately, American shad do not handle well and all fish placed in the holding tank succumb to stress. Therefore, in some cases these green fish were not released.

When enough shad were collected (at least 6 females and a similar number of males) the fish were quickly transferred to shore or another boat for stripping.

Sampling Intensity

Sampling has occurred each year since 1995, approximately four evenings per week from mid-April to mid-May.

Biases

A potential bias of the study is that only one mesh size used. Net saturation has been an issue in recent years, as the population has increased. While the nets can capture over 100 shad per net, the nets tend to start sinking and collapsing when they have caught approximately 50 fish.

Ageing Methods

Beginning in 1998, the first year in which returning adults with OTC marks were expected, otoliths and scales were collected from approximately 60 to 100 fish per year. To obtain these, blocks of approximately 8 to 10 fish were randomly collected over the duration of each annual brood stock collection. In addition, all American shad captured at Great Falls (Section 11.10.1 *ICPRB Dip Net Monitoring at Great Falls*) and a subset of angler-captured shad from the vicinity of Chain Bridge (Fletcher's Boat House) was targeted for ageing as well. As of December 2006, 525 fish have been analyzed from the years 1995 to 2005. Analysis has been performed by varying partner agencies over duration of project: 1998 to 2000 by Mike Hendricks with the Pennsylvania Fish and Boat Commission using otoliths and scales, and 2001 to 2002 from USFWS (contract with Virginia Commonwealth University (VCU)). VCU is expected to analyze fish collected in 2003 and 2004.

Catch Rates (Numbers)

Catch-per-net-set (CPUE) was calculated annually for fish retained for spawning. However, these estimates did not include fish not used for spawning and discarded. CPUE for all fish captured has been calculated since 2002.

Length, Weight, and Catch-at-Age

Collection of length, weight, and catch-at-age was coordinated by the USFWS. Collection data are summarized in Appendix II Table AII.1.

The percent of repeat spawners was determined by the presence of spawning checks on scales of a sample of the 2001 fish.

VDGIF Shad Egg Collection

Data Collection Methods

Survey Methods

Virginia Department of Game and Inland Fisheries staff has set gill nets in the Potomac River since 2004 to collect American shad broodfish to support stocking activities for the Rappahannock River. The methods, areas, and timing were similar to that described and used by MD DNR and the ICPRB; data from this egg collection are included in the ICPRB's section of this report.

Sampling Intensity

Between April 14 and May 19, 2005, thirteen sampling trips were made. Two to five nets were set per day, with a total of forty-one sets over the 13 trips. Most American shad were caught in late April and at water temperatures of 16 and 17˚ C (Table AII.2).

Biological Sampling

The sex and lengths, both fork and total length, were recorded for each of the broodfish. Otoliths and scale samples were taken from every tenth fish (Table AII.3).

Age

The age of each of the sub-sampled fish was determined from the otoliths by personnel from the VDGIF's Age and Growth Section. The otoliths were also examined for an OTC mark. Results were combined and reported with the ICPRB results.

ICPRB Dip Net Monitoring at Great Falls

Background

Direct monitoring of the new fishway on the Brookmont Dam at Little Falls, Potomac River, is not feasible due to the dangerous and remote location of the structure. Immediately downstream from the dam is a mile-long steep grade of rock outcrops and ledges. There is about 11,000 square miles of drainage above the dam, and springtime flows are typically very dangerous. Therefore, indirect monitoring is conducted at Great Falls, approximately 10 river miles upstream from the fishway. No adult-shad monitoring sites have been identified between Great Falls and Little Falls, primarily because of no or poor access and high risk.

Boat-electrofishing collections were performed in the Mather Gorge area about 4,000 feet downstream of Great Falls in 1999 through 2002. These electrofishing surveys had to be discontinued after 2002 due to budgetary reasons, but there were also concerns that this stretch of the river was not a good location to find the fish (high energy, not many resting areas, open to full sun), the boat ramp was difficult to use during low-flows (the apron wasn't deep or long enough) and very dangerous, with poor capture efficiencies, at higher flows. Several gill-net collections deployed by canoe in the first eddy below Great Falls on the Maryland side were performed in 2001; this was judged a poor method, and abandoned. Long handled dip-net monitoring, protocol developed by Mike Odom of the USFWS in 2000, has been used with varying effort by the USFWS and the ICPRB since that time. It is now the primary method of monitoring the effectiveness of fish passage at Little Falls and serves as another indicator of the relative strength of the migratory activity. It is also meant to replicate the type of gear used traditionally, first by early Americans and then by others through the early 1900s, at this location.

Sampling Intensity

The sampling target was at least twice a week from mid-April to late June. This target was not often reached. The duration of sampling was typically 2 to 4 hours near dusk or dawn. Occasionally it occurred in broad daylight, which is not preferred. The effort varied primarily due to flow because it cannot be performed when water flow is above the season's median. It also varied due to availability and health of personnel.

Biases

There are several biases in this monitoring survey. The survey employs one size net with uniform mesh. The net is deployed along the shore only in the fall-zone area—it is assumed that most movement by shad is along shoreline eddies. Capture efficiency is highly dependent on flow and reliant on the individual skill of the netter, although the three netters that have conducted this survey are likely of similar skill level because they are of similar age, size, and physical strength. Night sampling is not feasible due to a requirement to have National Park personnel present after dark. Netting can only be effectively done at flows of up to 14,000 cubic feet per second (cfs) and is best at 10,000 cfs, which is at or below the rough mean flow in this section of the Potomac in April and May. This means that approximately half the time dip nets are not effective sampling gear.

Ageing Methods

Otoliths and scales of captured fish were aged along with a subset of fish captured in tidal waters and were reported with the data from ICPRB egg collections.

11.10.2 Juvenile Sampling

MDNR YOY Survey

Introduction

MDNR has sampled by seine for juvenile shad abundance on the Potomac River since 1954. This survey was originally intended to collect YOY striped bass but it serves to generate indices on many different fish species.

Data Collection Methods

Survey Methods

Juvenile abundance indices (JAIs) are derived annually from sampling at 22 fixed stations within Maryland's portion of the Chesapeake Bay. They are divided among four of the major spawning and nursery areas—seven in the Potomac River (Figure 11.5). Stations have been sampled continuously since 1954, with changes in some station locations. Sampling is monthly, with rounds (sampling excursions) occurring during July (Round I), August (Round II), and September (Round III). Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which Bay-wide means are calculated.

From 1954 to 1961, juvenile surveys included various stations and rounds. Sample sizes ranged from 34 to 46. Indices derived for this period include only stations that are consistent with later years. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round added in 1966, increased the sample size to 132.

Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices. These data enhance geographical coverage in rivers with permanent stations or provide information from other river systems. They are also useful for replacement of permanent stations when necessary. Replicate hauls at auxiliary stations were discontinued in 1992 to conserve time and allow increased geographical coverage of spawning areas.

For a more complete description of the entire young-of-year program, including sampling protocol, seining locations, and species-specific data visit the MD DNR website at www.dnr.state.md.us.

Sample Protocol

A 30.5 m by 1.24 m bagless beach seine of untreated 6.4 mm bar mesh was set by hand. One end was held on shore while the other was fully stretched perpendicular to the beach and swept with the current. Ideally, the area swept was equivalent to 729-m^2. When depths of 1.6 m or greater were encountered, the offshore end was deployed along this depth contour. An estimate of distance from the beach to this depth was recorded.

Striped bass, shad and selected other species were separated into 0 and 1+ age groupings. Ages were based on length-frequencies and verified through scale examination. Age-0 fish were measured from a random sample of up to 30 individuals per site, per round. All other finfish were identified to species and counted. Additional data included: time of first haul, maximum distance from shore, weather, maximum depth, surface water temperature (ºC), tide stage, surface salinity (ppt), primary and secondary bottom substrates, and submerged aquatic vegetation within the sample area (ranked by quartiles). Dissolved oxygen (DO), pH, and turbidity (secchi disk) were collected beginning in 1997. All data were entered and archived in Statistical Analysis System (SAS) databases (SAS 1990).

CPUE was calculated as the geometric mean (GM) catch for the year. The GM is calculated from the $\log_e(x+1)$ transformation, where x is an individual seine haul catch. One is added to all catches in order to transform zero catches, because the log of 0 does not exist (Ricker 1975). It is almost always lower than the arithmetic mean (AM) (Ricker 1975). The GM is presented with 95 percent confidence intervals (CIs). These are calculated as antilog ($\log_e$ (x+1) mean ± 2 standard errors), and provide a visual depiction of sample variability.

The District of Columbia YOY Survey

Survey Methods

Seining and push-netting are currently used to calculate juvenile abundance indices and assess stock recruitment.

Sampling Intensity

Seining efforts are part of the annual biological survey of the fishery resource of the District of Columbia. This survey is conducted monthly at six standard sites from March through December.

In 2003 the District of Columbia began a multiyear push net survey for age-0 alosines. This sampling was conducted over 11 nights in August and September at five sites in the Potomac River and one site in the Anacostia River. These sites covered the entire distance of the Potomac within the District of Columbia's jurisdiction and a good portion of the lower Anacostia. Juvenile alosines were collected and subsequently sorted and counted in the lab. Non-alosine species that were occasionally collected were identified and measured immediately and released on site

11.11 RESULTS

11.11.1 Commercial Landings

Commercial Landings

The landings have declined from 466,000 pounds in 1964 to just several hundred pounds in 1985 and are presented in Table 11.5 and Figure 11.6.

Commercial Bycatch and Discards

Bycatch and discard information on shad is presented in Table 11.6 and Figures 11.7 and 11.8.

Sex Ratios

Data for American shad reported to PRFC from pound nets, the only gear in the Potomac River that is allowed a bycatch of American shad, has reflected changes in sex ratios since initiation of the reporting system (Figure 11.9). During the 1970s and early 1980s there were no regulations or limits on shad, so the entire catch was harvested and sex ratios likely reflect the run composition. In 1982, sex ratios reflect high grading for females, with males only kept to reach the bycatch quota (Carpenter, pers. comm.).

Commercial Catch Rates

The PRFC harvester-based reporting system includes estimates of effort (net-days, yards of net fished, etc.) for American shad by sex. The pound net data is presented in Table 11.7 and Figure 11.9.

The best fishery-dependent data on relative abundance of adult American shad is the 17-year series (1988-2005) of commercial pound net catch and bycatch data compiled by the PRFC (Table 11.7). As a result of regulatory actions instituted in 1982, pound net fishermen are allowed to keep one bushel per licensee per day of shad and must comply with mandatory reporting that includes providing effort, gear, and sex information on catches. Data on bycatch or discards are not available from 1982 through 1987. Additionally, fishers were not required to report numbers or weights of discarded shad until 1999. As a result, total catch is unknown for most of the period. In 1999, an additional regulation was established requiring reporting of discarded shad in catches. Total catch can be calculated from 1999 to 2005 as the total number of bycatch plus the total number of discards. The PRFC also calculated CPUE for American shad in pound nets for the years 1976 to 1980 based on landings data prior to the imposition of the fishing moratorium in 1980.

CPUE of the pound net bycatch of shad since 1976 is provided in Figure 11.10 and since 1986 in Figure 11.11. Bycatch and discard numbers were combined for estimates of total CPUE for 1999 to 2005 (Figure 11.12). This shorter time series depicts high annual variability, with a strong peak in 2003 and a trend towards higher catch rates in 2003 to 2005. The 2003 peak may be due in part to inflated reporting of discards by fishers who were aware of the possible use of these data in pending management actions (A.C. Carpenter, pers. comm.)

11.11.2 Fishery Independent Results

Age of Adults

MD DNR Striped Bass Spawning Stock Survey

Most shad were ages 4 to 6. Age distribution narrowed somewhat over the time period and mean age declined (Table 11.8; Figure 11.13).

ICPRB and VDGIF Shad Egg Collections

In 1998 age-4 fish were the most abundant, in 1999 through 2002 age-5 fish were predominant, and in 2005 age-6 fish accounted for the largest percentage (Table 11.9; Figure 11.14). Age structure broadened during the time period and mean age increased, especially in 2005. Mean fork length by sex increased through 2002 and decreased in 2005 (Table 11.9).

In 2001, 61 of the 88 fish (69%) were repeat spawners. Details are found in Table 11.10.

Abundance Indices for Adults

MD DNR Brood Fish Collection

CPUE has not been calculated for this sampling because sample gear and location varied among years and discards were not included in the total catch. Total catches of shad in the program varied from 400 to 2003 fish per year (Table 11.11).

MD DNR Striped Bass Spawning Stock Survey

Catch-per-set of American shad (sexes combined) depicts a strongly increasing trend in CPUE over the 10-year period. Catch rates increased several orders of magnitude between 1996 and 2005 (from 0.01 to 3.18 fish/yd^2; Table 11.12; Figure 11.15). This index provided the longest time series of fishery-independent data on adult abundance and was based on a sound sample design.

ICPRB Shad Egg Collections

Catch-per-net-set (CPUE) for fish retained for spawning (sexes combined) has increased throughout the time period (Table 11.13). However, these data do not include fish not used for spawning and discarded. CPUE of all fish caught since 2002 has varied without trend (Table 11.13).

ICPRB Dip Net Monitoring at Great Falls

In 2005, USFWS staff were unable to monitor as planned due to an injury to personnel. Monitoring was only performed for three events during the end of the spawning season and five shad were captured. In 2004, twenty-nine American shad were captured; however, 2004 had a reduced sampling window due to abnormally high flows. In 2003, a really wet year, we captured five American shad over a couple of days early in the season when flows were close to 10,000 cfs. Most of the time flows were above 20,000 cfs. There appeared to be a trend developing during the three drier preceding years; in 2000 (the first year the fishway was opened), we captured 3, then 12 in 2001, and 43 in 2002.

Presence of OTC Marks in Adults

ICPRB and VDGIF Shad Egg Collections

The fraction of adult American shad with OTC marks has remained very low since 1998 (Table 11.14). These results suggest that the stocking of larvae to this system have not yet influenced the number of adults.

Adult Survival

Total mortality was estimated using linear regression on the natural log (ln) of catch-at-age data versus age, and ln numbers in each repeat spawning category (e.g., numbers with one repeat spawning mark, with two marks) versus the number of categories. Numbers of virgins were not included in the latter regressions. Comparisons of estimates of total mortality using these two approaches are presented in Table 11.15 and Figure 11.16. Estimates derived from both methods were similar and followed similar annual trends. Total mortality has decreased in the four-year time series. On the Potomac River, Z-estimates ranged from 0.78 to 1.31 (catch-curve method) and 0.66 to 1.02 (repeat spawning method).

Juvenile Abundance

Five independent time series of juvenile abundance are available from the MD DNR Seine Survey (1959-2005, geometric mean; Table 11.16; Figure 11.17), MD DNR Mattawoman Creek Survey (1989-2005, CPUE), USFWS and ICPRB (1990-2002, total catch), and DCFW (2003-2004, total catch; Table 11.17). The time series are plotted together in Figure 11.18.

In general, indices were variable with respect to each other, except for the two MD DNR surveys, which show similar patterns. Due to gear changes, method changes, duration of survey, and lack of effort information in some of the data sets, we chose to exclusively work with the MD DNR Striped Bass Seine

Survey YOY Index for our JAI-adult correlation exercise as it provided the most consistent, reliable time series. The JAI is a geometric mean catch (number of fish) per haul.

The range and frequency of index values was variable over the course of the time series, with the highest JAI values (>0.5) recorded in 1962 to 1967, 1970 to 1972, 1975, 1978, 1995 to 1998, and 2000 to 2005 (Figures 11.17 and 11.19). The Potomac River time series suggests recruitment failure in 1959 to 1961, 1968 to 1969, 1973 to 1974, 1976 to 1977, 1979 to 1994, and 1999. In recent years, geometric mean juvenile abundance has increased. Since 2002, annual recruitment is above the time series average, with good production in 2004. The frequency distribution of MD DNR juvenile abundance indices was skewed with the mode at 1 (Figure 11.19).

To verify the JAI, we compared the indices with indices of relative abundance of the same year classes later in life. Adult abundance by age on the Potomac River is measured as CPUE (number of females/m/day) from the MD DNR Striped Bass Gill Net survey. Catch-at-age of adult shad (ages 4-10) was regressed with the corresponding JAI from the hatch year of that age class for all years available (2002-2005) on the Potomac River.

The Potomac River JAI correlated positively with adult abundance for all age classes but correlations were not significant (Table 11.18; Figure 11.20). It should be noted that the time series of adult abundance is very short resulting in low sample sizes.

11.11.5 Assessment

Abundance

To assess the status of American shad on the Potomac River, we compared current pound net landings (bycatch plus discards) with historic data from the 1970s and the 1940s to 1950s. Catch-per-unit-effort in 1944 to 1952 was estimated from landings data provided by Walburg and Sykes (1957; Table 11.19). The geometric mean of current pound net CPUE (only those years when bycatch plus discards were reported) was compared with the geometric mean of landings data from 1976 to 1980 and 1940s to 1950s (Walburg and Sykes 1957; Figure 11.21). From 1944 to 1956, Potomac River landings of American shad were relatively stable, averaging approximately 850,000 pounds annually, and ranging from about 500,000 to 1,300,000 pounds (Table 11.4). In the late 1970s, total landings of American shad decreased sharply from 120,000 pounds in 1976 to 17,000 pounds in 1980 (Table 11.4). A moratorium on the taking of shad was established in 1982.

The geometric mean of the 1940s to 1950s pound net landings is 31.1 pounds per net-day. The geometric mean of the 1970s data is 2.9 pounds per net-day. The geometric mean of the current data is 13.6 pounds per net-day. The mean of the current pound net catch (bycatch plus discard) is well below the 1940s to 1950s' average (when catches were sustainable presumably), but is greater than the 1970's average (when landings were declining sharply) and is increasing.

It should be noted that historic and current pound net catch data are combined landings from Virginia and Maryland pound nets. Locations of pound nets in the 1940s to 1950s may have been different than current locations, or locations in the 1970s, as fishers in the 1940s and 1950s were targeting river herring as well as American shad. The current pound net fishery in the Potomac River targets striped bass and menhaden (Carpenter, pers. comm.). Stevenson (1899) reported that pound nets in the Chesapeake Bay in 1886 were "of the single heart variety" and nets in the Potomac River shad fishery had multiple pounds ("first pound, second pound, main pound") of varying meshes. In our comparisons, we assume that the catching power of pound nets in the 1940s to 1950s is the same as in the current fishery (and in the 1970s).

Survival

There is no river-specific maturity schedule, fecundity, or recruitment vector data for the Potomac River. Given the lack of river-specific input parameters, there was no yield modeling exercise for the Potomac stock. Please see the Yield Model section in the Introduction for a regional yield model that may be used for the Potomac system until river-specific data are available.

Reference values of Z_{30} in the Chesapeake Bay region (York River, Virginia) derived from a yield model exercise ranged from 0.62 to 0.86 depending on the level of M. Catch curve estimates of Z tended to exceed the Z_{30} in 2001 and 2002, but has lowered to near or below Z in recent years. Total mortality estimated in 2005 from catch curve (0.82) and repeat spawning (0.66) data are within this range.

11.12 BENCHMARK

A benchmark for American shad in the Potomac River is the geometric mean of pound net landings reported in Walburg and Sykes (1957) for the years 1944 to 1952 or 31.1 pounds per net-day. A benchmark value of Z_{30}= 0.62 was calculated for Chesapeake Bay region American shad stocks (See Section 1.1.5 for York River, Virginia).

11.13 CONCLUSIONS AND RECOMMENDATIONS

Among Chesapeake Bay stocks of American shad, the Potomac River population shows the most promising signs of recovery. The gill-net index, the pound net index, and the JAI depict strongly increasing trends in relative abundance. Age structure has broadened and mean age increased. Since 2002, estimates of Z have declined. Reference values of Z_{30} in the Chesapeake Bay region (York River, Virginia) derived from a yield model exercise ranged from 0.62 to 0.86 depending on the level of M. Total mortality estimated in 2005 from catch curve (0.82) and repeat spawning (0.66) data are within this range.

A benchmark for American shad in the Potomac River is the geometric mean of pound net landings reported in Walburg and Sykes (1957) for the years 1944 to 1952, a value of 31.1 pounds per net-day. To continue stock rebuilding, there should be no new expansion of the fishery until the benchmark is reached. This requires continued monitoring of the pound net fishery, including discards. We recommend a study of discard mortality of American shad in the Potomac River. Credibility of discard reports is a concern that should be addressed. A fishery-independent monitoring program for American shad on the Potomac that produces data directly comparable to historic data is needed. Some immediate data needs recognized in this assessment are:

1. River-specific maturity schedules
2. Fecundity estimates
3. YOY age-length data
4. OTC prevalence for hatchery evaluation
5. Weights of shad captured in the fishery-independent survey
6. Hatch-date estimates
7. Validation of bycatch reporting rates through an observer program
8. System-wide coordination of fishery-independent monitoring

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Table 11.1 Potomac regulatory history, 1963-2005. Haul seine (HS); drift gill net (DG); stake gill net (SG); anchor gill net (AG); and pound net (PN). SG, AG, and PN are all fixed site non-moveable gears. Notes indicate changes to previous or existing requirements.

Year	Gear	Season	Size		Notes
			Length	Mesh	
1963	SG, DG	3/1- 5/26	1,200'		
	PN	All Year	1,200'		
	HS	All Year	1,800'		
1964	DG	4/1 –5/26		2.5"	
	SG	All Year		2.5"	
	HS		2,400'	2.5"	
	PN			2"	
1970	AG	All Year	600'	2.5"	New gear added
1972	SG	9/1 – 5/31	1,200'	2.5"	
	AG	9/1 – 5/31	1,200' L x 12' D	2.5"	36' MLW max.
	DG	4/1 – 5/31			
1974	PN			1.5"	
1979	SG, AG, DG			2.5" min, 7" max	
1980	AG	All Year			
1982	commercial				Shad limits imposed –2% bycatch by volume
	recreational				2/person/day
1983	DG		1,200' L x 12' D		Depth added
1984	SG, AG, DG	2/16 – 3/31 & 6/1 – 12/31	600' L x 12' D	3 ¼" min, 7" max	No new gill net licenses sold (limited entry)
1985	SG, AG, DG	6/1 – 12/31			
1986	SG, AG, DG	6/1 – 11/30			
1990	GN			5" min, 7" max	Hickory added to 2% bycatch
	commercial				Hickory added to 2% bycatch
1992	recreational				Hickory shad limit of 2/person/day
1994	DG				License repealed
	PN				Limited Entry Fishery
1996	commercial				2% bycatch capped at max. 1 bushel (bu) and limited to PN only
	recreational				American and hickory shad both closed
2004	GN				Added bycatch for GN 1 bu. limit

Table 11.2 Number (thousands) of American shad larvae stocked into the Potomac River for restoration efforts.

Year	ICPRB	MD DNR	VDGIF	USFWS	Total
1995	1175				1175
1996	1989				1989
1997	1535				1535
1998	1589				1589
1999	1304				1304
2000	3176				3176
2001	3336				3336
2002	1531				1531
2003	1400				1400
2004	3500				3500
2005	4319				4319
Total	**24854**	**0**	**0**	**0**	**24854**

Table 11.3 Annual number of removals of American shad from the Potomac River for restoration activities.

Year	ICPRB	MD DNR	VDGIF	USFWS	Total
1995	294				294
1996	375				375
1997	544				544
1998	316				316
1999	289				289
2000	757				757
2001	735	440			1175
2002	658	2003			2661
2003	615	1359			1974
2004	976	981			1957
2005	506	1576	562		2644
Total	**6065**	**6359**	**562**	**0**	**12986**

Table 11.4 Potomac River historical American shad landings, 1814-2005.

Year	Pounds	Year	Pounds	Year	Pounds	Year	Pounds
1814	108,453,000	1909	764,892	1945	537,700	1981	4,237
1815	106,356,000	-		1946	536,100	1982	2,133
1816	68,178,600	1915	664,008	1947	1,300,200	1983	3,722
1817	62,960,400	-		1948	721,300	1984	2,531
1818	42,679,200	1919	2,041,759	1949	909,600	1985	287
1819	34,012,800	1920	1,979,780	1950	931,600	1986	478
1820	16,763,400	1921	1,160,438	1951	877,100	1987	810
1821	28,953,600	1922	3,115,571	1952	1,161,400	1988	1,894
1822	25,436,400	1923	1,187,382	1953	846,300	1989	1,068
1823	31,185,000	1924	578,210	1954	897,300	1990	2,282
1824	48,390,600	1925	696,632	1955	805,700	1991	1,918
-		1926	1,034,206	1956	721,900	1992	1,553
1832	112,500,000	1927	636,581	-		1993	2,927
-		1928	2,077,622	1964	466,293	1994	1,305
1878	186,000	1929	1,052,284	1965	438,831	1995	2,641
-		1930	601,193	1966	243,012	1996	2,292
1880	552,872	1931	2,061,036	1967	214,882	1997	5,206
-		1932	2,264,168	1968	393,872	1998	2,372
1889	868,900	1933	1,837,623	1969	302,274	1999	1,966
1890	731,453	1934	567,100	1970	405,884	2000	1,508
1891	621,977	1935	631,171	1971	359,014	2001	4,882
-		1936	359,800	1972	421,318	2002	2,762
1896	2,565,237	1937	434,900	1973	203,717	2003	8,641
-		1938	519,635	1974	83,955	2004	5,344
1898	3,948,709	1939	428,503	1975	144,465	2005	6,820
1899	2,571,000	1940	322,800	1976	116,226	2001	4,882
1900	2,356,759	1941	371,300	1977	87,290	2002	2,762
1901	2,979,233	1942	328,175	1978	67,967	2003	8,641
-		-		1979	26,983	2004	5,344
1904	1,397,425	1944	883,000	1980	17,328	2005	6,820

Table 11.5 Potomac River American shad landings (pounds) by gear, sex, and state.

Year	Haul Seine	Pound Net	Fyke Net	Gill Net	Hook & Line	Misc.	ROE	BUCK	in MD	in VA	TOTAL
1964	-	-	-	-	-	466,293	-	-	68,200	398,093	**466,293**
1965	-	-	-	-	-	438,831	-	-	153,764	285,067	**438,831**
1966	-	-	-	-	-	243,012	-	-	91,821	151,191	**243,012**
1967	-	-	-	-	-	214,882	-	-	67,724	147,158	**214,882**
1968	-	-	-	-	-	393,872	-	-	106,623	287,249	**393,872**
1969	-	-	-	-	-	302,274	-	-	106,090	196,184	**302,274**
1970	-	-	-	-	-	405,884	-	-	235,702	170,182	**405,884**
1971	-	-	-	-	-	359,014	-	-	185,499	173,515	**359,014**
1972	-	-	-	-	-	421,318	-	-	226,656	194,662	**421,318**
1973	-	-	-	-	-	203,717	-	-	86,998	116,719	**203,717**
1974	-	-	-	-	-	83,955	-	-	43,118	40,837	**83,955**
1975	-	-	-	-	-	144,465	-	-	88,419	56,046	**144,465**
1976	-	20,877	-	99,425	-	-	86,175	34,127	71,312	48,990	**120,302**
1977	-	13,742	-	71,451	-	-	71,013	14,180	56,571	28,622	**85,193**
1978	-	7,787	-	52,463	-	-	49,745	10,495	33,091	27,149	**60,240**
1979	-	3,932	-	23,826	-	-	23,051	4,707	15,399	12,359	**27,758**
1980	-	2,680	-	13,849	-	-	11,423	5,106	5,990	10,539	**16,529**
1981	-	1,776	-	2,461	-	-	2,678	1,559	498	3,739	**4,237**
1982	-	988	-	1,141	-	4	657	1,476	400	1,733	**2,133**
1983	-	1,416	-	2,155	-	151	1,891	1,831	840	2,882	**3,722**
1984	-	2,412	-	119	-	-	1,717	814	277	2,254	**2,531**
1985	-	272	-	15	-	-	139	148	51	236	**287**
1986	-	476	-	2	-	-	207	271	139	339	**478**
1987	-	810	-	-	-	-	391	419	259	551	**810**
1988	-	1,894	-	-	-	-	766	1,128	753	1,141	**1,894**
1989	-	1,068	-	-	-	-	543	525	169	899	**1,068**
1990	-	2,282	-	-	-	-	1,299	983	352	1,930	**2,282**
1991	-	1,918	-	-	-	-	1,062	856	431	1,487	**1,918**
1992	-	1,553	-	-	-	-	957	596	345	1,208	**1,553**
1993	-	2,927	-	-	-	-	1,480	1,447	252	2,675	**2,927**
1994	-	1,305	-	-	-	-	677	628	328	977	**1,305**
1995	-	2,638	3	-		-	1,458	1,183	324	2,317	**2,641**
1996	-	2,292	-	-	-	-	1,357	935	99	2,193	**2,292**
1997	120	5,083	3	-	-	-	2,773	2,433	98	5,108	**5,206**
1998	121	2,251	-	-	-	-	1,680	692	623	1,749	**2,372**
1999	-	1,966	-	-	-	-	824	1,142	44	1,922	**1,966**
2000	-	1,508	-	-	-	-	897	611	124	1,384	**1,508**
2001	-	4,839	43	-	-	-	3,347	1,492	794	4,088	**4,882**
2002	-	2,762	-	-	-	-	1,727	1,035	-	2,762	**2,762**
2003	-	8,141	93	-	-	407	7,229	1,412	2,916	5,725	**8,641**
2004	-	5,051	-	293	-	-	4,701	643	1,656	3,688	**5,344**
2005	-	6,019	-	801	-	-	6,044	776	2,972	3,848	**6,820**

Table 11.6 American shad commercial discards.

Year	Pound Net			Gill Net			Other Gear		Total All Gears
	Roe	Buck	PN Total	Roe	Buck	GN Total	Roe	Buck	
1999	376	213	589	14	10	24			**613**
2000	28	56	84	55		55			**139**
2001	800	56	856	53		53	25		**934**
2002		59	59	25	2	27			**86**
2003	22,790	17,566	40,356	9,393	670	10,063	204	73	**50,696**
2004	1,800	1,100	2,900	1,053	54	1,107			**4,007**
2005	9,371	2,998	12,369	170	0	170			**12,539**

Table 11.7 American shad commercial pound net catch rates for all pound nets in the river and upriver pound nets (PN) only. American shad landings from 1982 on are bycatch.

Year	All Pound Net						Upriver PN Only (Area 200+300+400)			
	Buck	Roe	Total	CPUE - All	Net-days	Days	CPUE - Upriver	Days	Net-Days	Pounds
1976	14,933	5,944	20,877	6.44	3,241	1,744	38.57	80	120	4,628
1977	8,324	5,418	13,742	5.20	2,644	1,585	12.31	212	296	3,644
1978	4,090	3,697	7,787	2.98	2,611	1,541	2.14	118	159	340
1979	2,502	1,430	3,932	1.54	2,553	1,091	1.28	57	83	106
1980	1,926	754	2,680	1.42	1,881	856	1.10	103	313	345
1981	1,291	485	1,776							
1982	826	162	988							
1983	822	594	1,416							
1984	742	1,670	2,412							
1985	133	139	272							
1986	271	205	476							
1987	419	391	810							
1988	1,128	766	1,894	0.94	2021	729				0
1989	525	543	1,068	0.68	1574	592	0.28	88	184	52
1990	983	1,299	2,282	1.68	1361	527	1.26	104	104	131
1991	856	1,062	1,918	1.59	1208	338	2.77	62	65	180
1992	526	939	1,465	2.08	703	301	2.28	32	32	73
1993	1,447	1,480	2,927	4.79	611	305	2.17	59	59	128
1994	628	677	1,305	1.72	758	377	1.26	74	74	93
1995	1,180	1,458	2,638	3.55	743	340	2.46	94	205	504
1996	935	1,357	2,292	4.14	553	314	4.18	17	17	71
1997	2,310	2,773	5,083	6.90	737	341	5.60	18	72	403
1998	571	1,680	2,251	6.72	335	124	6.25	20	20	125
1999	917	1,049	1,966	5.07	388	134				0
2000	611	897	1,508	5.84	258	139				0
2001	1,492	3,347	4,839	11.18	433	216	13.67	8	24	328
2002	1,035	1,727	2,762	7.940	348	126	8.00	3	3	24
2003	1,170	6,971	8,141	14.88	547	300	9.84	50	50	492
2004	643	4,408	5,051	10.25	493	244	10.60	27	45	477
2005	764	5,255	6,019	12.21	493	238	15.17	18	18	273

Table 11.8 Age structure for American shad from MD DNR Potomac River American shad gill netting, 2003-2005.

Year	Age									Mean Age
	2	3	4	5	6	7	8	9	10	
2002	0	2	11	10	25	11	2	0	0	5.6
2003	0	1	30	46	36	16	11	16	0	5.9
2004	0	0	21	35	32	5	5	0	0	5.4
2005	0	1	33	27	24	8	2	1	1	5.2

Table 11.9 Age structure of mature American shad collected from the Potomac River by gill net.

Year	Gender	Age									Total	Mean Age	Mean Fork Length
		2	3	4	5	6	7	8	9	10			
1998	Males	3	8	26	18	7	1	1	1	0	65	4.5	407.2
	Females	0	5	21	25	10	2	0	0	0	63	4.7	433.8
	Total	**3**	**13**	**48**	**44**	**17**	**3**	**1**	**1**	**0**	**130**	**4.6**	
1999	Males	0	3	5	5	0	0	0	0	0	13	4.2	372.0
	Females	0	0	3	4	1	0	0	0	0	8	4.8	442.9
	Total	0	3	8	9	1	0	0	0	0	21	4.4	
2000	Males	0	3	18	20	10	4	0	0	0	55	4.9	410.8
	Females	0	1	10	34	20	4	0	0	0	69	5.2	460.7
	Total	**0**	**6**	**30**	**63**	**30**	**8**	**0**	**0**	**0**	**137**	**5.0**	
2001	Males	0	6	9	18	12	0	0	0	0	45	4.8	450.6
	Females	0	0	3	20	16	6	0	0	0	45	5.6	499.0
	Total	**0**	**6**	**12**	**39**	**29**	**6**	**0**	**0**	**0**	**92**	**5.3**	
2002	Males	2	7	15	15	14	1	0	0	0	54	4.7	483.0
	Females	0	1	7	15	11	6	2	0	0	42	5.5	517.2
	Total	**2**	**8**	**22**	**30**	**25**	**7**	**2**	**0**	**0**	**96**	**5.0**	
2005	Males	0	0	3	2	7	3	3	0	0	18	6.1	436.1
	Females	0	0	5	5	11	6	3	2	1	33	6.2	474.7
	Total	**0**	**0**	**8**	**7**	**18**	**9**	**6**	**2**	**1**	**51**	**6.2**	

Table 11.10 Spawning checks in American shad captured from the Potomac River, 2001. Analysis by Virginia Commonwealth University.

Scale Age (Sexes Combined)	N	# Repeat Spawn	% Repeat Spawn	# Specimens w /Spawning Checks By Age					
				2	3	4	5	6	7
2	1	0	-	1	-	-	-	-	-
3	8	0	0%	0	8	-	-	-	-
4	29	14	48%	2	17	29	-	-	-
5	32	30	94%	1	11	30	32	-	-
6	16	15	94%	1	8	11	14	16	-
7	2	2	100%	0	0	1	1	2	2
Total	**88**	**61**	**69%**	**5**	**44**	**71**	**47**	**18**	**2**

Scale Age (Female)	N	# Repeat Spawn	% Repeat Spawn	# Specimens w /Spawning Checks By Age					
				2	3	4	5	6	7
2	0	0		-	-	-	-	-	-
3	1	0	0%	0	1	-	-	-	-
4	14	8	57%	2	7	15	-	-	-
5	17	15	88%	0	5	15	17	-	-
6	11	10	91%	0	5	8	9	11	
7	1	1	100%	0	0	0	1	1	1
Total	**44**	**34**	**77%**	**2**	**18**	**38**	**27**	**12**	**1**

Scale Age (Male)	N	# Repeat Spawn	% Repeat Spawn	# Specimens w /Spawning Checks By Age					
				2	3	4	5	6	7
2	1	0	0%	1	-	-	-	-	-
3	7	0	0%	0	7	-	-	-	-
4	15	6	40%	0	10	14	-	-	-
5	15	15	100%	1	6	15	15	-	-
6	5	5	100%	1	3	3	5	5	-
7	1	1	100%	0	0	1	0	1	1
Total	**44**	**27**	**61%**	**3**	**26**	**33**	**20**	**6**	**1**

Table 11.11 Annual collection of American shad for broodfish from the Potomac River. Note that this does not include all collected fish.

Year	Ripe Female Shad	Total Adult Shad	Percent Viability	Number of Viable Eggs
2001	312	440		2,250,217
2002	568	2003	51	5,901,318
2003	458	1359		3,260,800
2004	230	981	56	2,779,298
2005	561	1576	45	3,492,647

Table 11.12 Potomac River American shad CPUE from Maryland spring striped bass spawning stock survey, 1996-2005. CPUE (number of fish caught per 1000 yards^2 of experimental drift gill net per hour fished) calculation uses all 10 meshes. An index with only the appropriate meshes would have the same trend.

Year	Effort	Catch	CPUE
1996	50.52	5	0.10
1997	54.44	9	0.17
1998	58.74	27	0.46
1999	48.69	7	0.14
2000	48.70	58	1.19
2001	58.00	84	1.45
2002	60.27	69	1.14
2003	52.51	150	2.86
2004	36.94	113	3.06
2005	34.81	132	3.79

Table 11.13 ICPRB summary of the number of American shad used, eggs collected, fry released, and catch-per-unit-effort (CPUE) for project period 1995-2005, including estimates of shad returns.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005[1]	Cumulative
# Ripe Females	135	166	245	105	119	373	338	245	240	387	246	2,599
# Green (unripe) Females	78	51	92	50	44	93	135	141	120	127	49	980
# Spent (post-spawn) Females	3	1	0	8	10	9	27	25	15	27	2	127
# Males	78	157	207	153	116	282	235	247	240	435	207	2,357
# Total Shad Used	294	375	544	316	289	757	735	658	615	976	506	6,065
# Eggs Collected (thousands)	2,405	4,353	5,744	2,626	2,594	6,383	6,565	5,943	5,327	5,773	8,129	55,842
# Collections:# Nets Set	11:22	11:22	12:24	14:28	15:30	11:22	16:32	18:36	10:16	14:25	13:25	145:282
CPUE (# Shad Used/Nets Set)[2]	13.4	17.0	22.7	11.3	9.6	34.4	22.9	18.3	35.9	39.0	20.2	21.5
# Eggs/Ripe Female	17,800	26,200	23,400	25,000	24,400	17,100	19,400	24,260	22,195	14,917	24,783	21,486
# Fry Stocked (thousands)	1,175	1,989	1,535	1,589	1,304	3,176	3,336	1,531	1,400	3,500	4,319	24,855
# Stocked in Rappahannock R.									1,200	3,100	3,400	7,700
# Fry Stocked/Each Shad Collected	4,000	2,800	2,800	5,000	4,500	4,200	4,500	2,326	2,435	3,586	5,690	4,098
Estimated # of Shad Returning	3,487	4,555	4,555	4,715	3,869	9,424	9,674	4,444	4,060	10,150	11,300	71,500
Estimated # of Shad Returning/Each Shad Collected[3]	11.9	8.4	8.4	14.9	13.4	12.4	13.5	6	5.9	10.6	14.9	11.8

[1]This number is just for the shad collected by the Louis Harley boat with approx. 3 crew members. If we assume that this boat collected 1.5 times the number of shad caught by the single person crew of Randy Kirby, the total number of shad captured in 2005 was approx. 760 fish.

[2]The CPUE of "Shad Used" is based on the number of shad actually kept (from the Louis Harley boat) for collection of eggs for restocking the Potomac and, starting in 2003, the Rappahannock rivers. It does not include green or spent females and surplus males, which were netted but then released. It does not include shad captured by Virginia waterman Randy Kirby, who started helping with these collections in 2004. The "Shad Used" CPUE has been used through the entire project, 1995-2005, and thus is the most consistent.

Starting in 2002, all American shad netted by the Louis Harley boat, including those released, have also been counted and a second type of CPUE--"Total Shad/Net"--has also been calculated (see below).

The total number of shad netted in 2002 was 1,801, with 1,143 released.
The 2002 "Total Shad/Net" CPUE = 1,801 shad/36 nets = 50 shad/net
The total number of shad netted in 2003 was 1,494, with 879 released.
The 2003 "Total Shad/Net" CPUE = 1,494 shad/16 nets = 93 shad/net
The total number of shad netted in 2004 was 1,852, with 896 released.
The 2004 "Total Shad/Net" CPUE = 1,852 shad/25 nets = 74 shad/net
The total number of shad netted in 2005 was 1,101, with 597 released.
The 2005 "Total Shad/Net" CPUE - 1,101 shad/25 nets = 44 shad/net

[3]Monitoring of the Conowingo Dam fish lifts (Hendricks 2000) found that is takes 337 hatchery fry stocked in the Susquehanna River to get one returning adult shad.

Table 11.14 Frequency of OTC marks in adult American shad collected in the Potomac River, 1998-2005.

Year	Statistic	Age									Total
		2	3	4	5	6	7	8	9	10	
1998	N	3	13	48	44	17	3	1	1	0	130
	N with OTC	0	0	0	1	0	0	0	0	0	1
	Fraction OTC	0	0	0	0.023	0	0	0	0	0	0.008
1999	N	0	3	8	9	1	0	0	0	0	21
	N with OTC	0	0	0	0	0	0	0	0	0	0
	Fraction OTC	0	0	0	0	0	0	0	0	0	0
2000	N	0	6	30	63	30	8	0	0	0	137
	N with OTC	0	0	1	4	0	0	0	0	0	5
	Fraction OTC	0	0	0.033	0.063	0	0	0	0	0	0.036
2001	N	0	6	12	39	29	6	0	0	0	92
	N with OTC		0	1	2	0	0	0	0	0	3
	Fraction OTC	0	0	0.083	0.051	0	0	0	0	0	0.033
2002	N	2	8	22	30	25	7	2	0	0	96
	N with OTC	0	0	0	4	2	1	0	0	0	7
	Fraction OTC	0	0	0	0.133	0.08	0.143	0	0	0	0.073
2005	N	0	0	8	7	18	9	6	2	1	51
	N with OTC	0	0	0	1	0	0	0	0	0	1
	Fraction OTC	0	0	0	0.143	0	0	0	0	0	0.020

Table 11.15 Estimates of total mortality (Z) of mature American shad in the Potomac River using catch-at-age and repeat spawning data, 2002-2005. Catch-at-age data is based on scale ages.

Year	Ages	Catch-at-Age Data	Repeat Spawning Data
2002	8-Jun	1.31	1.02
2003	9-Jun	1.05	0.92
2004	8-Jun	0.78	0.74
2005	10-Jun	0.82	0.66

Table 11.16 Potomac River American shad juvenile abundance indices, 1959-2005.

Year	N	Geometric Mean Index	95% CI (low)	95% CI (high)
1959	10	0	0	0
1960	10	0.41	0.04	0.92
1961	16	0.04	-0.04	0.14
1962	28	1.45	0.57	2.83
1963	28	0.88	0.27	1.78
1964	28	0.59	0.14	1.22
1965	28	1.44	0.57	2.81
1966	42	1.07	0.49	1.88
1967	42	0.78	0.32	1.38
1968	42	0.25	0.05	0.5
1969	42	0	0	0
1970	42	1.74	0.73	3.33
1971	42	0.8	0.36	1.39
1972	42	2.14	1.02	3.89
1973	42	0.31	0.11	0.55
1974	42	0	0	0
1975	42	0.94	0.48	1.56
1976	42	0	0	0
1977	42	0.02	-0.02	0.05
1978	42	0.98	0.4	1.82
1979	42	0.03	-0.01	0.08
1980	42	0.24	0.08	0.42
1981	42	0	0	0
1982	42	0.02	-0.02	0.05

Year	N	Geometric Mean Index	95% CI (low)	95% CI (high)
1983	42	0	0	0
1984	42	0.12	0	0.25
1985	42	0.07	-0.01	0.16
1986	42	0.03	-0.01	0.08
1987	42	0.11	-0.04	0.27
1988	42	0.09	0	0.2
1989	42	0.38	0.08	0.76
1990	42	0	0	0
1991	42	0.17	0.03	0.35
1992	42	0.05	-0.01	0.11
1993	42	0.15	-0.01	0.34
1994	42	0.36	0.13	0.65
1995	42	0.59	0.21	1.07
1996	42	1.2	0.51	2.21
1997	42	0.81	0.35	1.43
1998	42	2	0.9	3.75
1999	42	0.31	0.09	0.57
2000	42	2.89	1.38	5.34
2001	42	4.75	2.01	9.96
2002	42	4.16	1.9	8.19
2003	42	2.73	1.32	4.99
2004	42	13.3	6.13	27.68
2005	42	4.66	2.03	9.56

Table 11.17 Juvenile abundance indices of American shad in District of Columbia waters for all sites sampled, 1990-2005.

Year	American Shad
1990	0
1991	1.5
1992	3
1993	0
1994	0
1995	25
1996	0
1997	0
1998	2
1999	0
2000	15
2001	1
2002	0
2003	0
2004	5.9
2005	4.2
Average	**3.6**

Table 11.18 Linear regression results for Potomac River correlation of juvenile abundance index with adult year class abundance, 2002-2005. "ns" indicated no significant correlation (α=0.05).

Adult Age Class	*P*-value	r^2	Significance
4	0.5794	0.18	ns
5	0.776	0.05	ns
6	0.7999	0.04	ns
7	0.6637	0.11	ns
8	0.7781	0.04	ns
9	0.3934	0.37	ns
10	0.1621	0.70	ns

Table 11.19 Historic landings data and CPUE calculated from Walburg and Sykes (1957) for 1944-1952.

Year	Effort	Virginia Catch	Maryland Catch	Total Catch	CPUE (lbs/net-day)
1944	8,615	670,000	9,041	679,041	78.82
1945	15,413	294,200	8,359	302,559	19.63
1946	11,019	268,000	11,142	279,142	25.33
1947	11,403	992,900	22,697	1,015,597	89.06
1948	16,813	351,200	13,494	364,694	21.69
1949	22,778	356,400	27,055	383,455	16.83
1950	21,367	455,200	20,396	475,596	22.26
1951	13,792	424,000	5,658	429,658	31.15
1952	15,653	451,674	25,636	477,310	30.49

Figure 11.1 Potomac River herring and shad spawning areas from Lippson *et al.*'s *Environmental Atlas of the Potomac Estuary* Herring and Shad Spawning Areas.

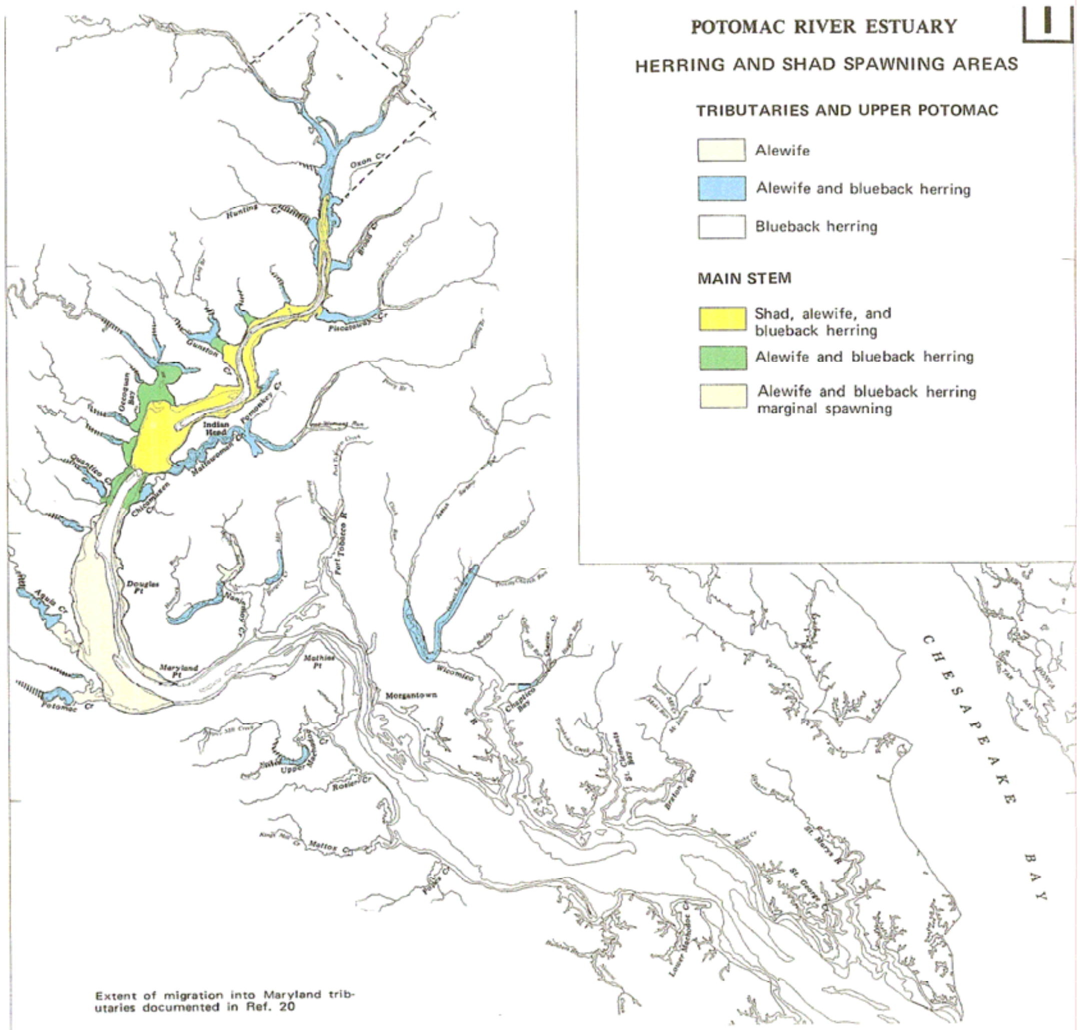


Figure 11.2 Historical American shad landings (lbs) in the Potomac River, 1814-2005. The 1814-1818 landings are only a representative estimate based on an expansion of the detailed records of one haul seine fishery. The CPUE inset is from the same records (Massman 1961). Numbers of fish were converted to pounds for the 1932 data. The 1898-1900 data come from *This Was Potomac* by Tilp (1978).

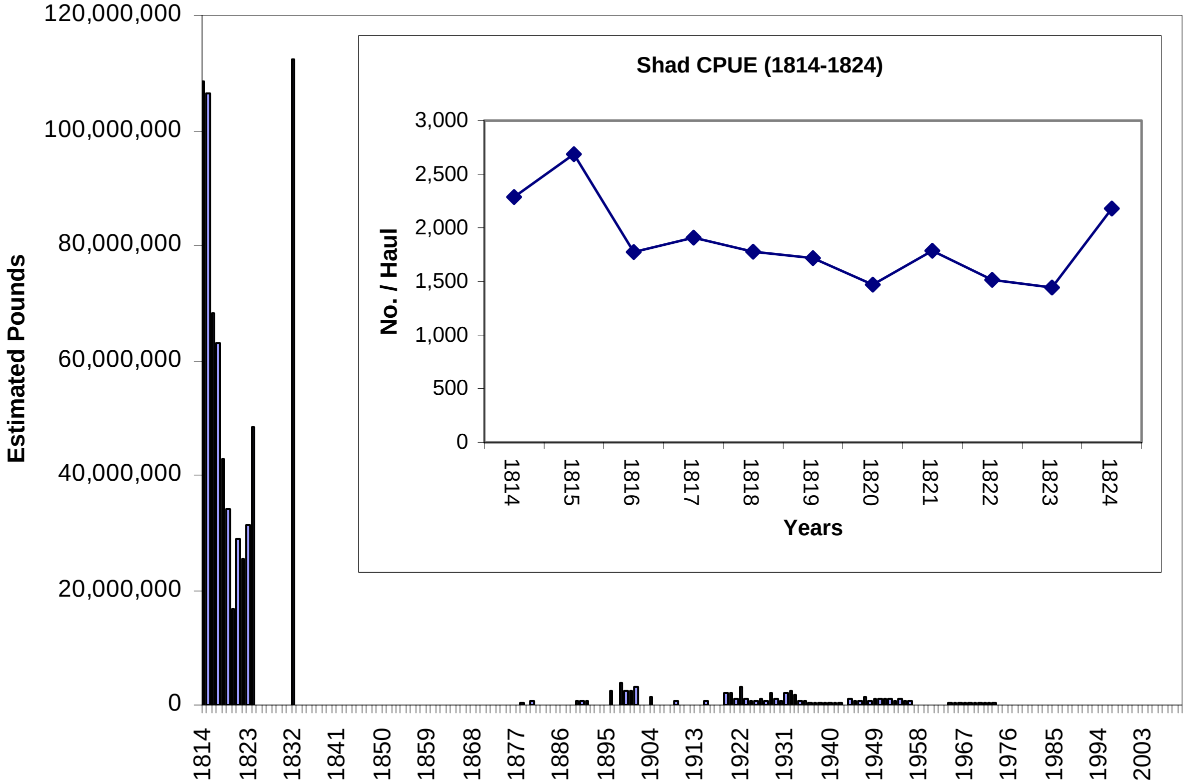


Figure 11.3 Historical American shad landings (lbs) from the Potomac River, 1878-2005. The 1878-1956 landings are from *Chesapeake Fisheries*. The 1964-2005 landings are from PRFC data.

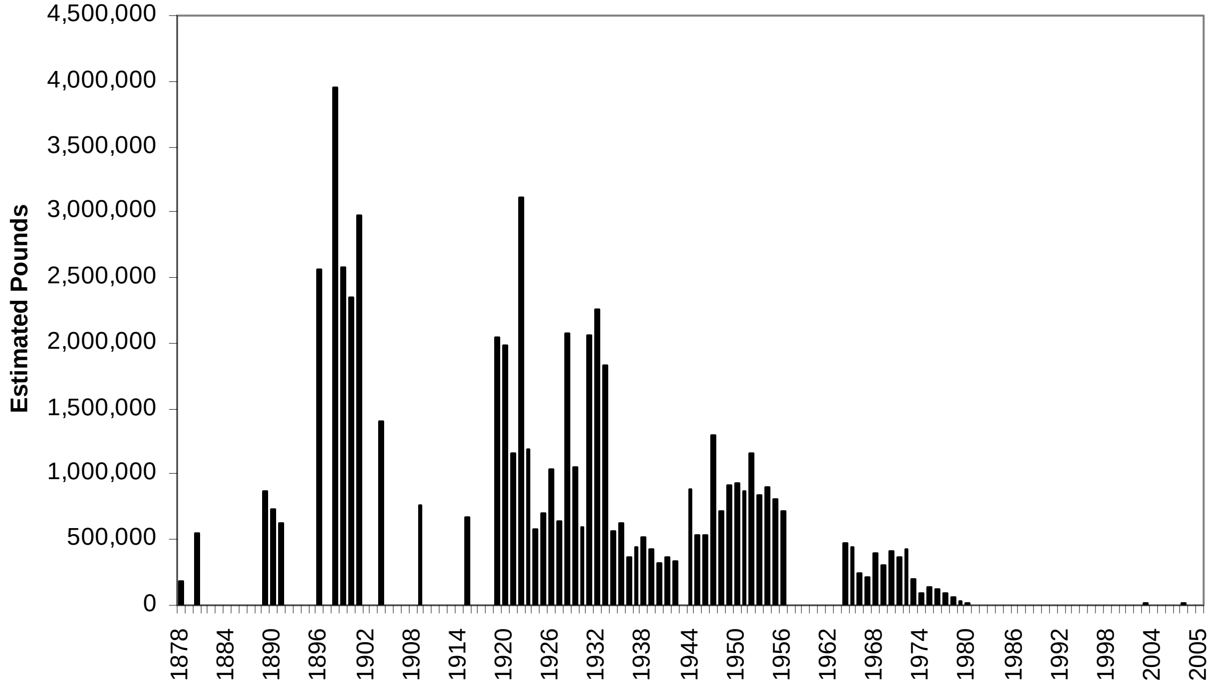


Figure 11.4 MD DNR drift gill net sampling locations in the spawning areas of the Upper Chesapeake Bay and the Potomac River, late March-May.

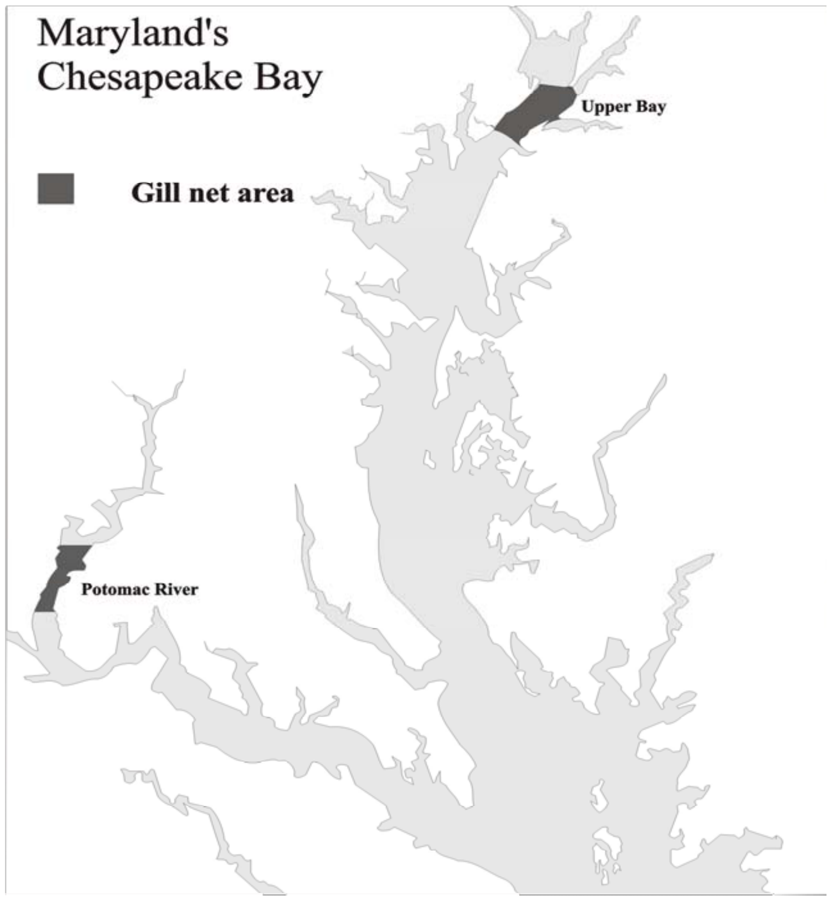


Figure 11.5 MD DNR Chesapeake Bay juvenile striped bass survey site locations.

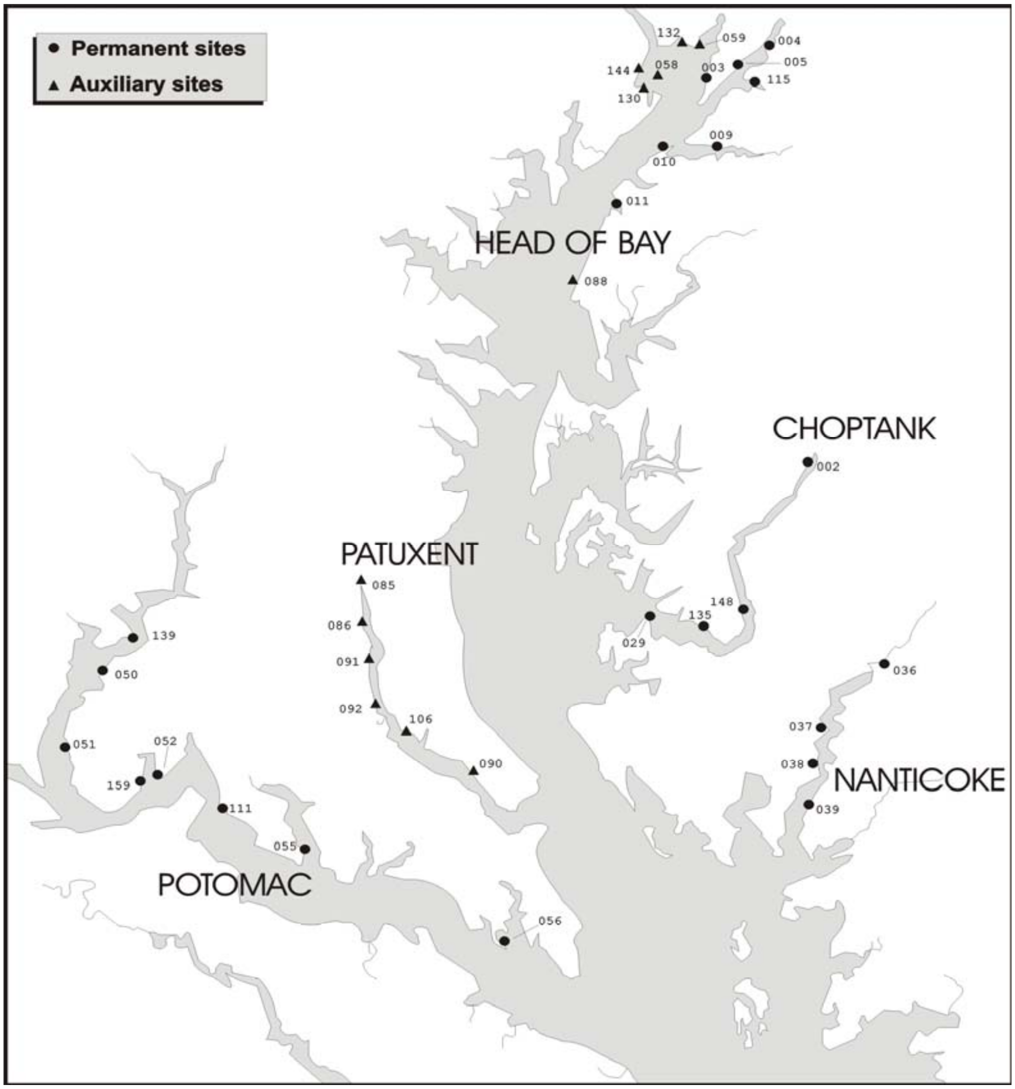


Figure 11.6 PRFC Potomac River American shad commercial landings data, 1964-2005.

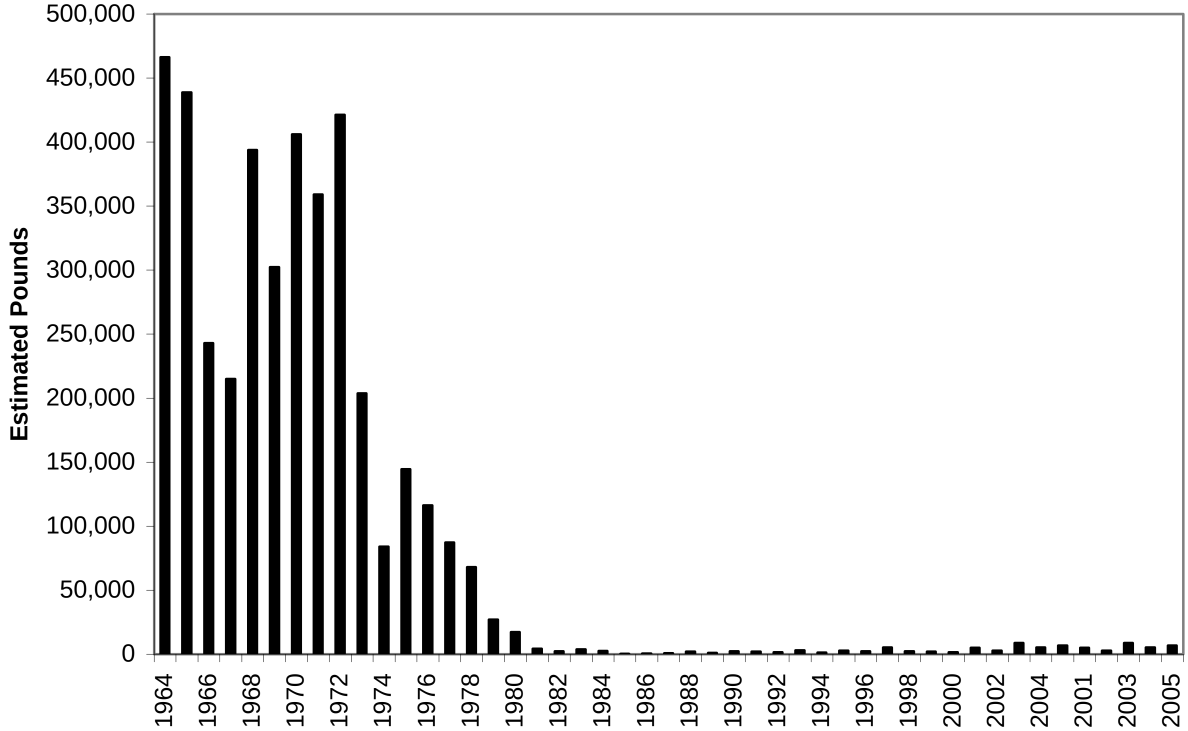


Figure 11.7 PRFC Potomac River American shad bycatch landings data, 1982-2005.

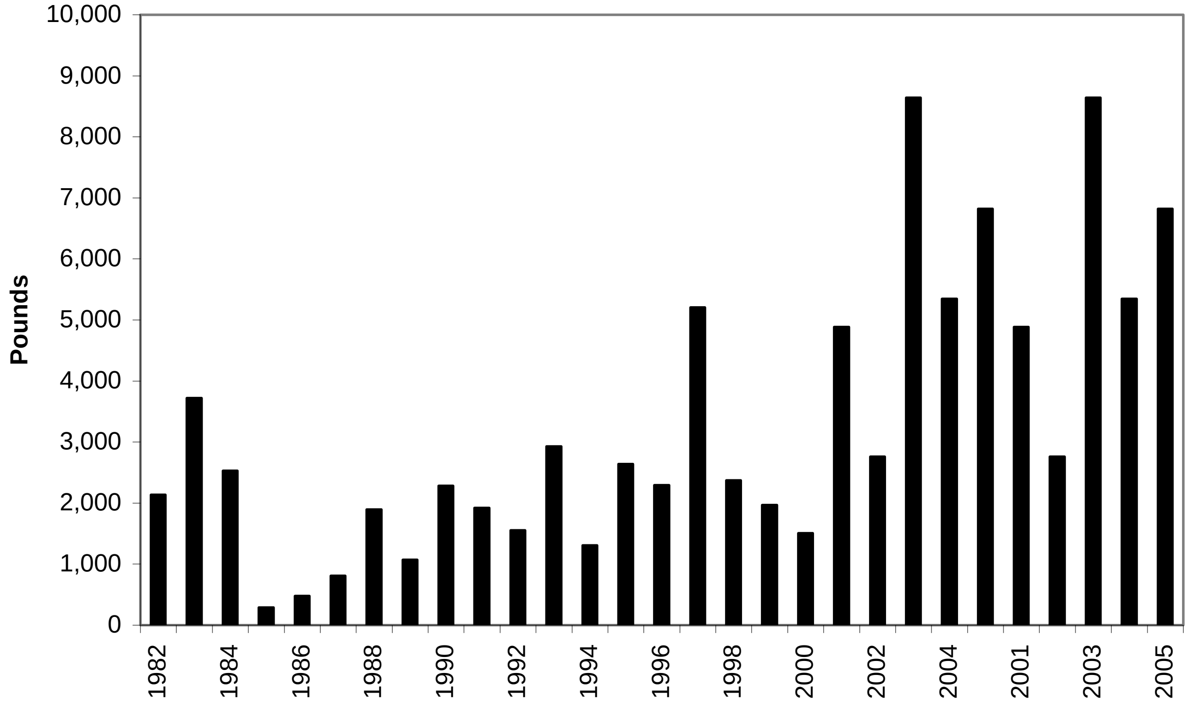


Figure 11.8 PRFC American shad commercial discard (lbs) data (log scale), 1999-2005.

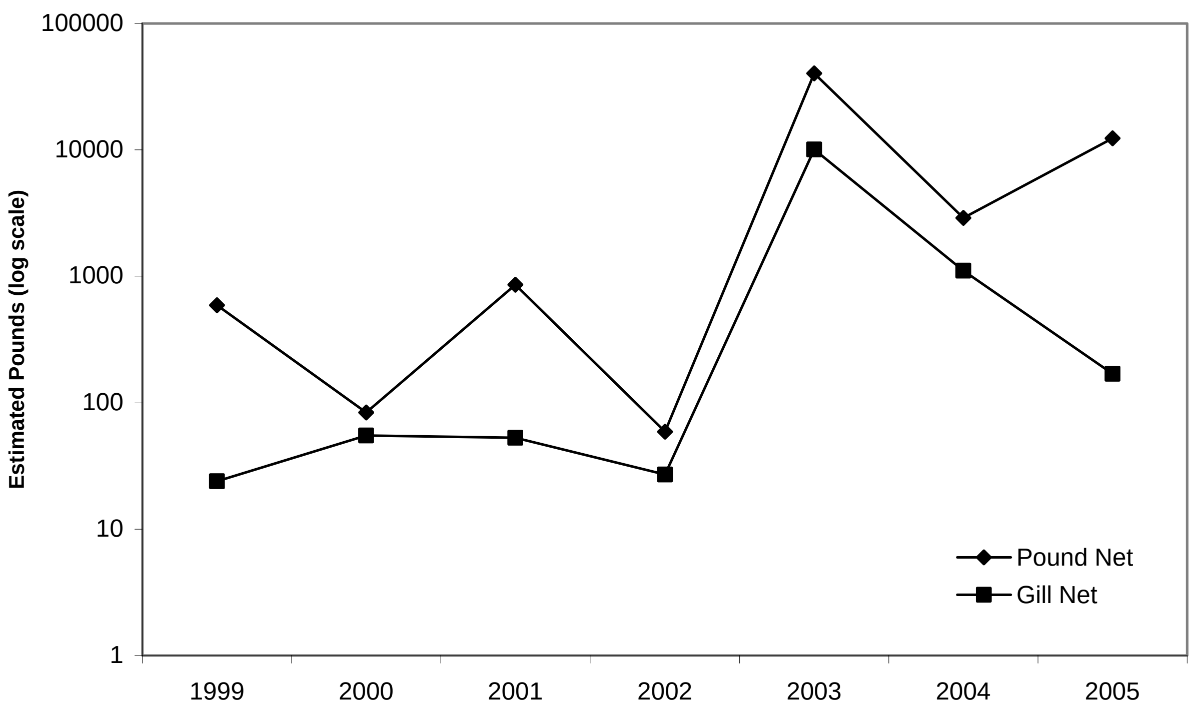


Figure 11.9 PRFC American shad commercial pound net catch (lbs) by sex, 1976-2005. Landings from 1982 on are bycatch.

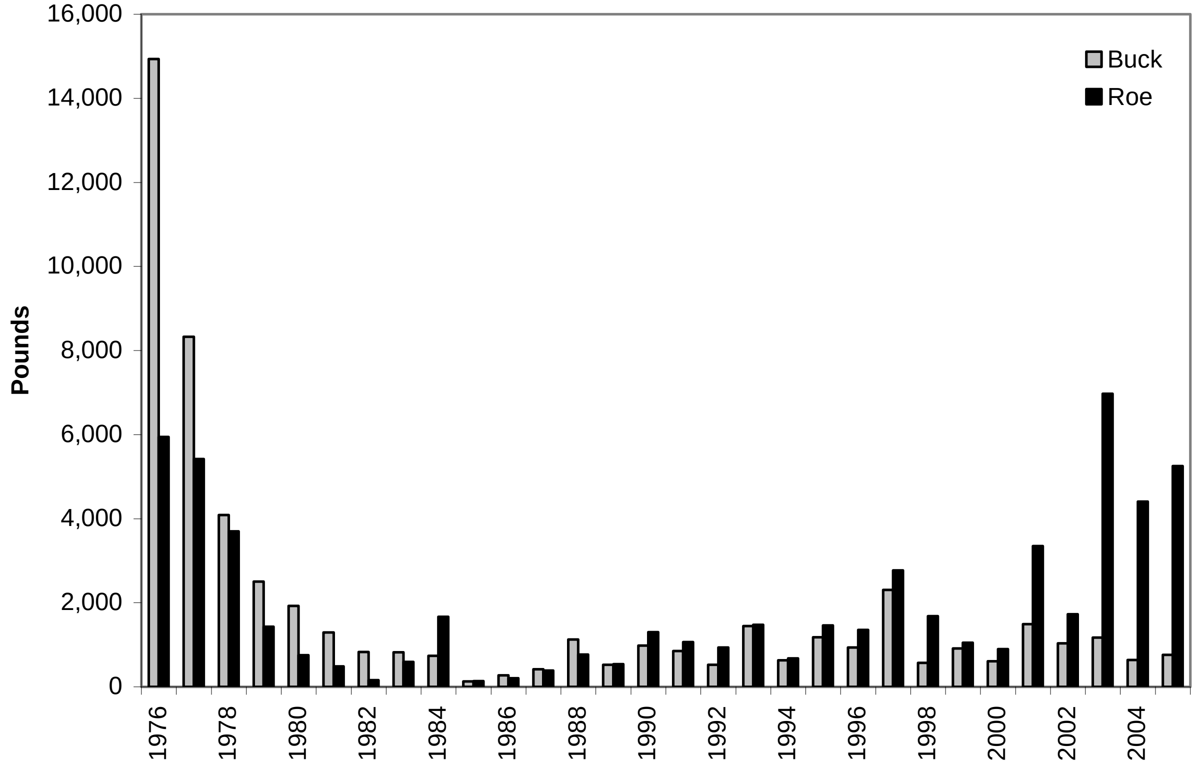


Figure 11.10 PRFC American shad commercial catch rates (pounds/net-day) for pound nets, 1976-2005. Pound net catch from 1976-1980. Pound net bycatch from 1988-2005. Data from 1981-1987 are not available.

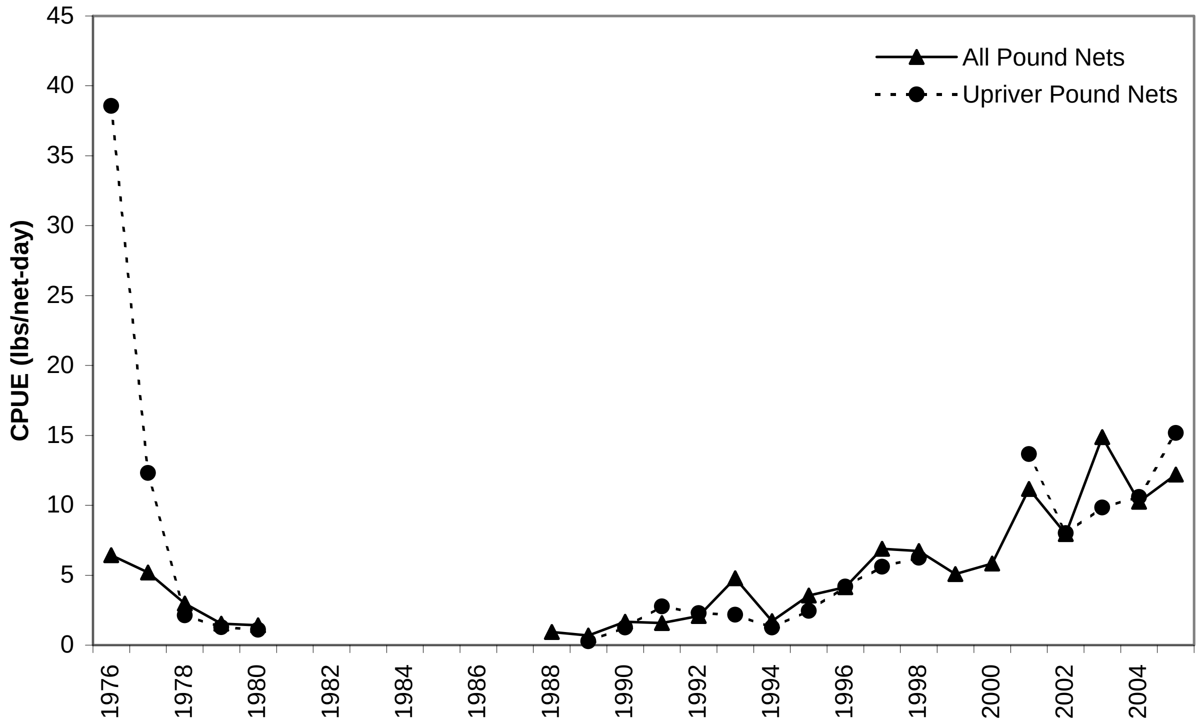


Figure 11.11 Potomac River pound net bycatch only index collected by PRFC, 1988-2005.

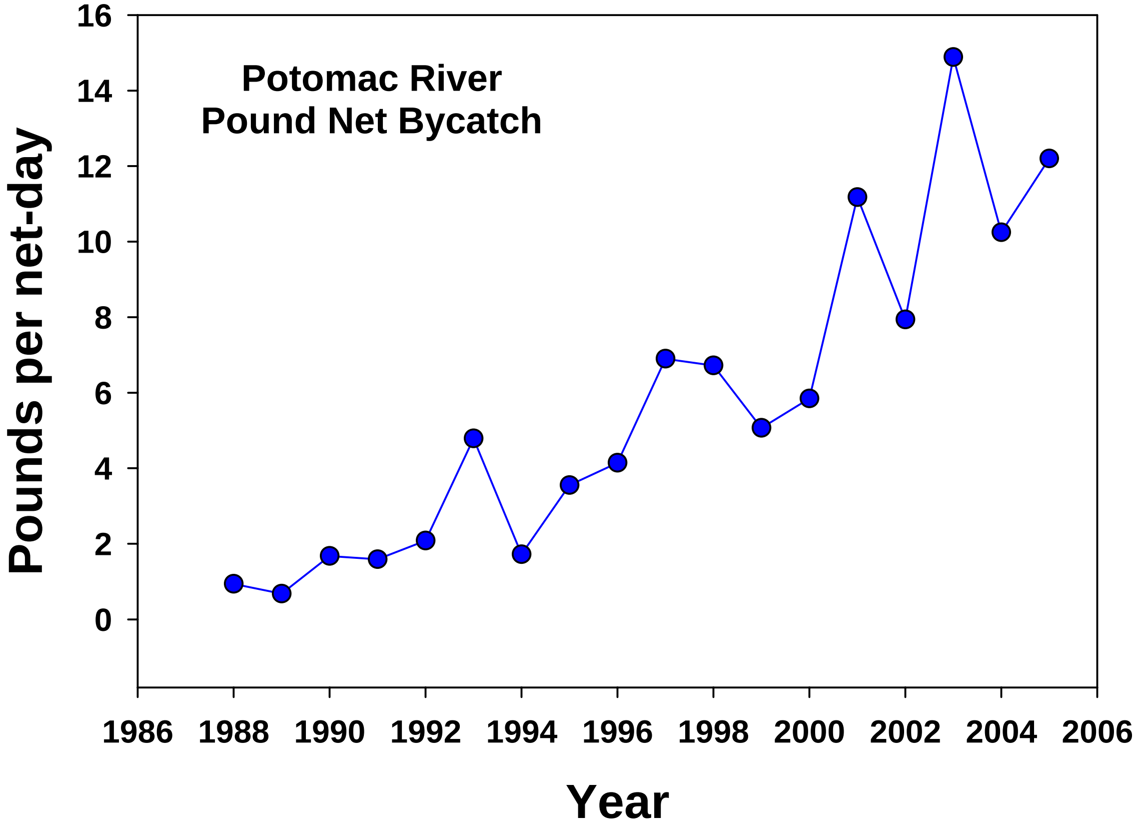


Figure 11.12 Potomac River pound net total catch (bycatch plus discards) index collected by PRFC, 1999-2005.

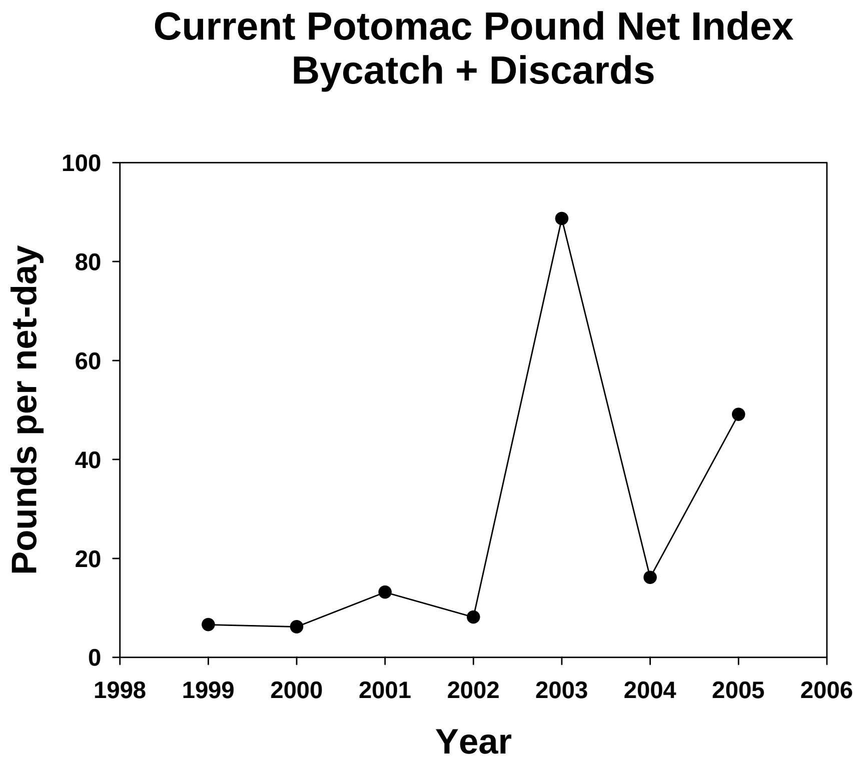


Figure 11.13 Potomac River American shad percent-at-age, 2002-2005 (MD DNR).

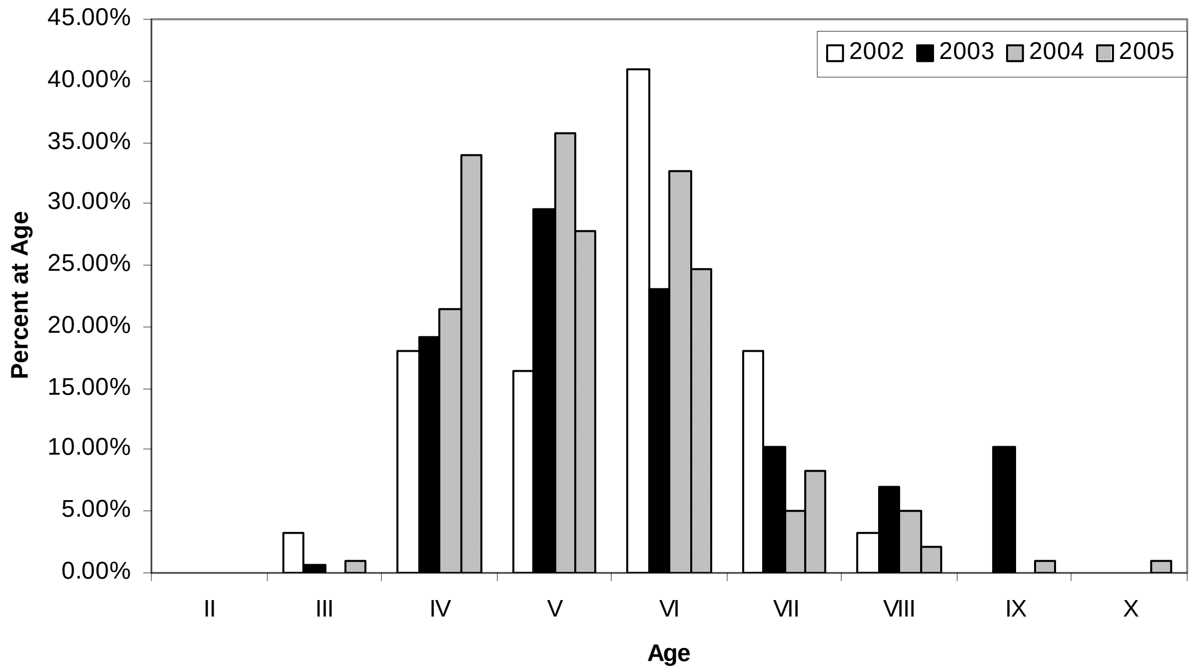


Figure 11.14 Potomac River American shad percent-at-age, 1998-2005 (ICPRB, USFWS, VDGIF).

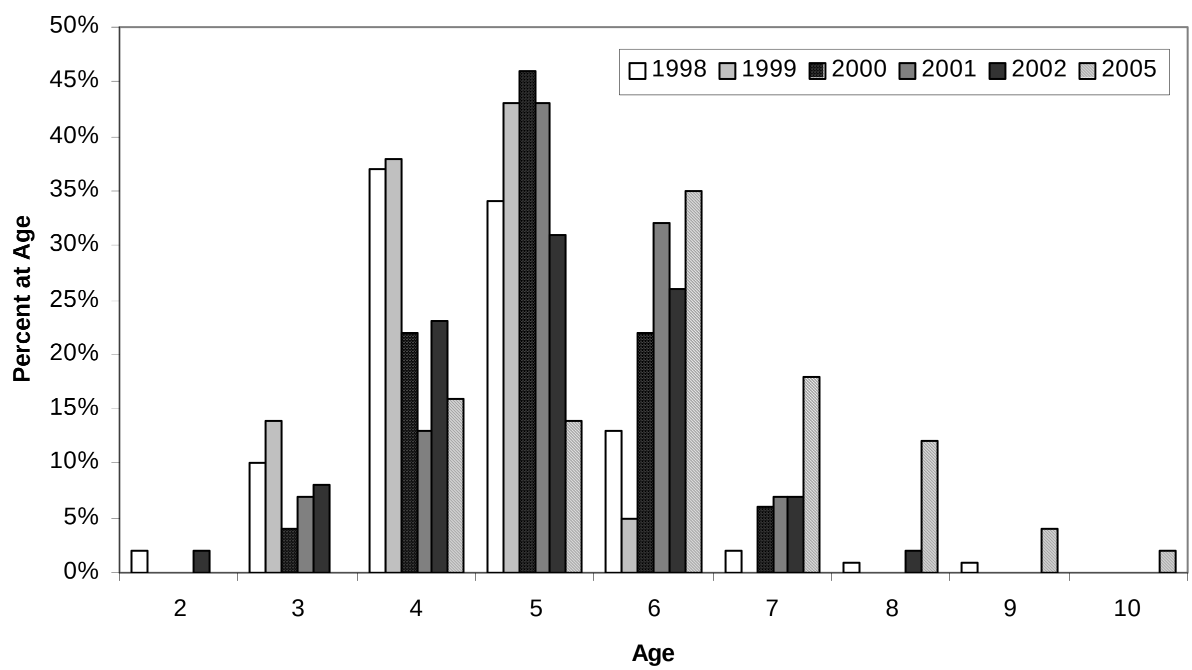


Figure 11.15 CPUE (fish per 1000 yd^2 net/h) of American shad caught with gill nets in the Potomac River, 1996-2005 (MD DNR). N is the number of fish.

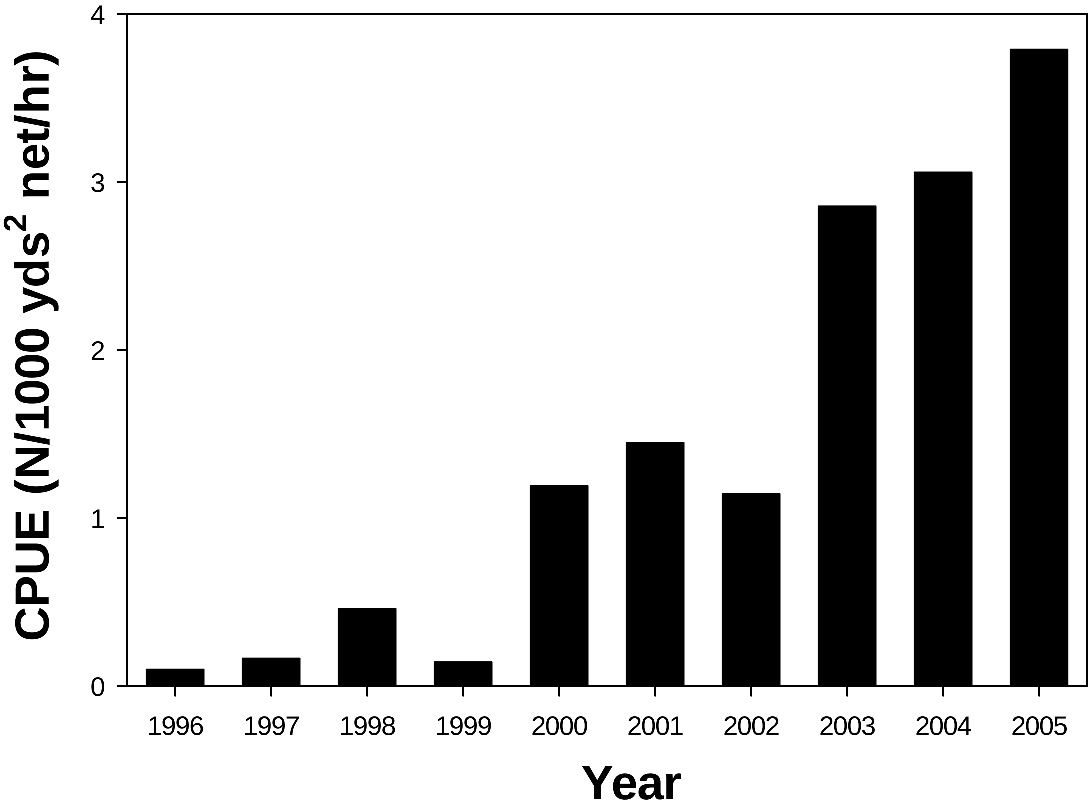


Figure 11.16 Estimates of total mortality (Z) of mature American shad in the Potomac River using catch-at-age and repeat spawning data.

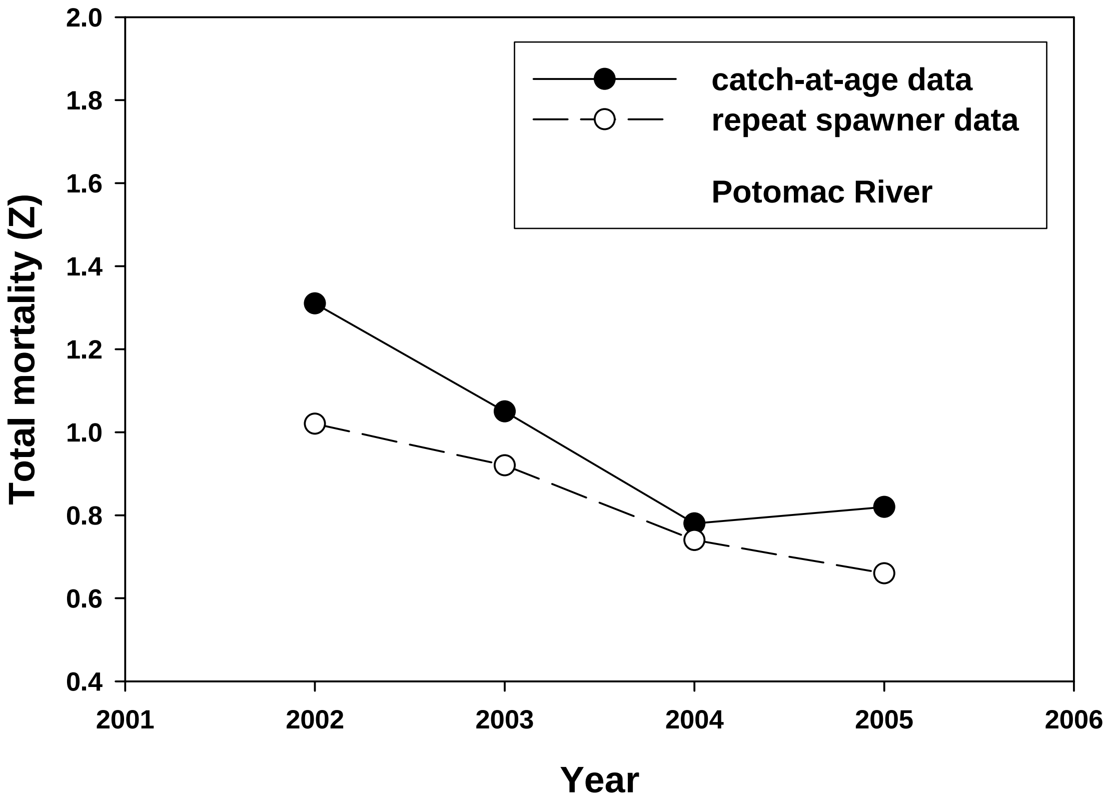


Figure 11.17 MD DNR Striped Bass Seine Survey American shad juvenile abundance index (geometric mean), 1959-2005.

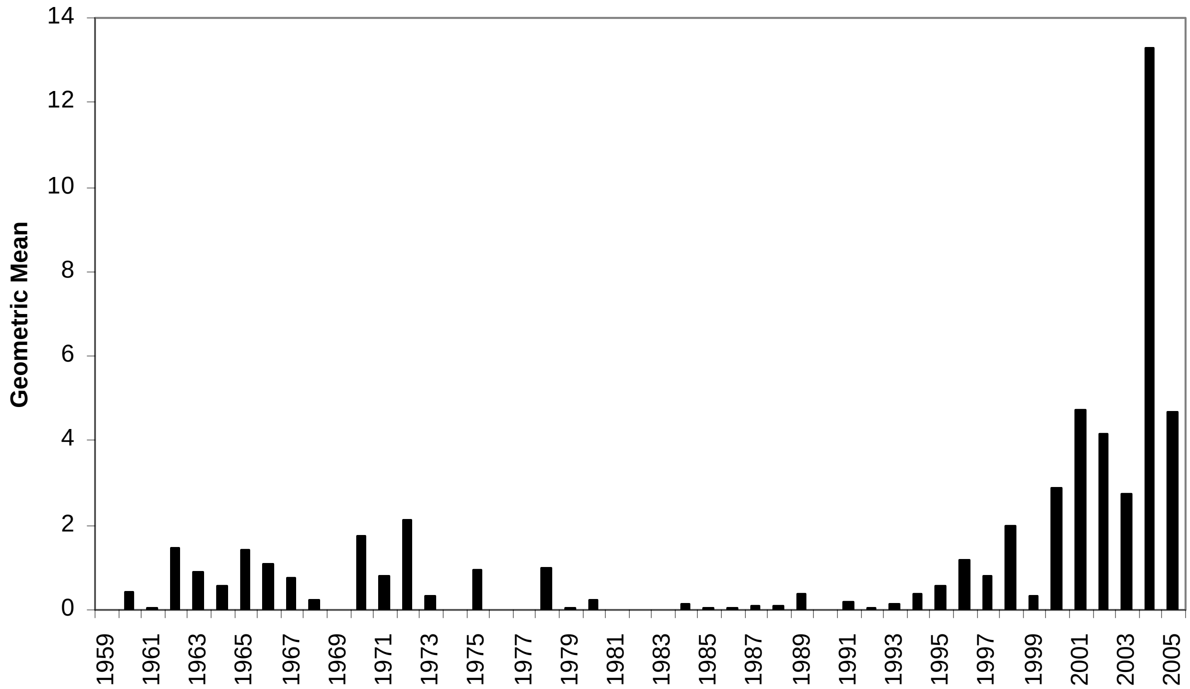


Figure 11.18 Juvenile abundance indices for the Potomac River.

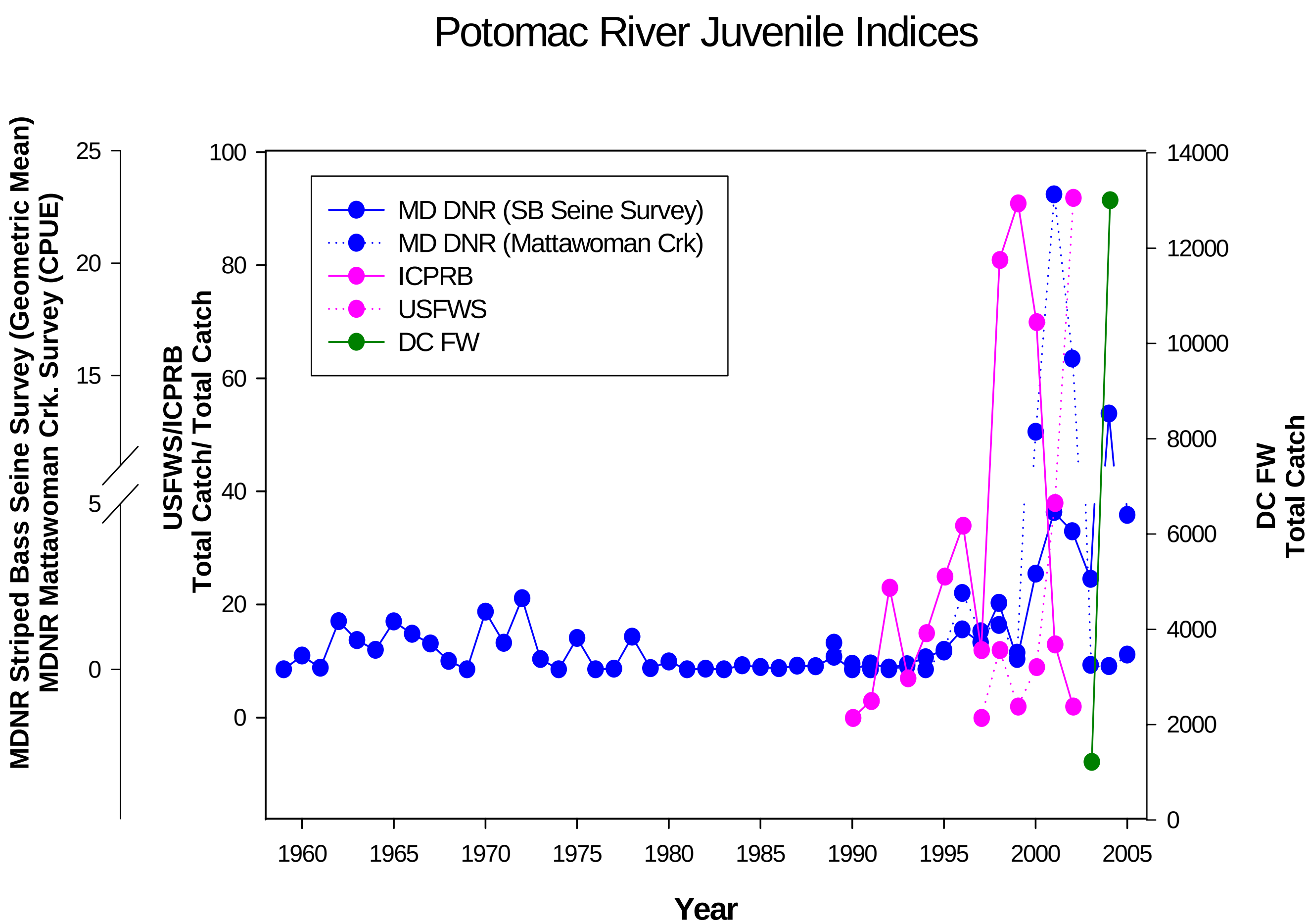


Figure 11.19 Frequency of American shad juvenile abundance index values during the course of the MD DNR Striped Bass Seine Survey, 1959-2005.

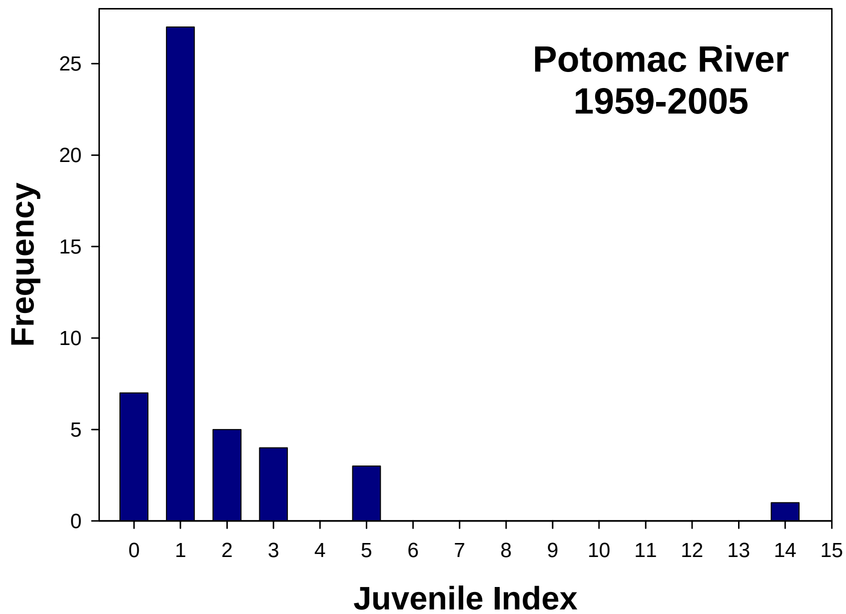


Figure 11.20 Linear regression results for the Potomac River correlation of juvenile abundance index with adult year class abundance, 2002-2005.

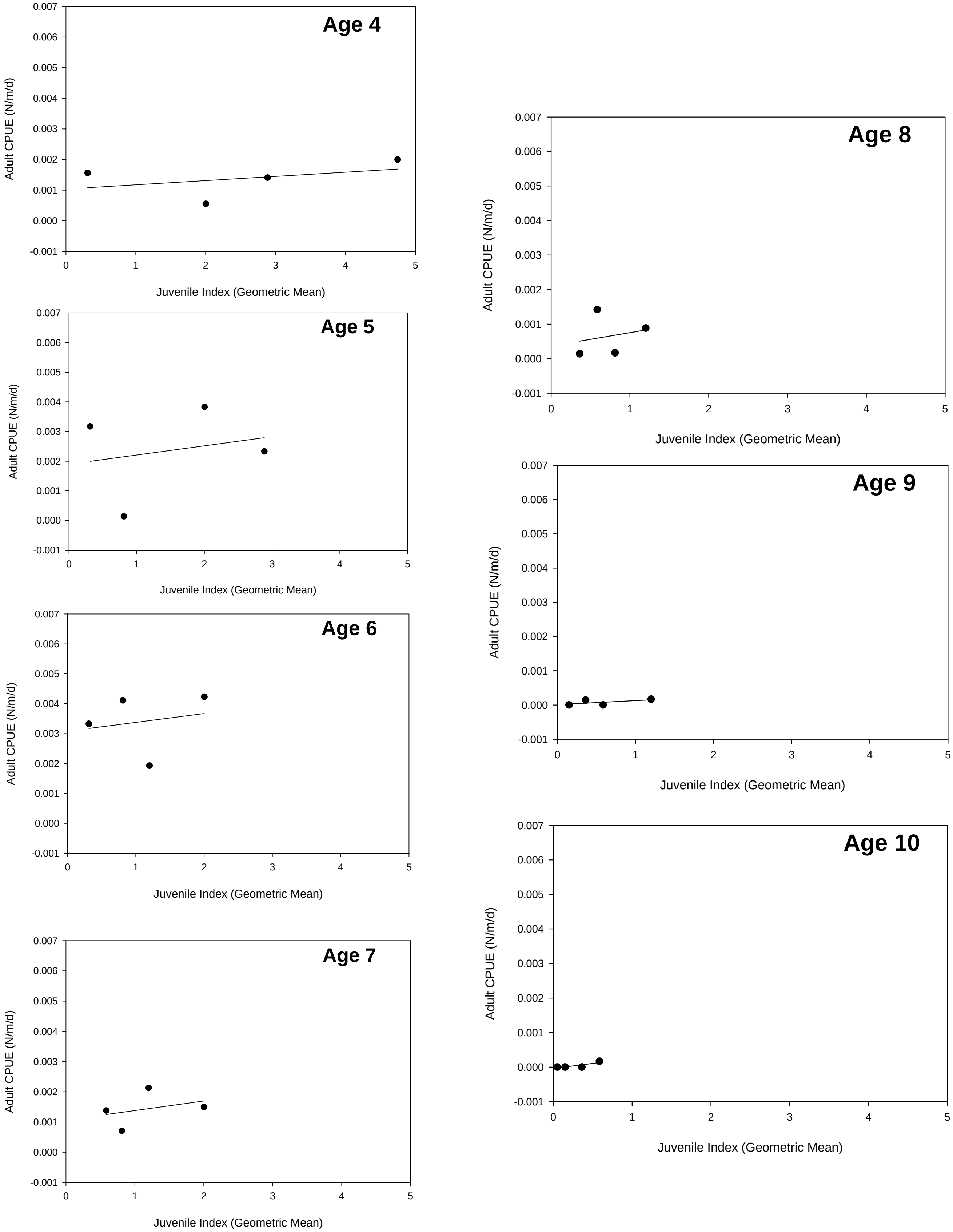
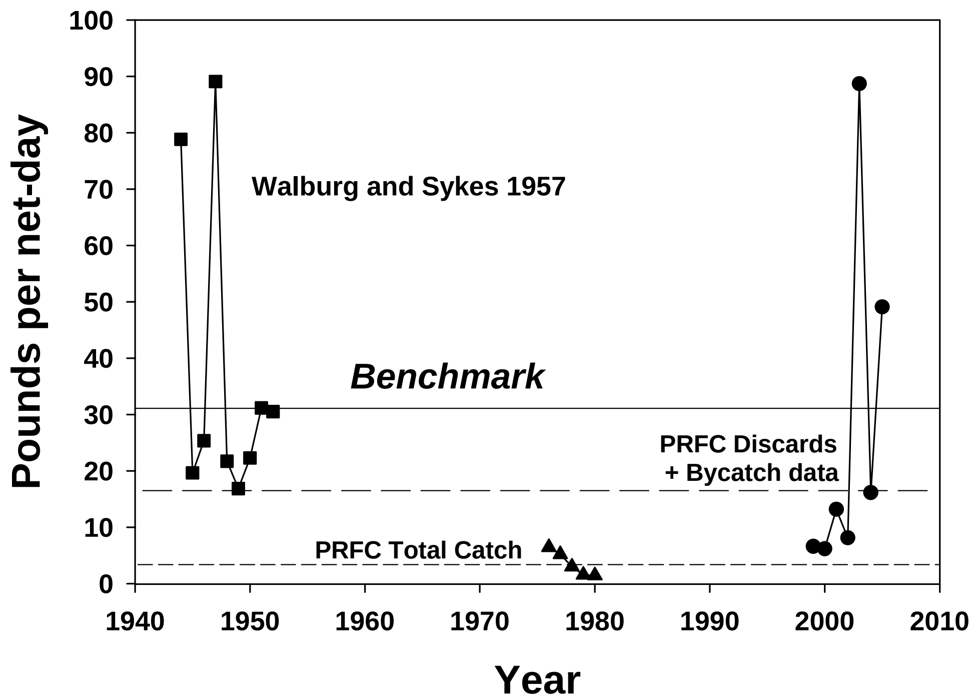


Figure 11.21 Catch indices of historic pound net data from the 1940s through 1950s (Walburg and Sykes), 1970s (PRFC), and current monitoring (PRFC). Horizontal lines are the geometric means of each data set (solid, 1940s-1950s; dotted, 1970s; dashed, current).



APPENDIX I

Growth Modeling

Data

The best (that is, largest sample size with ages) available adult size-at-age data for the Potomac River comes from the Maryland Department of Natural Resources' Striped Bass Gill Net Survey for the years 2002 to 2005. These data were received from Eric Durell (MD DNR, Striped Bass Survey) and Bob Sadzinski (MD DNR, Chesapeake Bay Finfish Programs). Growth was modeled using the length-age relationship in age-0, age-3, and older fish. Immature fish (ages 1 and 2) were not available for study and are not represented in these analyses. All ages were determined using scales, following the method of Cating (1953), and were read by one reader (Dale Weinrich, MD DNR). No age data are available for samples prior to 2002.

There were no age-length data available for young-of-year fish (age-0) on the Potomac River; therefore specimens collected by the Virginia Department of Game and Inland Fisheries electrofishing survey on a nearby river, the Rappahannock River, were used. A sub-sample of eighty fish was randomly selected for the age-0 year class sample. All fish with a total length of less than 90 mm were assumed to be young-of-year fish (age 30-90 d; Hoffman and Olney 2005); any fish larger than this size were discarded from the original sample to avoid including fish that were older.

Fractional ages were calculated for all fish (for a more detailed explanation, please see the Virginia Assessment, Growth Modeling section). Fractional ages used a mean hatch date (May 13) from the York River, Virginia stock (Hoffman and Olney 2005) since no hatch date data are available for the Potomac.

Model Selection

The candidate models fitted to the age-length data were: (1) von Bertalanffy, (2) Linear von Bertalanffy, (3) Gompertz, (4) Richards, (5) Schnute, and (6) Porch. Since these models are not hierarchical, model performance was evaluated using Akaike's Information Criterion (AIC).

The first model applied to the data was the standard von Bertalanffy growth curve expressed as:

$$L_t = L_\infty\left(1 - e^{-k[t-t_0]}\right), \tag{1}$$

where L_t is the length-at-age t, L_∞ is the asymptotic average maximum length, k is a growth coefficient that determines how quickly the maximum size is attained, and t_0 is the hypothetical age at which the species has zero length. The second model selected was the Linear von Bertalanffy growth curve, which expresses the asymptotic length as a linear function of age:

$$L_\infty = \left(b_0 + b_1 * t\right) * \left(1 - e^{(-k(t-t_0))}\right), \tag{2}$$

where b_0 is the intercept of the line and b_1 is estimated. The third model selected was the Gompertz model:

$$L_t = L_\infty * e^{\left(-\frac{1}{k}e^{-k(t-t_0)}\right)}, \quad (3)$$

which is an alternative sigmoidal growth curve with an upper asymptote. The fourth model selected was the Richards model:

$$L_\infty = \left(1 - d * e^{(-k(t-t_0))}\right)^{\frac{1}{d}} \quad (4)$$

The Richards model is a generalization of the von Bertalanffy model to allow for greater flexibility. The fifth model selected was the general Schnute growth model:

$$L_t = \left(\left(y_1^b + \left(y_2^b - y_1^b\right)\right) * \frac{\left(1 - e^{-a(t_0 - t_1)}\right)}{1 - e^{-a(t_2 - t_1)}}\right)^{\frac{1}{b}}, \quad (5)$$

which is a general four parameter model describing a relative, rather than instantaneous, rate of change in growth and that contains most of the preceding models as special cases. The last model considered was the damped model developed by Porch *et al*. (2002):

$$L_i = L_\infty (1 - e^{\beta_1 - k_0(t-t_0)})$$
$$\text{where } \beta_1 = \frac{k_1}{\lambda}(e^{-\lambda t} - e^{-\lambda t_0}), \quad (6)$$

where λ is the damping coefficient. The Porch model allows the growth rate, in proportion to length, to decrease gradually with age.

Parameter estimates for all models were obtained using nonlinear regression techniques, which require the following general assumptions: (1) the expected mean value of ε_i, the error term associated with the i^{th} observation, is equal to zero; (2) the ε_i are independent, identically distributed normal random variables: and (3) the variance of ε_i is constant regardless of the value of the independent variable.

For all three analyses, visual inspection of the ε_i showed that approximately 50 percent were negative implying that assumption (1) was reasonable. The null hypothesis that the ε_i were normally distributed was not rejected for all but two age classes (Kolomogorov-Smirnov test, $P>0.05$; SAS 2002). Hence, assumption (2) was adopted given the robustness of regression methods to failures of this assumption. Assumption (3) did not hold (Levene's test, $P<0.05$; SAS 2002), which presented a choice to either assume a multiplicative error structure or adjust for heteroscedasity. We opted to invoke the method of weighted least squares (WSS) for parameter estimation under the assumption of an additive error structure since visual inspection of the residuals showed only a marginal increase in variance about the von Bertalanffy growth curve. Implicit in the use of WSS is the notion that the variance of ε_i is a function of age and that the values of that function are known, at least up to a constant of proportionality. The weighting factor was assumed to be the inverse of the number of length observations at each age value (proc NLIN; SAS 2002).

Model performance was assessed using Akaike's Information Criterion. AIC compares the model performance of non-nested models using the following equation:

$$AIC = N \times \ln(WSS) + 2(p) \quad (7)$$

where N is the number of data points, WSS is the weighted sums of squares, and p is the number of parameters used in the model. AIC takes into account the number of parameters included in each model enabling an equal comparison between models with different numbers of parameters. A lower AIC value indicates better fit, however, it does not indicate how much better the "best" model is when compared to the others. Akaike Weights allow quantification of the relative probability that a model is correct (relative to the other models considered) for the given data. For a set of m (i = 1,2,…,m) models under consideration, the Akaike weight, w_i, for model i is calculated as:

$$w_i = \frac{e^{-0.5(AIC_i - AIC_{min})}}{\sum_{i=1}^{m} e^{-0.5(AIC_i - AIC_{min})}}, \quad (8)$$

where w_i is the Akaike weight for model i relative to all models under consideration, AIC_i is the computed value of AIC criterion for model i, and AIC_{min} is the lowest AIC value among the m models being considered (Burnham and Anderson 2002).

For a given model, significant differences between model parameter estimates from different rivers were tested for using the Fisher-Behrens statistic:

$$z = \frac{|\hat{k}_1 - \hat{k}_2|}{\sqrt{s_1^2 + s_2^2}}, \quad (9)$$

where s_i^2 are the square of the standard error associated with parameter estimate i. The calculated z statistic is compared to the area under the normal curve at the 95 percent confidence level.

Results

Model comparison results, AIC statistics, and growth curves are given in Table AI.1 and Figure AI.1. Growth model fits varied and some models were unable to converge given the available data. The Linear von Bertalanffy model best explained the Potomac River data according to the AIC statistic and AIC weights. The estimate of k was 0.6033 for the Potomac River stock (Table AI.2).

The Linear von Bertalanffy model assumes indeterminate growth, meaning that growth does not slow to some asymptote with increasing age. Although this is an unrealistic characterization, low sample sizes of the older age classes allowed this model to fit the data best. We have included the parameter estimates from the more biologically interpretable von Bertalanffy model since the Linear von Bertalanffy model is a generalization of the von Bertalanffy (Table AI.3). It should be noted that the Porch model did not converge using the current data; however, this problem may be alleviated with the addition of more years of data, more samples at older ages, or the inclusion of the missing 1 and 2 year-old age classes. The

Porch model differs from most other growth models in that it allows the growth coefficient to slow gradually with increasing age, a more biologically realistic characterization of growth in these fish. It can also allow seasonal variability in growth if seasonal patterns are suspected.

Table AI.1 Growth model Akaike's Information Criterion comparisons for the Potomac River data using fractional ages. WSS, weighted sums of squares; AIC, Akaike's Information Criterion.

Model	Number of Parameters	WSS	AIC	Weighted AIC
Linear von Bertalanffy	4	6,232.50	2,804.01	1
Richards	4	7,179.30	2,849.27	0
Schnute	6	7,179.30	2,853.27	0
von Bertalanffy	3	7,399.40	2,856.93	0
Gompertz	3	10,408.40	2,966.12	0
Porch	6	no convergence	no convergence	0

Figure AI.1 Best-fit growth model (Linear von Bertalanffy) for the Potomac River. Data are from 2002-2005.

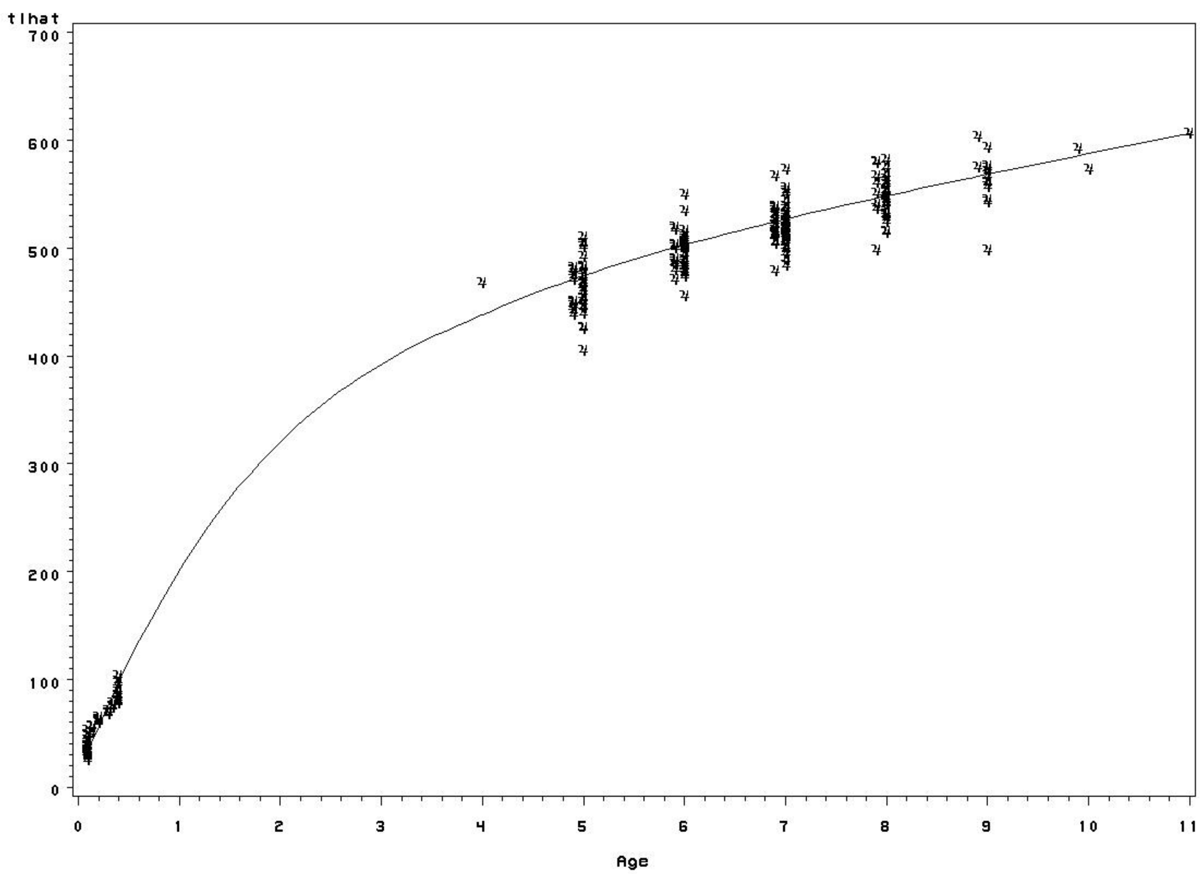


Table AI.2 Best fit (Linear von Bertalanffy) growth model parameter estimates for the Potomac River.

Linear von Bertalanffy Model Parameters	Estimate	SE
t_0	-0.046	0.018
k	0.6033	0.0531
b_0	407.3	13.2752
b_1	18.1887	1.3683

Table AI.3 Comparison of von Bertalanffy and Linear von Bertalanffy k value estimates for the Potomac River.

	k Values	
River	**Linear von Bertalanffy**	**von Bertalanffy**
Potomac	0.6033	0.2801

We compared growth in adjacent rivers along a latitudinal gradient in Chesapeake Bay using the k values derived from both the "best fit" model and the von Bertalanffy model for the Potomac, York, Rappahannock, and James rivers (Table AI.4). Estimates of k, as determined by the best fit models, increased with increasing latitude. Estimates of k, as determined by the von Bertalanffy model, were variable with respect to latitude.

Table AI.4 Latitudinal comparison of k value estimates from best fit and von Bertalanffy growth models for three Virginia Rivers (York, James, and Rappahannock) and the Potomac River.

		k Values	
Increasing Latitude	**River**	**Best Fit Model**	**von Bertalanffy**
↓	James	0.4351	0.3825
	York	0.4568	0.3647
	Rappahannock	0.5349	0.3758
	Potomac	0.6033	0.2801

Model parameter estimates were statistically tested for significant differences between the Potomac and the two Virginia rivers that had the same "best fit" models. The linear Von Bertalanffy model best explained the York, Rappahannock, and Potomac rivers. Model parameter estimates (Table AI.5) were tested for significant differences using the Fischer-Behrens statistic (Table AI.6). Estimates of *k* were significantly different ($P<0.05$; Fisher-Behrens Statistic, $\alpha=0.05$) between the Potomac and the York rivers with the Potomac having a significantly higher *k* value. This suggests that the Potomac River fish approach L_{inf} faster than York River fish; however, these results could also be explained by differences in sampling gear used on these rivers. A multi-mesh net ranging from 3.25 to 10 inch mesh is used in monitoring studies on the Potomac River whereas staked gill nets on the York River are 4.88 inch mesh, a difference that could result in the capture of larger individuals in a given year class on the Potomac than on the York River. Selectivity studies are needed. Values of k derived from growth models for American shad on the Potomac and Rappahannock River did not differ significantly.

Table AI.5 Linear von Bertalanffy parameter estimate comparisons for two Virginia Rivers (York and Rappahannock) and the Potomac River.

Linear von Bertalanffy Model Parameters	York		Rappahannock		Potomac	
	Estimate	SE	Estimate	SE	Estimate	SE
t_0	-0.0735	0.00956	-0.0326	0.0103	-0.046	0.018
k	0.4568	0.0234	0.5349	0.0251	0.6033	0.0531
b_0	498.2	12.7478	481.7	9.1184	407.3	13.2752
b_1	6.1166	1.2043	8.3424	0.8872	18.1887	1.3683

Table AI.6 Fischer-Behrens Z-statistic and significance (α=0.05) for Linear von Bertalanffy model parameter estimate comparisons between the York, Rappahannock, and Potomac Rivers.

Fischer-Behrens Statistic Significance				
Rivers Being Compared	**t_0**	**k**	**b_0**	**b_1**
Potomac-York	ns	0.0058	<0.005	<0.005
York-Rappahannock	0.00175	0.01	ns	ns
Potomac-Rappahannock	ns	ns	<0.005	<0.005

APPENDIX II

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(a) 1998

AGE	2	3	4	5	6	7	8	9	TOTALS[1]	Avg Age
Total #	3	13	48	44	17	3	1	1	**130**	**4.59**
% Of Total Sample	2%	10%	37%	34%	13%	2%	1%	1%	**100%**	
# FEMALE	0	5	21	25	10	2	0	0	**63**	**4.73**
% Of Total Sample (N=128)	0%	4%	16%	20%	8%	2%	0%	0%	**49%**	
Length Range (FL, mm)	-	415-465	400-472	407-483	432-487	450-483	-	-	**0**	
Average Length (FL, mm)	-	433	436	445	458	467	-	-	-	
# MALES	3	8	26	18	7	1	1	1	**65**	**4.46**
% Of Total Sample (N=128)	2%	6%	20%	14%	5%	1%	1%	1%	**50%**	
Length Range (FL, mm)	307-418	345-408	370-442	360-455	408-463	448	470	438	-	
Average Length (FL, mm)	370	374	403.962	414.944	434	448	470	438	-	
# WITH OTC MARK	0	0	0	1	0	0	0	0	**1**	
% w/OTC Mark	0%	0%	0%	2.27%	0%	0%	0%	0%	**0.77%**	
OTC Mark Sequence	-	-	-	5,9	-	-	-	-	-	

[1] Only 128 fish were sexed and aged—1 age-4 fish unsexed; 1 age-5 fish unsexed; age-9 fish's age was questioned by reader.

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(b) 1999

AGE	2	3	4	5	6	7	8	9	TOTAL[2]	Avg Age
Total #	0	3	8	9	1	0	0	0	**21**	**4.38**
% Of Total Sample	0	14%	38%	43%	5%	0%	0%	0%	**100%**	
# FEMALE	0	0	3	4	1	0	0	0	**8**	**4.75**
% Of Total Sample (N=128)	0%	0%	14%	19%	5%	0%	0%	0%	**38%**	
Length Range (FL, mm)	-	-	372-438	440-510	418	-	-	-	-	
Average Length (FL, mm)	-	-	426	461.75	418	-	-	-	-	
# MALES	0	3	5	5	0	0	0	0	**13**	**4.15**
% Of Total Sample (N=128)	0%	14%	24%	24%	0%	0%	0%	0%	**62%**	
Length Range (FL, mm)	-	353-370	348-400	340-450	0	0	0	0	-	
Average Length (FL, mm)	-	363.67	366.8	382.2	-	-	-	-	-	
# WITH OTC MARK	0	0	0	0	0	0	0	0	**0**	
% w/OTC Mark	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	
OTC Mark Sequence	-	-	-	-	-	-	-	-	-	

[2] Total number of fish in sample was 39 but only 21 were aged; all others were examined for OTC and otolith microstructure.

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(c) 2000

AGE	2	3	4	5	6	7	8	9	TOTAL[3]	Avg Age
Total #	0	6	30	63	30	8	0	0	**137**	**5.02**
% Of Total Sample	-	4%	22%	46%	22%	6%	-	-	**100%**	
# FEMALES	0	1	10	34	20	4	0	0	**69**	**5.23**
% Of Total Sample (N=124)	0%	1%	7%	25%	15%	3%	0%	0%	**50%**	
Size Range (FL, mm)	-	457	370-483	450-533	423-497	440-505	-	-	**0**	
Average Length (FL, mm)	-	457	439	467.471	457.65	473.25	-	-		
# MALES	0	3	18	20	10	4	0	0	**55**	**4.89**
% Of Total Sample (N=124)	0%	2%	13%	15%	7%	3%	0%	0%	**40%**	
Size Range	-	324-378	360-457	329-482	415-440	433-453	-	-	-	
Average Length (FL, mm)	-	356.667	395.444	416.95	429.5	443.5	-	-	-	
Regenerated Scale	-	0	0	0	2	0	-	-	**1.50%**	
Scale Age Agreement	-	83%	90%	83%	61%	38%	-	-	**78%**	
Total Repeat Spawners	-	0	2	31	18	8	-	-	**59**	
Repeat Spawn-F	-	0	1	16	11	4	-	-	**32**	
Repeat Spawn-M	-	0	1	11	7	4	-	-	**23**	
% Repeat Spawners-F	-	0	10%	47%	61%	100%	-	-	**48%**	
% Repeat Spawners-M	-	0	6%	55%	70%	100%	-	-	**44%**	
# WITH OTC MARK	-	0	1	4	0	0	-	-	**5**	
% w/OTC Mark	-	0	3%	6%	0	0	-	-	**4%**	
OTC Mark Sequence	-	0	3,13,17	All Day 5			-	-		

[3] Only 124 fish were aged and sexed.
Age-3: 2/6 fish were unsexed; 5/6 scales agreed with otolith ageing (one read age-4, male).
Age-4: 2/10 fish were unsexed; 2 males aged at age-5 and 1 female at age-3 with scales.
Age-5: 9/34 fish were unsexed; 2 females aged at age-6 and 3 at age-4; 5 males were aged at age-4 with scales.
Age 6: 8 females aged at age-5, 2 at age-4; 3 males were aged at age-5.
Age 7: 2 females aged at age-5, 1 at age-6; 2 males were aged at age-6.
47% of all fish 4+ years were repeat spawners.

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(d) 2001

AGE	2	3	4	5	6	7	8	9	TOTAL	Avg Age
Total #	0	6	12	39	29	6	0	0	**90**	**5.3**
% Of Total Sample	0	7%	13%	43%	32%	7%	0%	0%	**100%**	
# FEMALES	0	0	3	20	16	6	0	0	**45**	**5.56**
% Of Total Sample (N=45)	0	0%	3%	22%	18%	7%	0%	0%	**50%**	
Size Range (TL, mm)	-	-	417-504	450-541	482-557	488-553	-	-	**0**	
Average Length (TL, mm)	-	-	473	496	501	517	-	-		
# MALES	0	6	9	18	12	0	0	0	**45**	**4.8**
% Of Total Sample (N=45)	0%	7%	10%	20%	13%	0%	0%	0%	**50%**	
Size Range	-	373-403	390-490	413-508	445-501	-	-	-	-	
Average Length (TL, mm)	-	387	431	466	474	-	-	-	-	
Scale Age Agreement	-	50%	40%	36%	32%	17%	-	-		
Total Repeat Spawners (N= 88)	0	0	14	30	15	2	-	-	**61**	
Repeat Spawn-F (N=44)	0	0	8	15	10	1	-	-	**34**	
Repeat Spawn-M (N=44)	0	0	6	15	5	1	-	-	**27**	
% Repeat Spawners-Total	0%	0%	48%	94%	94%	100%				
% Repeat Spawners-F	0	0	40%	88%	100%	100%	-	-	**77%**	
% Repeat Spawners-M	0	0	6%	55%	70%	100%	-	-	**44%**	
# WITH OTC MARK	-	0	1	2	0	0	-	-	**5**	
% w/OTC Mark	-	0	8%	0.05%	0	0	-	-	**3%**	

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(e) 2002

AGE	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**TOTAL**	**Avg Age**
Total #	2	8	22	30	25	7	2	-	**96**	**5.01**
% Of Total Sample	2%	8%	23%	31%	26%	7%	2%	-	**100%**	
# FEMALES	0	1	7	15	11	6	2	0	**42**	**5.46**
% Of Total Sample (N=96)	0%	1%	7%	16%	11%	6%	2%	-	**44%**	
Size Range (TL, mm)	-	508	467-572	490-571	520-568	485-570	533-560	-	**0**	
Average Length (TL, mm)	-	-	510	523	547	533	546	-		
# MALES	2	7	15	15	14	1	-	-	**54**	**4.65**
% Of Total Sample (N=96)	2%	7%	16%	16%	15%	1%	-	-	**56%**	
Size Range	396-462	388-492	424-540	480-531	458-554	475	-	-	-	
Average Length (TL, mm)	429	442	479	497	501	475	-	-	-	
# WITH OTC MARK	0	0	0	4	2	1	-	-	**7**	
% w/OTC Mark	0	0	0%	13%	8%	14%	-	-	**7%**	

Table AII.1 Potomac River American shad length, weight, and catch-at-age, 1998-2002 and 2005 (USFWS, ICPRB, and VDGIF). Data from 2003 and 2004 not available.

(f) 2005

AGE[4]	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**TOTALS***	**Avg Age**
TOTAL #	0	0	8	7	18	9	6	2	1	**51**	**6.16**
% Of Total Sample	0%	0%	16%	14%	35%	18%	12%	4%	2%	**100%**	
# FEMALES	0	0	5	5	11	6	3	2	1	**33**	**6.21**
% Of Total Sample (N=51)	0%	0%	10%	10%	22%	12%	6%	4%	2%	**65%**	
Length Range (FL, mm)	-	-	409-475	431-545	451-517	472-526	474-516	405-535	538	-	
Average Length (FL, mm)	-	-	444	480	472	488	482	470	538	-	
# MALES	0	0	3	2	7	3	3	0	0	**18**	**6.06**
% Of Total Sample (N=51)	0%	0%	6%	4%	14%	6%	6%	0%	0%	**35%**	
Length Range (FL, mm)	-	-	335-382	386-499	435-462	436-485	444-495		-	-	
Average Length (FL, mm)	-	-	357	443	447	453	468	-	-	-	
# WITH OTC MARK	0	0	0	1	0	0	0	0	-	**0**	
% w/OTC Mark	0%	0%	0%	2%	0%	0%	0%	0%	-	**0.00%**	
OTC Mark Sequence	-	-	-		-	-	-	-	-	-	

[4] All ages based on reading otoliths.

Table AII.2 Potomac River VDGIF American shad egg collection data with CPUE, 2005. Dead adult shad not used for egg taking. Brood Fish includes those males and females reported by ICPRB.

Date	Temp (C°)	Time Fished	# Nets Set	# Brood Females	# Brood Males	# Released Females	# Released Males	CPUE Brood Females	CPUE Brood Males	CPUE Released Females	CPUE Released Males
4/13/2005	14.5	6:15-8:15	2	4	4	11	44	2	2	5.5	22
4/20/2005	18	5:25-7:10	2	13	15	23	52	6.5	7.5	11.5	26
4/21/2005	17	5:50-8:25	5	55	30	121	0	11	6	24.2	0
4/22/2005	17.5	6:30-8:30	3	58	30	42	0	19.33	10	14	0
4/27/2005	16	6:00-7:45	4	56	25	76	14	14	6.25	19	3.5
4/28/2005	16	6:45 - 8:45	4	55	28	26	28	13.75	7	6.5	7
4/29/2005	16	7:25-9:00	3	43	30	20	15	14.33	10	6.7	5
5/4/2005	17	5:30-7:25	4	35	15	31	9	8.75	3.75	7.8	2.3
5/5/2005	16.5	6:00-7:50	3	28	14	16	0	9.33	4.67	5.3	0
5/6/2005	16	Windy									
5/11/2005	20	5:00 - 7:00	4	5	8	58	28	1.25	2	14.5	7
5/12/2005	20	6:00-7:30	2	0	0	36	18	0	0	18	9
5/13/2005	19	6:45-8:20	3	6	5	14	2	2	1.67	4.7	0.7
5/19/2005	21	4:45-6:00	2	0	0	15	7	0	0	7.5	3.5
Totals			**41**	**358**	**204**	**489**	**217**	**7.87**	**4.68**		

Table AII.3 Potomac River American shad length, weight, and age, 2005 (VDGIF).

Fish #	Date	FL	TL	Grams	AGE	OTC
05PotM150	4/29/2005	335	385	538	4	No
05PotM160	4/29/2005	382	433	688	4	No
05PotM090	4/27/2005	355	403	594	4	No
05PotF090	4/22/2005	475	541		4	No
05PotF110	4/22/2005	475	535		4	No
05PotF170	4/27/2005	419	475	1220	4	No
05PotF320	5/5/2005	409	463	798	4	No
05PotF350	5/11/2005	443	451	1302	4	No
05PotM020	4/21/2005	386	439	852	5	No
05PotM050	4/22/2005	499	559		5	No
05PotF080	4/22/2005	471	533		5	No
05PotF100	4/22/2005	431	487		5	Yes
05PotF140	4/27/2005	545	623	2188	5	No
05PotF190	4/28/2005	468	524	1548	5	No
05PotF340	5/5/2005	485	553	1648	5	No
05PotM030	4/21/2005	452	511	1596	6	No
05PotM040	4/21/2005	437	503	1198	6	No
05PotM130	4/28/2005	440	506	1452	6	No
05PotM060	4/22/2005	435	507		6	No
05PotM070	4/22/2005	460	529		6	No
05PotM080	4/27/2005	445	516	1550	6	No
05PotM170	5/4/2005	462	527	1570	6	No
05PotF120	4/22/2005	468	533		6	No
05PotF010	4/20/2005	481	546	1854	6	No
05PotF330	5/5/2005	472	535	1676	6	No
05PotF030	4/21/2005	517	585	2004	6	No

Fish #	Date	FL	TL	Grams	AGE	OTC
05PotF040	4/21/2005	482	547	1830	6	No
05PotF050	4/21/2005	463	530	1854	6	No
05PotF060	4/21/2005	492	553	1504	6	No
05PotF260	4/29/2005	467	528	1588	6	No
05PotF270	4/29/2005	457	517	1494	6	No
05PotF280	4/29/2005	451	517	1418	6	No
05PotF290	5/4/2005	445	495	1272	6	No
05PotM110	4/28/2005	436	505	1348	7	No
05PotM190	5/5/2005	485	557	1666	7	No
05PotM140	4/29/2005	438	495	1242	7	No
05PotF021	4/21/2005	475	544	1720	7	No
05PotF130	4/22/2005	495	557		7	No
05PotF070	4/21/2005	526	595	1940	7	No
05PotF180	4/27/2005	515	580	2100	7	No
05PotF300	5/4/2005	445	508	1224	7	No
05PotF220	4/28/2005	472	538	1248	7	No
05PotM010	4/20/2005	444	504	1175	8	No
05PotM120	4/28/2005	495	560	1896	8	No
05PotM180	5/5/2005	466	531	1314	8	No
05PotF150	4/27/2005	474	537	1390	8	No
05PotF310	5/4/2005	454	514	1600	8	No
05PotF210	4/28/2005	517	580	1818	8	No
05PotF250	4/29/2005	405	572	1812	9	No
05PotF160	4/27/2005	535	611	2550	9	No
05PotF240	4/28/2005	538	613	2394	10	No

Section 12
Status of American Shad Stocks in Virginia

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12.0 INTRODUCTION

Management and conservation of Virginia's stocks of American shad date to colonial times. Before Virginia was settled in 1607, Native Americans caught American shad in large quantities using a seine made of bushes (Walburg and Nichols 1967). Shad were so plentiful that they could be speared with pointed sticks as they swam on the flats (Virginia Commission of Fisheries 1875). The early settlers used haul seines and utilized shad as a major food supply (Walburg and Nichols 1967). By 1740, shad were less abundant, presumably due to fishing and obstructions that prevented the fish from reaching their spawning grounds. Concerned colonists passed laws requiring the removal of dams or the building of fish passages, and prohibiting hedges and other obstructions (Virginia Commission of Fisheries 1875). In 1771, the Virginia Assembly passed a law requiring that a gap for fish passage be built in dams adhering to specific dimensions, and that it be kept open from February 10 to the last day of May. However, due to the approaching conflict of the Revolutionary War, the law was never enforced (Virginia Commission of Fisheries 1875).

The shad fishery of Chesapeake Bay became important about 1869, and developed greatly in the ensuing years. Fishing gear used included haul seines, pound nets, and staked gill nets (SGN) (Walburg and Nichols 1967). Catches reached a low in 1878, and the U.S. Fish Commission and Virginia Commission of Fisheries instituted an artificial hatching program in 1875. By 1879 the fishery began to improve, and the increase in catches led biologists to believe that the shad fishery was largely dependent upon artificial propagation. However, by the early 1900s the decline in shad harvests resumed despite improved hatching methods and increased numbers of fry released (Mansueti and Kolb 1953).

Stevenson (1899) provided important information on catch and effort in the American shad fishery in Virginia during the fishing season in 1896. Using an estimate of the average weight per female of 1.7 kg, the following fishery statistics can be obtained from his report. On the lower James River, 60,750 females (approximate weight: 103,278 kg) were landed by SGNs totaling approximately 79,263 m in length. On the York River, 28, 232 females (approximate weight: 49,994 kg) were landed by SGNs totaling approximately 5,874 m in length. The value of these roe shad was approximately $4,000. On the Rappahannock River, 104,118 females (approximate weight: 177,000 kg) were landed by SGNs totaling 24,694 m in length. The local value of these shad was approximately $8,000. Based on Stevenson's records, seasonal catch averages (total female weight/total length of net) depict higher seasonal catch rates on the York River (8.5 kg/m) and the Rappahannock River (7.2 kg/m) than on the James River (1.3 kg/m) in 1896. Stevenson (1899) also reported large catches of American shad on the Chickahominy and Appomattox rivers in 1896.

Nichols and Massmann (1963) estimated total catch, fishing rate, escapement, and total biomass of American shad in the York River in 1959 and summarized landings during the period 1929 to 1959.

Landings were low (~100,000 lbs annually) in the 1930s but rose abruptly in the years following World War II, reaching the highest levels (400,000-700,000 lbs annually) in the 1950s. During this latter period of higher annual landings, catch-per-unit-effort remained relatively constant. Of the major gears used in the fishery in 1959 (pound nets, haul seines, fyke nets, stake gill nets, and drift gill nets), gill nets (both stake and drift) accounted for the greatest effort expended and the highest total catches. A tagging study conducted in 1959 produced the following estimates: overall fishing rate, 55.2 percent; estimated population biomass, 838,892 pounds; and estimated escapement, 375,768 pounds. Using catch and effort data, Nichols and Massmann (1963) estimated population biomass for the period 1953 to 1959 to range from 839,000 to 1,396,000 pounds. Sex composition of the catch was not reported. Using the average female weight of 3.2 pounds in 1959 and assuming that the sex ratio of the catch was 1:1, the estimated total number of females in the York River in 1953 to 1959 ranged from about 131,000 to 218,125.

Today, large catches no longer occur as they did at the turn of the century. Commercial American shad landings in Virginia decreased from 11.5 million pounds in 1897 to less than a million pounds in 1982. Overfishing, dam construction, pollution, and loss of natural spawning grounds are a few of the factors that may be related to this decline. Historically, the majority of American shad were captured within the rivers. Beginning in 1984, the largest proportion of American shad taken in Virginia's fishery was captured offshore. Genetic studies of the catch composition of Virginia and Maryland's coastal landings have suggested that the intercept fishery claimed a highly variable proportion of Virginia's riverine stocks (Brown and Epifanio 1994). American shad are pursued also by recreational fishermen in Virginia but the full extent and success of this activity is not easily assessed.

Currently, monitoring of American shad stocks and fisheries in Virginia is conducted cooperatively by the Virginia Marine Resources Commission (VMRC), the U.S. Fish and Wildlife service (USFWS), the Virginia Department of Game and Inland Fisheries (VDGIF) and the Virginia Institute of Marine Science (VIMS).

12.2 MANGEMENT UNIT DEFINITION

The management area for American shad includes tidal and non-tidal waters within Virginia's portion of the Chesapeake Bay and coastal waters out to the 3-mile limit of state jurisdiction. Aquatic resources and habitat in tidal waters are managed by the VMRC and this agency has primary responsibility for the management of anadromous fishes. Aquatic resources and habitat in non-tidal waters are managed by VDGIF.

Historically, fisheries for American shad in Virginia have been prosecuted throughout the management area. Currently, there are no designated management units. Prior to the current moratorium, some gears (especially anchored gill nets, haul seines, and pound nets) were fished in presumed mixed stock areas. These mixed stock areas include all coastal waters, waters of Virginia's portion of the lower Chesapeake Bay (including the lower Mobjack Bay) and the mouths of rivers where American shad migrate upstream to spawn.

Historical in-river landings data are from the three primary spawning runs of American shad in the Rappahannock, York, and James rivers. Each is believed to represent a unit stock with little or no mixing of other stocks in areas upstream of the river mouth. Additional unit stocks of American shad in Virginia may include other smaller spawning populations in the Piankatank River, the Mobjack Bay system (Ware, North, East, and Severn rivers), the Nansemond River, and the Elizabeth River. Little data are available currently to define these smaller populations if they exist.

Ideally, in-river management areas would exclude those regions in the lower Chesapeake Bay or at the mouths of rivers where separate stocks of American shad might mix and be vulnerable to capture. This assumes that the degree of river fidelity for these stocks (especially those that have received extensive hatchery supplementation) is high. There are few existing data on genetic population structure of Virginia's shad populations, including the extent of annual and geographic variation. The geographic boundaries suggested below are tentative and subject to revision as more information becomes available.

12.2.1 Rappahannock River

The management area on the Rappahannock River system extends from a line drawn between Rogue Point and Urbanna, Virginia upstream to the extent of spawning.

12.2.2 York River

The management area on the York River system extends from Gloucester Point, Virginia at the George P. Coleman Bridge upstream to the extent of spawning and includes all drainage areas of the Pamunkey and Mattaponi rivers.

12.2.3 James River

The management area on the James River system extends from the James River Bridge at Newport News, Virginia upstream to the extent of spawning and includes all drainage areas of the Chickahominy, Appomattox, Willis, Rivanna, Slate, Hardware, Type, and Piney rivers.

12.3 REGULATORY HISTORY

Prior to 1991, there were no restrictions on the American shad commercial fishery in Virginia rivers and the Chesapeake Bay. A limited season (February 4-April 30) was established for 1991 by the VMRC, and kept in place in 1992. In 1993, a further limitation to the season was established (March 15-April 15, 1993). However, due to bad weather conditions, the season was extended through April 30. A complete moratorium was established in 1994. The current regulation states that: "On and after 1 January 1994 it shall be unlawful for any person to catch and retain possession of American shad from the Chesapeake Bay or its tidal tributaries" [VMRC Regulation 450-01-0069].

In spring 2003, Virginia imposed a 40 percent reduction in effort on the ocean-intercept (gill net) fishery prosecuted on the coast. This reduction in effort was mandated by the ASMFC. According to Amendment 1 (ASMFC 1999), "[states] must begin phase-out reduction plans for the commercial ocean-intercept fishery for American shad over a five-year period. States must achieve at least a 40% reduction in effort in the first three years, beginning January 1, 2000." The Virginia offshore fishery was closed on December 31, 2004.

Drift-net fishing by two Native American tribal governments and the taking of brood stock by federal and state agencies (USFWS, VDGIF) for stock restoration are permitted on the spawning grounds of the York River system (Mattaponi and Pamunkey rivers). In the former case, tribal landings and effort are unknown. In the latter case, brood stock is sacrificed for egg taking and the number of females killed is recorded (1997, 854 females; 1998, 1,610; 1999, 1,417; 2000, 1,533; 2001, 1,359; 2002, 1,945; 2003, 1,375; 2004, no data; 2005, 758).

In January 2006, a one-time, one-year relaxation of the moratorium on the taking of American shad was passed by the VMRC. The Commission opened each tributary to a 10 fish-per-vessel-per-day bycatch during the striped bass season. The open areas in each tributary were designated from the spawning areas downriver to the first bridge upstream of the river mouth. Approximately 55 special permits were issued for this experimental bycatch fishery. By emergency regulation in February 2006, the VMRC added the spawning reaches to the experimental bycatch fishery.

12.4 ASSESSMENT HISTORY

There was no assessment of Virginia stocks by Gibson *et al.* (1988). Using historic catch rate data (1980-1993) from commercial gill nets, ASMFC (1998) reported recent and persistent stock declines in the York River, no evidence of declines in the James and Rappahannock rivers and no evidence of recruitment failure during 1990 through 1996 in any Virginia river. Relative exploitation rates from the coastal intercept fishery on the York, Rappahannock, and James rivers exhibited no apparent trends (ASMFC 1998).

More recently, Olney *et al.* (2003) re-examined portions of the historic gill-net catch records that Crecco had utilized for the James River and evaluated the success of the hatchery restoration program. In contrast to the Crecco (1997) assessment, Olney *et al.* (2003) reported that the James River stock was severely depressed and that abrupt increases in the prevalence of hatchery-marked fish coincided with higher catch rates of American shad in monitoring gear. Olney *et al.* (2003) recommended the continuance of the hatchery-based restoration efforts in combination with the current in-river ban on fishing in the James River.

12.5 LIFE HISTORY OF AMERICAN SHAD IN THE YORK RIVER

The annual spawning run of American shad on the York River consists of virgin fishes 3 to 7 years in age plus repeat spawners (age-4 through age-12). American shad age-9 and older are rare (Nichols and Massmann 1963; Maki *et al*. 2001; Olney 2003, 2004). As maturing fish migrate 100 km up the estuary to the freshwater spawning grounds, ovary size increases. A multiple spawning cycle (hydration, ovulation, and release of oocytes followed by 1 to 3 days of no spawning before a repeat in the cycle) ensues (Olney *et al*. 2001; Hyle 2005). In most years, spawning begins in late February and ends in late June (Bilkovic *et al*. 2002b; Hoffman and Olney 2005). Post-spawning fish leave the spawning grounds beginning in mid-April and most of these (approximately 70%) are partially spent with ovaries that weigh 1 to 8 times those of spent fish. Thus, it appears that the potential annual fecundity of most female American shad is not realized during the spawning season on the York River system. Furthermore, partially spent ovaries contain energy reserves in the form of protein and lipids that could be recovered by resorption of un-spawned yolked oocytes. Upstream spawning migrations are energetically expensive for American shad, and tissues where energy is spared could presumably be used to enhance recovery from anadromous migrations. Glebe and Leggett (1981) observed that somatic energy resources used to fuel spawning migrations was relatively low for American shad in the York River compared to other populations in more southerly and more northerly rivers. Energy reserves in partially spent ovaries could augment somatic energy sources and enhance survival as post-spawning females in the York River re-enter the ocean. Since partially spent fish may have a greater potential for energy savings than spent fish, Olney *et al*. (2001) hypothesized that partially spent fish have a greater chance than spent fish to become repeat spawners in subsequent years.

Throughout its native range, American shad are batch spawners and exhibit indeterminant fecundity (Olney and McBride 2003). Histological observations and size frequency distributions of oocytes suggest continuous recruitment of immature oocytes during spawning. In an analysis of latitudinal trends in batch fecundity of American shad, Olney and McBride (2003) postulated that females would need to spawn ten times per season in order to attain values of total fecundity estimated by Leggett and Carscadden (1978). Mylonas *et al*. (1995) observed that captive fish spawned on a four-day cycle (two d of spawning followed by two d of no spawning), and Olney *et al*. (2001) estimated spawning frequency of 3.5 days, based on daily collections of hydrated female American shad in the Pamunkey River. Using these accounts, Olney and McBride (2003) predicted that the spawning period of American shad should be approximately 35 days (10 batches x 3.5 d). This prediction is consistent with average residence times of 34.4 days (York River, Olney *et al.* 2006) and 28.8 days (James River, Aunins 2006) estimated by separate studies of movements of American shad fitted with acoustic tags. The product of batch size and residence time divided by spawning frequency is an estimate of seasonal fecundity. For the average American shad that resides on the spawning grounds of the York River for 35 days, these estimates range from about 113,000 to 791,000 eggs per season, using batch size estimates of Olney and McBride (2003).

On the York River, the spawning grounds are located in two tributaries (Pamunkey and Mattaponi rivers) that form the York River at West Point, Virginia, situated approximately 55 km upstream of the York River mouth. At this confluence, York River American shad choose either tributary to complete the migration, spawning in upstream segments characterized by shallow depths, high dissolved oxygen and relatively high currents (Bilkovic *et al.* 2002b). Fishes spawning in each tributary probably do not constitute separate sub-stocks since there is evidence of mixing by spawners on either tributary (Olney *et al.* 2006; Walther *et al.*, in review). Interestingly, patterns of juvenile production in the two tributaries consistently differ, with the relative abundance of juveniles in the Mattaponi River almost always exceeding that on the Pamunkey River (Wilhite *et al*. 2003).

American shad in the York River feed during their anadromous migration, most heavily in the middle estuary. In the estuarine phase of their migration in the York River, American shad feed predominantly on mysids and calanoid copepods (Walter and Olney 2003). Feeding occurs during the pre-spawning migration but decreases on the spawning grounds where plant matter comprises the majority of stomach contents. After spawning, feeding intensity of York River shad increases significantly as they resume feeding on mysids and copepods during the downstream migration to the river mouth (Walter and Olney 2003).

Temporal patterns of spawning of American shad in the York River system are generally unrelated to production of cohorts of juveniles (Hoffman and Olney 2005). In a study of hatch date distribution of juveniles, most cohorts were produced during the latter half of the spawning season. This pattern was most exaggerated during years of higher flow. In 1998 and 1999, the instantaneous daily growth rate (G) of juvenile shad was relatively constant among cohorts (0.037 to 0.066) while instantaneous daily mortality (M) was more variable among cohorts (0.044 to 0.093). Most juvenile cohorts in 1998 and 1999 had a physiological mortality rate (M/G) close to unity, indicating that these cohorts were barely maintaining or losing biomass during the early juvenile phase (Hoffman and Olney 2005). The mean hatch date was May 13.

12.6 HABITAT DESCRIPTIONS

Stock-specific migratory pathways and seasonal habitats of Virginia stocks (especially summer and winter habitats of young-of-year and adults) are poorly known. Mixed stock assemblages enter the Chesapeake Bay entrance in late winter and early spring and segregate into river-specific populations in route. Olney *et al*. (2006) and Aunins (2006) have described in-river movements and migratory pathways once river-specific populations have segregated in the York and James rivers. There have been no studies of migratory behavior and habitats in the Rappahannock River. Hoffman (2006) investigated linkages between juvenile shad and their nursery habitats in the Mattaponi River. Juvenile shad use the nursery habitats heterogeneously, residing in 5 to 10 km segments for a month or longer before moving downriver. Spatial variability in primary production and subsidies from terrestrial inputs in each river segment are likely important since 30-day residence periods are sufficient for habitat differences to influence population demographics. Hoffman (2006) observed both size-based emigration and over-wintering of juvenile shad in the York River.

Although the roe fishery for American shad has been important historically, there is little information about the specific spawning locations of Virginia stocks. In Chesapeake Bay tributaries, American shad spawn semi-demersal eggs in freshwater portions of the rivers, usually beginning in March and ending in June with peaks in April (Klauda *et al*. 1991). Shad have historically ascended farther upriver than at present within tributaries that are obstructed. Recent construction of the Bosher's Dam fish way on the James River and breaching of the Embrey Dam on the Rappahannock River are intended to restore these historic habitats. For example, prior to dam building on the James River, American shad traveled 335 miles from the mouth of Chesapeake Bay into the Jackson and Cowpasture rivers (Mansueti and Kolb 1953).

There have been no plankton surveys for American shad eggs and larvae on the Rappahannock River.

While there is an active hatchery restoration program on the James River, little is known about where spawning occurs in the main stem of the river or the extent of spawning on the Chickahominy and Appomattox rivers, its largest tributaries. Stevenson (1899) provided a detailed account of commercial activity for American shad on the James River in 1896 and concluded that the Chickahominy River was one of the finest spawning tributaries for American shad on the U.S. east coast. Massmann (1952) found evidence of spawning on both the Appomattox and Chickahominy rivers by sampling for eggs with stationary plankton nets. In the Chickahominy River, only a few eggs were collected, and these were collected below Walker's Dam, which was constructed in 1943 to provide a reservoir impoundment and is a migration barrier. Some passage of alosines, especially river herrings, may occur through a Denil fishway located in the middle of the dam. Massmann hypothesized that Walker's dam had a minimal impact on the spawning of shad because spawning took place below the dam. On the Appomattox River, some fish eggs were collected but pollution around the Hopewell industrial area was hypothesized to have a strong impact on the remaining shad population there. More recently, Aunins (2006) conducted ichthyoplankton surveys and telemetry studies on the James River and found evidence of spawning along a 37-km reach from Shirley Plantation to the fall line in Richmond, Virginia (river km 120-157). Telemetry studies indicated that only a few adults (in a tagged sample of ~100 fish) migrated into the Chickahominy River and none into the Appomattox River in 2005.

Massmann (1952) and Bilkovic *et al*. (2002b) conducted ichthyoplankton surveys on the Mattaponi and Pamunkey rivers and found evidence for spawning through the water temperature range of 13to19ºC on both tributaries. Shad spawn in regions upstream of the primary spawning grounds of striped bass, with eggs collected over a 44-km reach on the Mattaponi (river km 81-124) and a 53-km reach on the Pamunkey River (river km 98-150).

Bilkovic *et al*. (2002a) designed and tested habitat suitability index models using occurrences of eggs and larvae of American shad and incorporating proximate river parameters and landscape features on the York River system. The model results indicated the importance of hydrographic parameters (current velocity, dissolved oxygen, and water depth), physical habitat features (sediment type and woody debris), forested shoreline, and land use features to the presence of eggs. Larvae were more dispersed than eggs and distinct habitat features could not be discerned. Hoffman (2006) reported that isotopic composition of juvenile American shad in the Mattaponi River indicated reliance on a mix of autochthonus (in situ primary production) and allochthonous (derived from adjoining terrestrial habitats) organic matter that was consistent with a diet of copepods and aquatic insect larvae. He observed that flow-mediated subsidies from terrestrial sources likely explained the positive, long-term relationship between river discharge and juvenile abundance.

12.7 RESTORATION PROGRAMS

In spring 1994, the VDGIF and the USFWS began hatchery-restocking efforts in the James and Pamunkey rivers. Adult shad from the Pamunkey River are used as brood stock—eggs are stripped and fertilized in the field, and larvae are reared in the VDGIF hatchery at Stephensville, Virginia, and the USFWS hatchery at Harrison Lake, Virginia. Prior to release, the larvae are immersed in an oxytetracycline (OTC) solution that marks otoliths with a distinctive epifluorescent ring. In spring 2004, stocking was initiated in the Rappahannock River using adult shad from the Potomac River as brood stock. Similar rearing and marking procedures are employed. In the James River system, fry are released at Brook Hill Road on the Appomattox River, at Columbia, Virginia in Cumberland County and at the Hardware River Wildlife Management Area in Fluvanna County. In the Rappahannock River system, fry are released at Kelly's Ford in Culpepper County and in the Hazel River near Monument Mills, Virginia. Stocking usually takes place between mid-April and mid-May in each year.

There are no trap and transport activities in Virginia.

12.7.1 Restoration Objectives

The primary objective of the cooperative program is to re-introduce and enhance spawning populations of American shad in the James and Rappahannock rivers through a hatchery stocking program. Marked fry are also released in the Pamunkey River to replace lost production from removal of brood stock. The production goals of the program are to annually stock the James and Rappahannock rivers with 4 to 5 million fry each. A cooperative sampling and laboratory processing program (VDGIF and VIMS) is designed to evaluate stocking success by estimating prevalence of hatchery marks in adult and juvenile shad annually.

Benchmarks and restoration targets for American shad stocks in Virginia are index values based on catch rates (female kg/m) by SGNs established on the basis of historical data in the 1950s (York River only) and the 1980s (Maki *et al*. 2006; see Section 12.12). The index is based on weekly monitoring of SGNs in each river (conducted by VIMS) and is calculated as the area under the catch curve for each stock during the spawning run in a given spawning season. Suggested criteria that are supplemental to these catch-rate targets relate to the duration of the spawning run, age structure of the spawning stock, the frequency of repeat spawners, and the percentage of the catch that has hatchery origin.

12.7.2 Hatchery Evaluations

The success of the restoration program in the James River was documented by Olney *et al*. (2003) who reported that adult catch rates by monitoring gear in 1998 through 2002 were increasing as large numbers of mature hatchery fish returned to the spawning grounds. Increased prevalence of hatchery fish coincided with higher catch rates by SGNs at the river mouth in 2000 to 2002 and the age composition of the catch corresponded to ages that were expected to return following the first larges releases of fry. The prevalence of hatchery fish and the time series of the VIMS catch rate index in the James River are depicted in Figure 12.1. Prevalence of hatchery fish is higher in upriver collections made by the VDGIF (Figure 12.2).

Hatchery-released fish constituted 0.1 to 8 percent of the total catch of juveniles on the Pamunkey River from 1999 through 2001 (Olney and Maki 2002). Prevalence of hatchery fish returning as adults to the York system is generally low (~2-4 % each year; Olney and Hoenig 2000a, 2000b, 2001; Olney and Maki 2002; Olney 2003; Olney 2004).

12.7.3 Fish Passage Efficiency and Monitoring

The vertical slot fish way at Bosher's Dam on the James River was operated and monitored for the first time in 1999. The VDGIF Fish Passage Project operates and monitors the fish way with a video camera and digital video recording unit from March 1 until at least June 15 annually. Weaver *et al*. (2003) provide additional details on sampling protocols and results of monitoring. Because flow variations in the James River often create conditions that greatly reduce visibility at the counting window, complete records of the spring run are rare.

Passage rates and total counts are depicted in Table 12.1. In general, passage of American shad has increased during the monitoring period, reaching a peak in 2002 (0.73 shad/hr) and dropping off in recent years. The cause of the current decline in fish passage counts is unknown. Observations in 2003 revealed that American shad do not exhibit any nocturnal passage behavior at the facility. Thus, night video recording is infrequent and designed only for other species (e.g., Atlantic sea lamprey and catfishes). Gizzard shad have exhibited tremendous passage rates (over 200,000 in some years) indicating that the facility is capable of passing large numbers of fish in the spring migration. To date, there are no fish passage efficiency studies for the Bosher's Dam fish way.

12.8 AGE

The VIMS monitoring programs estimates age using scales (Cating 1953) and VDGIF scientists use otoliths. Currently, there are no age validation studies using either method for Virginia stocks.

Estimates of age determined by scales and otoliths in samples collected in 1998 and 1999 were compared using a χ^2 test of symmetry (Hoenig *et al.* 1995). Hoenig *et al*. (1995) applied the method to a similar sample of alewife (*Alosa pseudoharengus*) from Lake Huron, and found that otolith and scale methods were not interchangeable in alewives since older ages did not occur in scale samples. In the 1998 and 1999 samples of American shad from the York River, scale and otolith methods of age determination were in agreement 41% of the time (125 of 305 comparisons) in 1998 samples, and 45% of the time (82 of 182 comparisons) in 1999 samples. The hypothesis that disagreements between the two methods were randomly distributed on either side of the diagonal in a contingency table was rejected in each year. It was concluded that the two methods of determining age are not interchangeable, and that further work to validate and compare the methods was required (Olney and Hoenig 2000).

Scales for age determination are cleaned, mounted and pressed on acetate sheets, and read on a microfilm projector by one individual (B. Watkins, 1998, 2002-present). Ages were determined by a different reader in 1998-2001 (K. Maki). Between-reader comparisons were conducted in 2003. In separate trials, B.Watkins and K. Maki agreed 52.1% (trial 1) and 59.2% (trial 2) of the time when both age and number of spawning marks were considered; 62.5% (trial 1) and 67.3% (trial 2) of the time when only age was considered. Test of symmetry in both trials yielded significant results ($p<0.05$), indicating that there were systematic differences between the readers when they disagreed. In both comparisons, one reader consistently assigned an age that was one year greater than the other reader when they disagreed.

An ASMFC age-determination workshop using known age fish from the Delaware system was held at VIMS in August 2004 to test the validity of scale-age techniques (McBride *et al.* 2005). Thirteen experienced biologists from the ASMFC Shad and River Herring Technical Committee estimated ages using Cating's (1953) method. Percent agreement between estimates for the same scale set was 50 to 76.5 percent. Percent agreement between estimated age and known age was highest for ages 3 to 6 (33.7-48.5%), markedly lower for age-7 (12.1%), and lowest for age-8 fish (3.9%). One recommendation of the workshop was to validate age determination in all major stocks. VIMS and VDGIF are currently assembling materials to conduct these trials on the York River stock in collaboration with Dr. Simon Thorrold (Woods Hole Oceanographic Institution).

Sagittal otoliths are cleaned by immersing in a 10 percent bleach and hydrogen peroxide bath. After immersion, the cleaning solution is drawn off by pipette, and otoliths are rinsed with distilled water. Otoliths are examined under a dissecting microscope at 40x with reflected light under immersion oil, and aged by several individuals. There have been no between-reader comparisons using otoliths.

The maximum age observed using scales is 12 (a specimen collected in 2004 on the York River with six spawning marks); the maximum age observed using otoliths is 11 (a specimen collected in 2005 on the Pamunkey River).

12.9 FISHERY DESCRIPTION

12.9.1 Brief Overview

Directed fisheries for migrating American shad were traditionally prosecuted anywhere along their route into Chesapeake Bay (coastal Atlantic Ocean, lower Chesapeake Bay, entrances to estuaries, along the axis of spawning rivers, and within the freshwater spawning grounds). A variety of capture gears were employed (hook and line, fyke nets, pound nets, dip and throw nets, entangling nets, and haul seines). Non-directed capture (bycatch) of mature and immature fishes often occurs since shad are vulnerable to many gear types used to harvest other species.

12.9.2 Commercial Landings

Virginia has maintained a mandatory fisherman harvest reporting system since 1993. This system pertains only to harvests from Virginia waters. Any landings data from offshore (EEZ) or other states is supplied by the National Marine Fisheries Service and appended to the Virginia data. VMRC landings data for American shad extends from 1973. Under-reporting and discards (primarily of male American shad) are undocumented and may be significant. Landings in subsistence fishing by Native Americans are also undocumented. In addition, dealers and some fishers do not distinguish between American shad and hickory shad (*Alosa mediocris*); as a result, harvest (especially of male shad) can be over-estimated.

Landings in Virginia's portion of the Chesapeake Bay (including in rivers) and in the ocean-intercept fishery in 1980 to 2005 are reported in Table 12.2. There are no reports of in-river landings since 1994 due to the moratorium on fishing. Annual landings in the coastal fishery averaged 193,000 pounds from 1994 through 2004. The ocean-intercept fishery was closed in 2004. In-river landings on the James, York, and Rappahannock rivers are reported in Table 12.3.

12.9.3 Commercial Bycatch

Removals of American shad as bycatch in commercial fishing gear (pound nets, haul seines, and gill nets) in Chesapeake Bay are known to occur but are currently unreported. Limited data on these interactions are available. Commercial logbooks of the total American shad bycatch in selected pound nets have been obtained by VIMS. The most complete time series (2002-2005) of logbook information is presented in Figures 12.3 and 12.4. These pound nets are located in the upper, western portion of Chesapeake Bay near the Great Wicomico River. The logs depict total daily number of American shad taken in four pound nets (the number and identity of nets fished varies in the times series). Highest catches were recorded in 2003. In that year, the maximum catch per day in all nets was approximately 450 fish. The average daily catches (all nets combined) during the 4-year period of the logbooks is 16.4 fish per trip.

12.9.4 Recreational Fisheries

In spring 2002, staff of VDGIF and VIMS conducted a pilot survey of recreational fishing effort and catch on the James, Rappahannock, Nottaway, and Mattaponi rivers. There have been no previous surveys of recreational fishing for American shad on these or other rivers in Virginia. The survey consisted of a weighted, random creel survey among multiple public access areas.

Approximately 87,000 hours of fishing effort was estimated along a 13-km section of the James River near the fall line (March 1-May 31) and 62,000 hours of effort along a 4.6-km section of the Rappahannock River near the fall line. On the James River, a total of 8,163 American shad were estimated in the 2002 creel survey, which were caught at a rate of 0.1 fish per hour. The Rappahannock River estimate was 52 American shad caught at a rate of 0.0008 fish per hour. Most American shad (99.1%) were released alive.

VIMS surveys were conducted on the Nottaway River (March18 -April 28) and the Mattaponi River (March20-April 28). Catches of American shad were highly variable in both river systems. A total of 220 fishers were interviewed in the VIMS survey. These individuals reported a total catch of 78 American shad for an overall estimate of 0.26 shad per hour of fishing effort. The highest catch rate was observed on the Nottaway River on April 3 (1.7 fish/hr).

12.10 FISHERY-INDEPENDENT SURVEYS

12.10.1 Juvenile Abundance Surveys

Time-series of juvenile abundance are available from the VIMS striped bass seine survey (multiple stations in all rivers, 1980-2005), the VDGIF electrofishing surveys (James and Rappahannock rivers) and the VDGIF push net surveys (sampling in a pool immediately upstream of Bosher's Dam on the James River and the tidal James below Richmond), and the tidal Rappahannock at Fredericksburg and Port Royal, Virginia. VDGIF electrofishing is conducted to supplement the push net sampling. Push net sampling is physically restricted to the main channel. Juvenile electrofishing sites are chosen randomly from a large group of sites that represent a variety of habitats (e.g., shoreline with woody debris, vegetated shoreline, mid-channel, etc.). Six to eight 15-minute transects are sampled per night.

The VIMS seine survey data on the James River (Table 12.4) depict no measurable recruitment during most years. This observation is consistent with VDGIF survey results below Bosher's Dam on the James River. A few juveniles were captured by VIMS seine in 1984, 1998, 2003, and 2004. Above Bosher's Dam, juvenile abundance is higher. Captures of American shad juveniles above Bosher's Dam are: 1999, 204; 2000, 24; 2001, 339; 2002, 225; 2003, no sampling; 2004, 270; and 2005, 255. Most of these juveniles (>99%) are hatchery fish.

On the Rappahannock River, the highest juvenile abundance index (JAI) values (>0.5) were recorded in 1982, 1989, 2003, and 2004 (Table 12.4). The Rappahannock River time series suggests recruitment failure in 1980, 1981, 1985, 1988, 1991, 1992, 1995, and 2002.

With the exception of 2003 data, VIMS juvenile abundance index values are consistently higher on the Mattaponi River than they are on the Pamunkey River and the York River (Table 12.5; also see Wilhite *et al.* 2003). In the time series, recruitment is highest (>7.0 on the Mattaponi River and >3.0 on the York River) in 1982, 1984, 1985, 1996, and 2003. Years of apparent recruitment failure are 1991, 2001, and 2002.

12.10.2 JAI Validation Studies

Catch-at-age of adult shad (ages 3-10) was correlated with the corresponding JAI from the year of hatching of that age class for all years available (1998-2005) on the York River. The York River index is a combined index, incorporating sampling on the Mattaponi and Pamunkey rivers. JAIs were low or zero in most years on the James and Rappahannock rivers (Figure 12.5) and adult ages were determined by multiple readers over the period of monitoring in these systems. As a result, we excluded these stocks in the analysis.

Adult abundance on the York River is measured in catch per unit effort (# females/m/day) from the VIMS annual adult shad monitoring program (see below). The juvenile abundance index is obtained through the VIMS Striped bass Seine Survey. The JAI is a geometric mean catch (# of fish) per haul, calculated by:

$$GM = e^{\left(\frac{\sum \ln(x+1)}{n}\right)-1},$$

where x is the observed catch on a particular sampling date and n is the total number of sampling events. We used the geometric mean as our juvenile abundance index based on the results of Wilhite *et al*. (2003) whose study compared different forms of the juvenile abundance index and concluded there was no superior form (compared maximum geometric mean, geometric mean, arithmetic mean, and areal index).

The York River JAI was not correlated with adult abundance over all age classes. Linear regression analysis showed a significant positive correlation of the JAI with age-6 adults ($p=0.04$). The JAI was positively correlated with age-4 through age-8 adults but these relationships were not significant (Table 12.6; Figure 12.6).

12.10.3 Adult Catch Data in the Lower Rivers (VIMS)

When the in-river fishing moratorium was imposed in 1994 in Virginia, commercial fishermen who held permits for existing stands of SGNs were allowed to retain priority rights for the locations of those stands. VIMS has records of the historic fishing locations, and one of these locations on each river (the James, York and Rappahannock) was selected to monitor catch rates by SGN in 1998 through 2004. The historic performance of these SGN stands relative to other fishing locations, the amount of fishing effort that would be required to mimic past performance, and the possible influence of fishing activity downstream of the historic locations on catch rates were evaluated by Olney and Hoenig (2001). Three commercial fishermen were contracted to prepare and set SGN poles, hang nets, replace or repair poles or nets, and set nets for each sampling event during the monitoring period. Two of these commercial fishermen were authors of the historical logbooks on the James and York rivers. Scientists accompany commercial fishermen during each sampling trip, and return the catch to the laboratory.

One SGN, 900 feet (approximately 273 m) in length, was set on the York and James rivers (Figures 12.7 and 12.8). One staked gill net, 912 feet (approximately 276 m) in length, was set on the Rappahannock River (Figure 12.9). Locations of the sets were as follows: lower James River near the James River Bridge at river mile 10 (36º 50.0' N, 76º 28.8' W); middle York River near Clay Bank at river mile 14 (37º 20.8' N, 76º 37.7' W); and middle Rappahannock River near the Rappahannock River bridge (at Tappahannock) at river mile 36 (37º 55.9' N, 76º 50.4' W). Historical catch-rate data on the York and James rivers were derived from nets constructed of 4 7/8-inch stretched-mesh monofilament netting, while historic data from the Rappahannock River were based on larger mesh sizes (nets constructed of 5" stretched-mesh). To insure that catch rates in the current monitoring program were comparable to logbook records, nets on the York and James rivers were constructed of 4 7/8-inch (12.4 cm) stretched-mesh monofilament netting, while nets on the Rappahannock River were constructed of 5-inch (12.7 cm) netting. Panel lengths were consistent with historical records (30 ft each on the James and York rivers; 48 ft each on the Rappahannock River). Each week, nets were fished on two succeeding days (two 24-h sets) and then hung in a non-fishing position until the next sampling episode. Occasionally, weather prevented the regularly scheduled sampling on Sunday and Monday, and sampling was postponed, canceled or re-scheduled for other days. Sampling usually occurred for 10 to 12 weeks on each river.

Catch data from each river are summarized as a standardized catch index (the area under the curve of daily catch rate versus time of year). The catch index, the duration of the run in days, the maximum daily catch rate in each year and the mean catch rate in each year were compared to summaries of historical logbook data to provide a measure of the relative size of the current shad runs. In the historical data, catches are reported daily through the commercial season with occasional instances of skipped days due to inclement weather or damaged fishing gear. In the current monitoring data, catches on two successive days are separated by up to five days (usually Tuesday-Saturday) in each week of sampling. In some rare cases, catches are separated by more than five days. To compute the catch index, we estimated catches on skipped days using linear interpolation between adjacent days of sampling.

The current spawning stock monitoring program yields catch rate information that is comparable with historic catch records recorded in commercial logbooks from the 1950s and the 1980s. However, multifilament gill nets were used in the 1950s and monofilament nets were used in the 1980s (as well as in the current monitoring program). A Latin square design was employed to test the differences in relative fishing power of the two gear types over two years of seasonal sampling on the York River (Maki *et al*. 2006). Estimates suggest that monofilament nets are roughly twice as efficient as the multifilament nets. Reported catch rates in the 1950s and 1980s are roughly equivalent. However, when adjustments are made for differences in fishing gear, catch rates for the 1950s (Table 12.7) are twice as high as during the 1980s (Table 12.8). These data are used to provide restoration targets for the York River stock (see Control Rules). The data collected with this gear may not collect data robust for male American shad as the commercial gear used was designed to target the more economically valuable female shad.

York River

During the seven years of VIMS monitoring on the York River (Table 12.8), the catch index has been variable with higher values (>12) in 1998 and 2001 and lower values (<9) in other years. The data suggest a slight trend towards decreasing catch rates during the period of monitoring (Figure 12.10).

James River

On the James River, VIMS catch index values in 2000 through 2005 are higher than those in 1998 and 1999 (2.57 and 2.99, respectively; Table 12.9). This increase in abundance is due to the first influx of mature hatchery fish into the spawning population (Olney *et al.* 2003). The data suggest a trend of increasing catch rates during the period of monitoring (Figure 12.10).

Rappahannock River

The 2003 and 2004 values of the VIMS catch index on the Rappahannock are higher than any previous year of monitoring. The data suggest a trend of increasing catch rates since 1998 (Table 12.10; Figure 12.10).

12.10.4 Adult Catch Data in the Upper Rivers (VDGIF)

The VDGIF conducts gill-net and electrofishing surveys. On the James, adult American shad are collected using a 300-foot floating style gill net set just below the fall line in Richmond, Virginia (2000-2004).

On the Pamunkey River, adult shad are collected during egg taking operations that support the hatchery-restoration program. Monitoring has been conducted since 1994. Commercial watermen are contacted to collect brood stock for this operation, using DGNs. Mesh sizes vary from 4.5 to 5.5 inches (stretched mesh). American shad that are not spawning (green or spent fish) are released, but their numbers are recorded. Catch data are expressed as the number of shad captured per net set. Standard electrofishing protocols are used to monitor adult abundance on the Appomattox, James, South Anna, and Rappahannock rivers (March to early June). Electrofishing effort is measured in units of time; 15 minutes of shocking time is used at most stations.

Appomattox River

American shad abundance in the vicinity of the first dam on the river, Harvell Dam, was extremely low during the last 10 years of VDGIF electrofishing. Only five American shad were collected during 46 sampling trips that included two to five transects per trip.

James River

Abundance in VDGIF electrofishing surveys in the vicinity of Bosher's Dam has been relatively stable and low during most years of monitoring. Catches were substantially higher in 2003 (Figure 12.11). In gill-net surveys, abundance was highest in 2002 with a slightly increasing trend during the monitoring period (Figure 12.2).

South Anna River

Monitoring of the South Anna River (Pamunkey tributary in the York Basin) in the vicinity of Ashland Mill Dam resulted in relatively stable catch rates from 1996 to 2005. Catches were highest in 1998 (Figure 12.12).

Rappahannock River

Sampling in the vicinity of Embrey Dam (breached in 2004 and completely removed in 2005) occurred consistently from 1997 to 2004. Relatively low and inconsistent American shad catch rates have been observed. In 2004 a single female American shad was collected approximately 8 km upstream of the breached dam indicating early success of the removal project in terms of actual fish passage potential. However, in 2005 upstream sampling did not yield American shad.

12.10.5 Adult Age Composition and Mortality in the Lower Rivers (VIMS)

In recent years of VIMS SGN monitoring (2000-2005), mean age of females has increased as a result of lower proportions of age-4 fish in the monitoring catch (Figure 12.13). Recruitment surveys suggest below average juvenile abundance in 1995 and 1997 to 2002 on the York and Rappahannock rivers and no measurable recruitment in most years on the James River (Tables 12.4 and 12.5). Relatively strong recruitment was observed on the Mattaponi River in 2000.

Total mortality was estimated using linear regression on (1) the natural log (ln) of catch-at-age data versus age and (2) ln numbers in each repeat spawning category (e.g., numbers with one repeat spawning mark, with two marks, etc.) versus number of categories. Numbers of virgins were not included in the latter regressions. Comparisons of estimates of total mortality using these two approaches are presented in Table 12.11 and Figure 12.14. For all stocks and in most years (except 1999, Rappahannock River), estimates derived from both methods were similar and followed similar annual trends. On the York River, Z-estimates ranged from 0.72 to 1.43 (catch-curve method) and 0.68 to 1.67 (repeat spawning method). On the James River, Z-estimates ranged from 0.98 to 1.59 (catch-curve method) and 0.98 to 1.62 (repeat spawning method). On the Rappahannock River, Z-estimates ranged from 0.77 to 1.89 (catch-curve method) and 0.71 to 1.36 (repeat spawning method).

12.10.6 Growth Modeling

Growth was modeled using the age-length relationship in age-0 and age-3 and older fish in all three Virginia stocks. Immature fish (age-1 and age-2) were not available for study and not represented in these analyses. Adult length (TL in mm) and age data were collected in the VIMS stake gill-net monitoring program in 2002 through 2005. All ages were determined using scales, following the method of Cating (1953). One reader, B. Watkins, read scales. Data from 1998 to 2001 were not used since a different reader aged them and ageing biases have been shown to be present between different scale readers (see previous section, Age Determination).

Age-length data for young-of- year fish (age-0) on the York River were collected by VIMS push net sampling on the Pamunkey and Mattaponi rivers. On the James and Rappahannock rivers, specimens were collection in electrofishing surveys by the VDGIF. A sub-sample of eighty fish was randomly selected for the age-0 year class on each river. All fish with a total length of less than 90 mm were assumed to be young-of-year fish (age 30-90 d; Hoffman and Olney 2005); any fish larger than this size were discarded from the original sample to avoid including fish that were older.

Integer Versus Fractional Ages

Prior to model selection analyses, we tested parameter estimates derived from a single model that was fitted to both integer and fractional ages. Fractional ages were calculated for all fish, assuming a hatch date of May 13. This hatch date is the average of hatch dates of 637 juvenile American shad in two consecutive years (1998-1999) in the Pamunkey River (Hoffman and Olney 2005). A fractional age was then calculated for each fish as the difference in days between the May 13 hatch date and the date of capture divided by 365. Capture dates prior to the hatch date in that year were counted from the previous year’s hatch date. The fraction was added or subtracted to the scale-determined age as appropriate. All parameter estimates were significantly different (Table 12.12). Estimates of k greater than 1 are unrealistic in American shad, suggesting poor model performance using integer ages. Additionally, the use of fractional ages gives more accurate resolution to length-at-age, further supporting our subsequent use of fractional ages for all model runs.

Model Selection

The candidate models fitted to age-length data from each river were: (1) von Bertalanffy, (2) Linear von Bertalanffy, (3) Gompertz, (4) Richards, (5) Schnute, and (6) Porch. Since these models are not hierarchical, model performance was evaluated using Akaike’s Information Criterion (AIC).

The first model applied to the data was the standard von Bertalanffy growth curve expressed as:

$$L_t = L_\infty \left(1 - e^{-k[t - t_0]}\right), \qquad (1)$$

where L_t is the length-at-age t, L_∞ is the asymptotic average maximum length, k is a growth coefficient that determines how quickly the maximum size is attained, and t_0 is the hypothetical age at which the species has zero length. The second model selected was the Linear von Bertalanffy growth curve, which expresses the asymptotic length as a linear function of age:

$$L_\infty = (b_0 + b_1 * t) * \left(1 - e^{(-k(t-t_0))}\right), \tag{2}$$

where b_0 is the intercept of the line and b_1 is estimated. The third model selected was the Gompertz model:

$$L_t = L_\infty * e^{\left(-\frac{1}{k}e^{-k(t-t_0)}\right)}, \tag{3}$$

which is an alternative sigmoidal growth curve with an upper asymptote. The fourth model selected was the Richards model:

$$L_\infty = \left(1 - d * e^{(-k(t-t_0))}\right)^{\frac{1}{d}} \tag{4}$$

The Richards model is a generalization of the von Bertalanffy model to allow for greater flexibility. The fifth model selected was the general Schnute growth model:

$$L_t = \left(\left(y_1^b + \left(y_2^b - y_1^b\right)\right) * \frac{\left(1 - e^{-a(t_0 - t_1)}\right)}{1 - e^{-a(t_2 - t_1)}} \right)^{\frac{1}{b}}, \tag{5}$$

which is a general, four-parameter model describing a relative, rather than instantaneous, rate of change in growth and that contains most of the preceding models as special cases. The last model considered was the damped model developed by Porch *et al.* (2002):

$$L_i = L_\infty (1 - e^{\beta_1 - k_0(t-t_0)})$$
$$\text{where } \beta_1 = \frac{k_1}{\lambda}(e^{-\lambda t} - e^{-\lambda t_0}), \tag{6}$$

where λ is the damping coefficient. The Porch model allows the growth rate, in proportion to length, to decrease gradually with age.

Parameter estimates for all models were obtained using nonlinear regression techniques, which require the following general assumptions: (1) the expected mean value of ε_i, the error term associated with the i^{th} observation, is equal to zero, (2) the ε_i are independent, identically distributed normal random variables, and (3) the variance of ε_i is constant regardless of the value of the independent variable.

For all three analyses, visual inspection of the ε_i showed that approximately 50 percent were negative implying that assumption (1) was reasonable. The null hypothesis that the ε_i were normally distributed was not rejected for all but two age classes (Kolomogorov-Smirnov test, *P*>0.05; Hatcher and Steppanski 1994). Hence, assumption (2) was adopted given the robustness of regression methods to failures of this assumption. Assumption (3) did not hold (Levene's test, *P*<0.05; Hatcher and Steppanski 1994), which presented a choice to either assume a multiplicative error structure or adjust for heteroscedasity. We opted to invoke the method of weighted least squares (WSS) for parameter estimation under the assumption of an additive error structure since visual inspection of the residuals showed only a marginal increase in variance about the von Bertalanffy growth curve. Implicit in the use of WSS is the notion that the variance of ε_i is a function of age and that the values of that function are known, at least up to a constant of proportionality. The weighting factor was assumed to be the inverse of the number of length observations at each age value (proc NLIN; Hatcher and Steppanski 1994).

Model performance was assessed using Akaike's Information Criterion (AIC). AIC compares the model performance of non-nested models using the following equation:

$$AIC = N \times \ln(WSS) + 2(p),$$

where N is the number of data points, WSS is the weighted sums of squares, and p is the number of parameters used in the model. AIC takes into account the number of parameters included in each model enabling an equal comparison between models with different numbers of parameters. A lower AIC value indicates better fit; however, it does not indicate how much more likely the "best" model is when compared to the others. Akaike weights allow quantification of the relative probability that a model is correct (relative to the other models considered) for the given data. For a set of m (i = 1,2,…,m) models under consideration, the Akaike weight, w_i, for model i is calculated as:

$$w_i = \frac{e^{-0.5(AIC_i - AIC_{min})}}{\sum_{i=1}^{m} e^{-0.5(AIC_i - AIC_{min})}},$$

where w_i is the Akaike weight for model i relative to all models under consideration, AIC_i is the computed value of AIC criterion for model i, and AIC_{min} is the lowest AIC value among the m models being considered (Burnham and Anderson 2002).

For a given model, significant differences between model parameter estimates from different rivers were tested for using the Fischer-Behrens statistic:

$$z = \frac{|\hat{k}_1 - \hat{k}_2|}{\sqrt{s_1^2 + s_2^2}},$$

where s_i^2 are the square of the standard error associated with parameter estimate i. The calculated z statistic is compared to the area under the Normal curve at the 95 percent confidence level.

Results

Model comparison results (using fractional-age model runs), AIC statistics and growth curves are given in Table 12.13 and Figure 12.15. Growth model fits varied significantly by river and some models were unable to converge given the available data sets. The Linear von Bertalanffy model best explained the York and Rappahannock River data according to the AIC statistic and AIC weights. The estimates of k were 0.4568 for the York River stock and 0.5349 for the Rappahannock River stock.

The model parameter estimates (Table 12.14) were tested for significant differences between rivers using the Fischer-Behrens statistic (Table 12.15). Estimates of k and t_0 were significantly different ($P<0.05$; Fischer-Behrens Statistic, $\alpha=0.05$) between the York and Rappahannock rivers, with the Rappahannock having a significantly higher k value. This suggests that the Rappahannock River fish approach L_∞ faster than York River fish; however, these results could also be explained by differences in sampling gear used on these rivers. The Rappahannock River nets use a slightly larger mesh size (5") than the York River nets (4.88"), which could result in the capture of larger individuals in a given year class. Selectivity studies are needed.

The Linear von Bertalanffy model assumes indeterminate growth, meaning that growth does not slow to some asymptote with increasing age. This is an unrealistic characterization given what we know about growth in these fish. However, low sample sizes of the older age classes allowed this model to fit the data best. The use of sampling gear that catches larger fish more efficiently or more years of data may provide larger sample sizes of older fish and allow more realistic models to emerge. We have included the parameter estimates from the more biologically interpretable von Bertalanffy model since the Linear von Bertalanffy model is a generalization of the von Bertalanffy (Table 12.16).

For the James River, the Richards model provided the best explanation of the data (Table 12.13). Model parameter estimates are reported in Table 12.17. The estimate of k was 0.4351 for the James River stock.

The Porch model did not converge on any of the three rivers using the current data sets; however, this problem may be alleviated with the addition of more years of data and the inclusion of the missing 1 to 2 year old age classes. The Porch model differs from most other growth models in that it allows the growth coefficient to slow gradually with increasing age, a more biologically realistic characterization of growth in these fish. It can also allow seasonal variability in growth if seasonal patterns are suspected.

12.10.7 Fecundity

Previous studies that estimated fecundity for York River American shad (Leggett and Carscadden 1978; Nichols and Massmann 1963) acknowledged the fact that American shad spawn in batches but estimated annual fecundity by counting all oocytes in ovaries and assuming determinate fecundity (see Olney and McBride 2003). However, American shad exhibit indeterminate fecundity (Olney *et al.* 2001). Thus, these previous studies do not accurately depict fecundity of shad in the York River. A more reliable method of estimating annual fecundity in batch spawners uses batch fecundity and spawning frequency (Hunter and Macewicz 1985). Spawning frequency is used to estimate the number of spawns in a season and batch size is multiplied by the number of spawns to determine annual fecundity. Hyle (2005) estimated batch fecundity, spawning frequency, and seasonal fecundity in the Mattaponi River. Batch fecundity was estimated for 70 specimens using the gravimetric method. Batch fecundity, though highly variable, was positively linearly correlated with eviscerated weight (EW) and ranged from 12,700 to 81,000 eggs per batch. Relative batch fecundity (eggs/g EW) ranged from 12.6 to 68.3. Mean relative batch fecundity was 30 to 36 eggs per gram EW. Spawning frequency was estimated using histological and macroscopic techniques with spawning frequency being the inverse of the fraction of females spawning daily. Histological techniques were more reliable and allowed the estimation of spawning frequency from animals containing migratory nucleus stage oocytes, hydrated oocytes, fresh postovulatory follicles, and 1-day old postovulatory follicles. Female shad were found to spawn once every two to three days. On average shad in the Mattaponi River release 11 to 17 batches per season based on mean spawning intervals of two to three days and a residence time of 34 days (determined by Olney *et al*. 2006). Seasonal fecundity for an average virgin (4.96 years old and 1,088g EW) was estimated to be between 380,000 and 550,000 eggs.

12.11 ASSESSMENT APPROACHES AND RESULTS

12.11.1 Catch Index

York River

The geometric mean of the historical catch index during the 1980s on the York River is 3.22. The average of the current catch index is higher (8.34), indicating some recovery from the severe declines in the 1980s and early 1990s. The 1950s data (Table 12.7) include two years of a high index (26-33), two years of a moderate index (14) and one low index year (8.7, 1955). VIMS monitoring in 1998 through 2005 suggests that the York River stock has recovered to a level that is close to its abundance during the 1980s (Figure 12.16). However, the stock level was low during that period and incapable of supporting an active fishery. The York River stock is currently well below the geometric mean of the 1950s data (Figure 12.17) when abundance of American shad was higher and harvest was apparently sustainable (Nichols and Massmann 1963). Catch indexes have been trending downward in recent years. In addition, low juvenile production in 1995 and 1997 through1999 has reduced recruitment of young fish to the spawning population in recent years.

James River

The geometric mean of the historical catch index during the 1980s on the James River is 6.40. The average of the current catch index is lower (5.39), indicating that the James River stock has not recovered from the severe declines in the 1980s and early 1990s. Although densities of larval shad are often high on the spawning grounds, there is little evidence of recruitment success on the James River, and the stock is dependent on hatchery inputs. As noted previously, hatchery cohorts are recruiting in higher proportions to the James River population and the VIMS catch rate is increasing (Figure 12.10). Logbook data from the 1950s are available from historic fishing sites upstream but are not directly comparable to the current monitoring location near the river mouth. As reported by Olney *et al.* (2003), the James River stock remains at a low level of abundance relative to the historical data and requires continued protection and restoration (Figure 12.1).

Rappahannock River

The 2003 to 2004 values of the VIMS catch index on the Rappahannock are higher than all years in the historical data (Figure 12.18). The geometric mean of the historical catch index during the 1980s on the Rappahannock River is 1.45. The geometric mean of the current VIMS catch index is higher (3.20). Low juvenile production in 1995 and 1997 through 1999 has resulted in an increase in mean age since fewer young fish are recruiting to the spawning population. Historical data from the 1950s that are directly comparable to the current monitoring location at the mouth of the river are not available. Thus, an interim restoration target for the stock is based on the 1980s data (Table 12.10). It should be noted that since the catch index for the Rappahannock River is low in the historical data relative to the York and James rivers, there is uncertainty about what an appropriate target level should be for this stock. There is little evidence of severe stock decline in the Rappahannock River. On the basis of historic and current catch rates, the present status of the Rappahannock River stock is stable with recent evidence of increasing abundance.

12.12 BENCHMARKS

York River

A benchmark of 17.44 (the geometric mean of the catch index values observed in 1953-1957) is appropriate to assess the stocks since American shad abundance in the 1980s was insufficient to support the fishery. In the 1950s, shad abundance was higher (estimated at 131,000-218,000 total females annually using data from Nichols and Massmann 1962), and landings were relatively stable in the face of a high fishing rate (50%). Thus, restoring the York River shad stocks to a 1950s level could allow for a sustainable fishery operating at a lower level of exploitation. The geometric mean of the current monitoring data (8.34) is lower than the geometric mean of catch indexes from logbook records in the 1950s (17.44; Tables 12.7 and 12.8; Figure 12.17).

Additional benchmarks are the benchmark fishing rate (F_{30}=0.27) for the Native American fishery and benchmark total mortality rate (Z_{30}= 0.62 to 0.85, depending on the estimate of natural mortality used as input in the yield model). To apply these rules, an estimate of F by the Native American fishery and a better understanding of natural mortality are required.

James River

An interim benchmark of 6.4 (the geometric mean of the catch index values observed in 1980-1993) is available. However, the James River stock is dependent on hatchery inputs and there is strong evidence of persistent recruitment failure of wild stocks. Additional studies are needed to relate current catch rates to historical data that are available in the form of 1950s commercial logbooks.

Rappahannock River

An interim benchmark of 1.45 (the geometric mean of the catch index values observed in 1980-1993) has been exceeded.

12.13 CONCLUSIONS AND RECOMMENDATIONS

Although harvest of American shad in Virginia has been banned since 1994, our index-based assessment suggests that stock abundance remains low relative to historic logbook data, especially in the James and York rivers. Current estimates of total mortality (Z) for the York River stock using catch-at-age and repeat spawning data (Figure 12.14) usually exceed the estimates of Z_{30} generated by the yield model.
The reasons for this slow recovery are unknown but probably include low levels of recruitment, unreported removals and discard mortality. The following are recommendations for research and data that would facilitate future assessments of Virginia stocks:

1. Stock-specific age validation studies
2. Estimates of fishing rates and harvest by the Native American fishery
3. Reliable estimates of natural mortality
4. Estimates of bycatch mortality and mixed stock composition
5. Studies of fish passage efficiency at Bosher's Dam
6. Studies of recruitment variability and bottlenecks, especially in the James River
7. Continue to monitor the Rappahannock to document the effects of dam removal

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Table 12.1 Summary of passage of adult American shad through the Bosher's Dam fishway in 1999-2005.

	1999	2000	2001	2002	2003	2004	2005
Total Hours Viewed	107	381	758	1026	959	1193	859
Shad/Hour	0.15	0.35	0.58	0.73	0.18	0.07	0.05
Day (0600-2100) Shad	16	133	437	751	174	79	46
Day Hours Viewed	107	381	744	1026	608	989	791
Day Fish/Hour	0.15	0.35	0.59	0.73	0.29	0.08	0.06
Night (2100-0600) Shad	0	0	0	0	0	0	0
Night Hours Viewed	0	1	14	0	351	204	68
Night Fish/Hour	0	0	0	0	0	0	0
Max. Passage/Hour	5	25	18	51	23	5	2

TOTAL SHAD (1999-2005)	**1636**
TOTAL HOURS VIEWED	**5283**
TOTAL SHAD/HOUR	**0.31**
TOTAL DAY HOURS VIEWED	**4646**
TOTAL DAY SHAD	**1636**
DAY SHAD/HOUR	**0.35**
DAY AVG. SHAD/HOUR	**0.32**
TOTAL NIGHT HOURS VIEWED	**638**
NIGHT SHAD	**0**
NIGHT SHAD/HOUR	**0**

Table 12.2 American shad landings (lbs) and percent of the total statewide landings by harvest area, 1980-2005.

Year	Bay Area	(%) Total	Coastal	(%) Total	Total Landings
1980	877,961	90	95,914	10	973,875
1981	223,440	45	275,679	55	499,119
1982	308,359	53	276,995	47	585,354
1983	463,225	69	207,777	31	671,002
1984	625,339	49	644,338	51	1,269,677
1985	300,827	48	332,157	52	632,984
1986	217,527	38	355,588	62	573,115
1987	237,653	38	395,227	62	632,880
1988	54,416	11	428,838	89	483,254
1989	102,472	20	399,761	80	502,233
1990	128,987	28	325,176	72	454,163
1991	50,833	11	399,634	89	450,467
1992	46,001	10	432,570	90	478,571
1993	66,371	12	486,775	88	553,146
1994	ND	ND	203,649	100	203,649
1995	ND	ND	146,019	100	146,019
1996	ND	ND	231,713	100	231,713
1997	ND	ND	332,205	100	332,205
1998	ND	ND	334,308	100	334,308
1999	ND	ND	228,632	100	228,632
2000	ND	ND	162,402	100	162,402
2001	ND	ND	242,381	100	242,381
2002	ND	ND	149,544	100	149,544
2003	ND	ND	45,795	100	45,795
2004	ND	ND	48,263	100	48,263
2005	ND	ND	ND	ND	ND

Table 12.3 Commercial landings (lbs; female and males combined) in Virginia's rivers, 1973-1995. A moratorium on in-river harvest was imposed in 1994.

Year	**James River**	**York River**	**Rappahannock River**
1973	1,375,450	297,152	66,373
1974	617,299	171,367	121,210
1975	515,257	198,281	75,883
1976	244,675	133,383	28,753
1977	303,658	919,277	49,566
1978	513,237	429,953	37,796
1979	355,700	410,861	17,104
1980	265,938	395,426	11,149
1981	31,685	126,194	4,288
1982	101,271	186,515	739
1983	189,628	231,820	4,846
1984	240,389	278,099	1,405
1985	28,637	213,988	
1986	1,450	127,406	
1987	3,970	128,077	
1988		42,912	500
1989	2	60,560	
1990	217	40,161	30
1991	50	23,302	67
1992	954	5,262	1,333
1993	3,112	25,973	1,761
1994	5		51,121
1995			111

Table 12.4 Indexes of American shad juvenile abundance collected in beach seine surveys (1980-2005) on the James and Rappahannock rivers. The index is the geometric mean catch-per-haul. Years of below average recruitment on the Rappahannock River are marked with an asterisk. Abbreviations are: SD – standard deviation; N – number of seine hauls.

Year	James River	SD	N	Rappahannock River	SD	N
1980	0		11	0*		4
1981	0		12	0*		4
1982	0		12	0.88	1.081	16
1983	0		8	0.32	0.549	4
1984	0.09	0.245	8	0.41	0.693	4
1985	0		16	0*		8
1986	0		12	0.06*	0.2	12
1987	0		16	0.12*	0.315	16
1988	0		16	0*		20
1989	0		16	0.52	0.894	25
1990	0		16	0.03*	0.131	28
1991	0		20	0*		31
1992	0		20	0*		35
1993	0		20	0.13*	0.441	31
1994	0		20	0.05*	0.22	34
1995	0		20	0*		33
1996	0		20	0.35	0.655	32
1997	0		20	0.16*	0.444	35
1998	0.04	0.155	20	0.12*	0.341	29
1999	0		20	0.02*	0.117	35
2000	0		20	0.03*	0.188	34
2001	0		20	0.04*	0.163	35
2002	0		20	0		35
2003	0.04	0.155	20	0.59	0.659	28
2004	0.04	0.155	20	0.7	0.901	35
2005	0	0	20	0.18	0.592	33
Mean	**0.01**			**0.18**		

Table 12.5 Indexes of American shad juvenile abundance collected in beach seine surveys (1980-2005) on the Mattaponi, Pamunkey, and York rivers. The index is the geometric mean catch-per-haul. Asterisk indicates years of below average recruitment. Abbreviations are: SD – standard deviation; N – number of seine hauls.

Year	**Mattaponi River**	**SD**	**N**	**Pamunkey River**	**SD**	**N**	**York River**	**SD**	**N**
1980	1.75*	1.059	21	0.51*	0.825	9	1.13*	1	33
1981	0.35*	0.564	16	0.33*	0.588	16	0.34*	0.567	32
1982	13.03	1.256	16	0.51*	0.543	12	4.4	1.502	28
1983	2.80*	0.954	16	0.63*	0.775	12	1.65	0.965	88
1984	16.97	1.125	16	0.06*	0.2	12	4.34	1.66	28
1985	7.21	1.369	32	0.56*	0.631	24	3.03	1.381	56
1986	0.87*	0.902	24	0.00*		18	0.43*	0.744	42
1987	0.17*	0.461	24	0.00*		18	0.09*	0.354	42
1988	0.00*		40	0.00*		24	0.00*		64
1989	0.41*	0.631	40	0.00*		32	0.20*	0.487	34
1990	0.18*	0.473	40	0.00*		32	0.09*	0.351	76
1991	0.04*	0.253	50	0.02*	0.111	39	0.03*	0.197	94
1992	0.00*		39	0.00*		32	0.00*		75
1993	0.18*	0.489	50	0.00*		39	0.09*	0.365	94
1994	1.69*	1.142	50	0.15*	0.435	39	0.80*	0.977	94
1995	0.03*	0.137	50	0.00*		40	0.01*	0.1	95
1996	14.61	1.352	49	1.97	1.294	39	5.79	1.572	93
1997	2.23*	1.107	50	0.36*	0.672	40	1.11*	1.017	95
1998	2.11*	1.206	48	0.06*	0.356	38	0.86*	1.052	91
1999	0.14*	0.407	47	0.00*		38	0.07*	0.303	88
2000	5.56	1.33	39	0.06*	0.23	31	1.76	1.338	74
2001	0.52*	0.665	48	0.11*	0.296	40	0.30*	0.541	94
2002	0.17*	0.408	48	0.02*	0.11	40	0.09*	0.308	93
2003	8.55	1.315	50	13.11	1.057	39	9.04	1.294	94
2004	7.4	1.389	47	0.05*	0.208	38	2.1	1.454	90
2005	1.66*	1.351	50	0.02*	0.11	40	0.68*	1.091	95
Mean	**3.41**			**0.71**			**1.48**		

Table 12.6 Linear regression results for York River correlation of juvenile abundance index with adult year class abundance, 1998-2005. Asterisk indicates a significant correlation; "ns" indicates a non-significant correlation (α=0.05).

Adult Age Class	*P*-value	r^2	Significance
3	0.62	0.04	ns
4	0.51	0.07	ns
5	0.48	0.09	ns
6	0.04	0.53	*
7	0.65	0.04	ns
8	0.2	0.26	ns
9	0.07	0.44	ns
10	0.07	0.45	ns

Table 12.7 Historical catch and effort data of American shad by staked gill nets in the York River, Virginia. Historical data are taken from the voluntary logbooks of Malvin Green, Aberdeen Creek, Virginia. The data were originally recorded as numbers of female shad per day and were converted using an average female weight of 3.2 lbs. Catch rates are expressed as female kg/d and multiplied by 2.16 to adjust for the lower fishing power of multifilament nets compared to monofilament nets.

Year	Total females	Effort (103m/yr)	Duration of Run (days)	Highest Catch Rate (female kg/m/day)	Mean Catch Rate (female kg/m/day)	Area Under the Catch Curve
1953	2161	36	56	0.549	0.443	14.88
1954	3046	45.5	54	0.699	0.434	14.04
1955	1643	40.1	55	0.31	0.27	8.7
1956	6835	68.8	85	1.201	0.663	33.95
1957	5645	56.2	65	0.955	0.667	26.14
Geometric Mean						**17.44**

Table 12.8 Summary of historical and recent catch and effort data of American shad by staked gill nets in the York River, Virginia. Historical data are taken from the voluntary logbooks of Mr. R. Kellum, Achilles, Virginia.

Year	**Effort (103m/yr)**	**Duration of Run (days)**	**Highest Catch Rate (female kg/m/day)**	**Mean Catch Rate (female kg/m/day)**	**Area Under the Catch Curve**
1980	79.4	44	0.556	0.268	10.15
1981	114.7	51	0.259	0.121	4.35
1982	86.4	44	0.326	0.101	5.31
1983	121.3	40	0.212	0.066	3.06
1984	171.4	48	0.548	0.139	8.21
1985	205.4	49	0.227	0.091	4.61
1986	185.2	38	0.145	0.055	2.17
1987	152.9	37	0.088	0.039	1.78
1988	126.2	40	0.134	0.028	1.34
1989	146.3	55	0.397	0.131	4.92
1990	106.9	38	0.951	0.037	1.31
1991	77.8	40	0.111	0.062	2.72
1992	60.8	41	0.079	0.041	1.6
Geometric Mean of Historical Data					**3.22**
1998	5.7	78	1.08	0.19	14.71
1999	6.3	65	0.209	0.075	5.42
2000	6.7	76	0.276	0.086	7.52
2001	6.3	79	0.627	0.163	12.97
2002	6.7	70	0.306	0.073	7.47
2003	6	70	0.39	0.111	8.98
2004	4.9	65	0.448	0.157	9.72
2005	5.5	73	0.135	0.0633	4.64
Geometric Mean of Current Data					**8.34**

Table 12.9 Summary of historical and recent catch and effort data of American shad by staked gill nets in the James River, Virginia. Historical data are taken from the voluntary logbooks of the Brown Family, Rescue, Virginia.

Year	Effort (103m/yr)	Duration of Run (days)	Highest Catch Rate (female kg/m/day)	Mean Catch Rate (female kg/m/day)	Area Under the Catch Curve
1980	20.5	41	2.239	0.699	29.2
1981	67.7	41	0.547	0.13	5.2
1982	49.3	35	0.331	0.115	4.2
1983	94	57	1.274	0.297	16.5
1984	89.7	50	0.897	0.036	19.3
1985	91.3	45	0.295	0.103	4.9
1986	31.5	26	1.289	0.152	6.1
1987	30.1	30	0.352	0.085	2.7
1988	19.1	20	0.487	0.193	9.3
1989	31.5	30	0.331	0.176	6.4
1990	29.7	25	0.184	0.079	2.1
1991	28.3	40	0.138	0.062	1.9
1992	59.8	50	0.562	0.232	7.7
Geometric Mean of Historical Data					**6.4**
1998	3.8	50	0.198	0.051	2.57
1999	6	66	0.183	0.042	2.99
2000	7.2	70	0.279	0.086	6.61
2001	6.8	78	0.285	0.064	5.01
2002	6.5	71	0.205	0.054	5.62
2003	6.6	79	0.284	0.112	9.34
2004	6	78	0.234	0.09	7.41
2005	5.3	72	0.357	0.099	7.16
Geometric Mean of Current Data					**5.39**

Table 12.10 Summary of historical and recent catch and effort data of American shad by staked gill nets in the Rappahannock River, Virginia. Historical data are taken from the voluntary logbooks of Mr. M. Delano, Urbanna, Virginia.

Year	Effort (103m/yr)	Duration of Run (days)	Highest Catch Rate (female kg/m/day)	Mean Catch Rate (female kg/m/day)	Area Under the Catch Curve
1980	43.4	35	0.121	0.036	1.79
1981	112.1	57	0.032	0.011	1.89
1982	82.3	51	0.046	0.009	1.68
1983	106.7	59	0.093	0.031	0.59
1984	30.5	48	0.139	0.033	0.6
1985	77.2	60	0.136	0.029	1.83
1986	34.9	43	0.155	0.039	2.18
1987	23.3	37	0.09	0.023	0.97
1988	23.2	53	0.073	0.025	1.25
1989	16.2	44	0.856	0.123	6.19
1990	41.3	55	0.092	0.023	1.31
1991	25.9	54	0.129	0.022	1.13
1992	8.6	51	0.299	0.044	1.44
Geometric Mean of Historical Data					**1.45**
1998	3.8	----	0.053	0.02	1.46
1999	5.7	42	0.055	0.026	1.3
2000	6.6	73	0.141	0.042	1.75
2001	6.6	72	0.167	0.07	5.77
2002	5.4	57	0.11	0.028	3.08
2003	7.2	72	0.311	0.094	7.1
2004	5.2	65	0.232	0.107	7.06
2005	5.5	65	0.164	0.054	3.69
Geometric Mean of Current Data					**3.2**

Table 12.11 Estimates of total mortality (Z) of mature American shad in (a) the York River, (b) the James River, and (c) the Rappahannock River calculated using catch-at-age and repeat spawning data. Catch-at-age data is based on scale ages, 1998-2005. Asterisk indicates scale age data was unavailable.

(a)

Year	Ages	Catch-at-Age Data	Repeat Spawning Data
1998	5-9	1.43	0.97
1999	5-9	1.04	0.99
2000	5-10	0.96	0.95
2001	5-9	1.07	1.17
2002	5-8	1.41	1.67
2003	6-10	1.2	1.07
2004	6-10	1.34	1.2
2005	6-10	0.72	0.68

(b)

Year	Ages	Catch-at-Age Data	Repeat Spawning Data
1998	*	*	*
1999	5-8	0.98	0.98
2000	5-8	1.31	1.44
2001	5-9	1.35	1.06
2002	5-8	1.59	1.62
2003	5-10	1.09	1.31
2004	5-10	0.98	1.06
2005	6-9	1.17	1.06

(c)

Year	Ages	Catch-at-Age Data	Repeat Spawning Data
1998	*	*	*
1999	5-8	1.89	0.71
2000	4-8	1.02	0.84
2001	5-9	1.29	1.36
2002	5-9	1.03	0.98
2003	5-9	0.77	0.92
2004	6-10	1.08	1.03
2005	6-10	0.98	0.97

Table 12.12 Best fit model (Linear von Bertalanffy) parameter estimates and Fischer-Behrens Z-statistic results for the York River, using both integer ages and fractional ages. Asterisk indicates a significant difference between integer and fractional age estimates of a given model parameter.

Linear von Bertalanffy	Z Statistic Significance: Integer vs. Fractional	Integer Ages		Fractional Ages	
		Estimate	SE	Estimate	SE
t_0	*	-0.1531	0.00928	-0.0735	0.00956
k	*	1.0047	0.0594	0.4568	0.0234
b_0	*	422.5	4.1793	498.2	12.7478
b_1	*	15.3234	0.5188	6.1166	1.2043

Table 12.13 Akaike's Information Criterion (AIC) comparison results for the York, James, and Rappahannock rivers using fractional ages. Asterisk indicates the model was unable to converge; "WSS" – weighted sums of squares.

	Model	Number of Parameters	WSS	AIC	Weighted AIC
York River	Linear von Bertalanffy	4	17,831.60	14,270.20	1
	Richards	4	18,034.60	14,286.70	0
	von Bertalanffy	3	18,100.60	14,290.00	0
	Schnute	6	18,034.60	14,290.70	0
	Gompertz	3	20,056.70	14,439.50	0
	Porch	6	*	*	*
James River	Richards	4	12,211.20	13,144.50	0.88
	Schnute	6	12,211.20	13,148.50	0.12
	von Bertalanffy	3	12,574.30	13,183.40	0
	Linear von Bertalanffy	4	12,571.80	13,185.10	0
	Gompertz	3	13,616.20	13,294.60	0
	Porch	6	*	*	*
Rappahannock River	Linear von Bertalanffy	4	13,314.40	9,504.60	1
	Richards	4	14,014.20	9,555.80	0
	von Bertalanffy	3	14,044.00	9,556.00	0
	Gompertz	3	17,111.20	9,753.50	0
	Schnute	6	*	*	*
	Porch	6	*	*	*

Table 12.14 Best fit (Linear von Bertalanffy) model parameter estimates for the York and Rappahannock Rivers.

Linear von Bertalanffy Model Parameters	York		Rappahannock	
	Estimate	SE	Estimate	SE
t_0	-0.0735	0.00956	-0.0326	0.0103
k	0.4568	0.0234	0.5349	0.0251
b_0	498.2	12.7478	481.7	9.1184
b_1	6.1166	1.2043	8.3424	0.8872

Table 12.15 Fischer-Behrens Z-statistic and significance (α=0.05) for Linear von Bertalanffy model parameter estimate comparison between the York and Rappahannock rivers.

	t_0	k	b_0	b_1
Z statistic	2.910434	2.275924	1.052747	1.488018
***P*-value**	0.0016	0.0094	ns	ns

Table 12.16 Von Bertalanffy model parameter estimates for the York, James, and Rappahannock rivers using fractional ages.

River	L_{inf}	L_{inf} SE	t_0	t_0 SE	k	k SE
York	565.4	1.699	-0.0969	0.00864	0.3647	0.00486
Rappahannock	573.4	1.6516	-0.0829	0.00932	0.3758	0.00515
James	564.1	1.4277	-0.0703	0.00547	0.3825	0.00494

Table 12.17 Richards model parameter estimates for the James River.

Richards Model Parameters	James	
	Estimate	SE
L_∞	559	1.4479
t_0	0.3947	0.0819
k	0.4351	0.0107
d	0.7608	0.0453

Figure 12.1 Recent (1998-2005) and historic values of the catch index of female American shad on the James River. Hatchery prevalence is the percent of the total catch (sexes combined) that had hatchery marks on the otoliths. Horizontal lines are the geometric means of each data set (solid 1980s; short dashes, current).

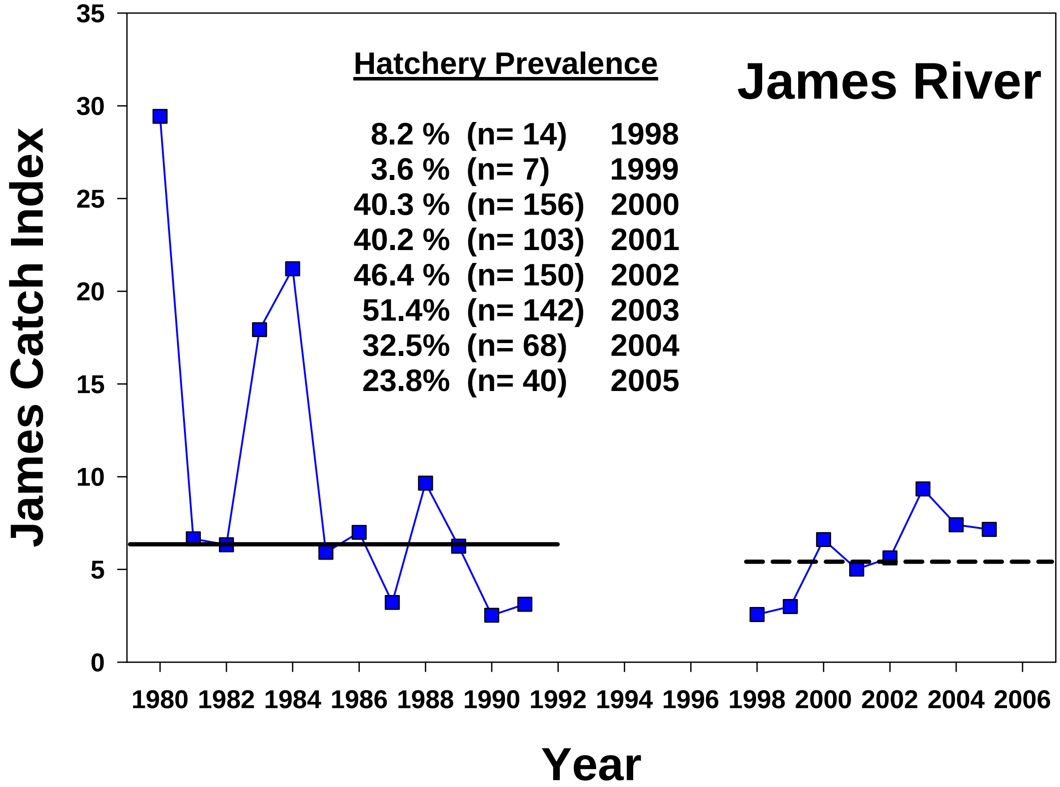


Figure 12.2 VDGIF catches (numbers of fish/net) and prevalence of hatchery marks in gill net sampling in the upper James River below Bosher's Dam, 2000-2004. Data from 2005 were not available.

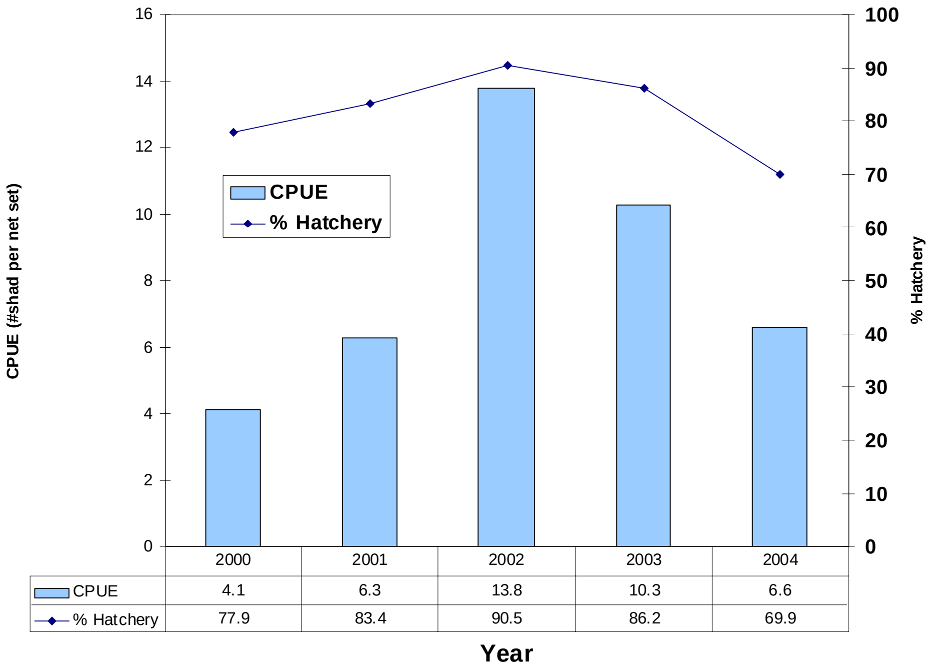
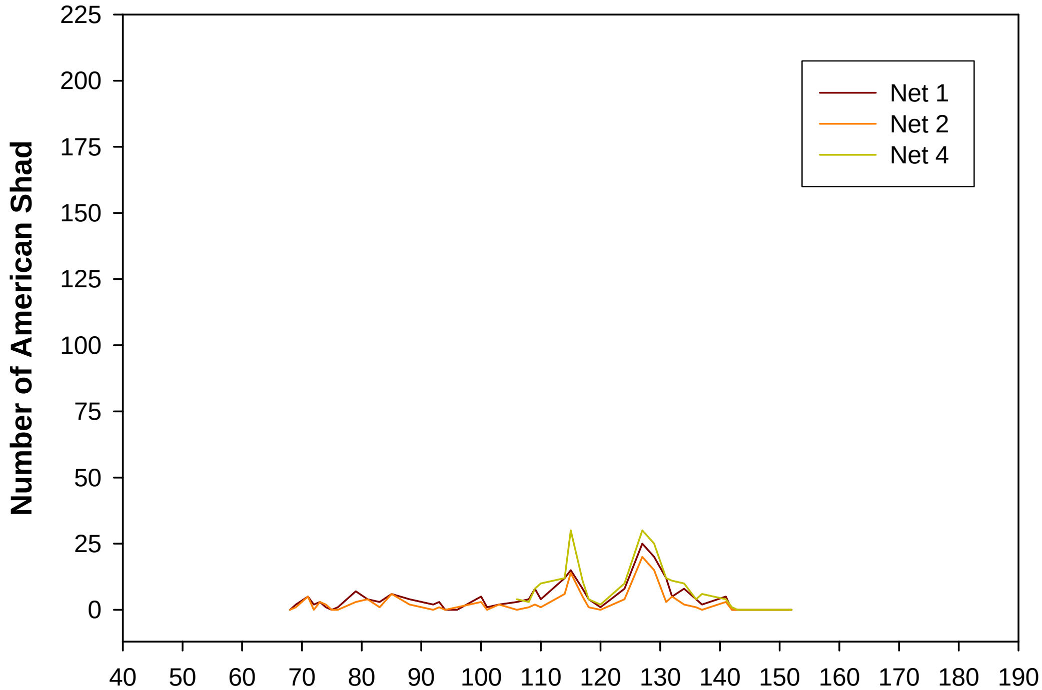


Figure 12.3 Logbook data on American shad bycatch in Greg Swift's pound net located near the Great Wicomico River in the upper, western portion of Virginia's Chesapeake Bay, (a) 2002 and (b) 2003.

(a)



(b)

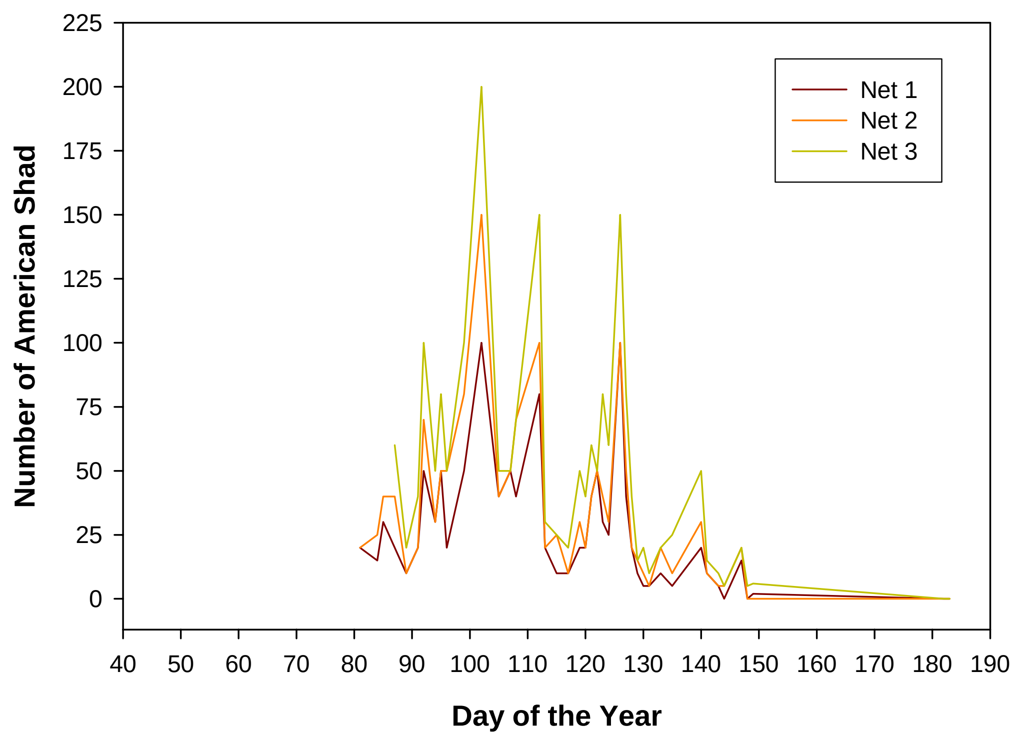
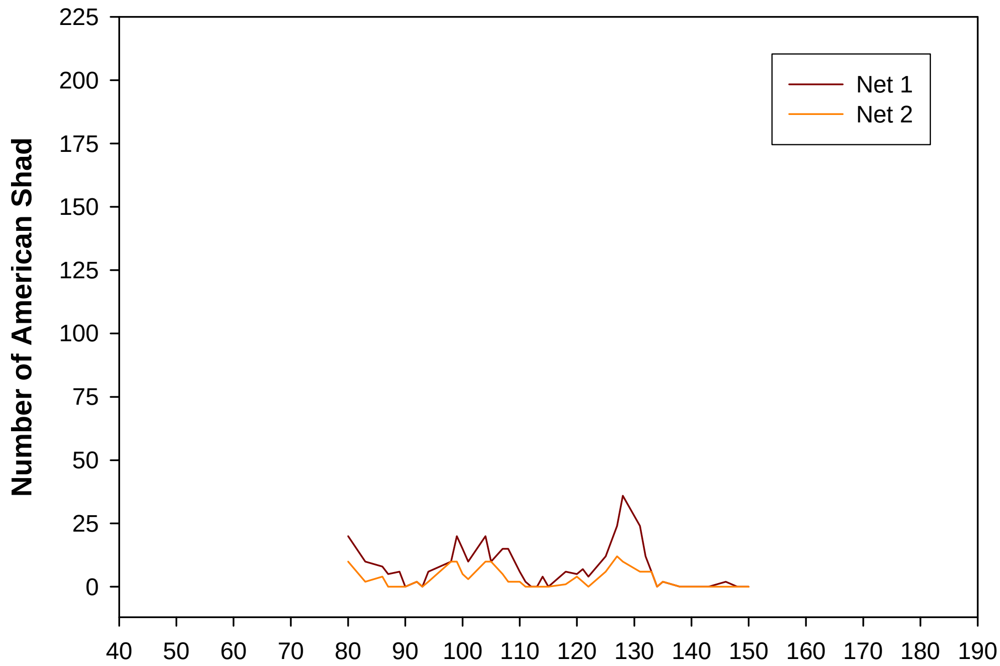


Figure 12.4 Logbook data from (a) 2004 and (b) 2005 on American shad bycatch in Greg Swift's pound net located near Great Wicomico River in the upper, western portion of Virginia's Chesapeake Bay.

(a)



(b)

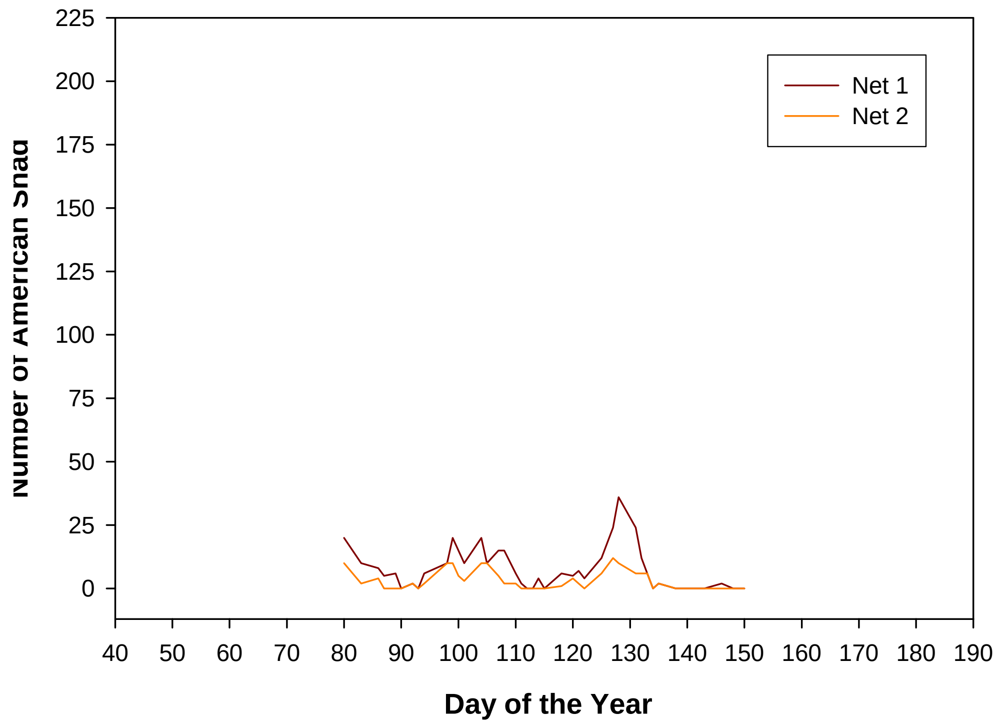


Figure 12.5 Frequency distributions of Juvenile Abundance Indices for the James, York, and Rappahannock rivers, 1998-2005.

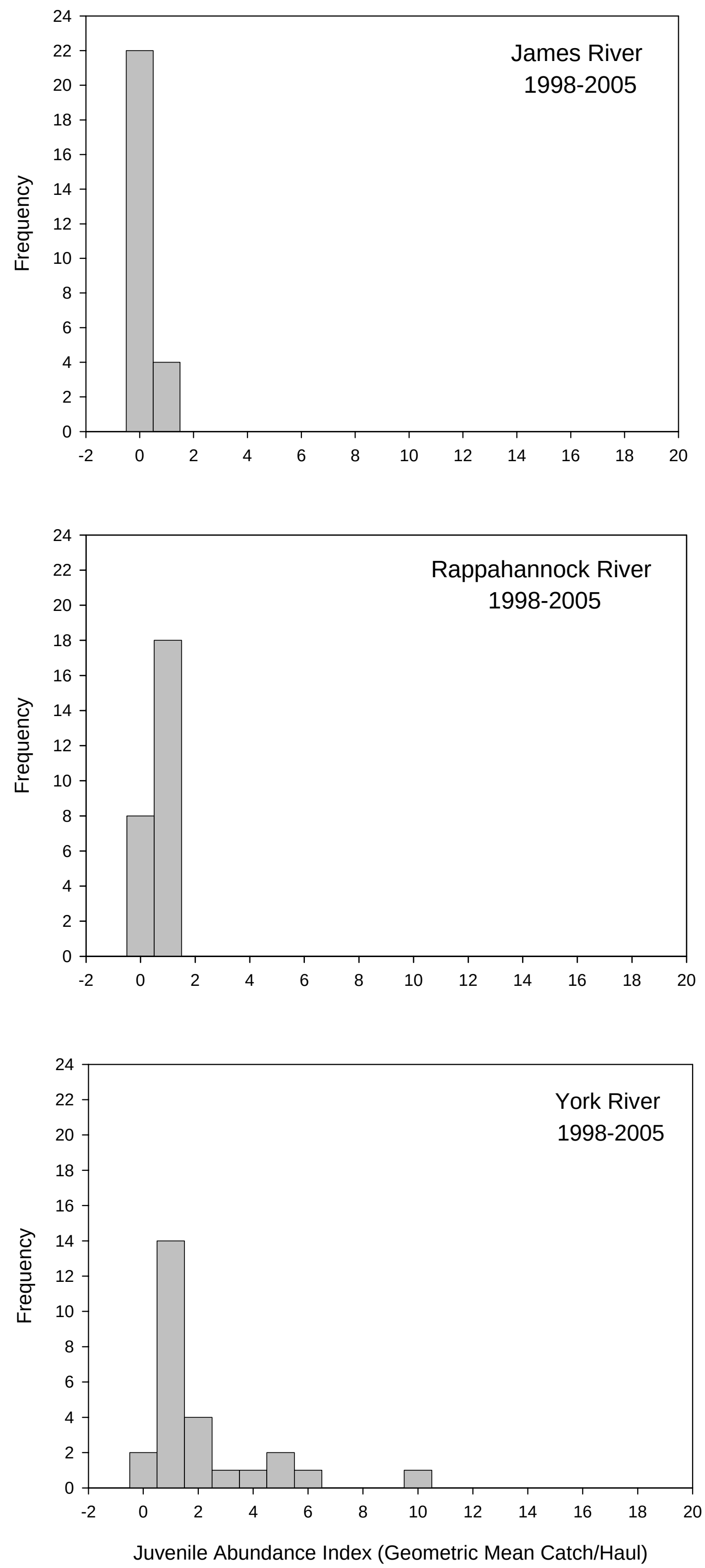


Figure 12.6 Linear regression results for York River correlation of Juvenile Abundance Index with adult year class abundance, 1998-2005.

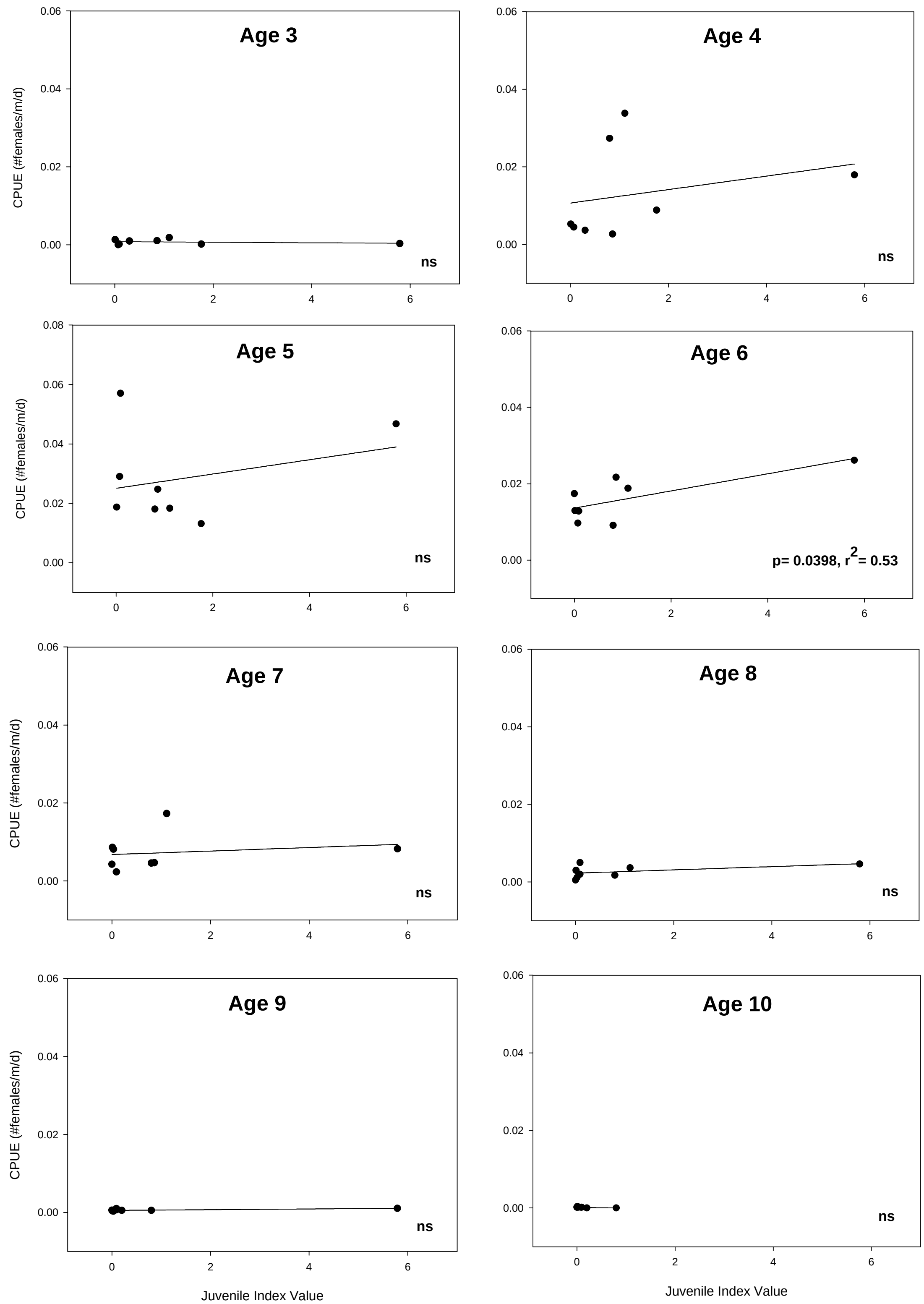


Figure 12.7 Location of the staked gill net fished by Mr. Raymond Kellum on the York River. The length of the net (273 m) is not to scale.

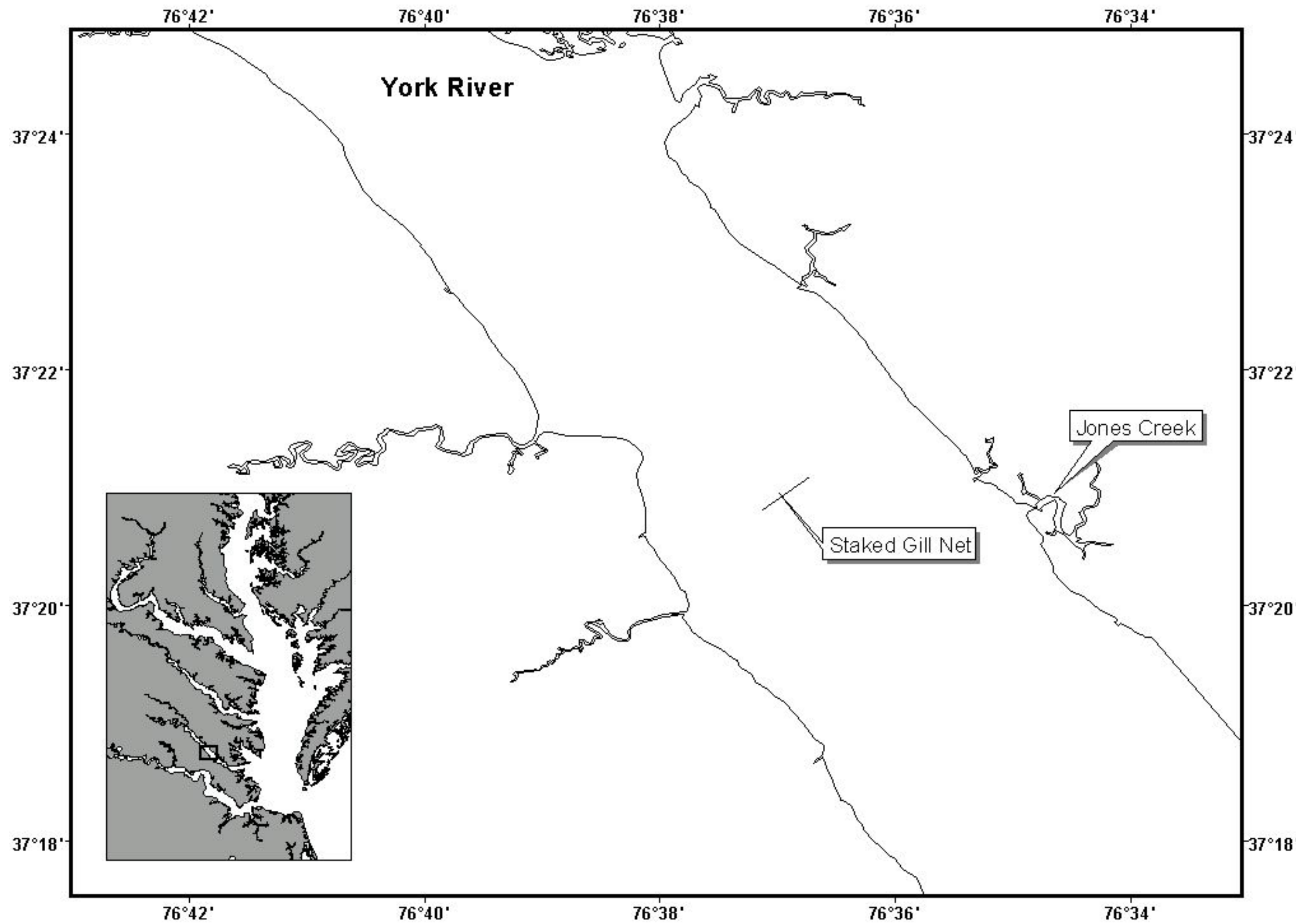


Figure 12.8 Location of the stake gill net fished by Mr. Marc Brown on the James River. The length of the net (273 m) is not to scale.

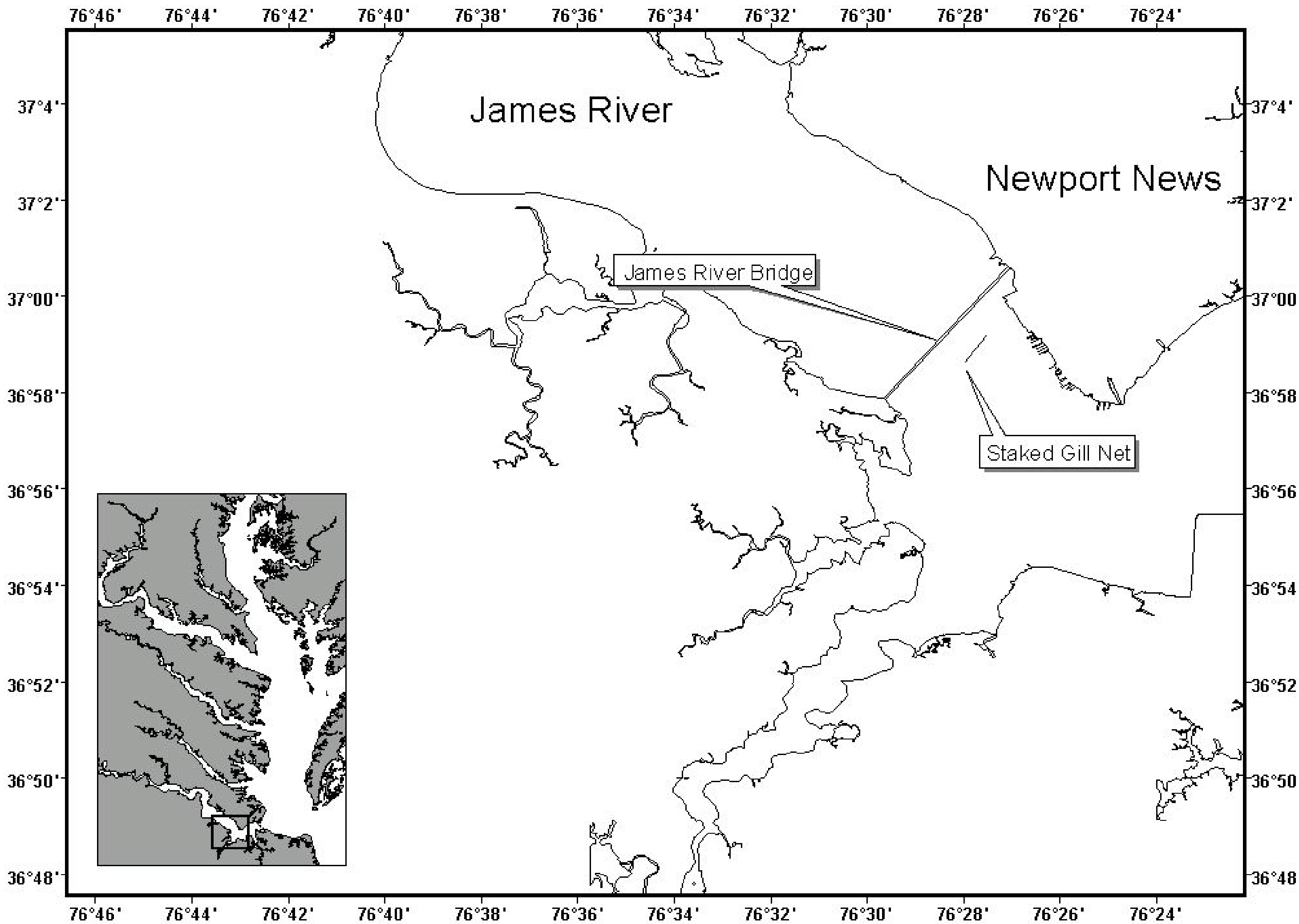


Figure 12.9 Location of the staked gill net fished by M. Jamie Sanders on the Rappahannock River. The length of the net (276 m) is not to scale.

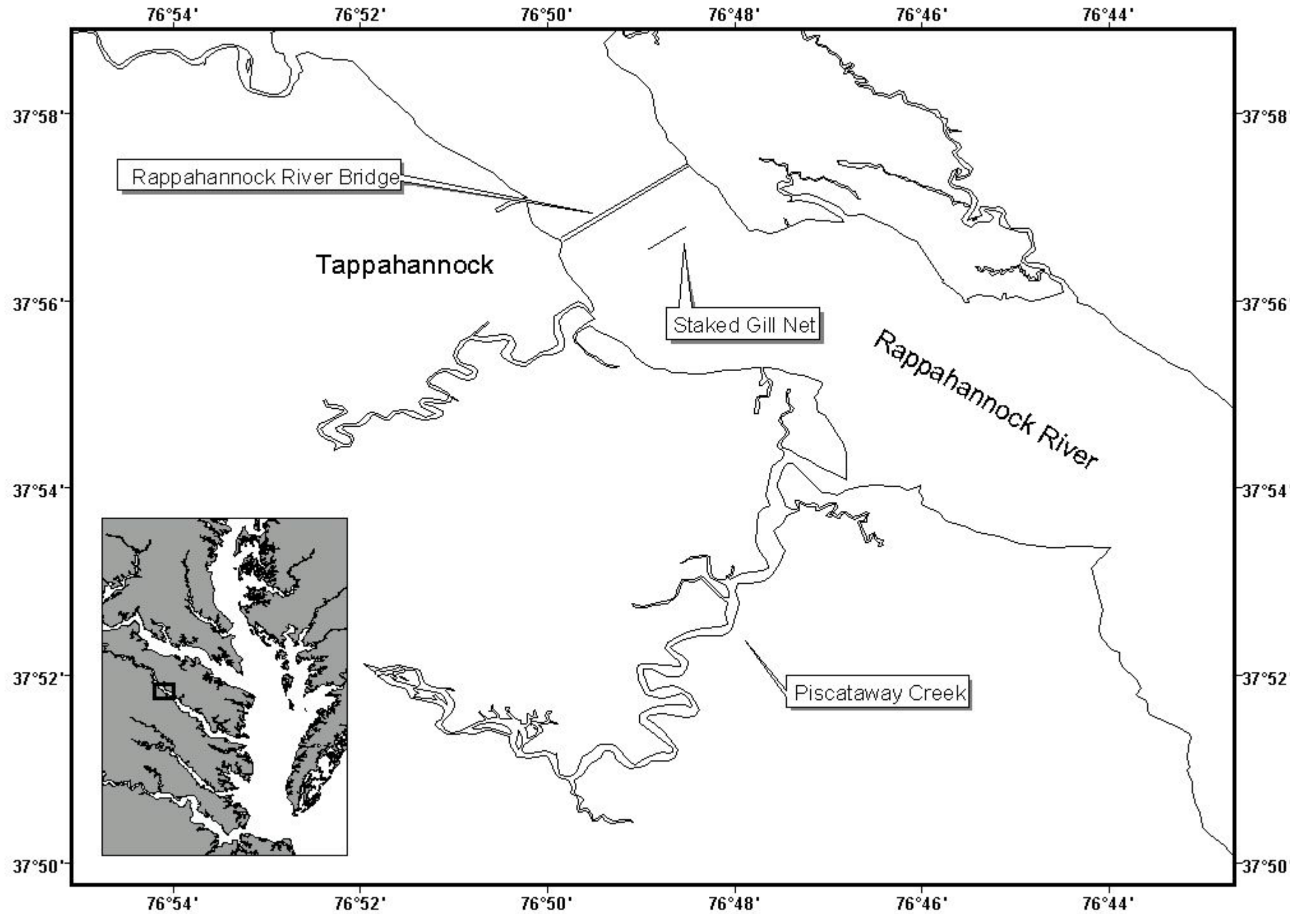


Figure 12.10 The VIMS catch index of American shad in three Virginia rivers, 1998-2005.

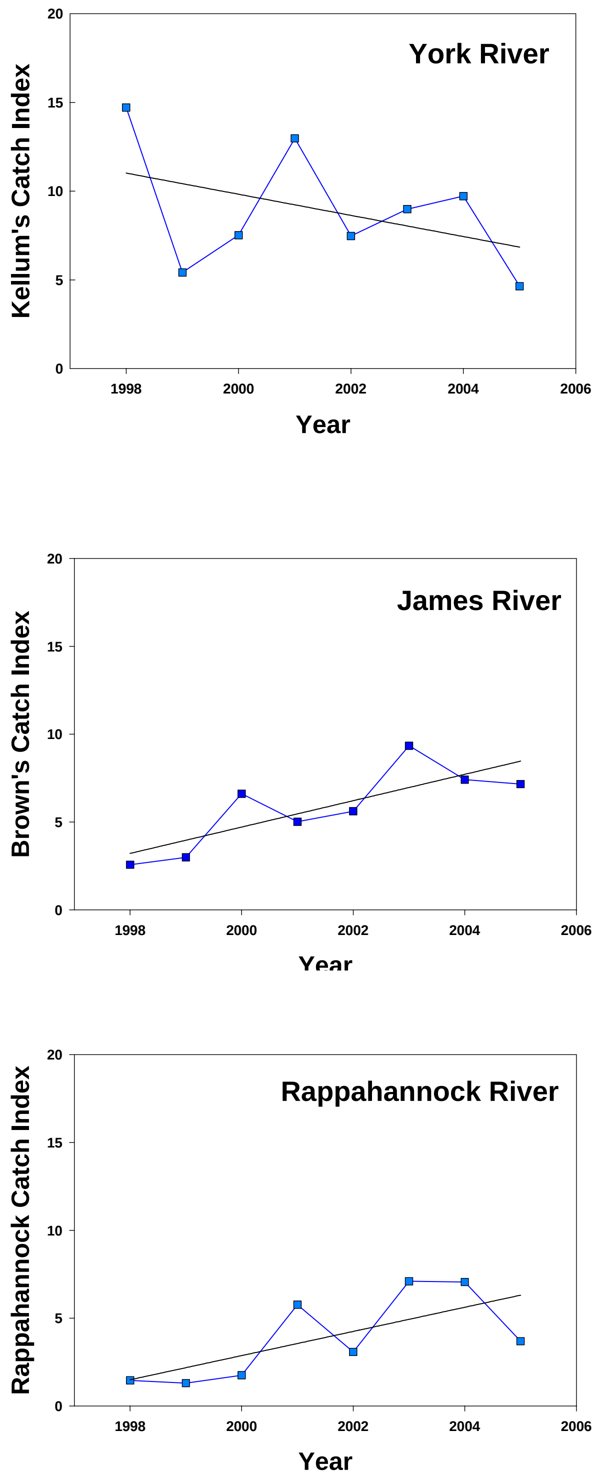


Figure 12.11 Relative abundance of American shad in VDGIF electrofishing samples downstream of Bosher's Dam (James River, Virginia). Values represent the combined CPUE from weekly sampling of three transects in each year (effort ranged from 750-900 seconds per transect).

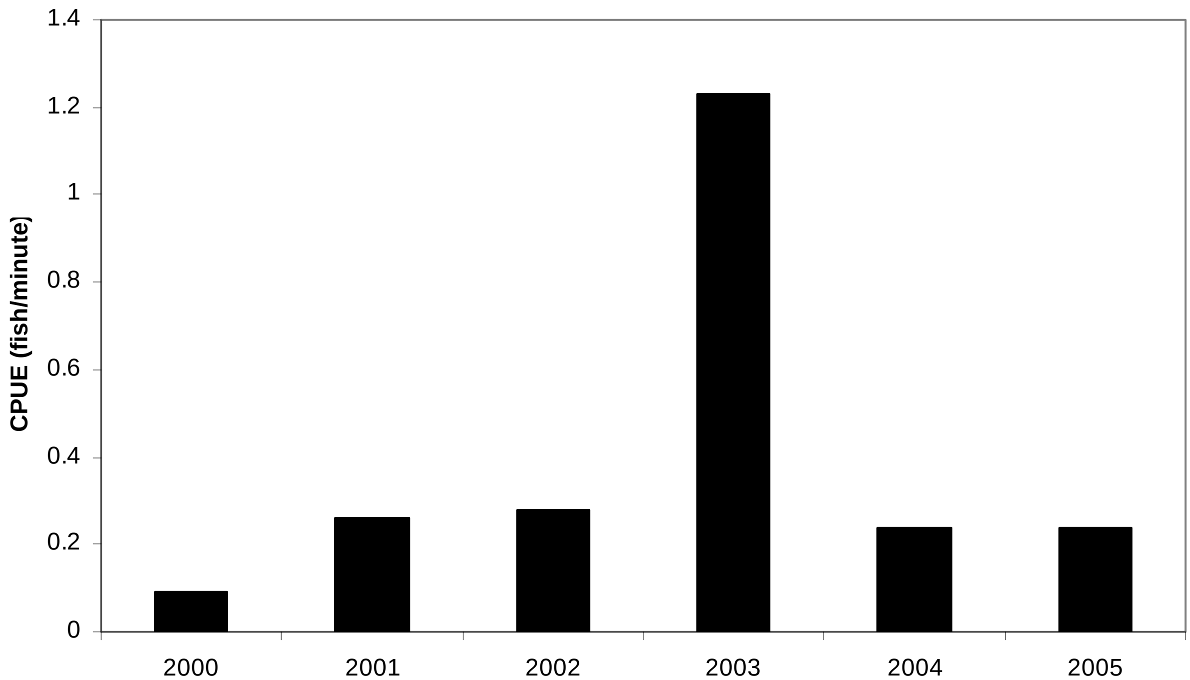


Figure 12.12 Relative abundance of American shad in VDGIF electrofishing samples at Asland Mill Dam (South Anna River, Virginia). Values represent the combined CPUE from weekly sampling of three transects in each year (effort ranged from 750-900 seconds per transect).

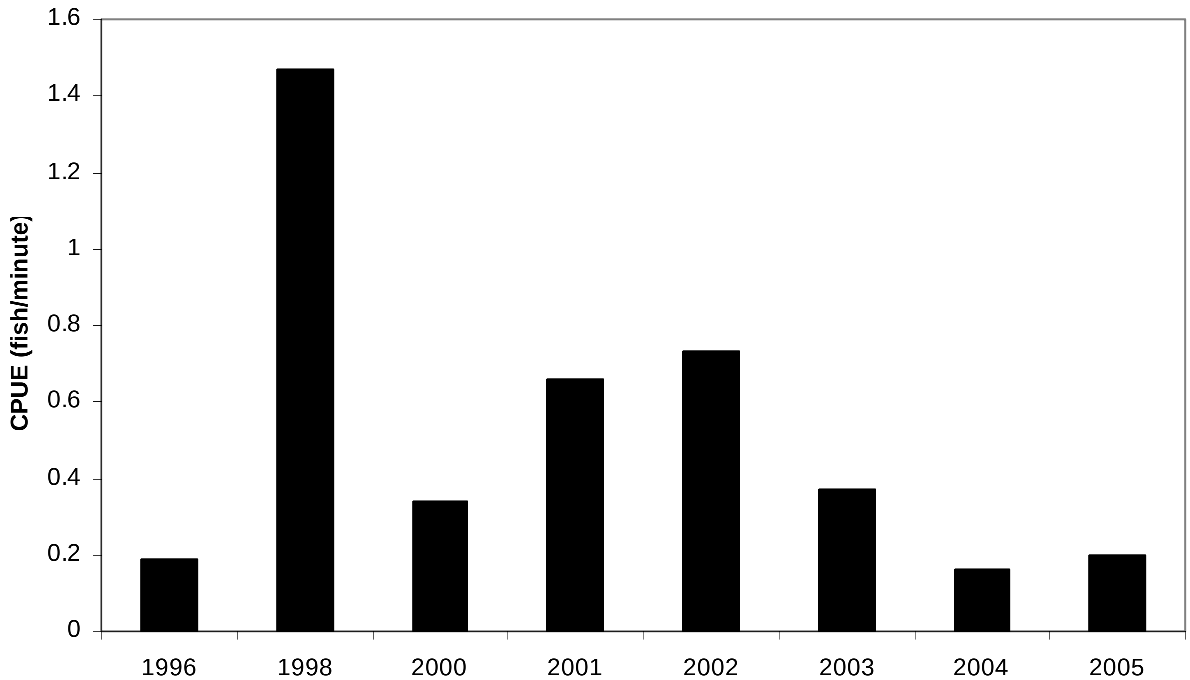


Figure 12.13 Mean age of females and proportion of age-4 fish in the VIMS monitoring catch in Virginia's rivers, 1998-2005.

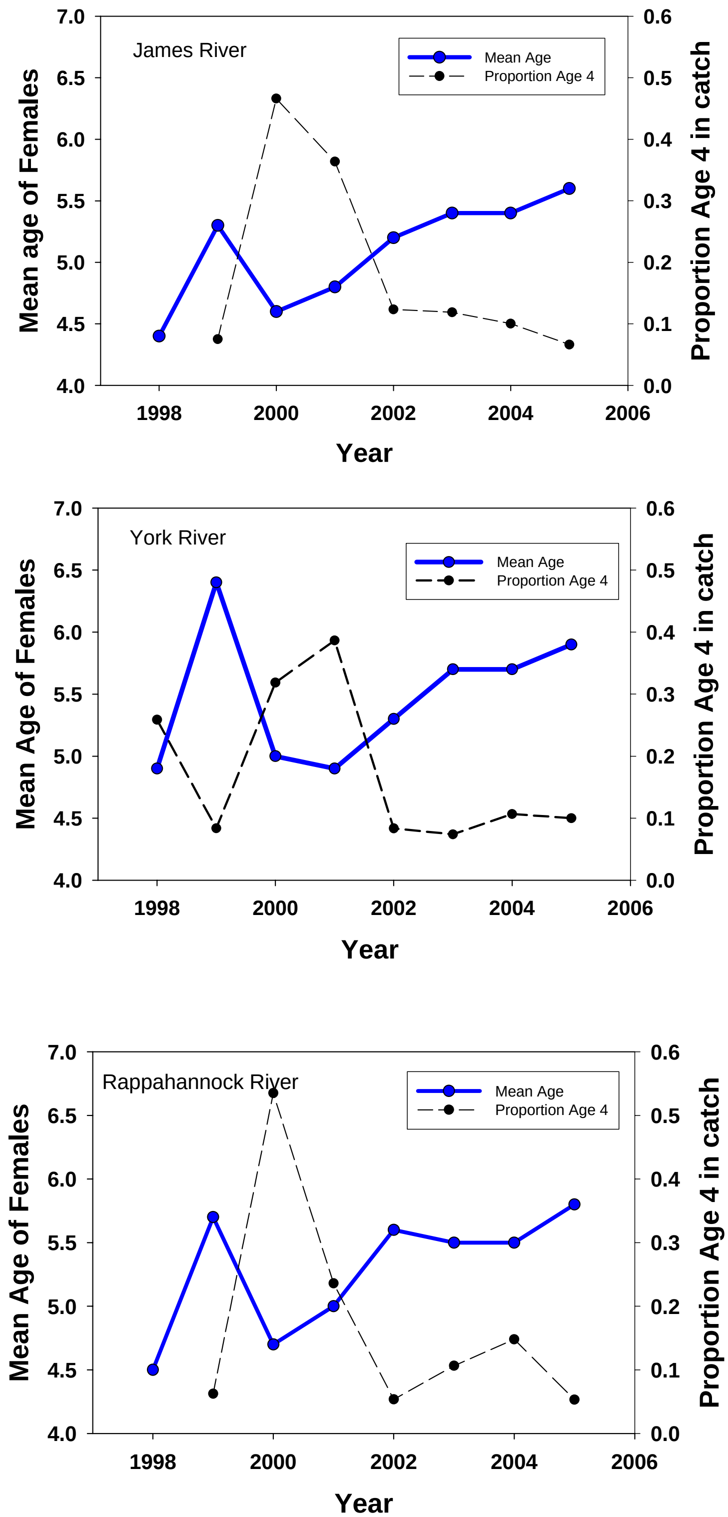
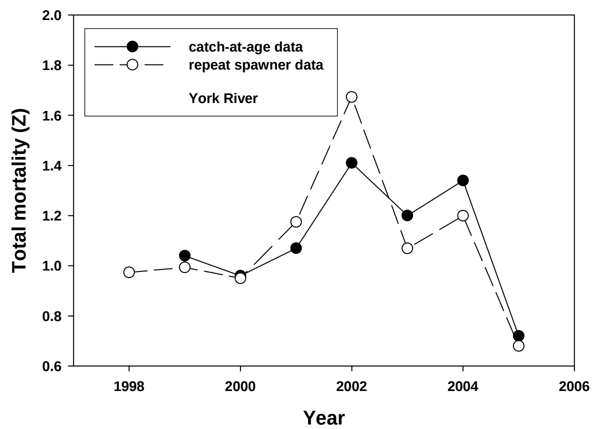
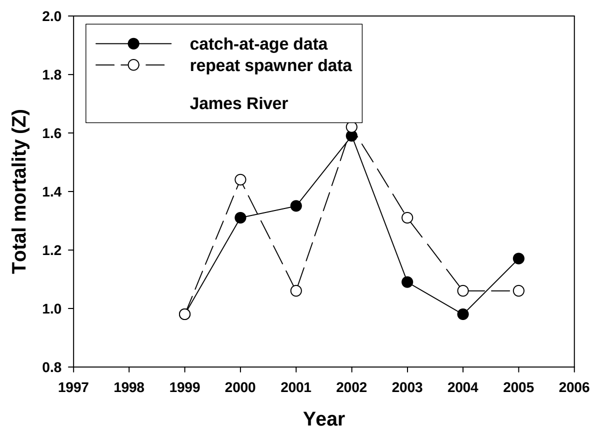


Figure 12.14 Estimates of total mortality (Z) of mature American shad in Virginia's rivers using catch-at-age and repeat spawning data.





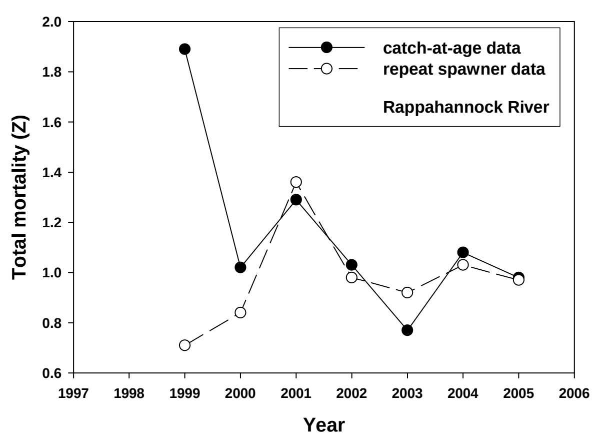
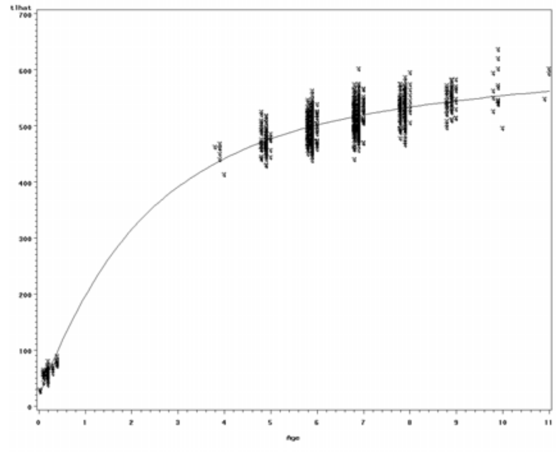
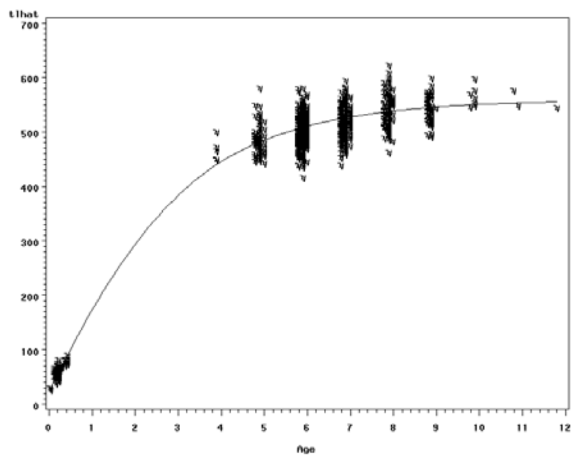


Figure 12.15 Best fit growth models on the (a) York—Linear von Bertalanffy; (b) James—Richards; and (b) Rappahannock—Linear von Bertalanffy—rivers, 2002-2005.

(a)



(b)



(c)

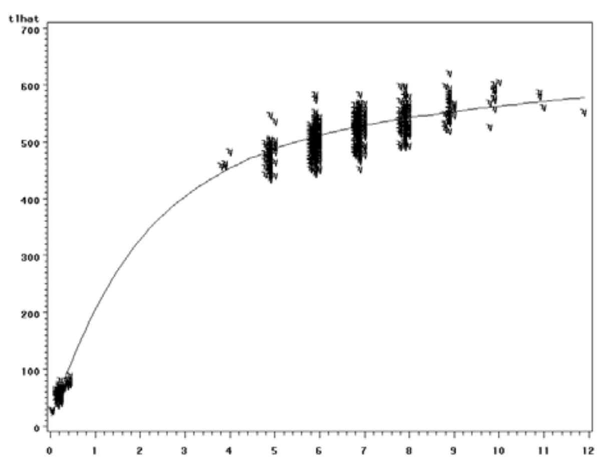


Figure 12.16 Recent (1998-2005) and historic values of the VIMS catch index of female American shad on the York River. Horizontal lines are the geometric means of each data set (solid, 1980s; short dashes, current).

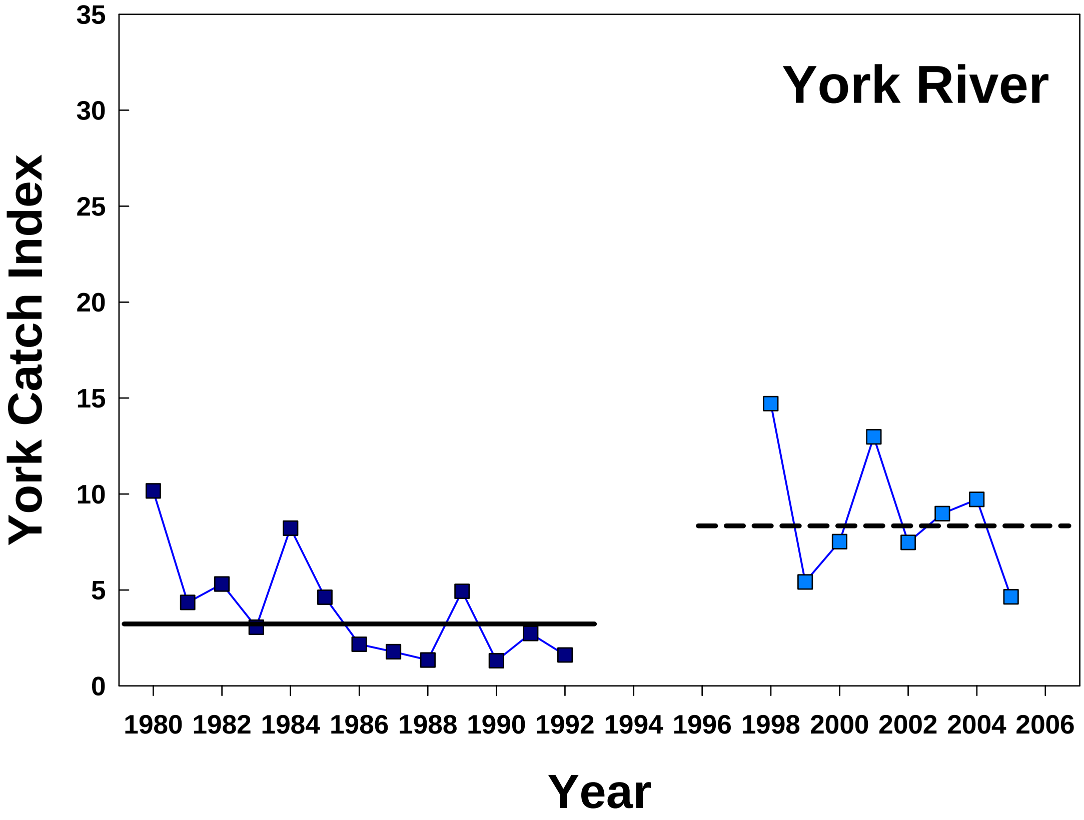


Figure 12.17 Catch indexes of historical logbook data from the 1950s (M. Greene), the 1980s (R. Kellum), and current VIMS monitoring. The 1950s data have been adjusted based on gear comparison trials following Maki *et al*. (2006). Horizontal lines are the geometric means of each data set (solid, 1950s; short dashes, current; long dashes, 1980s).

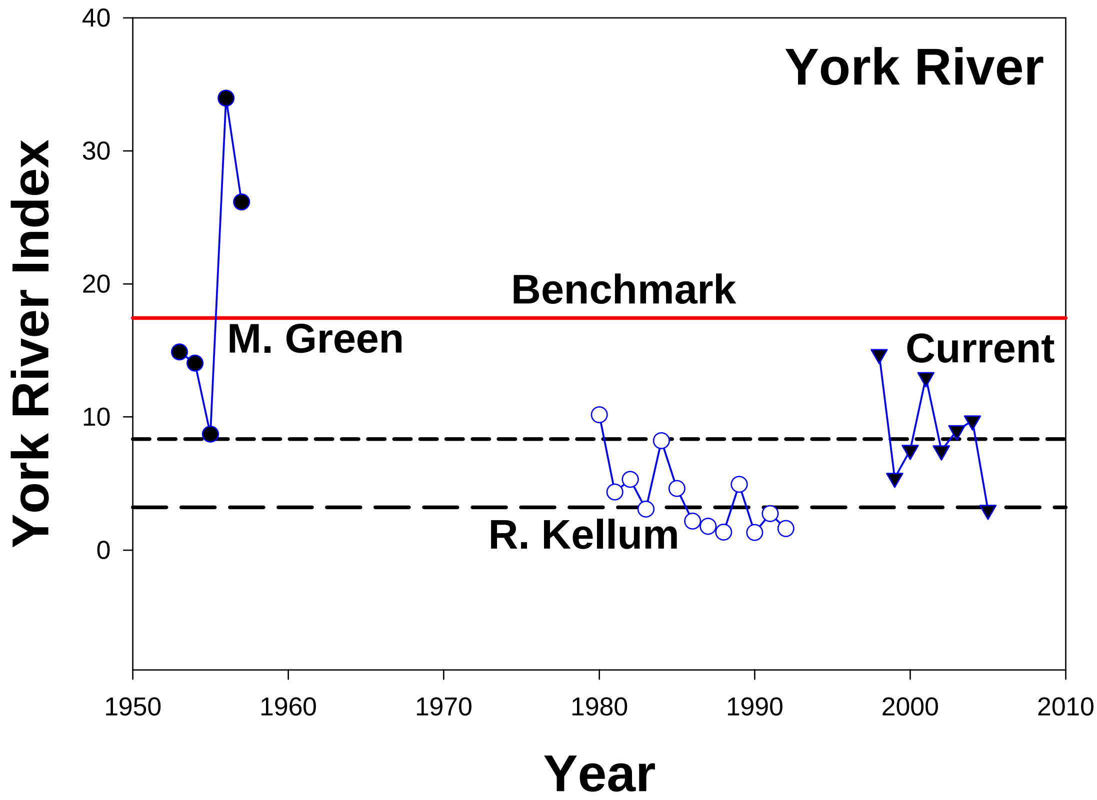
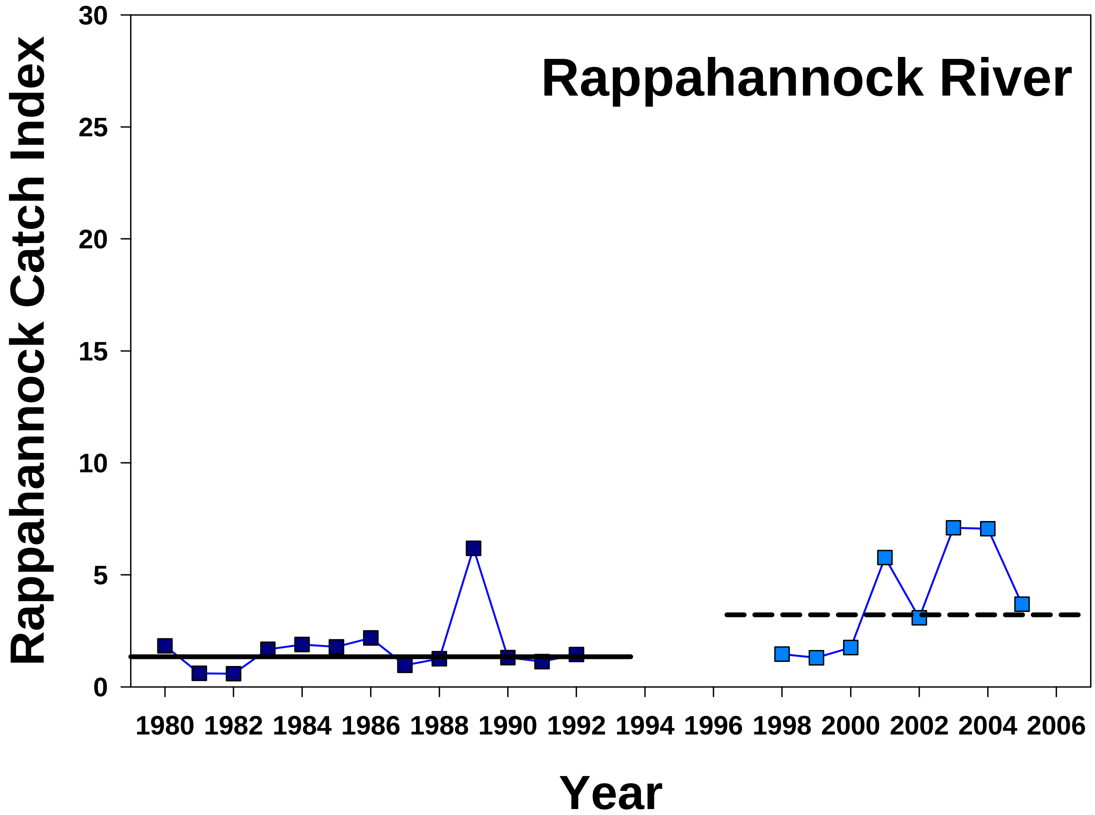


Figure 12.18 Recent (1998-2005) and historic values of the VIMS catch index of female American shad on the Rappahannock River. Horizontal lines are the geometric means of each data set (solid, 1980s; short dashes, current).



Section 13
Status of American Shad Stocks in North Carolina

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13.1 INTRODUCTION

American shad have historically supported a significant fishery in North Carolina. Native Americans and European colonists who settled along the extensive sounds and rivers found shad to be a valuable food source. Shad ascended the streams in large numbers during the spring and were caught, salted, and smoked, serving as an important seasonal food.

Shad are pursued extensively in the spring, both commercially and recreationally. In recent years, the commercial importance of shad has decreased in some areas, while the species supports an increasingly important recreational fishery in others.

American shad ascend all coastal rivers in North Carolina and are most abundant in the Roanoke, Chowan, Tar-Pamlico, Neuse, Northeast Cape Fear, and Cape Fear rivers as well as Albemarle and Pamlico sounds (Street *et al*. 1975; Marshall 1976; Sholar 1977; Fischer 1980; Hawkins 1980a; Hawkins 1980b; Johnson *et al*. 1981; Winslow *et al*. 1983; Winslow *et al*. 1985). Commercial fishermen indicate that significant anadromous populations once existed in the New River and were presumed to include American shad, but now it appears that these stocks are in low numbers, probably due to channelization and development (Sholar 1975). Throughout the coastal area, the fishery employs drift gill nets, anchor gill nets, pound nets, haul seines, bow nets, and hook and line to harvest shad.

As with other states, American shad stocks in North Carolina have been impacted by dam construction, loss of habitat, degradation of water quality, and in some instances excessive harvest. All of these factors combined have contributed to the decline in shad stocks.

Considerable research has been conducted on American shad in North Carolina, particularly in the Neuse River (Walburg 1957) and Cape Fear River (Davis and Cheek 1966; Nichols and Louder 1970). Some offshore work was conducted on shad during 1968 to 1971 (Holland and Yelverton 1973). In the early 1970s, the North Carolina Division of Marine Fisheries (NCDMF) began anadromous fish assessments in each of the major coastal sounds and river systems. Data have been collected on spawning areas, nursery areas, juvenile abundance, adult abundance, age and sex composition of the catch, and commercial and recreational fisheries statistics for each area. Most of this work was conducted with Anadromous Fish Conservation Act (PL 89-304) funds. Due to a reduction in these funds in 1981 and again in 1992, personnel and operations funds were lost. For a period of up to 23 years many of these systems were not surveyed for American shad and only commercial landings data were obtained. The NCDMF and the North Carolina Wildlife Resources Commission (NCWRC) began collecting fishery-dependent and fishery-independent data on American shad in 2000 to address compliance requirements of the ASMFC Interstate Fishery Management Plan for Shad and River Herring.

13.2 MANAGEMENT UNIT DEFINITIONS

The management area for American shad includes North Carolina's coastal and inland waters out to the 3-mile limit of state jurisdiction. Aquatic resources and habitat in coastal waters are managed by NCDMF and include the Atlantic Ocean out to three miles, coastal sounds, and estuarine waters. Aquatic resources and habitat in inland waters are managed by NCWRC.

13.2.1 Albemarle Sound

The Albemarle Sound area includes Albemarle Sound, all of its tributaries, Currituck, Roanoke, and Croatan sounds, and all of their tributaries. Albemarle Sound, located in the northeastern portion of North Carolina, is a shallow estuary extending 88.5 km in an east-west direction averaging 11.3 km wide and 4.9–6.1 m deep (Figure 13.1). Ten rivers drain into Albemarle Sound, which joins Pamlico Sound through Croatan and Roanoke sounds, and in turn, empties into the Atlantic Ocean via Oregon Inlet. Currituck Sound joins Albemarle Sound from the northeast. Although the headwaters of the Roanoke River are located in the Appalachian foothills of Virginia, most of the tributaries to the Sound originate in extensive coastal swamps. The Roanoke and Chowan Rivers are the principal tributaries, and areas of these rivers are known to function as American shad spawning areas (Street *et al.* 1975; Johnson *et al.* 1981; Winslow *et al.* 1983; Winslow *et al.* 1985; Hightower and Sparks 2003). American shad spawning occurs in the Chowan River system in Virginia where the River divides into the Blackwater and Nottoway Rivers. The upper Meherrin River, a tributary of the Chowan River, also functions as a spawning area in North Carolina and Virginia. Spawning also occurs in the Roanoke River near Weldon and Roanoke Rapids.

13.2.2 Roanoke River

The Roanoke River is a relatively narrow stream that follows a winding course to its mouth below Plymouth, where it enters western Albemarle Sound (Figure 13.1). The Roanoke River watershed arises in the mountains of Virginia and covers 25,035 square km; only 9,081 square km of the basin lies within North Carolina (NCDWQ 2001). Fifteen counties and 42 large municipalities (e.g., Greensboro, Winston-Salem, High Point, Roanoke Rapids, Williamston, Plymouth) are represented within the North Carolina portion of the basin. Near the North Carolina-Virginia border, John H. Kerr Reservoir, Lake Gaston, and Roanoke Rapids Lake impound the Roanoke River. The U.S. Army Corps of Engineers (USACOE) and Dominion/NC Power Company operate these reservoirs for flood control and hydropower generation. A dam was constructed in 1955 on the River at Roanoke Rapids, North Carolina, 220.6 km from the mouth (Carnes 1965). This dam does not have facilities for fish passage and is therefore the upper limit of migration. Recent studies have shown that American shad accumulate in the Roanoke Rapids area, and newly-spawned American shad eggs have been collected there (Knutzen 1997; Hightower and Sparks 2003; Thomas and Kornegay 2004; Harris and Hightower 2007). Downstream of Roanoke Rapids Lake, flows in the Roanoke River are highly regulated by discharges from the dams. From the Roanoke Rapids Dam, the Roanoke River flows 221 km through an expansive area of bottomland hardwood wetlands to its confluence with Albemarle Sound. Major tributaries of this lower section of the Roanoke River include Broad Creek, Devil's Gut, Broad Neck Swamp, Conoho Neck Swamp, and the Cashie River.

13.3.3 Tar-Pamlico River

The Tar-Pamlico watershed is the fourth largest in North Carolina encompassing 14,090 square km (Figure 13.1). From its headwaters in Person County, the Tar-Pamlico watershed is drained by 3,790 km of tributaries along its 290 km main-channel length to Pamlico Sound near the confluence of the Pungo River (NCDWQ 1999). River reaches upstream of the City of Washington are designated as the Tar River and are primarily freshwater, while the reach below Washington, referred to as the Pamlico River, has characteristics of an upper estuary. Sixteen counties and six large municipalities (Greenville, Henderson, Oxford, Rocky Mount, Tarboro, and Washington) are represented within the basin. Major tributaries to the river include Fishing, Swift, and Tranters creeks, Cokey Swamp, and the Pungo River. Main stem headwater reaches and tributaries are located within the outer piedmont physiographic region and are characterized by low flows during dry seasons due to minimal groundwater discharge (NCDWQ 1999). However, since the majority of the basin is located within the coastal plain, these waters are largely characterized by slow flowing, low gradient, brown and blackwater streams with extensive floodplains often comprised of bottomland hardwood forests and marshes.

13.3.4 Neuse River

The Neuse River is formed by the confluence of the Eno and Flat Rivers in the Piedmont region of North Carolina and flows in a southeasterly direction through the coastal lowlands discharging into Pamlico Sound 430 km from its origin (Hawkins 1980b; McMahon and Lloyd 1995; Figure 13.1). Through the Piedmont, the Neuse River has a relatively high gradient, and substrates tend to be rocky (McMahon and Lloyd 1995). As the river passes through the fall line into the coastal lowlands, it widens and slows with the reduced gradient. Downstream of the fall line, substrate is dominated by sand and silt (McMahon and Lloyd 1995). The Neuse River resides entirely within North Carolina and drains approximately 14,500 square km of land, which is composed of approximately 48% forest, 30% agriculture, 9% wetlands, 6% developed lands, and 5% water (Hawkins 1980b; McMahon and Lloyd 1995). Flow regimes in the Neuse River downstream of Raleigh, North Carolina are controlled by Falls Lake Dam (river km 370), which was built in 1983 by the USACOE to create an impoundment for flood control, water supply, water quality, and recreational purposes. Spawning of American shad has been documented in the main stem Neuse River up to the first dam near Raleigh and in several tributaries: Contentnea Creek, Mill Creek, Little River, Swift Creek, and Crabtree Creek (Burdick and Hightower 2006).

13.3.5 Cape Fear River

The Cape Fear River, the largest river system in the state, forms at the confluence of the Deep and Haw rivers in the Piedmont region of North Carolina and flows southeasterly for approximately 274 km where it discharges into the Atlantic Ocean at Cape Fear, near Southport, North Carolina (Figure 13.1). The basin lies entirely within the state, includes portions of 27 counties and 114 municipalities, and encompasses 9,984 km of freshwater streams and rivers, 36 lakes and reservoirs, and 15,864 ha of estuarine waters (NCDWQ 1995). Major tributaries include the Upper and Lower Little Rivers in Harnett County, the Black River in Bladen, Pender, and Sampson counties, and the Northeast Cape Fear River in Duplin, Pender, and New Hanover counties.

13.3 REGULATORY HISTORY

Since the early 1900s various commercial regulations have governed the American shad fisheries in North Carolina. Gear and area restrictions were adopted, as well as a closed season for American shad harvest from May through June, during 1955 to 1965. No recreational restrictions were in place during these years.

Prior to 1987, few limits were placed on commercial fishing (e.g., no mesh size or yardage limits, seasons, or closed areas). In 1988, the North Carolina Marine Fisheries Commission (NCMFC) instituted an area closure for a portion of Albemarle Sound, along with gill-net mesh restriction in other areas. In 1995, further rules were adopted that established a closed season for American shad. The rule made it unlawful to take American shad for commercial purposes by any method from April 15 through January 1 [15A NC Admin Code 3M.0513]. At the present time this season remains in effect. The season has greatly reduced the harvest, since historically a large portion of the American shad harvest occurred after April 15 and into May. Area closures to gill nets, as well as yardage and mesh size restrictions, occur and vary between management units. In addition, fishing restrictions for striped bass prohibited shad fishing in some years. No quotas exist for American shad in North Carolina. North Carolina's ocean fishery for American shad was closed in 2005 (see Section 13.9).

In North Carolina, it is unlawful to possess more than 10 American shad per person per day by hook and line for recreational purposes. It is unlawful to take American shad by any method except hook and line from April 15 through December 31 [15A NC Admin Code 3M.0513].

13.4 ASSESSMENT HISTORY

Regional assessments were conducted by Winslow (1990) and Hightower *et al*. (1996), and coastwide assessments were completed by Gibson *et al*. (1988) and ASMFC (1998).

13.4.1 Gibson *et al*. (1988)

Gibson *et al*. (1988) provided an assessment of selected Atlantic coast rivers that included the Chowan, Tar, Neuse, and Cape Fear rivers. North Carolina river systems were found to be more resilient to higher exploitation rates than other Atlantic coast systems. However, F_{msy} estimates were subject to bias from measurement errors in CPUE and stock-recruitment data, poor precision about F_{msy} estimates, and random variability about stock-recruitment models related to environmental effects on recruitment. The assessment recommended that F not exceed 0.50 for extended periods of time for all Atlantic coast rivers.

13.4.2 Winslow (1990)

This assessment focused primarily on Albemarle Sound. Winslow (1990) found that shad resources in Albemarle Sound, North Carolina continued to be depressed despite slight increases during previous years. Winslow (1990) stated that American shad and "civilization" are probably not compatible, and it is doubtful they can ever be restored to the status of the late 19th century. Changes have occurred in the spawning and nursery areas as a result of the encroachment of man, from reduction in size in some areas to complete elimination in others.

At the time, anadromous fish studies in Albemarle Sound did not yield sufficient information to evaluate the reason for the decline. One of the major deficiencies identified was a lack of catch-effort data. Once catch and effort statistics have been obtained for several years, studies could proceed to determine population sizes, trends, and factors responsible for fluctuations in abundance, and appropriate management measures could be developed. In addition, information on harvest and utilization was desperately needed; without it the shad population could never be adequately evaluated.

Winslow (1990) recommended that action be taken to reduce or eliminate pollution and habitat destruction. With needed biological data, reliable harvest data, and productive habitat, there was no reason why the American shad population in the Albemarle Sound area, as well as throughout eastern North Carolina, could not again support significant fisheries.

13.4.3 Hightower *et al*. (1996)

Hightower *et al*. (1996) examined catch-per-unit-effort (CPUE) data from a haul seine fishery that operated on western Albemarle Sound from 1845 through 1907. The authors fit a biomass-based model to the data and estimated a population growth rate (r) of 0.5 to 0.9. Estimated maximum sustainable yield was 0.9-1.8 million kg. The authors noted that recent harvest has been well under this level and recommended that current estimates of fishing rates be obtained for the stock.

13.4.4 ASMFC (1998)

ASMFC (1998) completed an assessment of American shad stocks along the Atlantic coast. Systems assessed in North Carolina included Albemarle Sound, Cape Fear River, Neuse River, and Pamlico River. ASMFC (1998) found that landings in Albemarle Sound had been relatively stable from 1982 to 1990 but had declined in the last few years and suggested a serious decline in overall abundance. However, there were no estimates of fishing effort available. ASMFC (1998) also noted that total mortality estimates from Albemarle Sound and landings of coastal shad had remained relatively stable for more than a decade, which suggests that the decline in landings was likely due to a decrease in effort and not due to an actual decline in stock abundance.

Downward trends were also noted in landings from the Pamlico, Neuse, and Cape Fear rivers from 1987 to 1996. However, fishing mortality could not be estimated. Therefore, it could not be determined whether the decline in in-river commercial landings indicated an actual decline in the stock or if it was caused by a reduction in fishing effort.

13.5 STOCK-SPECIFIC LIFE HISTORY

American shad in Albemarle Sound show a slightly different life history strategy than stocks found in other systems in North Carolina and closely mirror those systems to the north. American shad populations in North Carolina river systems south of Albemarle Sound form a region where stocks transition from the iteroparous stocks in the north to the semelparous stocks seen in the south. In addition, American shad take slightly longer to mature in Albemarle Sound than in the rest of the state. American shad are fully mature at age-7 and 8 in Albemarle Sound, while shad in other North Carolina systems reach full maturity at age-6 and 7 (Table 13.1). It should be noted that conclusions of life history traits based on ages, such as maturity and growth, are subject to errors due to differences in readers determining ages from scales across systems.

13.5.1 Growth

Fractional ageing was applied to von Bertalanffy growth curves for males and females in each system (Figures 13.2-13.8). All measurements of fork length were converted to total length by multiplying by a conversion factor of 1.128 derived from NCDMF data via linear regression. Female American shad are roughly 10 percent larger than males. American shad from Albemarle Sound have a higher asymptotic length (L_∞) than those from other systems in the state (Table 13.2).

Male American shad from Albemarle Sound have an L_∞ of 572 mm TL and females have an L_∞ of 608 mm TL. The L_∞ of males from other systems averaged 505 mm TL, and the L_∞ of females averaged 556 mm TL.

Shad are relatively fast growing fish. The rate at which shad approach L_∞ (k) is lowest for Albemarle Sound where both males and females have a k of 0.36 (Table 13.2). The k is higher for other systems in the state with an average of 0.59 for females and 0.51 for males.

13.5 Reproduction

American shad spawning has been documented in the Roanoke River (Johnson *et al*. 1978; Hightower and Sparks 2003; Harris and Hightower 2007), Chowan River (Meherrin, Blackwater, and Nottoway rivers) (Street *et al*. 1975; Johnson *et al*. 1981; Winslow *et al*. 1983; Winslow *et al*. 1985), Tar-Pamlico River (Hawkins 1980a; Winslow *et al*. 1983), Neuse River (Baker 1968; Hawkins 1980b; Burdick and Hightower 2006), and Cape Fear River systems (Sholar 1977; Fischer 1980; Winslow *et al*. 1983). Shad begin entering the sounds and rivers as early as February. Spawning of American shad normally occurs from early April to late May, depending on the water temperature and the system. There is generally a south to north progression in the systems.

13.5.3 Fecundity

Holland and Yelverton (1973) reported that the fecundity of American shad age-5 to 9 off of the North Carolina coast ranged from 197,323 to 457,530 with a mean of 281,137. There are no known fecundity estimates for American shad from the internal waters of North Carolina.

13.6 HABITAT DESCRIPTIONS

The NCDMF conducted American shad spawning area surveys between 1973 and 1984 in the major coastal tributaries. Physical characteristics of the spawning grounds vary somewhat between systems. Shad may spawn anywhere within a given spawning area but prefer shallow flats composed of sand, gravel, or a combination of the two bordering the rivers (Smith 1907; Walburg and Nichols 1967; Beasley and Hightower 2000; Hightower and Sparks 2003). Water conditions may vary from clear to very turbid, water depth ranges from 3 to 30 ft, and temperatures may range from 8 to 26°C (Walburg and Nichols 1967; Winslow 1990).

Shad eggs are non-adhesive and slightly heavier than water, so they gradually sink and are carried along by currents (Ulrich *et al*. 1979). Sufficient water current is required to keep eggs suspended in the water column for successful development (Cheek 1968; Sholar 1977). This requirement may explain why American shad spawning was found only in the Nottoway, Blackwater, Meherrin, Roanoke, Tar, Neuse and Cape Fear rivers, all of which have relatively strong currents compared to other coastal rivers in the state. All American shad spawning areas have been documented either by capture of eggs or larvae, or direct observation of spawning.

Numerous miles of spawning and nursery area habitat have been eliminated due to lock or dam systems that exist on the Cape Fear, Neuse, Tar, Roanoke, Meherrin, and Nottoway rivers. These “blockages” have greatly reduced the historical spawning runs of American shad in North Carolina. In general, recent cost-benefit evaluations of these impediments have revealed that some dams are more costly to operate and maintain than to remove (Hart *et al*. 2002). As such, recent and ongoing studies are documenting the effects of dams on anadromous fish migrations and spawning in North Carolina.

Removal of dams may enhance the migration of anadromous fish. On the Neuse River, the potential spawning habitat available to anadromous fish increased by a total of 127 main stem river kilometers (rkm) after the removal of the Quaker Neck Dam in 1998 (Beasley and Hightower 2000). Bowman and Hightower (2001) documented significant migration of American shad in the main stem beyond the previous impediment. In addition, Burdick and Hightower (2006) observed spawning activity of American shad during sufficient instream flow in the enhanced barrier-free stretch of the Neuse River.

Some dams must remain in place, but alternate measures are being studied to decrease their negative ecological effects. Currently, the Roanoke River is unimpeded for 221 rkm from the mouth to the hydroelectric dam at Roanoke Rapids (Hightower *et al*. 1996). In addition, there are two dams upstream of the Roanoke Rapids Dam: Gaston Dam and Kerr Dam. With the recent Federal Energy Regulatory Commission (FERC) relicensing of the Roanoke Rapids and Gaston dams, provisions have been made to include a trap and transport program to relocate adult American shad above Kerr Dam. During the relicensing period, Read (2004) estimated that there was over 300 rkm of potential spawning habitat available to American shad above Kerr dam. Thus, the proposed trap and transport program may be an alternative means of re-connecting historic, but currently inaccessible, shad spawning habitats.

13.7 RESTORATION PROGRAMS

The fluctuations of landings of the 1800s indicated that there was a problem with the American shad population; overfishing was thought to be the primary reason for the decline in harvest. To compensate for this, the federal government began artificial propagation of shad in New Bern, North Carolina in 1873. Fry that hatched were released into local waters. In 1877, the state began fish culture operations of its own on the Neuse River at several locations above New Bern (Smith 1907). The shad hatching of 1878 was noteworthy because it was conducted jointly with representatives from the U.S. Fish Commission, Virginia, Maryland, and North Carolina. The operation was sited at Salmon Creek at the head of Albemarle Sound and, having produced a million fry, the production was the most successful up to that time (Smith 1907). The federal government continued shad hatching in 1879 at the mouth of the Chowan River. In 1880, the state constructed a shad hatchery in Avoca, North Carolina and used eggs furnished by the Capehart seine fisheries at Sutton Beach and Scotch Hall. The MacDonald hatching jar was adopted in 1882, and North Carolina was the first state to employ this important device (Smith 1907). The state continued to operate the hatchery in Avoca until 1884, but all culture work ended in 1885.

Records indicate landings doubled from 1880 to 1887 through 1890, then doubled again by 1897. After this period of massive harvest, landings declined precipitously in spite of continued stocking. In 1943, the federal government decided artificial propagation as practiced was of little value in maintaining the shad population; consequently, stocking was discontinued (Walburg and Nichols 1967).

13.7.1 Restoration Objective

Restoration efforts are currently underway to increase the shad population in the Roanoke River and restore shad runs to historic spawning areas above the Gaston and Roanoke Rapids lakes hydroelectric dams. American shad fry reared at the U.S. Fish and Wildlife Service's Edenton National Fish Hatchery and at NCWRC's Watha Fish Hatchery have been stocked annually into the Roanoke River since 1998 (Table 13.3). This restoration project was initiated by NCWRC and funded by the North Carolina Department of Transportation as mitigation for aquatic habitat damages resulting from highway bridge construction on the Roanoke River.

13.7.2 Hatchery Evaluation

Initial attempts in 1998 at field collection and fertilization of American shad eggs met with limited success. In 1999, both hatcheries began developing hormone injection and tank spawning techniques to increase fry production. Also in 1999, NCWRC began coordination of fry marking (oxytetracycline (OTC)) and stocking activities with the ad hoc interstate OTC Marking Task Force.

Following protocols of other states involved in American shad restoration efforts, brood stock for fry production were obtained from nearby rivers with adequate shad stocks. American shad brood fish were collected by electrofishing. Upon collection, brood fish were placed in circular tanks with continuously circulating water onboard electrofishing boats, and were then transferred to large circular, trailer-mounted tanks for transport to the hatcheries. Upon arrival at the hatcheries, brood fish were injected with hormone

(LHRHa pellets) and transferred to circular spawning tanks. As spawning occurred, eggs were siphoned into a collection vessel and transferred to McDonald hatching jars for incubation. Hatched fry swam up and into aquaria and were fed brine shrimp until stocked.

From 1999 through 2001, American shad fry reared and stocked in the Roanoke River were OTC marked with a 3, 6, and 12-day combination in accordance with protocols established by the OTC Marking Task Force. In 2002, after revision of the discrete OTC marking requirements by the ASMFC Shad and River Herring Technical Committee, American shad fry reared in North Carolina were marked with a 3-day mark. In 2003, a single mark (3-day) was applied to fry stocked in the Roanoke River below Roanoke Rapids Dam and a double mark (3 and 6-day) was applied to fry to be stocked in the headwaters of the Roanoke River, above John H. Kerr Reservoir. A new marking protocol was established in 2004 that called for a 6-day single mark for fry stocked in the Roanoke River below Roanoke Rapids Dam, and a double mark (6 and 9-day) for fry stocked in headwater areas above John H. Kerr Reservoir. In 2005, a 9-day single mark was used for fry stocked in the Roanoke River below Roanoke Rapids Dam while a 3 and 9-day double mark was used for fry stocked in headwaters above the dams at Alta Vista, Virginia. The use of a single mark for fry stocked below the dams and a double mark for fish stocked above the dams has been consistent since 2003.

Success in tank spawning and rearing fry has varied from year to year but is generally increasing. Continuing experimentation with hormone formulations is expected to improve production although highly variable hatching success among batches of brood stock remains problematic.

Through 2002, all American shad fry produced were stocked in the Roanoke River below Roanoke Rapids Dam. In 2003, 1,081,289 American shad fry were stocked in the Staunton River, Virginia, a headwater tributary of the Roanoke River upstream of John H. Kerr Reservoir. Gaston and Roanoke Rapids dams, built in the 1950s and 1960s, along with John H. Kerr (USACOE) Dam, built in the 1940s, have blocked access for American shad to the upstream reaches of Roanoke River that once likely functioned as spawning habitat. Historical records indicate that before construction of dams on the Roanoke River, American shad ascended the river and its tributaries well into the Piedmont region of Virginia and to the Blue Ridge foothills near Salem, Virginia. This fry stocking in 2003 marked the first attempt at reintroducing American shad to the upper Roanoke River basin. An additional 1,204,340 fry were stocked in the Roanoke River below Roanoke Rapids Dam in 2003 as well. The strategy of stocking fry both in the Staunton River above John H. Kerr Reservoir and in the main stem Roanoke River below Roanoke Rapids Dam continued in 2004 and 2005. During 2005, an estimated 1,346,834 fry were stocked into the Roanoke River below Roanoke Rapids Dam in the vicinity of Weldon, North Carolina. An additional 1,226,000 fry were stocked above John H. Kerr Dam in the Staunton River near Alta Vista, Virginia. The total number of American shad fry stocked into the Roanoke River system in 2005 was 2,572,834 (Table 13.3).

In 2003, otoliths of young-of-year American shad collected from the lower Roanoke River in 2000, 2001, 2002, and 2003 were examined for the presence of OTC marks. In addition, otoliths from 50 small adult male American shad, presumably shad that could have been three and four year-old fish resulting from the initial fry stockings in 1998 and 1999, were examined. No OTC marks were detected on otoliths from the adults and no OTC marks were detected on otoliths of juveniles collected during 2000 and 2001 (Table 13.3). In 2002, out of 148 juvenile American shad collected in the lower Roanoke River, OTC marks were seen on otoliths from two specimens. In 2003, 130 juvenile American shad were collected; two having a single 3-day OTC mark on their otoliths (one 73 mm and one 87 mm in length) and four with the double 3 and 6-day OTC mark (lengths ranged from 58 to 86 mm; Table 13.3).

Otolith examination of 228 juvenile American shad collected in the lower Roanoke River in 2004 discovered 10 fish of hatchery origin (Table 13.3). Of these 10 juveniles, five had been stocked as fry below Roanoke Rapids Dam (6-day mark) and ranged in size from 78-94 mm; these fish were collected as early as August 16 and as late as October 25, 2004. The other five juveniles (size range 59-80 mm) had been stocked above John H. Kerr Reservoir and were recaptured on three separate dates in August 2004.

Examination of 420 juvenile American shad otoliths collected from the lower Roanoke River in 2005 revealed 38 fish of hatchery origin (Table 13.3). Of these 38 juveniles, 29 were stocked as fry below Roanoke Rapids Dam (9-day mark) while 9 were stocked above John H. Kerr Reservoir (3 and 9-day mark). The recovery of juvenile, hatchery-origin American shad that were stocked in the headwaters of the Roanoke River basin continues to suggest that these fish are able to successfully navigate through three main stem reservoirs and down the Roanoke River near its confluence with Albemarle Sound. In addition, 61 adult Roanoke River American shad were sacrificed for otolith analysis in 2005, one of which was an OTC-marked male from a 2002 fry stocking at Weldon. This was the first documented survival to spawning age of a hatchery-reared American shad in the Roanoke River. Otoliths from a total of 106 adults collected in 2006 are being analyzed at this time. Though confirmation by an independent expert reader is still in progress, indications are that two of these fish, both males, were of hatchery origin.

State and federal fisheries management agencies in North Carolina and Virginia have finalized negotiations with Dominion/North Carolina Power with regards to relicensing of the Gaston and Roanoke Rapids lakes hydroelectric dams through FERC. Among the mitigation measures agreed to as a condition of relicensing include a long-term, well-funded, and coordinated program to restore American shad in the Roanoke River basin. Measures outlined to be included in this effort are improvements in hatchery production of fry, continued intensive monitoring of fry stocking success upstream and downstream of the main stem reservoirs, experimentation with radio-telemetered spawners trapped and hauled to upstream reservoirs, and finally, assessment of the feasibility of providing upstream passage facilities. During 2005, Dominion purchased and assembled an American shad haul tank, stock assessment sampling continued, hydroacoustic-based population estimate work continued, an American shad turbine mortality study was completed, a bypassed reach flow management and monitoring plan was developed, a recreation plan was developed, and planning for studies of lower river erosion and the biological effects of hydropower peaking was initiated.

13.7.3 Trap and Transport

Initial trap and transport of adult American shad is scheduled for the Gaston and Roanoke Rapids lakes hydroelectric dams on the Roanoke River in 2007.

13.8 AGE

The NCDMF collected scale-based age data from the American shad commercial fisheries from 1972 to 1993 and 2000 to 2005 in the Albemarle Sound area and from the Pamlico, Neuse, and Cape Fear rivers during the mid 1970s through the mid 1980s. Collection of age data ceased from 1989 to 1999 but was reinstated in 2000 and has continued since. American shad samples were obtained from the ocean-intercept fishery from 2000 to 2004. Both NCDMF and NCWRC began collecting fishery-independent data in 2000.

American shad commercial fish house samples have generally been obtained from mid-February through May. The number of sample sites per system has varied over the years, but data collected at these sites were assumed to be representative of all commercial American shad landings. Project personnel visited various sites weekly to obtain samples.

Whenever possible, data from each site were obtained from unculled samples to determine sex composition and sex ratios. If an unculled sample was not available, data were recorded from as many fish as possible. During 1972 to 1978, sample sizes often varied with the number of fish available but normally did not exceed 100 fish per site per week. Up to 30 individuals were examined from each location, each week, during 1979 to 1993. The sampling years varied by system: Albemarle Sound (19720-1993), Pamlico River (1975-1976, 1978-1981, and 1983-1988), Neuse River (1977-1981 and 1983-1988), and Cape Fear River (1976-1980 and 1983-1988). All systems were sampled from 2000 to 2005. Since 2000, an annual target of 200 fish per system has been set.

Sex was determined and fork lengths (FL) were measured to the nearest millimeter for each fish sampled. For this assessment, fork lengths were converted to total lengths based on a conversion factor derived from North Carolina samples (TL = FL * 1.128). Individual weights in kilograms were taken only during 1972 and 1982 to 2005. Scale samples were taken from the left side below the insertion of the dorsal fin and just above the mid-line (Marcy 1969).

Age determination was based on Cating (1953) and Judy (1961). At least four of the most legible scales from each fish were read using a binocular microscope, an Eberbach projector, or a microfiche reader. For the majority of the time period two independent readings were made of scales for each fish. If readings were not in agreement, the fish was deleted from the sample. Following the method of Cating (1953), it was assumed that each fish had completed a full year's growth at the time of capture; thus, the scale edge was counted as a year mark.

Stratified sub-sampling for ageing was conducted during 1981 to 1993 and 2000 to 2003 due to the large number of American shad scale samples taken and the time-consuming process of ageing. The technique used, in which modal length groups were sub-sampled, was similar to that developed by Ketchen (1950). Shad were separated by sex into 25 mm modal size groups. If 15 or more samples were present, at least half of the scales in each size group were aged; in those groups with less than 15, all were aged. The sub-samples were expanded to obtain the age composition estimated for American shad.

Ageing methods differ between NCDMF and NCWRC. Therefore, the ageing data from each agency was analyzed separately. Age estimates from electrofishing collections from the Roanoke River and the Tar-Pamlico system were suspect. Change in annual mean age among years in these data sets did not mirror simultaneous changes in mean length suggesting inconsistent ageing techniques among years (see Section 13.11.1). Moreover, the numbers of repeat spawning marks were extremely high from the electrofishing collections in all river systems (see Section 13.9). The percent repeat spawners ranged from 5% to 89% for all systems averaging 55% for the Roanoke River, 70% for the Tar River, 67% for the Neuse River, and 53% for the Cape Fear River. These numbers were higher than most other systems along the Atlantic coast. Previous coastwide studies of American shad indicated that North Carolina is a transition zone between the iteroparous stocks in the north to the semelparous stocks in the south. For these reasons, age data from electrofishing collections from the Roanoke and Tar-Pamlico and all repeat spawning data from electrofishing collections were not used in assessment analyses. It should be noted that changes in readers among systems and through time could contribute to discrepancies in ageing results.

There has been no ageing validation done on American shad in North Carolina. It will be possible to validate ages upon return and recapture of OTC marked fish originally stocked by the NCWRC hatchery program in the Roanoke River.

13.9 FISHERY SURVEY DESCRIPTIONS

13.9.1 Brief Overview

Historically, American shad were abundant in all major rivers along the North Carolina coast. Shad fisheries became important around 1869, with the greatest development coming in the next 25 years

(Walburg and Nichols 1967). In 1896, the American shad harvest from Albemarle Sound was among the most important on the Atlantic coast. Historically, Virginia ranked first and North Carolina second (Walburg and Nichols 1967), but by 1960, the landings in North Carolina ranked third along the East Coast. Landings over the years have fluctuated widely but have shown a continued decline since the late 1800s (Figure 13.9).

There are four principal commercial fishing gears used in North Carolina to capture shad: anchor gill nets, stake gill nets, pound nets, and haul seines. These gears are essentially the same as those of the late 1800s although the length of these gears has changed and more modern materials are used for the manufacture of cordage. Gill nets now average 40 to 100 yards in length, and mesh sizes range from 4 to 5 ¾ inch stretch mesh (ISM). Fishermen may fish 1,000 to 6,000 yards per operation. The allowed mesh sizes and yardage vary by area in the state. Gill nets account for the majority of shad landings in the state.

During the late 1970s, an ocean-intercept fishery for American shad developed along the Outer Banks and in the southern part of the state (Table 13.4). The major gears for these fisheries were beach haul seines, gill nets, and trawls. Beginning in 1986, a significant ocean gill-net fishery for shad developed along the southern coast off the Cape Fear River area and accounted for up to 96 percent of the total ocean landings in the state (1986-2001).

In 1995, the North Carolina Marine Fisheries Commission (NCMFC) enacted a rule establishing a closed season for American shad making it unlawful to take American shad by any method except hook and line from April 15 through December 31. This season is in line with "historical" seasons that existed prior to 1960.

In 1999, NCMFC and NCWRC enacted a recreational hook and line creel limit of 10 fish per person per day in their respective jurisdictions. Substantial recreational fisheries occur within the Cape Fear, Neuse, and Tar rivers.

In 2000, North Carolina began a phase out program for the American shad ocean-intercept fishery. Annual total allowable catch (TAC) rates were set and dealers had to obtain permits, adhere to permit conditions, and report landings daily to NCDMF to monitor the TAC. Effective January 1, 2005, the ocean-intercept fishery for American shad was closed.

Currently, commercial American shad fisheries continue to occur in Albemarle Sound, Pamlico Sound, and the Pamlico, Neuse, and Cape Fear river systems. The commercial fishery operates under a set season (January 1-April 14); mesh size and yardage restrictions exist but vary by area. The recreational hook and line creel limit remains at 10 fish per person per day.

13.9.2 Commercial Fishery

Commercial Landings

Since the late 1800s, North Carolina has frequently ranked in the top three states for commercial landings of American shad along the East Coast (Walburg and Nichols 1967; NOAA 2007). American shad statewide landings records in North Carolina date back to the 1880s (Walburg and Nichols 1967). Chestnut and Davis (1975) reported that landings have fluctuated widely over the years but show a continued decline since the late 1800s (Figure 13.9). Landings of American shad peaked in 1897 at four million kg and had decreased to 0.7 million kg by 1918. A second peak of just over 1.4 million kg was reached in 1928. Landings declined and stabilized from 1930 to 1970 averaging 404,000 kg. Landings have declined since the early 1970s and have remained relatively stable with an average of 128,000 kg landed from 1973 to 2005. Since the late 1800s, overfishing, construction of dams, and pollution have been blamed for the decline in landings (Cheney 1896; Blackford 1916; Roelofs 1951; Chittenden 1969; Chittenden 1969; Klauda *et al*. 1976; Boreman 1981).

In North Carolina, commercial landings of American shad have been reported sporadically since 1880 and consistently since 1950 (Figure 13.9). Prior to 1978, North Carolina landings data were collected by the Division of Commercial Fisheries (U.S. Fish and Wildlife Service, Department of the Interior). From 1978 to 1993, commercial landings in North Carolina were acquired via an NCDMF and National Marine Fisheries Service cooperative statistics program on a monthly basis from licensed seafood dealers; however, reporting was not mandatory at that time. In 1994, NCDMF implemented a mandatory commercial harvest data collection system known as the Trip Ticket Program. The Trip Ticket Program is a dealer-based reporting program that obtains a trip-level census of commercial landings in North Carolina and continues to the present day.

Commercial Catch Rates

Estimates of fishery-dependent CPUE are only available after the inception of the North Carolina Trip Ticket Program (1994 to 2005). CPUE is calculated as total catch, in pounds, divided by the total number of directed shad trips. Directed trips are those trips landing at least 100 pounds of shad. This method assumes that effort was relatively uniform among trips with respect to net yardage and soak time. Exact estimates of yardage used are not available from the Trip Ticket Program. We feel estimates based on maximum yardage allowed are unrealistic and would over-inflate the amount of effort actually expended.

13.9.3 Recreational Fisheries

Prior to 1999, there were neither harvest restrictions on nor any directed fishery-independent survey of the American shad recreational fishery. Beginning in 2000, North Carolina was required to monitor the recreational harvest of American shad in one coastal river system each year on a rotating basis. To comply with ASMFC regulations, a creel survey was conducted by NCWRC on the Roanoke River in 2000 and 2001, Cape Fear River in 2002 and 2004, Neuse River in 2003, and Tar-Pamlico River in 2005. In 2002, NCDMF began surveying fishermen with Recreational commercial gear licenses (RCGLs); these licenses allow them to use limited types of commercial gear to harvest fish within recreational size and creel limits.

NCWRC personnel used a non-uniform probability stratified access-access creel survey design (Pollock *et al*. 1994) to estimate recreational fishing effort, catch, and harvest of sportfish from the various systems. Survey methods differed between river systems, and specific methods used are described in each system’s assessment section.

Recreational Commercial Gear License Survey

The North Carolina Fisheries Reform Act of 1997 required the NCMFC to establish limits on recreational use of commercial fishing gear. An individual holding a Recreational Commercial Gear License is allowed to use limited amounts of specified commercial gear to catch seafood for personal consumption or recreational purposes. The holder of the RCGL must comply with the recreational size and creel limits, and RCGL catch cannot be sold. Monthly surveys are conducted to collect data necessary for the production of RCGL catch and effort estimates. Estimates from RCGL surveys have been available since 2002.

The monthly survey questionnaires are designed to determine the number of trips taken and type and quantities of gear used during the month of survey. Participants are also requested to provide estimates for the numbers and pounds of each species caught and retained as well as the number of each species discarded. A sub-sample of the entire RCGL population is randomly selected to participate in monthly surveys. The population of RCGL holders for the monthly surveys includes all individuals who purchased a license within a year prior to each month sampled.

Two different rates of sampling are used throughout the year. A 30 percent coverage rate by county of residence for the period of May through December is used. This is the period when the bulk of RCGL holders are actively fishing and is sufficient for the gears used and majority of the species targeted. Species such as American shad are targeted during the months of January through April; however, many of the people that target these species are localized within the northern region where the RCGL population is relatively sparse, further exacerbating the ability to accurately produce landing estimates for this region and species combination. To provide more precise estimates for these species and regions, the sampling rate is increased from 30 to 40 percent.

Estimates are available for four regions in North Carolina: North, Pamlico, Central, and South (Figure 13.10). It is reasonable to assume that the majority of the American shad harvest comes from Albemarle Sound in the Northern Region, and the Cape Fear River in the Southern Region. The Pamlico and Central regions overlap several important spawning rivers, including the Tar-Pamlico and Neuse rivers. Because of the way the data for the Pamlico and Central regions are collected, we cannot distinguish which rivers within these regions are truly impacted by losses of American shad associated with this fishery.

Determination of the estimated catch for each species is calculated for each sample period and gear level by:

1. Summing the total catch by species, sample period, and gear combination,
2. Summing the total number of trips taken by sample period and gear combination,
3. Dividing the total catch by the total number of trips to determine the mean catch for each species for every sample period and gear combination, and
4. Multiplying the mean catch by the estimated effort.

A proportional standard error (PSE) was calculated for each trip and harvest estimate to provide a measure for comparing the precision of the estimates. The PSE expresses the standard error (SE) as a percentage of the estimate and is calculated as the SE divided by the estimate times 100. The precision of an estimate has an inverse relationship to the PSE—small PSEs indicating more precise estimates and larger PSEs indicating imprecise estimates. The de facto standard for acceptable levels of precision is a PSE of 20 (i.e., estimates with PSEs below 20 are considered good).

13.10 FISHERY-INDEPENDENT SURVEYS

13.10.1 NCDMF Adult Gill-net Survey

Since 1991, NCDMF has conducted an independent striped bass gill-net survey throughout the Albemarle Sound area; however, size, age, and sex data for American shad captured during this survey. Gill nets from 2 ½ to 7 ISM, in half-inch increments are used. Of these mesh sizes, commercial harvesters can only use gill nets of 3 ISM and ≥5 ½ ISM. The sound is divided into zones and grids, and random sites are selected within these areas for sampling. NCDMF also conducts gill-net surveys in the Pamlico River, and lower sections of the Neuse and Cape Fear rivers. CPUE is calculated as the number of fish per net sets for the months of March through May.

13.10.2 NCWRC Adult Electrofishing Survey

The NCWRC conducts electrofishing surveys for adult American shad on spawning grounds of the Roanoke (between Roanoke Rapids Dam and Weldon), Tar (between Rocky Mount Mills Dam and Tarboro), and Neuse (between Milburnie Dam and Goldsboro) rivers. On the Cape Fear River, electrofishing occurs in areas extending approximately 2 km downstream of the USACOE Locks and Dams numbers 1 (near East Arcadia), 2 (Elizabethtown), and 3 (Fayetteville). Sampling generally occurs one day per week during the spawning season and continues through the peak of the season. A boat-mounted electrofishing unit (Smith-Root 7.5 GPP) is used to capture fish during daylight hours and electrofishing time is recorded. All shad are collected as they are encountered. Annual relative abundance is indexed by CPUE expressed as number of fish captured per hour of electrofishing. Sex is determined, and each fish is measured for total length (TL mm). Scales are removed for ageing. To determine age, scales are examined at 33X magnification on a microfiche reader and annuli are counted. Spawning marks are recorded separately (Cating 1953). Shad that cannot be aged are assigned ages based on the gender-specific age-length key developed for each river, and included in CPUE and size-distribution analyses.

13.10.3 NCDMF Juvenile Sampling Survey

NCDMF samples young-of-year American shad only in Albemarle Sound. Eleven established seine stations have been sampled monthly from June to October of 1973 to 2005. During September, 13 additional seine samples are taken to determine distribution and annual variations of alosine species in the nursery area (Figure 13.11). Stations are sampled with an 18.5-m bag seine. Samples are sorted by species and fork length is measured on 30 randomly selected individuals. Other species are noted, in addition to water temperature, salinity, and dissolved oxygen levels.

No juvenile surveys are conducted for the Tar-Pamlico, Neuse, or Cape Fear Rivers.

13.10.4 Instantaneous Total Mortality Estimates

We compared estimates of instantaneous total mortality (Z) with a target rate (Z_{30}, see Section 1) developed with North Carolina stock data. Z-estimates were calculated using catch curve analysis. Sexes were analyzed separately for each river system for both fishery-dependent and fishery-independent data sets. Catch curves were performed using both ages and number of repeat spawning marks. Z-estimates were available from the NCDMF fishery-dependent gill-net survey sampling from 1972 through 1993. Since 2000, Z-estimates are available from both fishery-dependent and fishery-independent data collection programs. Age at full recruitment was determined from the top of the curve of the natural log of the catch-at-age for a given year.

13.11 ASSESSMENT APPRAOCHES, RESULTS AND CONCLUSIONS BY SYSTEM

13.11.1 Albemarle Sound and Roanoke River

Fishery-Dependent Data

Commercial Landings and Catch Rates

In Albemarle Sound, the majority of shad were landed with pound nets in the 1970s with gill nets composing the majority of the remaining harvest (Table 13.5; Figure 13.12). From 1978 to 1994, pound nets made up roughly a quarter of the total landings and gill nets roughly 75 percent. Since 1995, pound nets have been a relatively minor component of the landings, and the vast majority of shad are landed with gill nets.

Landings were fairly stable from 1972 to 1981, averaging 43,000 kg. Landings began to increase in 1982 and averaged 79,000 kg from 1982 to 1992. During this time, nearly half of the years had some of the highest landings on record. The period from 1993 to 1997 produced the lowest landings on record for Albemarle Sound, averaging only 28,000 kg. Since 1998, landings have fluctuated, averaging 70,000 kg. The landings for 2003 were the highest in recent years with 127,000 kg. However, all recent landings are a fraction of the 333,500 kg reported by Stevenson (1899) for the 1896 harvest year. It should be realized that harvest levels in the late 1800s are useful as an indicator of stock size, but they were likely not sustainable and should not be viewed as a goal for future harvest.

The CPUE of directed trips in Albemarle Sound ranged from a low of 144.8 in 1996 to a high of 280.6 in 2003 (Table 13.6; Figure 13.13). Effort expended as directed trips in Albemarle Sound exceeded that in all other North Carolina systems (Figure 13.14).

Commercial Catch Characteristics

The observed total length of American shad in the Albemarle Sound commercial gill-net fishery remained fairly consistent for both males and females from 1972 to 1993 (Table 13.7 and 13.8). Females are roughly 10 to 15 percent longer than males. Mean total length of males ranged from a low of 437 in 2005 to a high of 485 mm in 2003 (Table 13.9). Gill-net mesh size restrictions put in place during the break in the time series may be responsible for the decline in total length seen in females during the last six years, 2000–2005. Mean total length of females ranged from a low of 497 mm in 2005 to a high of 546 mm in 1972 (Table 13.9).

Females are roughly 50 to 75 percent heavier than males. The estimated mean weight of males in Albemarle Sound has remained fairly consistent ranging from a low of 0.95 kg in 2001 to a high of 1.36 kg in 2003 (Table 13.9; Figure 13.15). The mean weight of females appears to have declined from 1984 to 1993 when sampling ceased (Figure 13.15). Since 2000, the mean weight of females seems to have stabilized. The low mean weight of females from 2000 to 2005 may be a product of gill-net mesh restrictions put in place during the break in the time series. Over the entire time series, the mean weight of females ranged from a low of 1.53 kg in 2005 to a high of 2.61 kg in 1984 (Table 13.9).

Males in the Albemarle Sound commercial gill-net fishery ranged from 2 to 8 years of age (Table 13.10) and have had up to 4 spawning marks (Table 13.11). The mean age of males in Albemarle Sound was stable at higher levels from 1980 to 1993 (ranging from 0.53 to 0.63; Figure 13.16). Both mean age and mean number of repeat spawners were lower and variable at the beginning (1972-1979) and the end of the observed data series (2000-2005; Figure 13.16).

Female samples range in age from 3 to 10 years of age (Table 13.12) and had up to 4 spawning marks (Table 13.13). The pattern in percent repeat spawners and mean age varied the same as males being highly variable in the 1970s and after 2000, but stable from 1980 to 1993 (Figure 13.16).

Mean total length-at-age and weight-at-age for males declined slightly from 1972 to 1993 (Figure 13.17) and increased for the period 2000 to 2005 except for age-7 shad. For females, however, a decline in size-at-age occurred (Figure 13.18) over most years until 1993 and was stable for the most recent time period. Again, this decline may be due to gill-net mesh restrictions put in place during the break in the time series.

There were more males than females (sex ratio >1) in Albemarle Sound from 1972 to 1994 (Table 13.9). However, there have been more females than males (sex ratio <1) in Albemarle Sound since 2000. The sex ratio peaked in Albemarle Sound at 2.18 in 1980 and again at 2.77 in 1986. Since 2000, the sex ratio has ranged from a low of 0.60 in 2000 to a high of 0.90 in 2002.

Recreational Commercial Gear License Survey

The vast majority of RCGL holders harvest American shad with gill nets. Harvest and catch estimates were low in the northern region compared to other areas in North Carolina and have declined since 2002 (Table 13.14; Figure 13.19). Discards were highest in 2002, but remain low for subsequent years.

Recreational Creel Survey—Roanoke River

The Roanoke River, downstream of the dams (Weldon to Plymouth), was sampled from March 15 to April 30, 2000 and March 13 to April 29, 2001. Both creel surveys were originally designed to estimate harvest of striped bass from the Roanoke River, but data on shad harvest were collected concurrently with striped bass harvest data. These creel surveys were conducted only on days open to striped bass (Tuesdays, Wednesdays, Saturdays, and Sundays), and only boat anglers were interviewed. Because of budgetary restrictions, boat anglers were not interviewed on Mondays, Thursdays, and Fridays, and bank anglers were not interviewed on any days; therefore, the estimates of harvest and effort are underestimates.

Creel clerks interviewed anglers at boating access areas as they completed fishing trips. Probabilities of interviewing at each access area were based on anticipated use by anglers. Data collected from each fishing party interviewed included date and time of the interview; hours fished; number of anglers in the party; harvest of striped bass, hickory shad, American shad, largemouth bass, and other species; number of striped bass released; bait used; and the county of residence of the anglers.

Total fishing effort was estimated from counts of empty boat trailers at boating access areas along the entire river. Trailer counts were conducted each day of the open striped bass season. Total number of anglers was estimated by expanding trailer counts by the mean number of anglers per party as determined from interviews at access areas. The starting point for effort counts was randomly selected. Counts were made during mid-morning or mid-afternoon periods. Based on interview data, trailer counts were adjusted to eliminate commercial fishermen, hunters, and recreational boaters. Data were adjusted based on the proportion of recreational anglers interviewed by creel clerks within each zone, by period, and kind of day (weekday or weekend day). Harvest was estimated as the product of catch rates and total fishing effort stratified by period, zone, and kind of day.

No American shad were encountered during either creel survey and fewer than 10 shad were reported as caught and released by anglers.

Fishery-Independent Data

Adult Catch Rates

American shad are most susceptible to gill nets with 3.5 to 5.5 ISM with the majority being caught with mesh between 4 and 5 ISM (Figure 13.20). American shad catch rates from the NCDMF fishery-independent striped bass gill-net survey (FI-gill), which used mesh sizes ranging from 2.5 to 7 ISM, showed a variable, but gradual increase from 1991 to 2005 (Table 13.15; Figure 13.21). Catch rates ranged from a low of 0.022 shad per net day in 1992 to a high of 0.126 shad per net day in 2002. Catch rates from NCWRC electrofishing surveys for the Roanoke, a tributary of Albemarle Sound, follow the same slightly increasing trend as the gill-net data for the sound (Table 13.15; Figure 13.21). The commercial fishery CPUE follows the same gradual, but varying increasing trend as with both fishery-independent measures (Figures 13.13 and 13.21).

Size and Sex Composition

Mean length of American shad increased from 2000 to 2003 in the independent sampling programs (NCDMF fishery-independent gill-net samples and NCWRC electrofishing) then dropped in 2005 (Table 13.16; Figure 13.22). Length frequency data is also similar. The majority of males fell between 360 and 420 mm FL and females between 420 and 480 mm FL (Tables 13.17 and 13.18). Samples sizes were much larger in the electrofishing samples in most years yet mean lengths were similar among all gears. In 2005, drop in size could be explained by an influx of young fish as a year class recruits. However, the increase of young fish also coincided with the disappearance of larger fish present in previous years.

Sex Ratios

Sex ratios of shad caught by gill nets in fishery-independent samples versus fishery-dependent samples, were similar but varied in opposite directions (Table 13.16; Figure 13.23). Fishery-dependent samples had more females than males. In the fishery-independent gill-net samples, the sex ratio was more balanced with slightly more females caught in some years. Electrofishing samples of shad from the Roanoke River were variable and highly skewed toward males in all years. It is not clear if the bias toward males in the Roanoke River (electrofishing) was caused by loss of females in the downriver fishery or less time actually spent on the spawning grounds by females, extreme size selection, or time and location of sampling.

Age Composition

Age compositions from fishery-independent surveys are available since 2000 from both NCDMF gill-net and NCWRC electrofishing surveys.

NCDMF Gill Net—Albemarle Sound

The sample size was somewhat small for most years (Tables 13.19 and 13.20). The age composition was fairly consistent for males; dominated by ages four and five; mean age varied little among years (Table 13.19; Figure 13.24). Most females were between four and seven. The number of spawning marks from 2000 to 2005 on both male and female American shad in Albemarle Sound samples ranged from zero to two (Table 13.20). Most males were virgins with few having more than one spawning mark. The mean number of repeat spawners was well under one. Females had a higher incidence of repeat spawning occurrence each year (Table 13.20; Figure 13.25).

NCWRC Electrofishing—Roanoke River

Sample sizes for males were all fairly high (n = 93 to 232), while sample sizes in recent years were very low for females (n = 20 to 33; Tables 13.21 and 13.22). Individual age and mean age of American shad sampled by NCWRC in the Roanoke River were older than those sampled by NCDMF independent gill nets in Albemarle Sound in 2000 and 2001, but were similar in 2002 through 2005 (Table 13.19-13.22). The number of repeat spawning marks was very high in all years compared to the NCDMF samples (Figures 13.24 and 13.25). Moreover, mean age in male shad in electrofishing collections decreased, while mean number of spawning marks increased. The repeat spawning mark data from the Roanoke is questionable, as it is very unusual to have similarities in age structure among collection gears and widely varying repeat spawning occurrences.

Age Data Summary

Minor differences were apparent in mean age between sample programs. Mean age collected by gill net (both sexes) from Albemarle Sound was greater than those from electrofishing collections in the Roanoke River in 2000 and 2001 (Figure 13.26). However, patterns of change among years were quite different between sample programs, even though the patterns of change in mean length were similar. The differences were apparently caused by age estimates for the Roanoke River fish. Variation in mean age among years for the Albemarle Sound fish mirrored that of mean length. Conversely, variation in mean age among years for the Roanoke River fish did not track that of mean age from simultaneous collections. Results suggest a change in ageing techniques for the ageing of the Roanoke River fish. Another source of inconsistency is that shad found in Albemarle Sound are actually part of a mixed stock and results may inherently differ from Roanoke River shad.

Data concerns remain for both fishery-independent sample programs. Independent sampling by electrofishing was most effective for males (sample size greater than 100 individuals), while, with the exception of 2004, female sample size was small. The independent gill-net survey actually targets striped bass; shad are incidental bycatch—the primary reason why sample size remains relatively small. Because the sample sizes are relatively small, the data may not be representative of what is actually present and can only be used to indicate relative trends. The differences in ageing may be a direct result of experience, training, or both, or may simply reflect the difficulty of accurately ageing shad using scales. It appears likely that the repeat spawning data from NCWRC electrofishing surveys are not accurate. As mentioned previously, the percent of repeat spawners from these samples are unusually high and do not compare to most other system on the East Coast. Repeat spawning data are presented to show the contrast in results and should not be used for anything other than discussion indicating the need for resolution of ageing issues. Both NCDMF and NCWRC need to resolve ageing differences, and joint training will allow for comparable results in the future.

Juvenile Survey

Catches of juvenile American shad in the Albemarle Sound survey have been consistently low since the survey began in 1972. This survey was originally designed to sample juvenile river herring and does not sufficiently sample areas occupied by juvenile American shad. In order to obtain more accurate information, areas inhabited by juvenile American shad need to be identified and an adequate sampling scheme should be developed. The authors feel this survey does not adequately reflect the true abundance of juvenile American shad and should not be used for determining benchmarks as currently designed.

The relative abundance of American shad from the data indicates consistently low level of catches (Table 13.23). However, in three years (1985, 2003, and 2005) catches were high, indicating that a large year class may have occurred during these years. The peak in 2003 reflects a similar dramatic increase in the number of adults that occurred that spring in fishery-independent sampling.

Mortality

Instantaneous total mortality rates (Z) of male American shad in Albemarle Sound (using both age and repeat spawning methods) were highly variable in the 1970s, ranging from a low of 1.12 in 1973 to a high of 2.79 in 1978 and averaging 1.92 from 1972 to 1979 (Table 13.24; Figure 13.27). The total mortality rate then stabilized from 1980 to 1993, remaining in the range between 0.6 and 2.0. Sampling was discontinued in 1994 through 1999. Since 2000, Z-estimates were extremely variable, ranging from 0.23 to 2.30, although a slight decline is suggested based on age. In most years, Z values were well above the Z_{30} of 0.76.

Instantaneous total mortality rates of females from the fishery (using both age and repeat spawning methods) followed similar trends as males. Estimates were highly variable in the 1970s ranging from a low of 0.83 in 1972 to a high of 2.87 in 1978 (Table 13.24; Figure 13.27). The total mortality rate stabilized from 1980 to 1993 varying above and below 1.0. Since 2000, Z-estimates have been more variable, ranging from 0.09 to 1.90.

For NCDMF independent gill-net data, age at full recruitment varied among years. For males, Z values based on age or repeat spawning marks track each other. However, Z values from repeat spawning data are an order of magnitude higher than those calculated for age (Table 13.24; Figure 13.28). When compared to the fishery-dependent data, both data series (age and repeat spawning) track with each other. For females, Z-age for both fishery-independent and fishery-dependent data follow the same trend. Estimates were over 2.0 in 2000, declined to approximately 0.5 in 2002 and 2003, then bounced up in 2004, and were down slightly in 2005 (Table 13.24; Figure 13.28). This level of year-to-year variability suggests either that sample sizes are too low or that the estimates are strongly affected by year-class variability. For females, the Z-repeats for the fishery-independent and fishery-dependent data varied in opposite directions. It is not clear what is influencing this variation in the repeat spawning data.

For NWRC fishery-independent electrofishing data, catch curves using the number of repeat spawning marks were determined to be unrepresentative and were not used for this assessment. Z-estimates using age followed the same varying pattern as the other two data series (Figure 13.29). In some years the Z values fell below the Z_{30} target; however, the assumption on age at full recruitment may be incorrect.

Both NCDMF fishery-independent and fishery-dependent data sets agree since 2000. The NCWRC estimates are based on fish captured in the Roanoke River where sampling is approximately 124 miles from the Sound and follow the general pattern; although, Z values less than 0.30 are unlikely.

Status Summary

Mean statewide commercial harvest from Albemarle Sound since 1973 has been about three percent of the high reported in 1897. However, it should be realized that harvest levels in the late 1800s are useful as an indicator of stock size, but they were likely not sustainable and should not be viewed as a goal for future harvest. Since landings from the Albemarle Sound fishery have made up a significant portion of statewide landings since the late 1980s, it is reasonable that current abundance in Albemarle Sound and its tributaries is well below the historic potential for these stocks. Current landings are much less than the MSY of 1-2 million kg estimated for these stocks by Hightower *et al.* (1996). Estimates of Z based on commercial monitoring samples from the Albemarle Sound fishery suggest that total mortality on stocks of Albemarle Sound and its tributaries have generally exceeded the target value since the early 1970s, especially for males. Catch-per-trip in the commercial fishery since the mid 1990s and CPUE from more recent fishery-independent sampling programs have all increased slightly, suggesting a recent improvement in stocks of Albemarle Sound and the Roanoke River; although, preliminary estimates from a hydroacoustic survey currently underway indicate that adult abundance is still low (J. Hightower, pers. comm.). High mortality rates may have affected stocks in the 1970s and 1980s, but a recent stock increase suggests that mortality levels have not affected stock levels in the last 15 years; however, these improvements may be a result of artificial enhancement via the ongoing stocking program in the Roanoke River. Harvest and presumably stock levels remain very low in the historical context.

13.11.2 Pamlico Sound

American shad encountered in Pamlico Sound are considered a mixed stock and most likely originated from either the Tar-Pamlico or the Neuse river systems. Pound nets made up the majority of the landings in this area in the early 1970s, but gill nets dominated the catch beginning in 1978 (Table 13.25; Figure

13.30). Commercial landings for Pamlico Sound reached as high as 60,000 kg in the 1970s, declined throughout the 1980s, and have remained under 10,000 kg since 1990. No other sampling targeting American shad occurs in this area.

13.11.3 Tar-Pamlico River

Fishery-Dependent Data

Commercial Landings and Catch Rates

Commercial landings in the Pamlico River are dominated by gill nets (Table 13.26; Figure 13.31). Pound nets made up roughly one quarter of the catch in the Pamlico River in 1972, but have been virtually nonexistent since that time. Landings were highest in the 1970s and mid way through the 1980s, then began to decline and remained low (below 10,000 kg) from 1990 through the present. Recent harvest has been much less than the 30,400 kg from the Tar-Pamlico River reported by Stevenson (1899) for 1896. It should be realized that harvest levels in the late 1800s are useful as an indicator of stock size, but they were likely not sustainable and should not be viewed as a goal for future harvest.

Catch (pounds)-per-trip for directed trips in the Pamlico River varied without trend from 1994 through 2005 (Table 13.6; Figure 13.13). Annual commercial gill-net trips in the River varied without trend and were generally lower than the annual number of trips reported for other North Carolina rivers (Figure 13.14).

Commercial Catch Characteristics

From 1975 through 1989, most males ranged from 380 to 460 mm FL (Table 13.27). Sample size from 2000 to the present was very small; the size of these fish was similar to earlier years. Females were larger, most ranged from 440 to 500 mm FL, with little change over the period 1975 to 1989. In recent years since 2000, female shad were slightly smaller, where most ranged between 420 to 480 mm (Table 13.28).

Males and females from the Pamlico River ranged from 3 to 8 years old (Tables 13.29 and 13.20). The majority of shad from the Pamlico River were either virgins or had one or occasionally two spawning marks (Tables 13.31 and 13.32). The percentage of repeat spawners was similar for males and females, but was extremely variable, perhaps driven by the few repeat spawners that occurred in some years (Figure 13.32). Mean age of males remained relatively stable and averaged 5.0 (Table 13.29; Figure 13.32). Mean age of females was also stable among years, but was slightly higher and averaged 5.5 (Table 13.30; Figure 13.32). Similar trends in annual mean age and concurrent mean length suggest that ageing techniques were consistent among years for these samples (Figure 13.33).

Recreational Commercial Gear License Survey

American shad harvested by RCGL holders in the Pamlico region (Figure 13.10) could be part of the Tar-Pamlico River, Neuse River, or possibly Albemarle Sound stocks. Because of the way the data is collected, it is not possible to allocate harvest or discards to a particular stock. In 2002, the Pamlico region dominated both the harvest (4,306 kg) and discards (6,676 kg; Table 13.14; Figure 13.19). In 2003, the Pamlico region made up roughly half of the total harvest with (7,109 kg) and dominated the discards (7,436 kg). Since that time harvest has been reduced to just over 1,000 kg and discards have been minimal.

Recreational Creel Survey

The Tar-Pamlico River was surveyed in 2005. The survey area was stratified into two creel zones based on jurisdictional boundaries and habitat characteristics. The upper zone (Zone 1) included access areas from Battle Park in Rocky Mount downstream to Grindle Creek near Grimesland. Zone 2 included access areas from Grindle Creek downstream to the US-17 Bridge at Washington. Zone 2 also included the private boating access area located at Whichard's Beach and Haven's Garden Park in Washington.

Selection of access points where interviews occurred was based upon sample probabilities derived from prior knowledge of recreational fishing activity at the various access points. Probability of fishing activity for time of day was equal for both AM and PM samples (except for the 2005 Tar-Pamlico River survey where the probability of fishing activity for time of day varied by season with greater probability allocated to morning interview periods during the spring). Interview sessions covered half of the calculated day length and were held on two randomly selected weekdays and both weekend days each week. Creel clerks interviewed anglers as they completed fishing trips at boating access areas. Data collected from each fishing party interviewed included date and time of the interview, hours fished, number of anglers in the party, harvest of American shad and other species, and number of American shad released.

Estimates of American shad catch and effort for each sample day were computed by expanding interview data by the sample unit probability (product of the access point probability and time of day probability; Pollock *et al*. 1994). Within sample periods, catch and effort estimates for weekdays and weekend days were separately averaged. The averages were then expanded to the total number of days of each type for that sample period.

An estimated 4,619 angler hours (SE = 3,977) of total effort was expended during the 12-month creel survey period for anadromous shads (American and hickory combined) on the Tar-Pamlico River. As expected given the timing of the spawning migration, all of the effort occurred between February and April (peaked in April) and was exerted in Zone 1. Angling effort for anadromous shads was highest on weekdays.

Total catch of anadromous shads was 7,575 fish (SE = 6,903) with an estimated harvest of 1,212 fish (SE = 1,182) or 16 percent of the total catch. Estimated American shad harvest alone was 1,192 fish (SE = 1,181). As expected, anadromous shad catch and harvest both peaked in April in Zone 1. Anglers targeting anadromous shads had a success rate of 1.6 fish caught per angler hour.

Each of these systems has only one or two point estimates in time to date. Therefore, it is nearly impossible to determine trends in recreational catch rates without data from other years to serve as reference. Although ASMFC requirements are currently being met with the rotating creel surveys, annual data collection for each river using consistent methods would more effectively determine the level of recreational harvest by hook and line and associated trends. A dedicated, funded program to sample each system on a yearly basis is recommended to obtain more complete trend information on recreational hook and line landings for all anadromous species.

Fishery-Independent Data

Adult Catch Rates

Catch-per-unit-effort from the electrofishing survey in the Tar River was quite high, compared to other North Carolina rivers (Table 13.33; Figure 13.34); however, this may be more a function of the size and the physical configuration of the sampling sites at different rivers rather than a reflection of actual abundance. Catch rates of males and females combined varied without trend from 2000 through 2005.

Size, Sex, and Age Composition

Sample size for males and females from the fishery-independent gill-net survey were very small and need to be increased to adequately describe the population; however, most fish from the survey ranged from 420 to 480 mm FL (Table 13.34). The electrofishing survey had a much higher sample size and is probably more reliable. Most males were between 360 and 400 mm FL in 2000 to 2002, after which size range widened. In 2004 most fish from the electrofishing survey were between 340 and 440 mm FL (Table 13.35). Large fish did not appear in the 2005 sample, which is reflected in mean length. The largest males appeared in 2003 with a mean TL of 449 mm, followed by a quick drop to 415 mm by 2005 (Table 13.36). For females, the size distribution was relatively stable through all years with most fish between 400 and 460 mm FL except for 2005 when size decreased (Tables 13.35 and 13.36). Mean length also declined in the last few of years. The sex ratio was highly skewed toward males (Table 13.36).

Female ages from the NCDMF fishery-independent survey were generally older and had lower percent repeat spawners (Tables 13.37 and 13.38) than shad captured in the NCWRC electrofishing collections upstream in the Tar River (Tables 13.39 and 13.40). Variation in annual mean age among years from electrofishing samples differed somewhat from variation in mean length for concurrent samples. This disconnect in interannual trends suggest variation in ageing techniques among years for this data set. Because of these observations, we deferred using age and repeat spawning data from the electrofishing data until ageing techniques can be verified.

Mortality

Total mortality estimates calculated from the commercial fishery-dependent data (Table 13.41; Figure 13.35) may be more reliable since sample sizes from the fishery-independent gill-net survey were generally small (Table 13.37; Figure 13.36). Male Z-estimates from fishery-dependent data varied from a low of 0.21 to a high o 3.56 indicating that low sample size (less than 100 fish) may have been problematic (Table 13.41; Figure 13.35). Female Z-estimates were just as variable (Table 13.41; Figure 13.35). Age at full recruitment varied from as young as four (1975) and as old as six (1983; Table 13.29). The same issue occurred for females (Table 13.30). For most years Z-estimates remain high (over 1.0). Estimates of Z from the NCWRC fishery-independent electrofishing survey on the Tar River generally ranged from one to two (Figure 13.37).

Status Summary

Current status of American shad of the Tar-Pamlico River remains unknown. Landings from the Pamlico River were much higher 20 years ago than in recent years. Current landings have been less than 10,000 kg since the late 1980s; however, we do not know if the decline in landings is related to change in effort. Historical data are needed to provide perspective on the potential harvest from this system. Estimates of total mortality have been relatively high since the mid 1970s. Gill-net CPUE and total effort have remained low and stable since 1994. Electrofishing CPUE on the spawning grounds, however, has been higher in the Tar than in other NC rivers since 2000, which may be a function of stream size and physical configuration of the sampling sites. Apparently, mortality levels are high enough to keep the stock depressed, but not high enough to lead to stock collapse.

13.11.4 Neuse River

Fishery-Dependent Data

Commercial Landings and Catch Rates

Most of the American shad landings from the Neuse River since 1972 have come from gill nets (Table 13.42; Figure 13.38). Landings decreased from a high of 37,066 kg in 1972 to a low of 2,787 kg in 1977. A small increase in landings occurred again in the mid 1980s reaching just over 32,000 kg. A new low of 1,300 kg occurred in 1991 and landings remained depressed through the 1990s. Landings increased to less than 20,000 kg in 2002 and have been slowly declining since that time. However, all recent landings have been much lower than the 93,919 kg reported by Stevenson (1899) for 1896. Again, it should be realized that harvest levels in the late 1800s are useful as an indicator of stock size, but they were likely not sustainable and should not be viewed as a goal for future harvest.

Catch (pounds)-per-trip of American shad in the commercial gill-net fishery of the Neuse River declined from 1994 through 1999, increased through 2003, and have since declined (Figure 13.13). Annual number of commercial gill-net trips on the Neuse River remained relatively stable from 1994 through 2001, increased in 2002, and have declined slightly since (Figure 13.14).

Commercial Catch Characteristics

Commercial catch samples were collected from 1977 to 1989, and did not occur again until 2000 through 2005. Sample size in all years was small, barely reaching over 100 males per year; sample sizes for females were slightly larger. Most males were between 400 and 420 mm FL in the earlier period, while fish in the later period were slightly smaller (Table 13.43). Females were larger, between 420 mm FL and 500 mm FL, in the 1970s and 1980s and smaller in the 1990s when the majority of females were less than 480 mm FL (Table 13.44).

Males from the Neuse River commercial gill-net fishery ranged from 3 to 7 years (Table 13.45) and females from 3 to 8 years old (Table 13.46). Most male American shad were virgins with very few fish having more than one spawning mark (Table 13.47). Mean age was most always under five. Females were generally older, with most fish ages five and six in 1977 to 1988 and ages four through seven years in 2000 to 2005. Mean age and mean female repeat spawners increased in the later period (Tables 13.46 and 13.48). A slightly broader age structure in both sexes occurred in the 1990s compared to the 1970s and 1980s.

Recreational Commercial Gear License Survey

American shad harvested by RCGL holders in the Pamlico region (Figure 13.10) could be part of the Tar-Pamlico River, Neuse River, or possibly Albemarle Sound stocks. Shad encountered in the Central region may have originated from the Neuse River. Because of the way the data is collected, it is not possible to allocate harvest or discards to a particular stock. In 2002, the Pamlico region dominated both the harvest (4,306 kg) and discards (6,676 kg; Table 13.14; Figure 13.19). In 2003, the Pamlico region made up roughly half of the total harvest with (7,109 kg) and dominated the discards (7,436 kg). Since that time harvest has been reduced to just over 1,000 kg and discards have been minimal. Both harvest and discards have been minimal for the Central region usually with less than 1,000 kg each.

Recreational Creel Survey

A creel survey of the shad fishery on the Neuse River was conducted in 2003. Methods for the recreational creel survey are the same as for other systems described above. Because hickory shad and American shad are present in the Neuse River simultaneously, and because fishing methods for the two species are identical, anglers indicated to the creel clerks that they were fishing for "shad;" therefore, directed angling effort for American shad could not be estimated. Anglers exerted a combined effort for "shad" totaling 28,148 hours (SE = 10,604). Anglers targeting shad were first encountered on February 22, 2003 and the last anglers targeting shad were encountered on April 26, 2003. Estimated catch of American shad was 317 fish (SE = 277) and harvest was 274 fish (SE = 274). The estimates of American shad harvest were based upon only five harvested fish observed by the creel clerks and, as evidenced by the associated high standard errors, the estimates are quite imprecise. Because of funding limitations, the creel survey did not include bank anglers. In addition, creel sampling effort had to be spread across the entire reach of the Neuse River, preventing further stratification that would have allowed for concentrated sampling of the recreational shad fishery. Inclusion of bank anglers and increased sampling effort in future creel surveys will increase the accuracy and precision of American shad harvest estimates.

Fishery-Independent Data

Adult Catch Rates

The CPUE from the NCWRC electrofishing survey was the lowest among all North Carolina Rivers (Table 13.33; Figure 13.34), but may have been a function of stream size and physical configuration of sampling locations affecting the efficiency of the electrofishing unit. The CPUE remained relatively stable from 2000 through 2005 (Figure 13.34).

Size and Sex Composition

The independent gill-net survey sample size was small for both sexes in all years (Table 13.49). The electrofishing length frequency (2000-2005) suggested a general increase in size for both sexes through 2004 followed by a decline in 2005 (Table 13.50) that may be the result of year-classes moving through the spawning population. The mean TL of males increased to 453 mm in 2003 then dropped quickly by 2005 (Table 13.51). The mean size of females increased from 2001 to 2004 to a high of 517 mm TL in 2004 and then dropped in 2005. Electrofishing samples were predominantly male in most years; however, it is not clear if the bias toward males was caused by loss of females in the downriver fishery, less time actually spent on the spawning grounds by females, extreme size selection, or time and location of sampling.

Age Composition

Sample sizes of shad in Neuse River gill-net samples were too small to draw any conclusions (Tables 13.52 and 13.53). Estimated age structure from the electrofishing samples (Tables 13.54 and 13.55) tends to follow the observed trend in length frequency data (Tables 13.50 and 13.54; Figure 13.39). Interannual change in mean age also mimicked that in mean length suggesting stability in ageing techniques among years. However, the frequency of repeat spawning was much greater than that from commercial gear and unrealistically high compared to values observed in other Atlantic coastal populations. The sample size that was aged was much smaller than the number of fish actually collected. Mean age tended to be slightly higher in electrofishing collections than those from samples of the commercial catch in the same years.

Mortality

Total mortality estimates calculated from the commercial fishery-dependent data (Table 13.56; Figure 13.40) may be more reliable since sample sizes from the fishery-independent gill-net survey were generally small (Table 13.52; Figure 13.41). Estimates from the fishery-dependent gill-net survey for both sexes were highly variable, but were generally greater than Z = 1.0 and even higher when repeat spawning data were used to estimate Z (Table 13.56; Figure 13.40). Estimates of Z from the NCWRC fishery-independent electrofishing survey on the Tar River generally ranged from 0.5 to 2.0 for males and 0.4 to just under 4.0 for females (Figure 13.42). Estimates of Z calculated using repeat spawning marks from the electrofishing survey were not presented because the results were unrealistic.

Status Summary

Adequate historic harvest data specific to the Neuse River are not available to provide perspective to current landings. Landings displayed several peaks since 1972, but peaks were progressively lower. Effort data is not available for the entire time series making it difficult to determine whether declining stock size or effort caused the reduction. Years of increased effort generally corresponded to years of increased harvest with the exception of the last few years when effort remained high but catch and CPUE declined. The recent decline in CPUE also corresponded to relatively high estimates of total mortality and a decline in mean length.

13.11.5 Cape Fear River

Fishery-Dependent Data

Commercial Landings and Catch Rates

Over the last thirty-two years, commercial landings have cycled through several highs in 1972 (30,376 kg), 1982 (35,464 kg), 1993 (28,066 kg), and 2003 (15,603 kg) followed by years of low landings (Table 13.57; Figure 13.43). The last three succeeding peaks were progressively lower. Landings have remained somewhat low since 1994, averaging only 7,751 kg, with one small peak in 2003.

Commercial CPUE (lb/trip) was relatively high in the mid 1990s and the early 2000s (Figure 13.13). It declined substantially from 2004 to 2005. Effort (number of trips) increased from 1999 to 2003 and has since declined (Figure 13.14).

Commercial Catch Characteristics

Commercial catch length data were taken in two short periods, 1983 through 1989 and again in 2000 through 2005. In the early time period, male shad were slightly larger with most between 400 and 460 mm FL; fish were slightly smaller (340 to 420 mm FL; Table 13.58) in the later period. Female length frequency trends were similar Most females were between 460 and 500mm FL, and smaller in later years (440 to 480mm FL; Table 13.59). Lengths of both sexes declined in 2005.

Most male American shad age samples were four to seven years old (Table 13.60) in all years with some younger fish to age-3 collected during the years after 2000. Mean age of males was approximately 4.5 in the late 1970s, increased slightly during the 1980s, and then varied at the higher level from 2000 to 2005 (Table 13.60). Females were mostly four to eight years old (Table 13.61), with older fish more common in the later time period of 2000 to 2005. Mean age also indicates fish were older during the early (1970s) and late (2000s) time period than during the 1980s (Table 13.61). The number of females exceeded that of males in most years.

The number of spawning marks on both male and female shad from the Cape Fear River commercial fishery ranged from zero to two (Tables 13.62 and 13.63); however, the majority were virgins, a few had spawned once, and it was rare to see any that had spawned twice. The percentage of repeat spawners was lower for males than females in most years. Values over 20 percent were rare (Tables 13.62 and 13.63).

Recreational Commercial Gear License Survey

Shad encountered by RCGL holders in the Southern region likely came from the Cape Fear River (Figure 13.10). Estimates of harvest were less than 1,000 kg for 2002, over 6,000 kg in 2003, and near 2,500 kg for 2004 and 2005 (Table 13.14; Figure 13.19). Discards were less than 1,000 kg for all years.

Recreational Creel Survey

The Cape Fear River was sampled from March 4 to May 19, 2002, and yearlong in 2004. Each survey was stratified by time (period in the Cape Fear River in 2002 and month in all subsequent surveys) and type of day (weekdays and weekend days).

Because past experience has shown differential catch rates of American shad through the progression of the spring months, the 2002 Cape Fear River survey was stratified into 2-week sample periods, except for the final period, which was truncated to one week when angling effort for American shad dropped markedly. The fishing effort and catch is known to vary as a function of day type, so survey samples and estimates were further stratified by type of day within periods.

For the 2004 Cape Fear River survey, the river was further stratified into two creel zones based on jurisdictional boundaries and observed fishing effort. The upper zone (Zone 1) included access areas from Lillington downstream to Lock and Dam 2 at Elizabethtown. Zone 2 included access areas from Elwell's Ferry downstream to Wilmington. Zone 2 also included the private boating access area located at Lane's Ferry and the NCWRC boating access area located at Castle Hayne.

Cape Fear River 2002

Anglers exerted a total of 19,839 hours (SE = 4,809) of effort specifically for American shad on the Cape Fear River during 2002 with effort peaking during the period 15 April through 28 April (7,402 angler-hours). During the 7-day period of May 12 through May 19, angling effort dropped to approximately 600 angler-hours. Catch of American shad peaked during the periods March 18 through March 13 and April 15 through April 28. Harvest increased steadily each period until peaking during the period April 15 through April 28 (8,751 fish). An estimated 25,995 American shad (SE = 7,494) were caught during the study period and overall approximately 50 percent (12,879 fish, SE = 3,292) of the catch was harvested.

Cape Fear River 2004

An estimated 2,283 angler hours (SE = 479) of total effort was expended during the 12-month creel survey period for American shad on the Cape Fear River. As expected given the timing of the spawning migration, all of the effort occurred in March and April with the majority of effort (82%) being exerted in Zone 2 at Lock and Dam 1. Mean trip length for American shad anglers was 5.1 hours, with an average of 1.6 anglers per party.

In comparison, a total of 19,839 angler hours (SE = 4,809) were expended by Cape Fear River shad anglers during the 2.5-month intensive creel survey conducted on the river in 2002. The most probable explanation for the difference in angler effort between the two surveys is that the 2002 survey was conducted only at the lock and dams, where the majority of shad fishing takes place, and specifically targeted shad anglers only. In addition, the boat ramp at Lock and Dam 2, located in Elizabethtown, North Carolina, was closed most of the 2004 creel year due to renovation, thereby reducing the total number of potential interviews with shad anglers.

American shad catch and harvest estimates reflect this species seasonal abundance in the Cape Fear River during their spawning migrations. Despite there being large numbers of American shad in the Cape Fear River during the spring of the year, overall estimated catch and harvest for this species were low. Total catch of American shad was 3,473 fish (SE = 3,056) with an estimated harvest of 2,141 fish (SE = 444) or 61.6 percent of the total catch. As expected, virtually all of the shad catch and harvest occurred from March through May with both estimates peaking in May in both zones. Zone 2 catch (2,552 fish, SE = 582) and harvest (1,282 fish, SE = 325) estimates were more than double the catch (921 fish, SE = 333) and harvest (859 fish, SE = 303) estimates for Zone 1. A total of 78 American shad was measured, ranging from 283 to 560 mm. Anglers targeting American shad had a success rate of 1.5 fish caught per angler hour. Comparison of catch and harvest estimates generated during this creel with catch and harvest estimates from the 2002 directed American shad creel survey reveal much lower numbers of shad were caught and harvested in 2004 than in 2002 (catch = 25,995 fish (SE = 7,494), harvest = 12,879 fish (SE = 3,292)). The boat ramp at Lock and Dam 2 was closed most of the creel year (opened in May 2004), resulting in the loss of potential interviews with shad anglers at this location. This ramp closure may help explain the apparent underestimate of total catch and harvest of American shad in 2004; however, it is not clear whether the closure actually reduced effort in 2004 or just redistributed it into other areas.

Fishery-Independent Data

Adult Catch Rates

The CPUE from the electrofishing survey in 2000 to 2005 were among the highest values among all North Carolina rivers (Table 13.33; Figure 13.34); however, this may be more a function of the size and the physical configuration of the sampling sites at different rivers rather than a reflection of actual abundance. Values increased through 2004 and then decreased in 2005. This trend among years mimicked that seen in the commercial CPUE.

Size and Sex Composition

Sample size in the Cape Fear independent gill-net survey was low, but reasonably representative. Most males ranged from 360 to 480 mm FL (Table 13.64). Females ranged from 360 to 520 mm FL, but the majority fell between 420 and 480 mm FL (Table 13.64). The electrofishing samples caught similar size ranges for both sexes (Table 13.65). Mean TL was relatively stable in 2000 to 2004 and then declined in 2005. The same trend occurred for females (Table 13.66). The sex ratio in the electrofishing samples was skewed toward males. It is not clear whether this was because females were selectively taken out in the downriver commercial fishery or if it was an artifact of electrofishing time and location.

Age Composition

Ages of male American shad in the Cape Fear River independent gill-net survey ranged from two to seven (Table 13.67) with most between the ages of three and six. Age composition was fairly stable among years. Most all were virgins with very few repeat spawners (Table 13.68). Female age ranged from four to eight, dominated by ages five through seven. The numbers of spawning marks on female and male American shad are presented in Table 13.68. Most were virgins, but repeats were more frequent among the females than males. Frequency of repeat spawning marks from electrofishing data collections were several times greater than those from commercial catch samples and generally exceeded comparable values seen in other Atlantic coast stocks. Given the southern location of the Cape Fear River, these values seem unrealistic.

It appears as that some of the same ageing issues persist for this system, as for other systems described above for the electrofishing data. Age data from fishery-independent electrofishing sampling were similar to those obtained from samples taken from the fishery-independent gill-net survey. However, mean age from electrofishing often varied in the opposite direction from mean TL (Figure 13.44). If the repeat spawning and age data are looked at together, it would appear that a lot of females began spawning at a very early age (three), which is not a common occurrence, and the percent of repeat spawners from electrofishing samples are extremely high and likely unrealistic (Tables 13.69 and 13.70).

Mortality

Mortality estimates were calculated for the commercial fishery-dependent and independent gill-net data (Table 13.71; Figures 13.45 and 13.46). Estimates fluctuated among years, but generally exceeded Z = 1.0. Values over 2.0 or 3.0 may have resulted from small sample sizes that occurred in some years. Estimates since 2001 have generally been lower than those for 1976 through 1988. Data from the independent surveys was similar for males. However, Z-estimates for females were the lowest of all values. Estimates of Z from the NCWRC electrofishing survey followed the same trend for males and females (Figure 13.47). Estimates were at or above 1.0 from 2000 to 2003, below 1.0 in 2004, and about 1.0 in 2005. Estimates of Z calculated using repeat spawning marks from the electrofishing survey were not presented because the results were unrealistic.

Status Summary

Current abundance of American shad of the Cape Fear River is unknown as is abundance relative to the maximum potential for this stock. Adequate historic landings are not available for comparison with recent landings. Estimated mortality for Cape Fear shad appear high relative to desired levels. The CPUE from the commercial fishery suggest that stock levels in recent years have been about what it was in the mid 1990s. The CPUE from both the commercial gill-net fishery and fishery-independent electrofishing suggest a stock increase from about 2000 or 2001 through 2004. Since effort also increased during this time period, it would appear that recent levels of fishing mortality have been high enough to keep the stock from increasing.

13.12 BENCHMARKS

A benchmark of $Z_{30} = 0.76$ has been developed for Albemarle Sound and Roanoke River.

13.13 RECOMMENDATIONS

Much remains unknown about the status of American shad in North Carolina river systems. The following are areas where data collection can be improved:

A spawning area survey is needed for American shad in all river systems in North Carolina. It is critical to identify current spawning areas used by American shad for the potential protection of spawning habitat and to help identify appropriate sampling locations for collecting juvenile abundance data.

A juvenile abundance survey needs to be developed for all systems in North Carolina. The juvenile abundance index currently available for Albemarle Sound targets river herring, and it does not adequately reflect the true abundance of juvenile American shad. There are no sampling programs designed to assess juvenile abundance in the Roanoke, Tar-Pamlico, Neuse, or Cape Fear River systems.

There is much debate over the use of scales to age shad along the East Coast, and there are large discrepancies in the determination of the number of spawning marks present on shad between NCDMF and NCWRC. Current techniques have not been validated in any of North Carolina's river systems and have been found to be difficult to use on shad from the Delaware River system (McBride *et al.* 2005). North Carolina agencies need samples of known-age shad from North Carolina river systems to verify current ageing techniques and aid in determining differences in counting the number of spawning marks that currently exist between agencies. Until known-age shad are obtained, consistency between agencies could be improved by performing blind reads on a common set of scales and comparing results to assure agreement of ageing methods.

Currently, NCWRC is marking shad stocked in the Roanoke River with OTC. Upon successful return and collection of marked shad, it will be possible to validate the current ageing method used by both agencies. NCDMF sampling programs do not currently collect otoliths, so identification of OTC-marked adults returning to spawn in the Roanoke River is only done by NCWRC. To date, one OTC-marked adult has been identified from a 2005 sample and two OTC-marked adults have been tentatively identified from a 2006 sample (B. Wynne, pers. comm.). Perhaps examining carcasses from the commercial catch or marking juvenile shad with tags would increase the ability to identify hatchery fish and increase recovery rates.

Current efforts to monitor catch and effort in the commercial and recreational fisheries as well as relative catches from fishery-independent gill-net surveys should continue; however, both indices of abundance need to be improved. The CPUE (catch-per-trip) estimated through the Trip Ticket Program likely gives fairly reasonable estimates of commercial catch rates; however, it does not take into account any trips in which shad were the intended target but less than 100 pounds were actually harvested (an indication of low abundance). Fishery-independent CPUE estimates are currently available in Albemarle Sound since 1991, but it would be helpful to begin establishing annual indexes of abundance based on fishery-independent surveys in the Pamlico, Neuse, and Cape Fear river systems as well.

As fishery-independent surveys are further developed, environmental factors that may influence shad abundance should be identified and recorded.

The fishery-independent electrofishing survey used to monitor relative abundance in upriver areas needs to be evaluated to verify if current methodology and sample design provide a complete picture of sex, size, and age composition of spawning stocks. Such sampling should continue.

There are currently no estimates of natural mortality from any of North Carolina's river systems. Tagging studies could help to determine estimates of these rates for each system. Determination of natural mortality rates through the use of maximum age from current stocks may produce inaccurate estimates since these populations have been fished for several hundred years. Commercial catch data indicates that current population levels are much lower than that of a virgin stock, which suggests that the age structure may be truncated thus giving an underestimate of maximum age.

Small sample sizes of age, size, and spawning marks from NCDMF fishery-independent data collection programs in the Pamlico, Neuse, and Cape Fear river systems over several years made it difficult to assess and compare the age and size composition as well as the composition of repeat spawners of males and females among all years. Increasing sample sizes of both males and females in fishery-independent surveys of these systems would alleviate that problem in the future.

There are no current estimates of ocean bycatch for North Carolina stocks. Programs should be developed and initiated to better understand the extent and impact of bycatch on North Carolina stocks.

Current surveys do not adequately sample recreational harvest of American shad. Although the surveys currently performed on each river once every four years comply with ASMFC requirements, they are inefficient at estimating the amount and impact of recreational harvest of American shad stocks. They do not allow the annual, continuous time series needed to establish solid trends and provide indexes of abundance for more advanced assessment techniques. Development of dedicated, adequately funded surveys using consistent methods to estimate recreational catch rates and amount of total recreational harvest is needed for American shad as well as several other anadromous species.

The ultimate goal should be to estimate run size (number of returning spawners) for the four largest coastal rivers. Without abundance estimates, it is very difficult to judge the impact of fishing and to determine whether harvest regulations are appropriate. One possible approach is a biomass-based model (e.g., Hightower *et al*. 1996) although direct estimates using hydroacoustics (e.g., Mitchell 2006) or tagging may be more reliable.

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Table 13.1 Percent of American shad mature at age in North Carolina.

Age	Albemarle Sound	Pamlico River	Neuse River	Cape Fear River
3	1	5	1	1
4	11	27	16	16
5	53	67	67	60
6	89	95	97	92
7	99	100	100	100
8	100	100	100	100
9	100	100	100	100

Table 13.2 Growth parameters of American shad populations in North Carolina by sex.

Sex	River system	L_∞	k	t_0
Male	Albemarle Sound	571.9	0.3628	-0.1142
	Pamlico River	508.4	0.6728	0.1135
	Neuse River	*	*	*
	Cape Fear River	502.1	0.4995	0.0237
Female	Albemarle Sound	608.0	0.3648	-0.0926
	Pamlico River	553.4	0.5233	0.0797
	Neuse River	549.6	0.5484	0.0474
	Cape Fear River	563.7	0.4721	0.0394

*Not enough adult male observations to accurately estimate growth parameters.

Table 13.3 American shad fry produced in North Carolina and stocked in the Roanoke River Basin, along with evaluation marks recovered, 1998-2005.

Year	Edenton NFH	Watha Hatchery	Total	Hatchery Evaluation		
				N-Hatchery Marks Recovered	YOY Examined	% Hatchery
1998	481,000*	-	481,000	-		
1999	225,000	50,000	275,000	-		
2000	535,000	308,000	843,000	0		
2001	700,000	1,369,000	2,069,000	0		
2002	-	820,000	820,000	2	148	1.35%
2003	612,000	1,673,629	2,285,629	3	130	2.31%
2004	589,822	1,740,000	2,329,822	10	228	4.39%
2005	1,346,834	1,226,000	2,572,834	38	420	9.05%

* Eggs were fertilized in the field (strip spawned).

Table 13.4 American shad commercial landings (kg) from the Atlantic Ocean, 1972-2005. The Atlantic Ocean fishery closed January 1, 2005.

Year	Atlantic Ocean (kg)
1972	
1973	
1974	
1975	
1976	702
1977	
1978	2,268
1979	11,369
1980	1,789
1981	48,723
1982	29,021
1983	1,718
1984	6,129
1985	1,433
1986	28,615
1987	18,671
1988	22,720
1989	17,485
1990	16,812
1991	8,717
1992	10,866
1993	12,756
1994	15,375
1995*	46,714
1996*	26,385
1997*	44,594
1998*	53,533
1999*	14,955
2000*	50,307
2001*	5,370
2002*	3,800
2003*	5,677
2004*	3,050
2005*	101

*Closed season April 15-January 1.

Table 13.5 Commercial harvest (kg) of American shad in Albemarle Sound, 1972-2005.

Year	Gill Net			Pound Net			Other Gears			Total		
	Number	Total Weight (kg)	Mean Weight (kg)	Number	Total Weight (kg)	Mean Weight (kg)	Number	Total Weight (kg)	Mean Weight (kg)	Number	Total Weight (kg)	Mean Weight (kg)
1972	15,313	27,089	1.8	22,799	32,060	1.4				37,257	59,149	1.6
1973	5,422	8,853	1.6	17,014	27,784	1.6				22,436	36,637	1.6
1974	19,582	31,088	1.6	12,426	19,728	1.6	1,278	2,028	1.6	33,286	52,845	1.6
1975	5,153	8,182	1.6	19,454	30,885	1.6	268	425	1.6	24,875	39,492	1.6
1976	10,513	16,227	1.5	10,651	16,427	1.5	1,856	2,863	1.5	23,030	35,517	1.5
1977	5,452	8,656	1.6	17,219	27,337	1.6		111	1.6	22,741	36,104	1.6
1978	34,962	55,506	1.6	10,440	16,575	1.6				45,402	72,081	1.6
1979	18,580	28,655	1.5	5,825	8,984	1.5	641	989	1.5	25,046	38,628	1.5
1980	10,244	16,729	1.6	8,551	13,964	1.6	203	331	1.6	18,999	31,024	1.6
1981	17,768	22,567	1.3	5,841	7,418	1.3	224	285	1.3	23,833	30,270	1.3
1982	27,766	41,562	1.5	7,946	11,895	1.5	286	428	1.5	35,998	53,885	1.5
1983	47,963	78,322	1.6	8,003	13,069	1.6	4,050	6,613	1.6	60,016	98,004	1.6
1984	51,935	89,520	1.7	5,933	10,227	1.7	1,949	3,360	1.7	59,818	103,107	1.7
1985	21,725	35,476	1.6	18,638	30,435	1.6	902	1,474	1.6	41,265	67,385	1.6
1986	23,090	37,705	1.6	10,345	16,893	1.6				33,435	54,598	1.6
1987	40,291	60,311	1.5	5,140	7,694	1.5				45,431	68,005	1.5
1988	29,502	45,499	1.5	7,869	12,136	1.5	294	454	1.5	37,665	58,088	1.5
1989	49,246	80,416	1.6	8,756	14,298	1.6				58,002	94,715	1.6
1990	40,220	58,380	1.5	26,953	39,123	1.5				67,173	97,503	1.5
1991	51,561	74,842	1.5	13,269	19,260	1.5	764	1,109	1.5	65,594	95,211	1.5
1992	26,705	44,819	1.7	8,779	14,735	1.7	34	94	1.7	35,540	59,648	1.7
1993	12,757	20,253	1.6	8,244	13,089	1.6	36	58	1.6	21,609	33,399	1.6
1994	7,723	11,911	1.5	6,844	10,555	1.5	54	84	1.5	14,621	22,550	1.5
1995	16,067	24,779	1.5	1,825	2,816	1.5	34	53	1.5	17,927	27,648	1.5
1996	18,622	28,719	1.5	773	1,193	1.5	3	4	1.5	19,398	29,916	1.5
1997	14,667	23,285	1.6	3,496	5,550	1.6	6	10	1.6	18,168	28,844	1.6
1998	47,144	74,845	1.6	958	1,520	1.6	25	40	1.6	48,127	76,406	1.6
1999	18,455	29,299	1.6	1,457	2,312	1.6	109	173	1.6	20,020	31,784	1.6
2000	36,451	56,217	1.5	2,051	2,420	1.2	93	143	1.5	41,801	58,779	1.4
2001	26,327	39,408	1.5	2,860	2,984	1.0	469	702	1.5	31,668	43,094	1.4
2002	48,988	73,329	1.5	5,643	5,887	1.0	141	211	1.5	58,368	79,427	1.4
2003	80,212	123,706	1.5	2,250	2,347	1.0	846	1,266	1.5	93,562	127,320	1.4
2004	47,795	75,880	1.6	1,582	1,650	1.0	3,228	4,832	1.5	60,525	82,362	1.4
2005	38,384	55,715	1.5	647	881	1.4	642	962	1.5	39,673	57,557	1.5

Table 13.6 Commercial CPUE (pounds/trip) for directed American shad trips by river system, 1994-2005.

	Albemarle Sound				Pamlico River			
Year	Pounds	Trips	CPUE	Dealers	Pounds	Trips	CPUE	Dealers
1994	14,586	93	156.8	14	No directed trips			
1995	29,319	173	169.5	12	3,115	16	194.7	5
1996	21,282	147	144.8	11	2,643	17	155.5	3
1997	15,268	91	167.8	12	3,810	17	224.1	3
1998	104,972	508	206.6	15	6,567	35	187.6	3
1999	16,680	100	166.8	9	*	*	155.6	2
2000	58,609	339	172.9	19	8,897	34	261.7	4
2001	26,271	173	151.9	15	1,580	9	175.6	3
2002	115,741	512	226.1	18	6,934	39	177.8	6
2003	221,702	790	280.6	20	7,892	46	171.6	8
2004	128,787	553	232.9	12	4,923	29	169.8	7
2005	75,192	374	201.0	11	*	*	174.1	2

	Neuse River				Cape Fear River			
Year	Pounds	Trips	CPUE	Dealers	Pounds	Trips	CPUE	Dealers
1994	*	*	199.5	2	4,146	20	207.3	6
1995	6,015	37	162.6	7	4,787	22	217.6	9
1996	10,455	71	147.3	7	18,420	86	214.2	10
1997	4,938	38	130.0	4	7,997	44	181.7	6
1998	5,741	38	151.1	5	7,167	42	170.6	8
1999	1,311	11	119.2	3	1,385	10	138.5	4
2000	2,451	17	144.1	6	6,399	32	200.0	4
2001	2,257	16	141.1	9	6,786	39	174.0	8
2002	25,657	119	215.6	7	14,079	77	182.8	10
2003	22,551	91	247.8	8	29,019	141	205.8	14
2004	21,891	105	208.5	9	20,832	100	208.3	10
2005	11,560	66	175.2	6	9,658	61	158.3	12

*Confidential.

Table 13.7 Length-frequency of male American shad samples from the Albemarle Sound commercial gill-net fishery, 1972-2005.

FL (mm)	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
300		1			1	4	1						1			1	2					
320		3			6	4			1		5	1	1		2	3	3		1	3	1	2
340	8	12	15	5	14		2	5	1	1	4	6	6	3	6	10	5	8	13	10	11	13
360	11	35	29	18	27	15	12	18	14	15	5	17	32	29	11	44	25	18	24	27	33	17
380	12	56	63	34	98	51	28	90	86	62	48	35	75	49	21	86	36	27	34	33	41	44
400	47	124	77	67	81	50	77	167	110	165	102	72	74	46	28	44	76	39	51	63	47	43
420	83	61	33	52	56	52	108	72	89	98	110	101	71	50	58	27	106	71	40	68	55	26
440	75	41	7	24	29	25	40	21	54	68	63	109	64	35	26	27	25	34	27	35	37	4
460	41	16	1	13	12	5	7	6	11	13	24	26	29	20	5	14	7	10	12	6	6	2
480	5	12		6	7	3	3	1	3	4	5	4	14	3	3		5	1	1	3	2	1
500	1	4		3	5	1				1		1	3			1	3					
520				3																		
540												2										
560																						
580																						
600																						
Total	**283**	**365**	**225**	**225**	**336**	**210**	**278**	**380**	**369**	**427**	**366**	**374**	**370**	**235**	**160**	**257**	**293**	**208**	**203**	**248**	**233**	**152**

FL (mm)	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300								1				
320								1	2		1	2
340							5	10	6	1	1	12
360							33	16	8		7	11
380							31	29	11	5	9	12
400							33	21	7	13	8	6
420							10	12	11	23	14	13
440							4	4	7	12	18	7
460							1	3	4	5	5	5
480									1	2	2	
500								1				
520								1		1		
540												
560												
580												
600												
Total							**117**	**99**	**57**	**62**	**65**	**68**

Table 13.8 Length-frequency of female American shad samples from the Albemarle Sound commercial gill-net fishery, 1972–2005.

FL (mm)	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
300																						
320											2											
340											8	1								1		
360	1	11			3						10					1				2		
380	1	3	2		6	5	1	1	1		3			1	1	1	1			1	3	3
400	4	6	13	2	9	5	13	8			3	4	3	3	1	8	9	1	5	11	13	21
420	14	25	16	9	26	11	31	13	2	5	3	11	11	13	1	8	18	5	8	38	46	48
440	18	38	38	28	58	31	49	33	21	27	19	19	27	27	2	11	37	21	27	87	84	66
460	41	59	58	70	68	38	58	70	84	44	51	92	52	45	10	42	48	76	32	85	83	47
480	81	71	22	54	57	40	34	45	39	77	77	79	87	55	18	66	68	76	49	67	60	19
500	66	87	18	39	22	23	20	12	19	55	56	55	90	39	18	32	54	26	26	35	10	11
520	15	36	6	8	7	3	4			10	15	12	33	20	4	10	10	6	6	3	1	1
540		9	4							2		3	8	4	2	2	1		1			1
560	2				1									1								1
580																			1			
600																						
Total	**243**	**345**	**177**	**210**	**257**	**156**	**210**	**182**	**166**	**220**	**247**	**276**	**311**	**208**	**57**	**181**	**246**	**211**	**155**	**330**	**300**	**218**

FL (mm)	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300												
320												
340								1	1			2
360												
380							3	1				5
400							11	5	5	4		13
420							38	29	11	16	7	22
440							56	62	13	22	19	27
460							55	25	16	23	27	30
480							29	7	15	13	20	5
500							2	2	2	4	9	2
520										1	1	
540												
560										1		
580												
600												
Total							**194**	**132**	**63**	**84**	**83**	**106**

Table 13.9 Mean total length and weight, and sex ratios of American shad sampled from the Albemarle Sound commercial gill-net fishery, 1972-2005.

Year	Male					Female					Sexes Combined					Sex Ratio
	N	Length	SD	Weight	SD	N	Length	SD	Weight	SD	N	Length	SD	Weight	SD	M:F
1972	239	484	33.69	1.38	0.36	222	546	31.60	2.17	0.42	461	513	45.22	1.75	0.55	1.08
1973	346	465	36.55	1.1	0.23	302	543	43.41	2.24	0.55	648	502	55.71	1.94	0.71	1.15
1974	199	449	26.84			149	526	35.92			348	483	48.93			1.34
1975	165	465	35.89			140	538	26.96			305	504	48.37			1.18
1976	301	460	40.75			231	519	35.34			532	485	48.28			1.3
1977	230	457	36.36			171	520	40.94			401	484	49.67			1.35
1978	285	474	27.35			205	520	31.40			490	493	37.13			1.39
1979	298	460	23.90			207	526	26.68			505	485	40.16			1.44
1980	297	466	27.67			136	536	19.62			433	488	41.00			2.18
1981	413	472	27.59	1.18	0.26	228	548	27.26	2.17	0.36	641	499	45.93	1.53	0.56	1.81
1982	362	473	32.22	1.18	0.31	214	526	58.36	1.88	0.58	576	494	51.73	1.47	0.56	1.69
1983	367	481	37.93	1.32	0.35	273	540	34.27	2.07	0.4	640	506	46.98	1.64	0.53	1.34
1984	366	474	40.92	1.29	0.41	310	552	35.55	2.61	0.5	676	512	54.54	1.93	0.54	1.18
1985	236	469	37.74	1.15	0.36	210	544	39.05	2.1	0.52	446	505	53.17	1.6	0.65	1.12
1986	158	469	39.82	1.21	0.33	57	552	38.85	2.29	0.51	215	495	54.66	1.54	0.64	2.77
1987	260	455	39.72	1.06	0.3	179	540	37.96	2.02	0.45	439	493	57.72	1.49	0.61	1.45
1988	291	470	39.94	1.2	0.33	260	535	35.84	1.9	0.43	551	501	49.76	1.54	0.52	1.12
1989	208	474	36.76	1.26	0.33	211	540	25.32	1.99	0.33	419	506	45.76	1.62	0.49	0.99
1990	205	465	39.16	1.09	0.3	157	540	36.74	1.91	0.41	362	499	53.72	1.46	0.54	1.31
1991	257	465	37.49	1.09	0.33	351	522	34.23	1.75	0.38	608	497	45.91	1.46	0.49	1.31
1992	233	460	38.44	1.06	0.31	301	515	29.50	2.04	0.48	534	492	43.60	1.88	0.64	1.31
1993	153	451	34.45	1.01	0.25	221	518	38.75	1.6	0.34	374	488	49.63	1.34	0.42	1.31
1994-1999									No samples							
2000	117	442		0.99		194	511		1.7		311	483		1.41		0.6
2001	99	444		0.95		132	506		1.55		231	479		1.3		0.75
2002	57	456		1.13		63	515		1.73		120	487		1.45		0.9
2003	62	485		1.36		84	518		1.77		146	504		1.6		0.74
2004	65	464		1.19		83	520		1.75		148	495		1.5		0.78
2005	73	437		1.03		107	497		1.53		180	473		1.32		0.68

Table 13.10 Age structure from fishery-dependent samples of male American shad from the Albemarle Sound commercial gill-net fishery, 1972-2005.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
2				1															
3	8	32	18				3	8	11	6	7	1		2	3	11	6	1	1
4	46	195	145	70	103	53	54	88	25	42	97	34	28	44	14	65	33	24	28
5	131	88	34	76	160	150	188	120	134	140	170	203	190	107	81	104	136	112	93
6	44	22	0	15	36	27	39	14	69	130	72	109	93	62	36	52	90	62	47
7	9	7	2	2	2		1	3	44	83	14	18	35	17	22	25	21	9	33
8	1	2		1					14	12	2	2	20	4	2	3	5		3
9																			
10																			
Total	**239**	**346**	**199**	**165**	**301**	**230**	**285**	**233**	**297**	**413**	**362**	**367**	**366**	**236**	**158**	**260**	**291**	**208**	**205**
Mean Age	**5.01**	**4.37**	**4.11**	**4.69**	**4.79**	**4.89**	**4.93**	**4.64**	**5.51**	**5.67**	**4.99**	**5.31**	**5.53**	**5.25**	**5.42**	**5.09**	**5.35**	**5.26**	**5.45**

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2															
3	3	2	13									2		4	21
4	14	27	26							10	8	23	9	22	12
5	145	101	59							11	15	15	22	27	11
6	68	52	26							5	5	8	22	8	6
7	27	43	27									9	9	4	4
8		8	2								1				
9															
10															
Total	**257**	**233**	**153**							**26**	**29**	**57**	**62**	**65**	**54**
Mean Age	**5.40**	**5.56**	**5.22**							**4.81**	**5.00**	**4.98**	**5.50**	**4.78**	**4.26**

Table 13.11 Repeat spawning mark frequencies of male American shad in the Albemarle Sound commercial gill-net fishery, 1972-2005.

Number of Spawning Marks	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0	151	284	189	116	215	212	266	252	180	254	240	194	206	130	93	163	176	127
1	67	47	9	46	66	18	18	41	67	89	89	141	103	83	52	76	78	54
2	15	6	1	3	18		1	4	35	67	25	29	45	20	11	20	30	26
3	4	6			2			1	15	1	6	3	12	3	2	1	7	1
4	2	3								2	2							
Total	**239**	**346**	**199**	**165**	**301**	**230**	**285**	**298**	**297**	**413**	**362**	**367**	**366**	**236**	**158**	**260**	**291**	**208**
Mean Repeat	**0.49**	**0.26**	**0.06**	**0.32**	**0.36**	**0.08**	**0.07**	**0.17**	**0.61**	**0.57**	**0.46**	**0.57**	**0.63**	**0.56**	**0.51**	**0.46**	**0.55**	**0.52**
% Repeat	**0.37**	**0.18**	**0.05**	**0.30**	**0.29**	**0.08**	**0.07**	**0.15**	**0.39**	**0.38**	**0.34**	**0.47**	**0.44**	**0.45**	**0.41**	**0.37**	**0.40**	**0.39**

Number of Spawning Marks	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0	119	148	131	89							20	15	45	33	48	40
1	51	83	61	45							3	13	11	23	13	10
2	33	24	37	18							3	1	1	6	4	4
3	2	2	4	1												
4																
Total	**205**	**257**	**233**	**153**							**26**	**29**	**57**	**62**	**65**	**54**
Mean Repeat	**0.60**	**0.53**	**0.63**	**0.55**							**0.35**	**0.52**	**0.23**	**0.56**	**0.32**	**0.33**
% Repeat	**0.42**	**0.42**	**0.44**	**0.42**							**0.23**	**0.48**	**0.21**	**0.47**	**0.26**	**0.26**

Table 13.12 Age structure from fishery-dependent samples of female American shad from the Albemarle Sound commercial gill-net fishery, 1972-2005.

Age	1972	1973	1974	1975	1976	1977	1978	1979*	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
2																			
3																			
4	14	38	49	21	17	2	9		2		12	6		1	1	2	4	6	1
5	86	120	87	81	155	94	110		18	34	61	81	76	50	11	36	69	69	43
6	99	136	12	33	55	71	78		44	80	84	114	79	99	18	73	71	77	31
7	20	7	1	4	3	4	8		45	52	47	65	90	42	15	49	78	47	52
8	2	1		1	1				24	50	8	7	47	18	11	18	30	8	28
9	1								3	12	2		18		1	1	8	4	2
10																			
Total	**222**	**302**	**149**	**140**	**231**	**171**	**205**		**136**	**228**	**214**	**273**	**310**	**210**	**57**	**179**	**260**	**211**	**157**
Mean age	**5.61**	**5.38**	**4.77**	**5.16**	**5.20**	**5.45**	**5.41**		**6.59**	**6.68**	**5.93**	**5.95**	**6.52**	**6.12**	**6.47**	**6.27**	**6.33**	**5.97**	**6.44**

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2															
3													3		24
4	7	2	3							6	1	1	24	6	11
5	106	72	71							35	28	19	18	39	15
6	127	71	68							26	37	13	13	32	18
7	95	103	51							2	8	8	22	6	9
8	12	50	25								1	20	4		1
9	4	3	3									2			
10															
Total	**351**	**301**	**221**							**69**	**75**	**63**	**84**	**83**	**78**
Mean age	**6.03**	**6.45**	**6.15**							**5.35**	**5.73**	**6.52**	**5.46**	**5.46**	**4.74**

*Data deleted; irresolvable data entry error.

Table 13.13 Repeat spawning mark frequencies of female American shad in the Albemarle Sound commercial gill-net fishery, 1972-2005.

Number of Spawning Marks	1972	1973	1974	1975	1976	1977	1978	1979*	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
0	140	263	141	100	163	158	194		81	159	157	180	180	132	30	103	166	136
1	42	31	6	31	38	12	11		29	33	33	75	74	71	9	40	57	51
2	30	5	2	8	29	1			20	20	17	14	52	6	14	33	29	19
3	10	3		1	1				5	12	5	3	4	1	4	3	8	5
4									1	4	2	1						
Total	**222**	**302**	**149**	**140**	**231**	**171**	**205**		**136**	**228**	**214**	**273**	**310**	**210**	**57**	**179**	**260**	**211**
Mean Repeat	**0.59**	**0.17**	**0.07**	**0.36**	**0.43**	**0.08**	**0.05**		**0.65**	**0.55**	**0.42**	**0.42**	**0.61**	**0.41**	**0.86**	**0.64**	**0.53**	**0.49**
% Repeat	**0.37**	**0.13**	**0.05**	**0.29**	**0.29**	**0.08**	**0.05**		**0.40**	**0.30**	**0.27**	**0.34**	**0.42**	**0.37**	**0.47**	**0.42**	**0.36**	**0.36**

Number of Spawning Marks	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0	91	242	183	154							33	66	47	45	50	53
1	39	79	67	45							27	8	13	27	29	17
2	21	25	38	18							8	1	3	12	4	8
3	6	3	13	4							1					
4		2														
Total	**157**	**351**	**301**	**221**							**69**	**75**	**63**	**84**	**83**	**78**
Mean Repeat	**0.63**	**0.42**	**0.60**	**0.42**							**0.67**	**0.13**	**0.30**	**0.61**	**0.45**	**0.42**
% Repeat	**0.42**	**0.31**	**0.39**	**0.30**							**0.52**	**0.12**	**0.25**	**0.46**	**0.40**	**0.32**

* Data deleted; irresolvable data entry error

Table 13.14 RCGL landings and discards of American shad by region, 2002-2005.

Year	Region	Harvested		Discarded		Total Catch	
		kg	PSE	kg	PSE	kg	PSE
2002	North	833	11.0	3,394	8.7	4,227	7.7
2003		1,283	9.3	736	12.2	2,019	7.1
2004		0	-	*	*	*	*
2005		18	50.0	165	46.7	183	40.5
2002	Pamlico**	4,306	4.1	6,676	8.1	10,982	4.9
2003		7,109	2.4	7,436	6.6	14,545	3.3
2004		1,391	9.1	73	33.3	1,464	8.2
2005		1,576	5.4	251	11.8	1,828	4.7
2002	Central	561	42.9	700	31.4	1,261	34.7
2003		818	29.9	179	21.7	997	22.5
2004		0	-	0	-	0	-
2005		348	31.6	1,284	15.4	1,631	12.2
2002	South	513	15.5	94	26.8	607	10.6
2003		6,188	4.8	559	9.6	6,747	4.6
2004		2,557	8.7	482	14.4	3,039	4.5
2005		2,678	6.9	894	12.3	3,571	6.9
2002	All	6,214	9.5	10,734	10.1	16,948	8.2
2003		15,399	5.4	8,752	7.6	24,151	4.8
2004		3,948	8.9	698	13.4	4,645	5.6
2005		4,620	8.5	0	23.0	4,620	11.8

* Confidential.

**The Pamlico region encompasses two major spawning runs of American shad: the Pamlico and Neuse rivers.

Table 13.15 Catch-per-unit-effort of American shad from the NCDMF fishery-independent (FI) gill-net survey, the NCDMF fishery-dependent (FD) gill-net survey, and the NCWRC FI electrofishing survey in Albemarle Sound, 1991-2005.

Year	NCDMF		NCWRC
	FI Gill Net (# shad/set)	FD Gill Net (# shad/trip)	FI Electrofishing (# shad/hour)
1991	0.04		
1992	0.02		
1993	0.03		
1994	0.03	156.84	
1995	0.06	169.47	
1996	0.05	144.78	
1997	0.04	167.77	
1998	0.08	206.64	
1999	0.02	166.80	
2000	0.08	172.89	41.8
2001	0.08	151.86	58.8
2002	0.13	226.06	40.7
2003	0.10	280.64	43.1
2004	0.04	232.89	49.3
2005	0.09	201.05	72.0

Table 13.16 Mean total length and weight and sex ratios of American shad collected by fishery-independent gears in the Roanoke River and Albemarle Sound, 2000–2005.

Year	NCWRC Electrofishing Survey - Roanoke River							NCDMF Gill-net Survey - Albemarle Sound			
	N	Mean TL	SD	N	Mean Wt	SD	Sex ratio (M:F)	N	Mean TL	SD	Sex ratio (M:F)
Males											
2000	139	442.0	20.1	140	846.7	178.6	7.0	54	434.0		1.3
2001	290	452.7	24.2				5.9	40	449.0		0.8
2002	202	449.0	37.6	89	782.7	194.2	1.8	44	458.3		0.8
2003	250	459.0	36.4				2.3	49	455.1		0.8
2004	147	451.2	34.6				4.5	35	450.8		0.9
2005	314	421.8	32.3				9.5	90	425.3		1.0
Females											
2000	20	496.4	24.2	20	1300.0	344.9		42	499.7		
2001	49	502.6	20.6					53	499.4		
2002	113	519.2	29.0	21	1243.2	222.2		52	506.8		
2003	108	525.8	33.5					58	523.8		
2004	33	520.7	26.4					40	525.3		
2005	33	501.4	33.3					89	490.0		

Table 13.17 Length frequency of American shad from NCDMF fishery-independent gill-net samples in Albemarle Sound, 2000–2005.

FL	Males						Females					
(mm)	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
280												
300						1						
320				1		5						
340	3	1	2	3	5	9						
360	13	7	6	5	3	27	2		1			2
380	20	8	5	10	4	26	1	2		1	1	8
400	13	14	10	10	13	11	3	7	6	2	2	10
420	4	7	14	10	7	8	8	14	6	7	2	23
440	1	1	5	8	1	2	12	14	18	8	7	22
460		2	2		1		11	7	8	17	10	15
480				2		1	3	5	10	14	12	7
500							1	2	3	7	5	2
520							1	1		2	1	
540					1			1				
560												
580												
600												
620												
640												
Total	**54**	**40**	**44**	**49**	**35**	**90**	**42**	**53**	**52**	**58**	**40**	**89**

Table 13.18 Length frequencies of American shad from NCWRC fishery-independent electrofishing samples in the Roanoke River 2000–2005.

FL (mm)	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
300			1	1		1						
320			2	3		1						
340		4	6	1	8	26						
360	6	11	14	20	13	79						
380	38	29	33	36	12	98			1			
400	60	92	43	41	42	51			2	4		3
420	29	109	44	70	41	31	6	5	3	6	4	5
440	6	42	31	47	23	21	6	12	11	17	10	7
460		3	8	28	7	6	5	24	29	21	7	7
480			2	3	1	1	3	7	36	28	7	7
500			1					1	15	25	5	3
520									1	5		1
540										2		
560												
580												
600												
620												
640												
Total	**139**	**290**	**185**	**250**	**147**	**314**	**20**	**49**	**98**	**108**	**33**	**33**

Table 13.19 Age frequencies of American shad from NCDMF fishery-independent gill-net samples in Albemarle Sound, 2000–2005.

Age/Year	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
2												
3	1	3	3	6	15	18					7	9
4	42	9	14	16	17	19	10	2	15	11	6	14
5	12	21	8	8	2	7	23	19	14	8	10	16
6		7	18	17	0	3	8	26	8	14	10	7
7			1	2	1		1	6	11	18	6	6
8									4	7	1	
9												
10												
Total	**55**	**40**	**44**	**49**	**35**	**47**	**42**	**53**	**52**	**58**	**40**	**52**
Mean Age	**4.20**	**4.80**	**5.00**	**4.86**	**3.71**	**3.89**	**5.00**	**5.68**	**5.52**	**6.03**	**5.13**	**4.75**

Table 13.20 Repeat spawning mark frequencies of American shad from NCDMF fishery-independent gill-net samples in Albemarle Sound, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
0	50	26	34	35	31	41	23	45	40	33	24	33
1	5	14	9	12	3	5	13	6	11	16	9	16
2			1	2	1	1	6	2	1	9	7	3
3												
4												
Total	**55**	**40**	**44**	**49**	**35**	**47**	**42**	**53**	**52**	**58**	**40**	**52**
Mean Repeat	**0.09**	**0.35**	**0.23**	**0.29**	**0.11**	**0.13**	**0.45**	**0.15**	**0.23**	**0.43**	**0.40**	**0.37**
% Repeat	**0.09**	**0.35**	**0.25**	**0.33**	**0.14**	**0.15**	**0.60**	**0.19**	**0.25**	**0.59**	**0.58**	**0.42**

Table 13.21 Age frequencies of American shad from NCWRC fishery-independent electrofishing samples in the Roanoke River, 2000–2005.

Age/Year	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2				1								
3			3	18	20	50				4		
4	9	13	46	51	26	68			2	16	2	
5	47	43	48	45	25	19	1		18	52	5	16
6	57	83	39	20	15	4	6	4	29	27	10	10
7	19	72	27	2	6		8	12	10	6	9	7
8	1	21	5		0		5	11	8	1	6	
9			1		1			3	1		0	
10											1	
Total	**133**	**232**	**169**	**137**	**93**	**141**	**20**	**30**	**68**	**106**	**33**	**33**
Mean age	**5.67**	**6.19**	**5.36**	**4.52**	**4.62**	**3.84**	**6.85**	**7.43**	**6.10**	**5.17**	**6.48**	**5.73**

Table 13.22 Repeat spawning mark frequencies of American shad from NCWRC fishery-independent electrofishing samples in the Roanoke River, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0	93	107	58	70	45	74	3	15	10	55	8	2
1	34	101	75	40	21	50	10	9	36	33	8	18
2	6	21	24	23	16	14	6	5	16	18	8	7
3		3	8	3	11	3	1	1	5		5	6
4			3	1							4	
5			1						1			
Total	**133**	**232**	**169**	**137**	**93**	**141**	**20**	**30**	**68**	**106**	**33**	**33**
Mean Repeat	**0.35**	**0.66**	**0.97**	**0.72**	**0.92**	**0.62**	**1.25**	**0.73**	**1.29**	**0.65**	**1.67**	**1.52**
% Repeat	**0.30**	**0.54**	**0.66**	**0.49**	**0.52**	**0.48**	**0.85**	**0.50**	**0.85**	**0.48**	**0.76**	**0.94**

Table 13.23 American shad relative abundance index from 11 core seine stations in the Albemarle Sound area, 1972–2005.

Year	Number of Hauls	Number of Shad	Arithmetic Mean	Geometric Mean
1972	13	3	0.23	
1973	45	7	0.15	0.40
1974	51	0	0.00	0.00
1975	53	9	0.17	0.90
1976	50	0	0.00	0.00
1977	54	21	0.39	1.10
1978	55	26	0.47	0.40
1979	43	14	0.32	0.50
1980	54	32	0.59	0.90
1981	55	3	0.05	0.80
1982	54	25	0.46	0.90
1983	55	1	0.01	0.60
1984	55	8	0.14	0.70
1985	51	102	2.00	0.60
1986	55	6	0.11	0.30
1987	55	8	0.14	0.30
1988	55	7	0.13	0.20
1989	55	0	0.00	0.00
1990	55	0	0.00	0.00
1991	55	0	0.00	0.00
1992	55	0	0.00	0.00
1993	54	0	0.00	0.00
1994	55	0	0.00	0.00
1995	55	1	0.01	0.60
1996	55	1	0.01	0.60
1997	55	43	0.78	0.70
1998	55	10	0.18	0.90
1999	55	19	0.34	0.80
2000	55	14	0.25	0.26
2001	55	35	0.64	0.64
2002	55	25	0.45	0.57
2003	55	252	4.60	0.80
2004	55	32	0.58	0.30
2005	55	92	1.70	0.30

Table 13.24 Total instantaneous mortality estimates for American shad in Albemarle Sound, 1972–2005. Age = catch curve using ages; RS = catch curve using repeat spawning marks.

Year	Fishery-Dependent Gill Net				Fishery-Independent Gill Net			
	M-age	F-age	M-RS	F-RS	M-age	F-age	M-RS	F-RS
1972	1.62	1.61	1.15	0.83				
1973	1.17	2.46	1.12	1.52				
1974	1.43	2.23	2.62	2.13				
1975	1.50	1.53	1.83	1.52				
1976	2.19	1.80	1.53	1.56				
1977	1.71	1.58	2.47	2.53				
1978	2.62	1.31	2.79	2.87				
1979	1.84		1.89					
1980	0.72	1.35	0.81	1.05				
1981	0.78	0.57	1.42	0.84				
1982	1.50	1.30	1.23	1.06				
1983	1.57	1.40	1.41	1.36				
1984	0.77	0.80	0.94	1.18				
1985	1.12	0.85	1.27	1.71				
1986	1.16	0.90	1.31	0.56				
1987	1.14	1.39	1.66	1.08				
1988	1.14	1.14	1.06	0.98				
1989	1.26	1.06	1.53	1.09				
1990	1.07	1.63	1.27	0.88				
1991	0.84	1.24	1.42	1.29				
1992	0.78	1.77	1.10	0.85				
1993	1.01	0.73	1.44	1.19				
1994								
1995								
1996								
1997								
1998								
1999								
2000	0.79	1.43	0.95	0.71	1.25	1.57	2.30	0.67
2001	0.89	1.81	1.35	2.09	1.10	1.47	0.62	1.56
2002	0.34	2.30	1.90	1.38	2.89	0.29	1.76	1.84
2003	0.89	0.34	0.85	0.66	2.14	0.94	1.43	0.65
2004	0.95	0.94	1.24	1.26	0.86	0.74	1.72	0.62
2005	0.39	1.45	1.15	0.95	0.92	0.49	1.86	1.20

Table 13.25 Commercial harvest of American shad in the Pamlico Sound, 1972–2005. N = number; TW = total weight; MW = mean weight.

Year	Gill Net			Pound Net			Other Gears			Total		
	Number	TW (kg)	MW (kg)	Number	TW (kg)	MW (kg)	Number	TW (kg)	MW (kg)	Number	TW (kg)	MW (kg)
1972	6,046	10,971	1.8	16,971	30,792	1.8				23,017	41,762	1.8
1973	12,211	22,155	1.8	14,098	25,580	1.8				26,309	47,736	1.8
1974	11,479	20,827	1.8	21,752	39,468	1.8				33,231	60,295	1.8
1975	7,152	12,977	1.8	10,174	18,460	1.8				17,326	31,438	1.8
1976	1,476	2,544	1.7	2,140	3,690	1.7				3,616	6,234	1.7
1977				834	1,438	1.7				834	1,438	1.7
1978	29,995	51,702	1.7	2,131	3,673	1.7	569	981	1.7	32,695	56,357	1.7
1979	17,147	28,777	1.7	1,633	2,742	1.7				18,790	31,519	1.7
1980	8,367	14,043	1.7	2,765	4,641	1.7	912	1,530	1.7	12,044	20,214	1.7
1981	23,309	39,121	1.7	2,731	4,583	1.7	204	343	1.7	26,244	44,047	1.7
1982	32,245	54,117	1.7	964	1,618	1.7	7	11	1.7	33,216	55,747	1.7
1983	9,666	24,114	2.5	847	2,113	2.5	92	229	2.5	10,605	26,456	2.5
1984	12,422	24,229	2.0	7,317	14,272	2.0	70	136	2.0	19,809	38,636	2.0
1985	12,234	23,863	2.0							12,234	23,863	0.0
1986	11,324	21,575	1.9	59	113	1.9	368	700	1.9	11,751	22,388	1.9
1987	11,141	21,225	1.9	335	639	1.9	468	892	1.9	11,944	22,756	1.9
1988	7,506	12,598	1.7	1,525	2,560	1.7	18	30	1.7	9,049	15,189	1.7
1989	5,855	9,827	1.7	1,465	2,459	1.7	20	34	1.7	7,340	12,319	1.7
1990	3,976	6,672	1.7	7	12	1.7	18	30	1.7	4,001	6,715	1.7
1991	2,558	4,178	1.6	166	272	1.6		8	1.6	2,724	4,458	1.6
1992	2,373	3,876	1.6							2,373	3,876	0.0
1993	820	1,376	1.7				19	31	1.7	839	1,407	0.0
1994	1,266	2,124	1.7	31	53	1.7	39	66	1.7	1,336	2,243	1.7
1995	1,396	2,344	1.7	15	25	1.7	3	5	1.7	1,414	2,373	1.7
1996	2,510	4,100	1.6	19	31	1.6	2	3	1.6	2,531	4,135	1.6
1997	3,453	5,639	1.6	14	23	1.6	7	12	1.6	3,474	7,264	1.6
1998	1,317	2,270	1.7	1	2	1.7				1,318	2,272	1.7
1999	1,571	2,709	1.7	5	9	1.7	16	29	1.7	1,592	2,746	1.7
2000	4,171	7,001	1.7	85	143	1.7	17	29	1.7	4,273	7,173	1.7
2001	1,984	3,600	1.8	459	833	1.8	4	7	1.8	2,447	4,440	1.8
2002	2,758	4,754	1.7	895	1,543	1.7	5	9	1.7	3,658	6,306	1.7
2003	2,745	4,732	1.7	209	361	1.7	47	82	1.7	3,001	5,174	1.7
2004	452	738	1.6				1	2	1.6	454	741	1.6
2005	1,432	2,469	1.7	6	8	1.4	1	2	1.7	1,561	2,479	1.6

Table 13.26 Commercial harvest of American shad in the Pamlico River, 1972–2005. N = number; TW = total weight; MW = mean weight.

Year	Gill net			Pound net			Other gears			Total		
	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)
1972	18,019	32,694	1.8	5,756	9,400	1.6				23,775	42,094	1.7
1973	7,575	13,744	1.8							7,575	13,744	1.8
1974	8,042	14,591	1.8							8,042	14,591	1.8
1975	8,539	15,494	1.8							8,539	15,494	1.8
1976	8,460	14,583	1.7							8,460	14,583	1.7
1977	3,535	6,093	1.7							3,535	6,093	1.7
1978	10,765	18,556	1.7							10,765	18,556	1.7
1979	2,965	4,976	1.7							2,965	4,976	1.7
1980	1,738	2,917	1.7							1,738	2,917	1.7
1981	2,638	4,428	1.7							2,638	4,428	1.7
1982	1,373	2,304	1.7							1,373	2,304	1.7
1983	9,775	24,387	2.5							9,775	24,401	2.5
1984	24,537	47,859	2.0	853	1,315	1.5				25,390	49,175	1.7
1985	9,424	18,382	2.0	44	68	1.5				9,468	18,450	1.7
1986	4,319	8,227	1.9							4,319	8,227	1.9
1987	5,390	10,270	1.9							5,390	10,270	1.9
1988	12,596	21,141	1.7							12,596	21,141	1.7
1989	4,598	7,717	1.7							4,598	7,717	1.7
1990	1,543	2,590	1.7				253	368	1.5	1,796	2,957	1.5
1991	705	1,151	1.6	9	14	1.5				714	1,165	1.6
1992	3,953	6,455	1.6							3,953	6,455	1.6
1993	820	1,376	1.7							820	1,376	1.7
1994	1,069	1,794	1.7				25	39	1.5	1,094	1,832	1.6
1995	2,483	4,167	1.7				113	175	1.5	2,596	4,342	1.6
1996	2,409	3,934	1.6							2,409	3,934	1.6
1997	2,580	4,213	1.6				2	4	1.5	2,582	5,392	1.6
1998	3,077	5,304	1.7				1	2	1.5	3,078	5,306	1.6
1999	1,804	3,109	1.7	1	2	1.5	17	27	1.6	1,822	3,139	1.6
2000	4,441	7,453	1.7				95	152	1.6	4,536	9,708	1.6
2001	1,604	2,911	1.8							1,604	2,911	1.8
2002	3,927	6,769	1.7				14	23	1.6	3,941	6,792	1.6
2003	4,489	7,738	1.7					100	1.6	4,710	7,838	1.6
2004	4,784	7,812	1.6				4	7	1.6	4,536	7,819	1.7
2005	3,863	6,658	1.7				5	8	1.7	3,867	6,667	1.7

Table 13.27 Length-frequency of male American shad samples from the Pamlico River commercial gill-net fishery, 1975–2005.

FL (mm)	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
300																					
320	1								2						1						
340	2								2	2		1		4							
360	2	1		1						1	3			2	16						
380	12	2		4	1				1	11	2		1	12	11						
400	49	5		13	5		1		8	10	9	8	6	17	10						
420	67	12		34	8	1	3		35	32	20	25	4	19	46						
440	23	17		4	3	4	9		47	39	14	20	6	8	33						
460	8	10				2	3		8	20	3	6	7	1	7						
480	2	8			1		1		1	2	1	5		1							
500		2			1																
520																					
540																					
560																					
580																					
600																					
Total	**166**	**57**		**56**	**19**	**7**	**17**		**102**	**117**	**54**	**64**	**25**	**60**	**128**						

FL (mm)	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300										
320										1
340									1	
360						2		1	1	3
380						1		2	1	2
400					11	2	8	8		1
420					3	1	9	19	1	3
440					2	1	4	8	5	2
460					1		1	2	3	2
480										
500								1		
520										
540										
560										
580										
600										
Total					**17**	**7**	**22**	**41**	**12**	**14**

Table 13.28 Length-frequency of female American shad samples from the Pamlico River commercial gill-net fishery, 1975–2005.

FL (mm)	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
300																					
320																					
340					1																
360																					
380				1																	
400		4							1	2	1	1	1	4							
420	21	1		6	5	1	1		6	5	4	2	4	17	4						
440	48	18		23	21	12	4		11	9	22	10	9	43	11						
460	88	48		16	42	29	5		20	18	34	30	21	37	38						
480	88	46		10	29	18	23		27	31	33	37	26	29	49						
500	53	17		2	9	2	18		9	23	28	23	19	13	9						
520	15	5		1	3		7			4	16	9	4	3	3						
540	2	4					1			1	1	2	1	1							
560		3			1																
580		1													1						
600																					
Total	**315**	**147**		**59**	**111**	**62**	**59**		**74**	**93**	**139**	**114**	**85**	**147**	**115**						

FL (mm)	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300										
320									1	
340										
360										1
380										
400					1	2	4	5	2	4
420					7	18	14	12	9	30
440					7	78	36	16	19	57
460					7	79	52	18	4	52
480					3	22	23	5	37	29
500						9	4	9	11	7
520									3	
540										
560										1
580										
600										
Total					**25**	**208**	**133**	**65**	**86**	**181**

Table 13.29 Age structure from fishery-dependent samples of male American shad from the Pamlico River commercial gill-net fishery, 1975–2005.

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2																			
3	2			2						1									
4	89			7	8		3		4	18	6	16	5	9					
5	68	3		35	6	21	29		20	31	16	27	16	23					
6	2	1		1	4	8	8		22	12	13	4	3	5					
7	2						1		4	2		1	1						
8																			
9																			
10																			
Total	**163**	**4**		**45**	**18**	**29**	**41**		**50**	**64**	**35**	**48**	**25**	**37**					
Mean Age	**4.47**	**5.25**		**4.78**	**4.78**	**5.28**	**5.17**		**5.52**	**4.94**	**5.20**	**4.79**	**5.00**	**4.89**					

Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2												
3										1	2	2
4							2	8	8	7	1	1
5							11	15	7	10	6	3
6							2	5	5	14	3	1
7									1	7		
8								1		1		
9												
10												
Total							**15**	**29**	**21**	**40**	**12**	**7**
Mean Age							**5.00**	**5.00**	**4.95**	**5.55**	**4.83**	**4.43**

Table 13.30 Age structure from fishery-dependent samples of female American shad from the Pamlico River commercial gill-net fishery, 1975–2005.

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2																			
3																			
4	52			2	6					3	3	7	3	10					
5	209	7		34	63	46	24		27	25	40	42	24	42					
6	49	5		15	28	99	66		20	21	36	13	17	27					
7	1			1	2	13	9		4	4	4	1	4	3					
8																			
9																			
10																			
Total	**311**	**12**		**52**	**99**	**158**	**99**		**51**	**53**	**83**	**63**	**48**	**82**					
Mean Age	**5.00**	**5.42**		**5.29**	**5.26**	**5.79**	**5.85**		**5.55**	**5.49**	**5.49**	**5.13**	**5.46**	**5.28**					

Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2												
3									1	1	1	5
4							2	1	24	16	3	19
5							11	28	32	9	49	40
6							12	37	33	13	52	27
7							2	8	34	21	16	11
8								1	2	5	1	2
9												
10												
Total							**27**	**75**	**126**	**65**	**122**	**104**
Mean Age							**5.52**	**5.73**	**5.64**	**5.80**	**5.67**	**5.25**

Table 13.31 Repeat spawning mark frequencies of male American shad in the Pamlico River commercial gill-net fishery, 1975–2005.

Number of Spawning Marks	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	130	2		40	18	30	36		27	56	27	42	21	28				
1	31	1		5			5		19	6	8	6	4	9				
2	2	1							4	2								
3																		
4																		
Total	**163**	**4**		**45**	**18**	**30**	**41**		**50**	**64**	**35**	**48**	**25**	**37**				
% Repeat	**0.20**	**0.50**		**0.11**	**0.00**	**0.00**	**0.12**		**0.46**	**0.13**	**0.23**	**0.13**	**0.16**	**0.24**				

Number of Spawning Marks	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0								10	15	15	32	10	6
1								5	13	5	8	2	1
2									1	1			
3													
4													
Total								**15**	**29**	**21**	**40**	**12**	**7**
% Repeat								**0.33**	**0.48**	**0.29**	**0.20**	**0.17**	**0.14**

Table 13.32 Repeat spawning mark frequencies of female American shad in the Pamlico River commercial gill-net fishery, 1975–2005.

Number of Spawning Marks	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
0	283	5		52	95	156	96		30	44	70	57	45	50				
1	27	4			3	2	3		19	7	12	6	3	29				
2	1	3							2	2	1			3				
3					1													
4																		
Total	**311**	**12**		**52**	**99**	**158**	**99**		**51**	**53**	**83**	**63**	**48**	**82**				
% Repeat	**0.09**	**0.58**		**0.00**	**0.04**	**0.01**	**0.03**		**0.41**	**0.17**	**0.16**	**0.10**	**0.06**	**0.39**				

Number of Spawning Marks	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0								15	66	97	50	67	71
1								8	8	24	12	47	22
2								4	1	5	3	8	11
3													
4													
Total								**27**	**75**	**126**	**65**	**122**	**104**
% Repeat								**0.44**	**0.12**	**0.23**	**0.23**	**0.45**	**0.32**

Table 13.33 CPUE of American shad from fishery-independent electrofishing surveys in the inland rivers of North Carolina, 2000–2005.

Year	Catch			Effort	CPUE (shad/hr)		
	Male	Female	Total	(hr)	Male	Female	Total
Roanoke River							
2000	139	20	160	3.83	36.3	5.2	41.80
2001	290	49	313	5.33	54.4	9.2	58.76
2002	185	98	292	7.17	25.8	13.7	40.74
2003	250	108	358	8.32	30.1	13.0	43.05
2004	147	33	180	3.65	40.3	9.0	49.35
2005	314	33	347	4.82	65.2	6.8	72.00
Tar River							
2000	154	47	201	0.85	180.9	55.2	236.16
2001	140	63	203	1.37	102.5	46.1	148.60
2002	155	44	199				
2003	109	71	180	0.58	186.4	121.4	307.80
2004	333	221	554	2.92	114.2	75.8	190.03
2005	147	70	217	1.66	88.7	42.3	131.00
Neuse River							
2000	122	75	197	20.90	5.84	3.59	9.43
2001	168	115	283	15.52	10.82	7.41	18.23
2002	218	69	286	18.80	11.60	3.67	15.22
2003	566	233	799	38.98	14.52	5.98	20.50
2004	140	107	247	16.15	8.67	6.63	15.30
2005	131	65	196	8.79	14.90	7.40	22.30
Cape Fear River							
2000	123	32	155				
2001	142	64	206	2.25	63.05	28.42	91.47
2002	316	44	360	1.50	140.31	19.54	240.62
2003	145	165	310	3.69	64.38	73.26	83.94
2004	505	397	902	8.68	224.23	176.27	103.96
2005	192	76	268	5.18	85.25	33.74	51.70

Table 13.34 Length frequency of American shad from NCDMF fishery-independent gill-net samples in the Pamlico River, 2000–2005.

FL (mm)	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300												
320												
340					1	1						
360						1						
380				1		1						
400			1	4		1				1		
420				7	4	1				22	1	2
440				5					2	20	11	4
460			1	1	1				5	24	11	4
480					1					13	14	1
500									1	3	4	2
520											3	1
540												
Total			**2**	**18**	**7**	**5**			**8**	**83**	**44**	**14**

Table 13.35 Length frequency of American shad from NCWRC fishery-independent electrofishing samples in the Tar River, 2000–2005.

FL (mm)	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300		1			5	2						
320	1	7	3	3	25	12						
340	7	22	23	11	62	44						
360	45	15	36	11	45	45				1		
380	53	38	55	29	64	31	2	1	1	0	7	10
400	42	44	26	37	72	6	6	8	4	6	20	15
420	5	12	8	13	43	5	17	13	7	13	54	8
440		1	3	3	15	1	12	26	14	19	41	15
460	1		1	1	2	1	5	14	8	24	56	13
480				1			4	1	8	8	35	9
500							1		2		8	
520												
540		1			5	2						
Total	**154**	**140**	**155**	**109**	**333**	**147**	**47**	**63**	**44**	**71**	**221**	**70**

Table 13.36 Mean length and weight, and sex ratio of American shad collected by fishery-independent surveys in the Tar-Pamlico River, 2000–2005.

Year	NCWRC Electrofishing Survey - Tar River							NCDMF Gill-net Survey - Pamlico River			
	N	Mean TL	SD	N	Mean Wt	SD	Sex ratio (M:F)	N	Mean TL	SD	Sex ratio (M:F)
Males											
2000	154	440.9	21.9	154	853.0	197.6	3.3				
2001	140	440.8	32.3	137	769.0	174.1	2.2				
2002	155	436.9	26.7	154	810.9	186.8	3.5	2	488.9		0.3
2003	109	448.7	29.6				1.5	18	478.7		0.2
2004	333	435.6	38.3				1.5	7	480.7		0.2
2005	147	414.6	29.1				2.1	5	431.9		0.4
Females											
2000	47	500.3	29.5	47	1379.8	280.7					
2001	63	503.4	23.6	62	1156.5	247.4					
2002	44	513.8	31.3	44	1629.3	711.3		8	523.0		
2003	71	512.1	27.6					83	509.9		
2004	221	510.0	31.8					44	532.4		
2005	70	494.8	36.7					14	523.0		

Table 13.37 Age structure from fishery-independent gill-net samples of American shad from the Pamlico River, 2000–2005.

Age/Year	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2												
3					4	3					1	
4				5	1	2				10	5	2
5			1	4					2	19	4	6
6				7					2	19	15	2
7			1	2	1				2	29	15	3
8					1				1	6	4	
9												
10												
Total			**2**	**18**	**7**	**5**			**7**	**83**	**44**	**13**
Mean Age			**6.00**	**5.33**	**4.43**	**3.40**			**6.29**	**6.02**	**6.14**	**5.46**

Table 13.38 Repeat spawning mark frequencies of American shad in the Pamlico River independent gill-net sampling, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0			1	15	5	4			5	63	20	8
1				3	1	1			2	17	16	3
2			1		1					3	8	2
3												
4												
Total			**2**	**18**	**7**	**5**			**7**	**83**	**44**	**13**
% Repeat			**0.50**	**0.17**	**0.29**	**0.20**			**0.29**	**0.24**	**0.55**	**0.38**

Table 13.39 Age structure from fishery-independent electrofishing samples of American shad from the Tar River, 2000–2005.

Age/Year	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2		1		2								
3	11	28	25	85	20	26						
4	80	80	104	18	28	69	5	13	12	22	16	3
5	59	24	20	2	20	30	29	38	25	48	26	26
6	4	2	1		4	8	12	9	5		14	22
7					1	2	1				6	12
8												2
9												
10												
Total	**154**	**135**	**150**	**107**	**73**	**135**	**47**	**60**	**42**	**70**	**62**	**65**
Mean Age	**4.36**	**3.99**	**3.98**	**3.19**	**4.15**	**4.19**	**5.19**	**4.93**	**4.83**	**4.69**	**5.16**	**5.75**

Table 13.40 Repeat spawning mark frequencies of American shad in the Tar River independent electrofishing sampling, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0	55	48	29	28	31	32	11	8	13	24	27	11
1	86	74	105	35	31	79	25	36	25	28	25	30
2	13	13	16	37	10	23	11	16	4	12	10	22
3				6	1	1				6		2
4				1								
Total	**154**	**135**	**150**	**107**	**73**	**135**	**47**	**60**	**42**	**70**	**62**	**65**
Mean Repeat	**0.73**	**0.74**	**0.91**	**1.22**	**0.74**	**0.95**	**1.00**	**1.13**	**0.79**	**1.00**	**0.73**	**1.23**
% Repeat	**0.64**	**0.64**	**0.81**	**0.74**	**0.58**	**0.76**	**0.77**	**0.87**	**0.69**	**0.66**	**0.56**	**0.83**

Table 13.41 Total instantaneous mortality estimates for American shad in the Pamlico River, 1972–2005. Age= catch curve using ages, RS = catch curve using repeat spawning marks.

Year	Fishery-Dependent - Gill Net				Fishery-Independent - Gill Net			
	M-age	**F-age**	**M-RS**	**F-RS**	**M-age**	**F-age**	**M-RS**	**F-RS**
1972								
1973								
1974								
1975	1.49	2.67	2.09	2.82				
1976	1.10	0.34	0.35	0.26				
1977								
1978	3.56	1.76	2.08					
1979	0.35	1.72		3.46				
1980	0.97	2.03		4.36				
1981	1.68	1.99	1.97	3.47				
1982								
1983	1.70	0.95	0.95	1.35				
1984	1.37	0.92	1.67	1.55				
1985	0.21	1.15	1.22	2.12				
1986	1.65	1.87	1.95	2.25				
1987	1.39	0.90	1.66	2.71				
1988	1.53	1.32	1.13	1.41				
1989-1999				No samples				
2000	1.70	1.79	0.69	0.66				
2001	0.89	1.81	1.35	2.09				
2002	0.66	1.40	1.35	1.48		0.69		0.92
2003	1.32	1.44	1.39	1.41	0.35	1.58	1.61	1.52
2004	0.69	1.98	1.61	1.06		1.32	0.80	0.46
2005	1.10	0.99	1.79	0.93		035	1.39	0.69

Table 13.42 Commercial harvest of American shad in the Neuse River, 1972–2005. N = number; TW = total weight; MW = mean weight.

Year	Gill net			Pound net			Other gear			Total		
	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)
1972	21,173	36,495	1.7	370	571	1.5				21,543	37,066	1.6
1973	18,011	31,045	1.7	319	492	1.5				18,330	31,537	1.6
1974	16,076	27,711	1.7							16,076	27,711	1.7
1975	6,038	10,134	1.7	1,595	2,460	1.5				7,633	12,594	1.6
1976	9,489	15,495	1.6							9,489	15,495	1.6
1977	1,575	2,787	1.8							1,575	2,787	1.8
1978	7,931	14,391	1.8							7,931	14,391	1.8
1979	8,318	14,339	1.7							8,318	14,339	1.7
1980	2,619	4,277	1.6				643	992	1.5	3,262	5,269	1.6
1981	3,971	6,845	1.7				135	208	1.5	4,106	7,053	1.6
1982	4,770	8,223	1.7							4,770	8,223	1.7
1983	12,235	20,534	1.7				32	49	1.5	12,267	20,583	1.7
1984	17,576	31,890	1.8							17,576	31,890	1.8
1985	14,518	25,683	1.8							14,518	25,683	1.8
1986	17,288	32,151	1.9							17,288	32,151	1.9
1987	11,421	21,372	1.6							11,421	21,372	1.6
1988	4,193	6,847	1.6				4	7	1.6	4,197	6,854	1.6
1989	3,281	6,102	1.9							3,281	6,102	1.9
1990	2,960	5,236	1.8							2,960	5,236	1.8
1991	753	1,297	1.7							753	1,297	1.7
1992	3,634	6,263	1.7							3,634	6,263	1.7
1993	2,307	3,873	1.7							2,307	3,873	1.7
1994	1,899	3,273	1.7							1,899	3,273	1.7
1995	3,952	6,454	1.6				309	491	1.6	4,261	6,945	1.6
1996	6,605	11,086	1.7							6,605	11,086	1.7
1997	4,622	7,758	1.7				13	21	1.6	4,635	9,891	1.6
1998	3,333	5,291	1.6					23	1.6	3,383	5,314	1.6
1999	2,144	3,501	1.6							3,333	3,501	1.6
2000	2,634	4,182	1.6							2,144	4,182	1.6
2001	3,234	4,842	1.5							3,234	4,842	1.5
2002	11,157	18,219	1.6					5	1.5	11,168	18,224	1.6
2003	9,759	16,379	1.7							9,759	16,379	1.7
2004	9,893	15,257	1.5							9,893	15,257	1.5
2005	6,563	11,014	1.7							6,563	11,014	1.7

Table 13.43 Length-frequency of male American shad samples from the Neuse River commercial gill-net fishery, 1977–2005.

FL (mm)	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
300																					
320													1								
340		1								3											
360	5	7	3					1		3	1	2									
380	8	17	12	2	1		5	8	2	4	3	2	2								
400	8	32	28	8	5		22	24	15	8	1	10									
420	11	23	39	9	11		48	28	51	27	1	19	1								
440	9	4	16	6	9		41	13	23	27		1	4								
460		1	2	1	1		5	10	8	7											
480	1			1	1		1			1											
500			1							1											
520																					
540																					
560																					
580																					
600																					
Total	**42**	**85**	**101**	**27**	**28**		**122**	**84**	**99**	**81**	**6**	**34**	**8**								

FL (mm)	1998	1999	2000	2001	2002	2003	2004	2005
300								
320					1			
340					6	2		
360				1	7	7		8
380			1	5	7	15	1	2
400			7	4	6	12		3
420			1		9	9	7	4
440			3	2	1	7	10	
460			1			1	2	
480								
500								
520								
540								
560								
580								
600								
Total			**13**	**12**	**37**	**53**	**20**	**17**

Table 13.44 Length-frequency of female American shad samples from the Neuse River commercial gill-net fishery, 1977–2005.

FL (mm)	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
300																					
320																					
340																					
360	1			1																	
380			2																		
400	11		4	3			2	1	1			1									
420	23	12	20	1	1		5	6	3	1		9									
440	90	39	58	6	3		10	12	14	7		24	2								
460	111	44	109	13	13		42	23	26	22	2	12	12								
480	81	19	46	12	11		22	33	26	40	5	8	16								
500	33	7	6	4	5		12	28	14	35	1	6	1								
520	3	1	1				1	10	5	9		1									
540								3	4	1											
560									2			1									
580									1												
600																					
Total	**353**	**122**	**246**	**40**	**33**		**94**	**116**	**96**	**115**	**8**	**62**	**31**								

FL (mm)	1998	1999	2000	2001	2002	2003	2004	2005
300								
320								
340								
360								
380				1				1
400			2	4	2	2		7
420			11	19	8	8	5	44
440			15	71	42	41	32	81
460			17	59	52	46	41	99
480			3	20	17	16	29	55
500			1	1	1	2	12	12
520						1	3	
540						1		1
560							1	
580								
600								
Total			**49**	**175**	**122**	**117**	**123**	**300**

Table 13.45 Age structure from fishery-dependent samples of male American shad from the Neuse River commercial gill-net fishery, 1975–2005.

Age	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
2																		
3	13	3																
4	46	44	36	5	11		15	13	20	20	1	12						
5	24	75	52	17	26		29	27	28	32	5	11						
6	9	8	13	4	8		22	8	2	4								
7	3						2	2										
8																		
9																		
10																		
Total	**95**	**130**	**101**	**26**	**45**		**68**	**50**	**50**	**56**	**6**	**23**						
Mean Age	**4.40**	**4.68**	**4.77**	**4.96**	**4.93**		**5.16**	**4.98**	**4.64**	**4.71**	**4.83**	**4.48**						

Age	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2											
3							1	12	12		1
4						7	9	14	23	1	7
5						3	4	7	7	12	2
6						3		4	7	7	
7									4		
8											
9											
10											
Total						**13**	**14**	**37**	**53**	**20**	**10**
Mean Age						**4.69**	**4.21**	**4.08**	**4.40**	**5.30**	**4.10**

Table 13.46 Age structure from fishery-dependent samples of female American shad from the Neuse River commercial gill-net fishery, 1977–2005.

Age	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
2																	
3					1												
4	24	4	19				3		4	5	1	9					
5	192	131	124	14	10		24	34	40	41	4	27					
6	151	58	54	35	35		24	24	19	16	2	6					
7	6	2	2	3	3		7	10	1		1						
8												1					
9																	
10																	
Total	**373**	**195**	**199**	**52**	**49**	**0**	**58**	**68**	**64**	**62**	**8**	**43**					
Mean Age	**5.37**	**5.30**	**5.20**	**5.79**	**5.80**		**5.60**	**5.65**	**5.27**	**5.18**	**5.38**	**5.00**					

Age	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
2												
3												5
4							4	35	21	17	3	14
5							29	80	38	22	50	33
6							17	34	35	17	52	40
7							1	3	28	22	15	19
8								1		3	3	1
9												
10												
Total							**51**	**153**	**122**	**81**	**123**	**112**
Mean Age							**5.29**	**5.05**	**5.57**	**5.65**	**5.72**	**5.51**

Table 13.47 Repeat spawning mark frequencies of male American shad in the Neuse River commercial gill-net fishery, 1977–2005.

Number of Spawning Marks	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0	73	124	100	26	40		49	43	44	45	6	20						
1	13	6	1		5		19	7	6	11		3						
2	7						4	4										
3	2																	
4																		
Total	**95**	**130**	**101**	**26**	**45**		**72**	**54**	**50**	**56**	**6**	**23**						
Mean Repeat	**0.35**	**0.05**	**0.01**	**0.00**	**0.11**		**0.38**	**0.28**	**0.12**	**0.20**	**0.00**	**0.13**						
% Repeat	**0.23**	**0.05**	**0.01**	**0.00**	**0.11**		**0.32**	**0.20**	**0.12**	**0.20**	**0.00**	**0.13**						

Number of Spawning Marks	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0						12	12	34	49	17	10
1						1	2	3	4	3	
2											
3											
4											
Total						**13**	**14**	**37**	**53**	**20**	**10**
Mean Repeat						**0.08**	**0.14**	**0.08**	**0.08**	**0.15**	**0.00**
% Repeat						**0.08**	**0.14**	**0.08**	**0.08**	**0.15**	**0.00**

Table 13.48 Repeat spawning mark frequencies of female American shad in the Neuse River commercial gill-net fishery, 1977–2005.

Number of Spawning Marks	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
0	328	192	196	52	45		43	50	61	57	8	32						
1	39	3	4		3		14	17	3	5		10						
2	6						1	1				1						
3																		
4																		
Total	**373**	**195**	**200**	**52**	**48**		**58**	**68**	**64**	**62**	**8**	**43**						
Mean Repeat	**0.14**	**0.02**	**0.02**	**0.00**	**0.06**		**0.28**	**0.28**	**0.05**	**0.08**	**0.00**	**0.28**						
% Repeat	**0.12**	**0.02**	**0.02**	**0.00**	**0.06**		**0.26**	**0.26**	**0.05**	**0.08**	**0.00**	**0.26**						

Number of Spawning Marks	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
0						30	100	99	64	84	69
1						18	34	21	15	31	31
2						3	17	2	2	8	12
3							2				
4											
Total						**51**	**153**	**122**	**81**	**123**	**112**
Mean Repeat						**0.47**	**0.48**	**0.20**	**0.23**	**0.38**	**0.49**
% Repeat						**0.41**	**0.35**	**0.19**	**0.21**	**0.32**	**0.38**

Table 13.49 Length frequency of American shad from NCDMF fishery-independent gill-net samples in the Neuse River, 2000–2005.

FL (mm)	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300												
320												
340												
360		1										
380		1										
400		1									1	
420				1	1					1	7	
440		1			2			9		4	10	
460					1			4		2	27	
480								3		3	29	
500											7	
520												
540												
Total		**4**		**1**	**4**	**0**		**16**		**10**	**81**	**0**

Table 13.50 Length frequency of American shad from NCWRC fishery-independent electrofishing samples in the Neuse River, 2000–2005.

FL (mm)	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
300		2		1	1	1						
320		10	1	1	3	1				1		
340	2	10	7	7	13	19		1				
360	7	23	55	34	16	35			1	2		1
380	26	50	65	91	21	29	1	2	2	9	1	3
400	38	48	44	160	23	21	3	9	4	19	2	10
420	33	19	34	186	23	10	7	36	9	55	4	10
440	12	6	11	70	32	9	22	36	12	52	20	10
460	2			12	5	5	29	24	18	68	38	11
480	2			3	3	1	12	6	19	23	28	9
500							1	1	4	5	10	7
520											3	4
540											1	
Total	**122**	**168**	**217**	**565**	**140**	**131**	**75**	**115**	**69**	**234**	**107**	**65**

Table 13.51 Mean length and weight and sex ratio of American shad collected by fishery-independent surveys in the Neuse River, 2000–2005.

Year	NCWRC Electrofishing Survey - Neuse River							NCDMF Gill-net Survey - Neuse River			
	N	Mean TL	SD	N	Mean Wt	SD	Sex ratio (M:F)	N	Mean TL	SD	Sex ratio (M:F)
Males											
2000	122	445.7	28.1				1.6				
2001	168	443.2	31.5				1.5	4	449.0		0.25
2002	218	429.2	27.5				3.2				
2003	566	453.2	28.2				2.4	1	477.5		0.10
2004	140	445.7	42.6	140	841.9	255.8	1.3	4	500.3		0.05
2005	131	423.5	37.6	131	711.2	222.2	2.0				
Females											
2000	75	499.8	24.8								
2001	115	502.4	26.9					16	514.5		
2002	69	502.4	35.2								
2003	233	511.8	30.5					10	516.2		
2004	107	517.1	29.6	107	1276.6	340.5		81	527.5		
2005	65	497.1	45.7	65	1183.8	347.1					

Table 13.52 Age structure from fishery-independent gill-net samples of American shad from the Neuse River, 2000–2005.

Age	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2												
3											2	1
4		2				1		1			11	3
5		2			3			11			10	
6					1			4		5	27	
7				1						5	29	
8										2	2	
9												
10												
Total		**4**		**1**	**4**	**1**		**16**		**12**	**81**	**4**
Mean Age								**5.19**		**6.75**	**5.94**	

Table 13.53 Repeat spawning mark frequencies of American shad in the Neuse River independent gill-net sampling, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0		3		1	3	1		8		10	36	4
1		1			1			6			31	
2								2			14	
3												
4												
Total	**0**	**4**	**0**	**1**	**4**	**1**		**16**		**10**	**81**	**4**
% Repeat								**0.50**			**0.56**	

Table 13.54 Age structure American shad from NCWRC fishery-independent electrofishing samples in the Neuse River, 2000–2005.

Age	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2												
3				12	10	18					1	2
4	23	28	79	33	18	22	2	3	4	4	5	8
5	81	60	69	39	24	20	30	36	24	22	14	24
6	16	32	33	39	10	4	42	43	38	33	12	16
7	2			10	3	2	1		2	24	12	4
8				2							5	3
9												1
10												1
Total	**122**	**120**	**181**	**135**	**65**	**66**	**75**	**82**	**68**	**83**	**49**	**59**
Mean Age	**4.98**	**5.03**	**4.75**	**5.06**	**4.66**	**4.24**	**5.56**	**5.49**	**5.56**	**5.93**	**5.90**	**5.51**

Table 13.55 Repeat spawning mark frequencies of American shad in the Neuse River independent electrofishing sampling, 2000–2005.

Number of Spawning Marks	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0	84	20	98	49	27	26	26	3	9	12	6	13
1	33	68	62	33	15	25	45	46	32	26	8	17
2	5	32	21	33	16	11	4	32	27	25	15	11
3				18	5	4		1		18	11	12
4				2	2					2	8	3
5											1	3
Total	**122**	**120**	**181**	**135**	**65**	**66**	**75**	**82**	**68**	**83**	**49**	**59**
Mean Repeat	**0.35**	**1.10**	**0.57**	**1.19**	**1.08**	**0.89**	**0.71**	**1.38**	**1.26**	**1.66**	**2.20**	**1.73**
% Repeat	**0.31**	**0.83**	**0.46**	**0.64**	**0.58**	**0.61**	**0.65**	**0.96**	**0.87**	**0.86**	**0.88**	**0.78**

Table 13.56 Total instantaneous mortality estimates for American shad in the Neuse River, 1972–2005. Age= catch curve using ages, RS = catch curve using repeat spawning marks.

Year	Fishery-Independent Gill Net				Fishery-Independent Gill Net			
	M-age	F-age	M-RS	F-RS	M-age	F-age	M-RS	F-RS
1972								
1973								
1974								
1975								
1976								
1977	1.04	1.73	1.14	2.00				
1978	2.24	2.09	3.03	4.16				
1979	1.39	2.06	4.61	3.89				
1980	1.45	2.46						
1981	1.18	2.46	2.08	2.71				
1982								
1983	1.34	1.23	1.25	1.88				
1984	1.30	0.61	1.19	1.96				
1985	2.64	1.84	1.99	3.01				
1986	2.08	0.94	1.41	2.43				
1987		0.69						
1988		1.07	1.90	1.73				
1989–1999		No sampling						
2000	0.00	1.68	2.48	1.15				
2001		1.56	1.79	1.24		1.01	1.10	0.69
2002	0.56	0.15	2.43	1.95				
2003	0.28	1.99	2.51	1.73		0.92		
2004	0.54	1.43	1.73	1.18	1.10	2.67	1.10	0.47
2005		1.84		0.87				

Table 13.57 Commercial harvest of American shad in the Cape Fear River, 1972–2005. N = number; TW = total weight; MW = mean weight.

Year	Gill net			Pound net			Other gears			Total		
	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)	N	TW (kg)	MW (kg)
1972	17,17	30,377	1.8							17,17	30,377	1.8
1973	8,922	14,570	1.6							8,922	14,570	1.6
1974	5,321	9,171	1.7							5,321	9,171	1.7
1975	5,737	10,410	1.8							5,737	10,410	1.8
1976	1,869	3,306	1.8							1,869	3,306	1.8
1977	3,928	7,306	1.9							3,928	7,306	1.9
1978	8,684	14,968	1.7							8,684	14,968	1.7
1979	12,40	23,634	1.9							12,40	23,634	1.9
1980	11,66	20,632	1.8							11,66	20,632	1.8
1981	13,56	24,000	1.8							13,56	24,000	1.8
1982	22,33	35,464	1.6							22,33	35,464	1.6
1983	20,54	29,814	1.5							20,54	29,814	1.5
1984	16,05	31,317	2.0							16,05	31,317	2.0
1985	3,632	6,425	1.8				100	1,644	1.6	4,638	8,069	1.7
1986	8,233	16,805	2.0							8,233	16,805	2.0
1987	2,917	6,352	2.2							2,917	6,352	2.2
1988	1,254	2,389	1.9							1,254	2,389	1.9
1989	3,437	5,769	1.7							3,437	5,769	1.7
1990	6,977	12,029	1.7							6,977	12,029	1.7
1991	7,905	13,626	1.7							7,905	13,626	1.7
1992	11,64	20,072	1.7							11,64	20,072	1.7
1993	17,18	28,067	1.6				115	183	1.6	17,30	28,249	1.6
1994	2,748	4,487	1.6				279	444	1.6	3,027	4,931	1.6
1995	2,639	4,550	1.7				328	522	1.6	2,967	5,071	1.6
1996	6,988	11,728	1.7				275	436	1.6	7,263	12,165	1.6
1997	4,072	7,019	1.7				31	49	1.6	4,103	7,069	1.6
1998	3,095	5,055	1.6							3,095	5,055	1.6
1999	1,757	3,029	1.7				36	57	1.6	1,793	3,086	1.6
2000	2,874	4,954	1.7				51	80	1.6	2,925	5,034	1.6
2001	3,595	5,708	1.6							3,595	5,708	1.6
2002	5,311	8,673	1.6				18	29	1.6	5,329	8,702	1.6
2003	8,820	15,603	1.8				39	64	1.6	8,859	15,667	1.7
2004	7,160	12,667	1.8							7,160	12,667	1.8
2005	4,555	7,852	1.7							4,555	7,852	1.7

Table 13.58 Length-frequency of male American shad samples from the Cape Fear River commercial gill-net fishery, 1983–2005.

FL (mm)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300																							
320																			1	1	1		1
340	1		1	1																12	5	2	4
360	2	1	4	2															2	18	5	2	3
380	12	1	9	1			1												6	27	12	4	1
400	6	4	23	5	1	8													3	16	4	10	3
420	7	11	31	6	3	18													6	10	6	13	5
440	3	11	13	7	4	6													2	5	3	3	3
460		5	4	2	2																	4	
480		3		1		1														1			
500		1																					
520																							
540																							
560																							
580																							
600																							
Total	**31**	**37**	**85**	**25**	**10**	**33**	**1**												**20**	**90**	**36**	**38**	**20**

Table 13.59 Length-frequency of female American shad samples from the Cape Fear River commercial gill-net fishery, 1983–2005.

FL (mm)	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
300																							
320																							1
340																							
360																			1				
380																							4
400					1														3	3	2	2	6
420	1	1	3	1		1													9	10	14	4	22
440	3	2	15	5	6	9	3												32	17	10	10	60
460	6	16	38	19	12	18	3												42	32	23	32	40
480	3	31	26	31	31	29	4												18	20	14	29	33
500	4	27	24	34	23	32	3												3	2	11	10	5
520		11	9	10	12	43														1	1	1	
540		3		2	1	18																	
560																							
580				1																			
600																							
Total	**17**	**91**	**115**	**103**	**86**	**150**	**13**												**108**	**85**	**75**	**88**	**171**

Table 13.60 Age structure from fishery-dependent samples of male American shad from the Cape Fear River commercial gill-net fishery, 1976–2005.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2																		
3		1								3								
4	31	45	23	42	29			9	10	17	6	4	9					
5	21	42	19	27	28			11	20	25	4	5	14					
6	2	4	1	1	5			2	3	5		2	1					
7	1	2																
8																		
9																		
10																		
Total	**55**	**94**	**43**	**70**	**62**			**22**	**33**	**50**	**10**	**11**	**24**					
Mean Age	**4.51**	**4.59**	**4.49**	**4.41**	**4.61**			**4.68**	**4.79**	**4.64**	**4.40**	**4.82**	**4.67**					

Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2												
3								1	21	8	5	2
4								20	34	12	7	6
5								24	20	7	21	4
6								2	12	6	5	3
7								1	3	2		
8												
9												
10								1	21	8	5	2
Total								**48**	**90**	**35**	**38**	**15**
Mean Age								**4.63**	**4.36**	**4.49**	**4.68**	**4.53**

Table 13.61 Age structure from fishery-dependent samples of female American shad from the Cape Fear River commercial gill-net fishery, 1976–2005.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
2																		
3																		
4	6	14	2	6	7			2	3	6	9	9	18					
5	35	103	28	14	39			6	31	35	32	36	42					
6	13	23	20	12	16			6	22	18	12	9	18					
7	1	2	2	1	6			1	3				4					
8		1																
9																		
10																		
Total	**55**	**143**	**52**	**33**	**68**			**15**	**59**	**59**	**53**	**54**	**82**					
Mean Age	**5.16**	**5.11**	**5.42**	**5.24**	**5.31**			**5.40**	**5.42**	**5.20**	**5.06**	**5.00**	**5.10**					

Age	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2												
3											1	3
4								7	16	14	1	11
5								55	15	12	41	30
6								66	23	13	25	38
7								11	32	22	18	14
8										3	2	1
9												
10												
Total								**139**	**86**	**64**	**88**	**97**
Mean Age								**5.58**	**5.83**	**5.81**	**5.73**	**5.54**

Table 13.62 Repeat spawning mark frequencies of male American shad in the Cape Fear River commercial gill-net fishery, 1983–2005.

Number of Spawning Marks	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0	17	30	47	9	11	21													42	82	33	37	14
1	5	3	3	1		3													5	8	3	1	1
2																			1				
3																							
4																							
Total	**22**	**33**	**50**	**10**	**11**	**24**													**48**	**90**	**36**	**38**	**15**
Mean Repeat	**0.23**	**0.09**	**0.06**	**0.10**	**0.00**	**0.13**													**0.15**	**0.09**	**0.08**	**0.03**	**0.07**
% Repeat	**0.23**	**0.09**	**0.06**	**0.10**	**0.00**	**0.13**													**0.13**	**0.09**	**0.08**	**0.03**	**0.07**

Table 13.63 Repeat spawning mark frequencies of female American shad in the Cape Fear River commercial gill-net fishery, 1983–2005.

Number of Spawning Marks	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
0	12	51	55	49	53	76													118	73	52	71	73
1	3	8	6	4	1	6													16	12	10	16	20
2																			5	1	2	1	4
3																							
4																							
Total	**15**	**59**	**61**	**53**	**54**	**82**													**139**	**86**	**64**	**88**	**97**
Mean Repeat	**0.20**	**0.14**	**0.10**	**0.08**	**0.02**	**0.07**													**0.19**	**0.16**	**0.22**	**0.20**	**0.29**
% Repeat	**0.20**	**0.14**	**0.10**	**0.08**	**0.02**	**0.07**													**0.15**	**0.15**	**0.19**	**0.19**	**0.25**

Table 13.64 Length frequency of American shad from NCDMF fishery-independent electrofishing and hook and line samples in the Cape Fear River, 2000–2005.

FL (mm)	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
280	1											
300												
320	2	2	1									
340	7	5	12			1						
360	37	7	18			1		1				
380	42	13	27	3								
400	37	10	16	9			3	6	3			2
420	8	9	10	4	1		10	20	10	2		7
440	2	2	5	4		1	16	43	17	1	5	26
460					1		9	44	32	3	5	22
480	1		1		1		1	22	21	3	4	16
500								3	2		5	2
520									1			
540												
Total	**137**	**48**	**90**	**20**	**3**	**3**	**39**	**139**	**86**	**9**	**19**	**75**

Table 13.65 Length frequency of American shad from NCWRC fishery-independent electrofishing samples in the Cape Fear River, 2000–2005.

FL (mm)	Males						Females					
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
280												
300	1											
320			1	1	9							
340	2	10	10		31	16		1				
360	12	26	61	16	65	76		2				
380	27	32	86	29	62	49		2		1	4	1
400	42	40	90	37	118	26	1	2	2	8	12	5
420	30	31	51	34	147	11	2	3	4	12	25	7
440	6	2	16	19	60	11	9	16	8	26	68	12
460	2	1	1	8	11	2	13	15	15	43	107	23
480	1			1	2	1	7	18	10	43	110	14
500								4	3	26	62	12
520								1	1	6	8	2
540									1		1	
Total	**123**	**142**	**316**	**145**	**505**	**192**	**32**	**64**	**44**	**165**	**397**	**76**

Table 13.66 Mean length and weight and sex ratio of American shad collected by fishery-independent surveys in the Cape Fear River, 2000–2005.

Year	NCWRC Electrofishing - Cape Fear River							NCDMF Electrofishing - Cape Fear River			
	N	Mean TL	SD	N	Mean Wt	SD	Sex Ratio (M:F)	N	Mean TL	SD	Sex Ratio (M:F)
Males											
2000	123	441.1	27.0				3.8	137	429.9		3.5
2001	142	430.8	30.6	142	799.0	170.4	2.2	48	437.1		0.3
2002	316	431.3	27.7	316	801.8	175.9	7.2	90	434.7		1.0
2003	145	449.5	32.5	145	892.1	230.5	0.9	20	464.9		2.2
2004	505	441.6	35.4				1.3	3	515.4		0.2
2005	192	418.1	30.8				2.5	3	431.9		0.04
Females											
2000	32	500.5	19.5					39	497.3		
2001	64	506.0	30.3	64	1515.8	347.8		139	510.3		
2002	44	508.9	33.4	44	1508.2	359.0		86	518.3		
2003	165	515.6	32.2	165	1630.4	338.5		9	518.0		
2004	397	515.8	30.3					19	533.8		
2005	76	509.7	33.9					75	515.1		

Table 13.67 Age structure from fishery-independent electrofishing and hook and line samples of American shad from the Cape Fear River, 2000–2005.

Age	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2												
3	1	1	21			1						
4	58	20	34	3		1	1	7	16	1	3	4
5	54	24	20	10	1	1	22	55	15	3	6	23
6	10	2	12	6	2		9	66	23	3	3	27
7		1	3	1				11	32	2	6	15
8											1	
9												
10												
Total	**123**	**48**	**90**	**20**	**3**	**3**	**32**	**139**	**86**	**9**	**19**	**69**
Mean Age	**4.59**	**4.63**	**4.36**	**5.25**	**5.67**	**4.00**	**5.25**	**5.58**	**5.83**	**5.67**	**5.79**	**5.77**

Table 13.68 Repeat spawning mark frequencies of American shad in the Cape Fear River fishery-independent electrofishing and hook and line sampling, 2000–2005.

Number of Spawning Marks	Male						Female					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0	122	42	82	17	2	3	26	119	73	8	15	52
1	1	5	8	3	1		3	15	12	1	3	16
2		1					3	5	1		1	1
3												
4												
Total	**123**	**48**	**90**	**20**	**3**	**3**	**32**	**139**	**86**	**9**	**19**	**69**
% Repeat	**0.01**	**0.15**	**0.09**	**0.15**	**0.33**	**0.00**	**0.28**	**0.18**	**0.16**	**0.11**	**0.26**	**0.26**

Table 13.69 Age structure American shad from NCWRC fishery-independent electrofishing samples in the Cape Fear River, 2000–2005.

Age	Males						Females					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
2	1											
3	58	6	79	28	23	16	1		1		1	
4	54	47	87	37	21	17	22	2	6	16	6	4
5	10	54	57	48	17	14	9	7	16	34	15	7
6		25	1	11	5	8		17	10	52	19	32
7		2		1	1	1		21	1	19	16	12
8								8		2		
9								2				
10												
Total	**123**	**134**	**224**	**125**	**67**	**56**	**32**	**57**	**34**	**123**	**57**	**55**
Mean Age	**3.59**	**4.78**	**3.91**	**4.36**	**4.10**	**4.30**	**4.25**	**6.56**	**5.12**	**5.65**	**5.75**	**5.95**

Table 13.70 Repeat spawning mark frequencies of American shad in the Cape Fear River independent electrofishing sampling 2000–2005.

Number of Spawning Marks	Males						Female					
	2000	2001	2002	2003	2004	2005	2000	2001	2002	2003	2004	2005
0	122	78	118	61	33	21	26	9	6	26	44	6
1	1	54	91	25	20	17	3	26	20	27	33	11
2		2	15	33	10	14	3	14	8	49	28	24
3				6	3	4		7		19	18	14
4					1			1		2	1	
Total	**123**	**134**	**224**	**125**	**67**	**56**	**32**	**57**	**34**	**123**	**124**	**55**
Mean Repeat	**0.01**	**0.43**	**0.54**	**0.87**	**0.79**	**1.02**	**0.28**	**1.39**	**1.06**	**1.54**	**1.19**	**1.84**
% Repeat	**0.01**	**0.42**	**0.47**	**0.51**	**0.51**	**0.63**	**0.19**	**0.84**	**0.82**	**0.79**	**0.65**	**0.89**

Table 13.71 Total instantaneous mortality estimates for American shad in the Cape Fear River, 1972–2005. Age = catch curve using ages, RS = catch curve using repeat spawning marks.

Year	Fishery-Dependent Gill Net				Fishery-Independent Electrofishing			
	M-age	F-age	M-RS	F-RS	M-age	F-age	M-RS	F-RS
1972								
1973								
1974								
1975								
1976	1.27	1.78						
1977	1.17	1.63						
1978	1.57	1.32						
1979	1.87	1.32						
1980	0.88	0.94						
1981								
1982								
1983	1.70	1.79	1.22	1.39				
1984	1.90	1.17	2.30	1.85				
1985	1.61	0.66	2.75	2.22				
1986	0.41	0.98	2.20	2.51				
1987	0.92	1.39		3.97				
1988	2.64	1.18	1.95	2.54				
1989–1999		No sampling						
2000					0.88	0.89	4.80	1.08
2001	1.59	0.80	1.87	1.58	1.59	1.79	1.87	1.58
2002	0.78		2.33	2.15	0.78		2.33	2.15
2003	0.55	1.99	2.40	1.63	1.15	0.41	1.73	2.08
2004	1.44	0.94	3.61	2.13		1.79	0.69	1.35
2005	0.35	1.82	2.64	1.45		0.59		1.98

Figure 13.1 Map of North Carolina river systems including major dams.

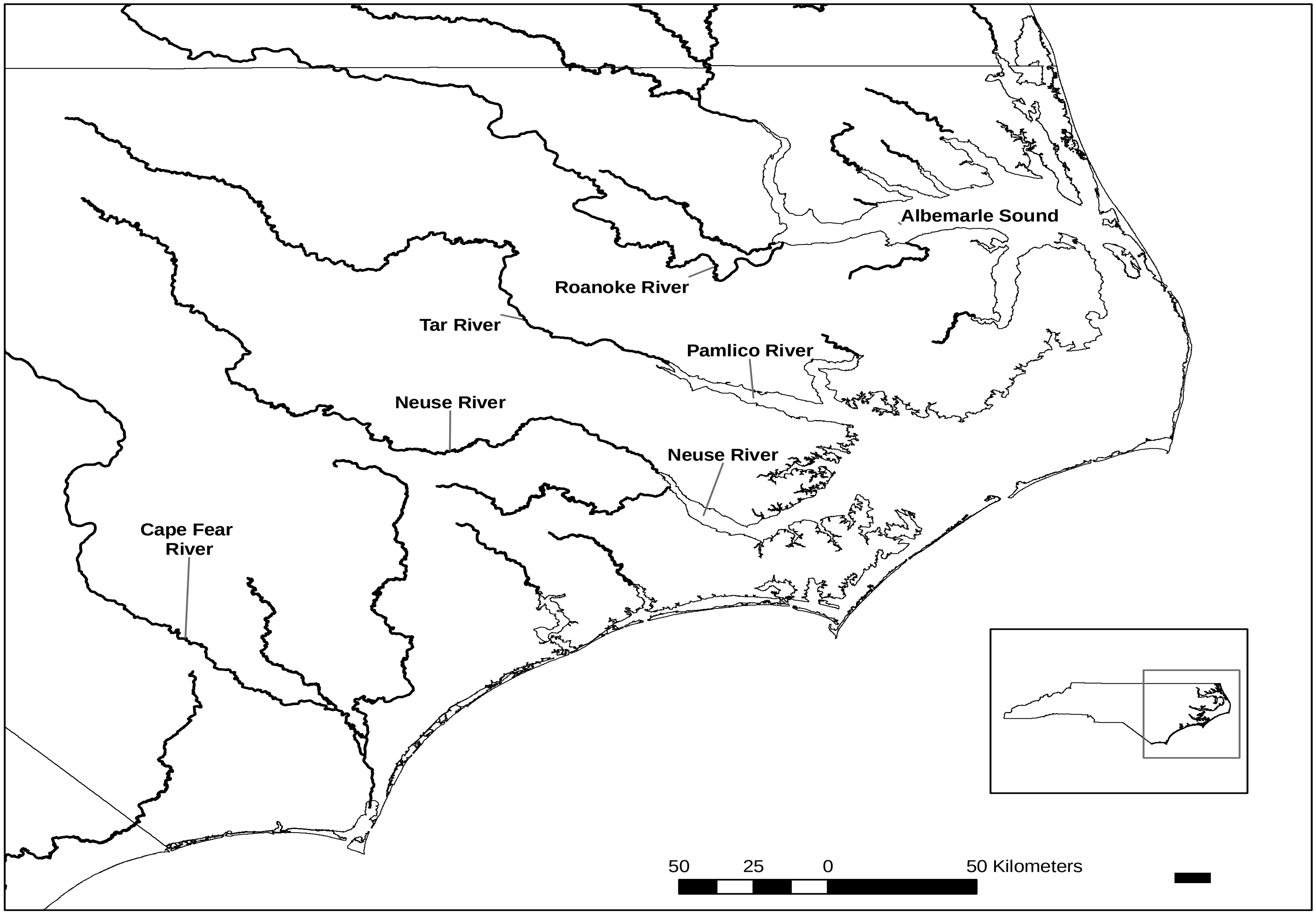


Figure 13.2 Von Bertalanffy growth curve using fractional ageing for male American shad from Albemarle Sound.

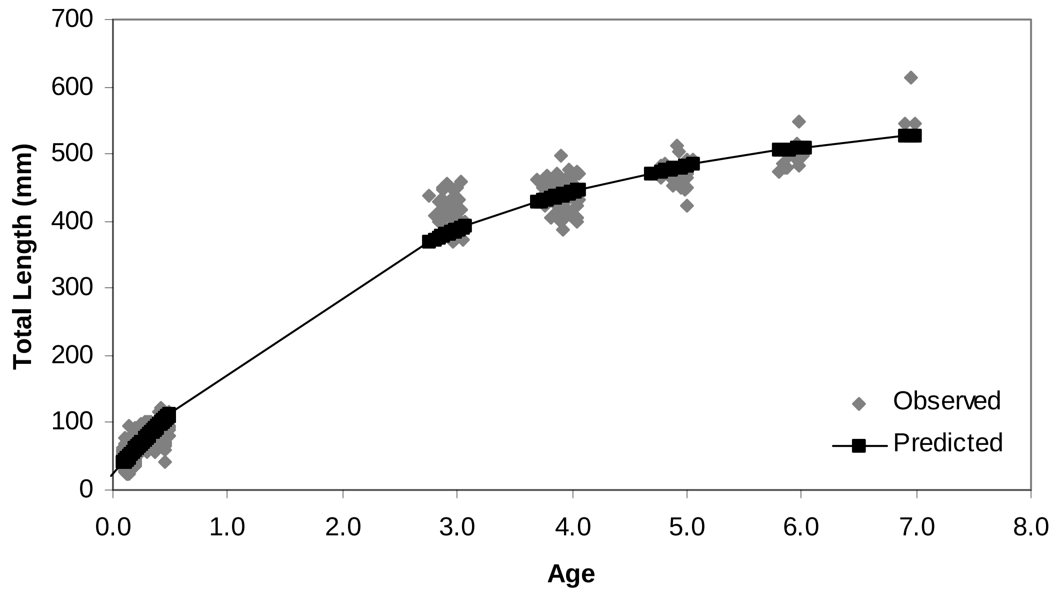


Figure 13.3 Von Bertalanffy growth curve using fractional ageing for female American shad from Albemarle Sound.

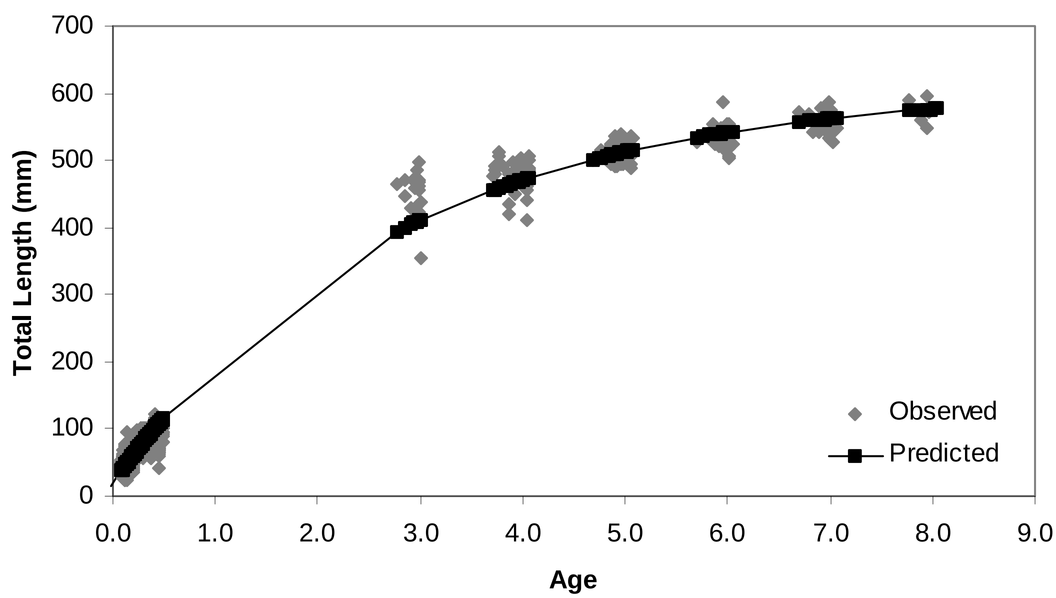


Figure 13.4 Von Bertalanffy growth curve using fractional ageing for male American shad from Pamlico River.

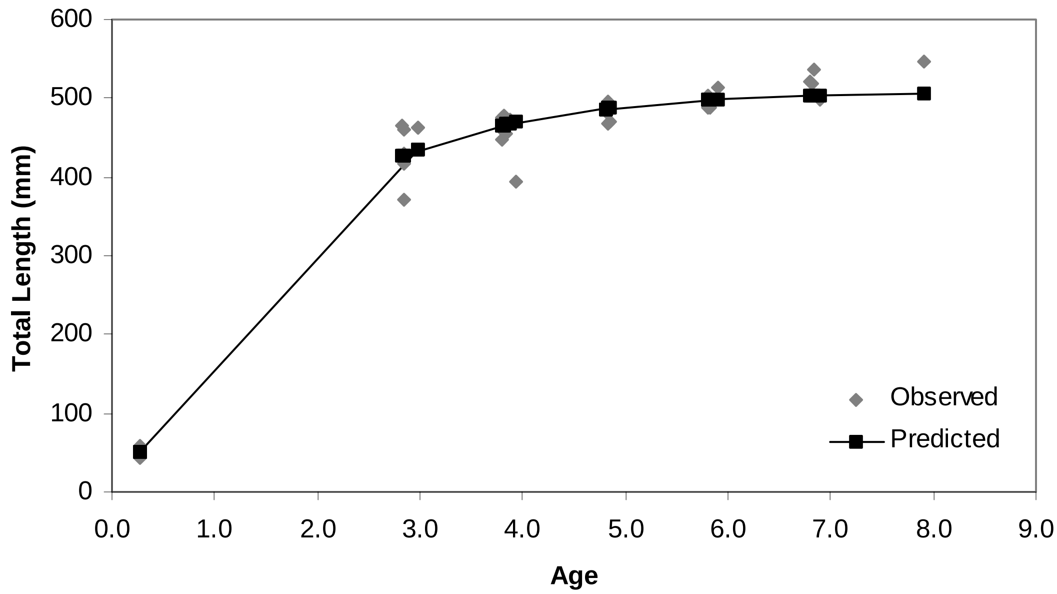


Figure 13.5 Von Bertalanffy growth curve using fractional ageing for female American shad from Pamlico River.

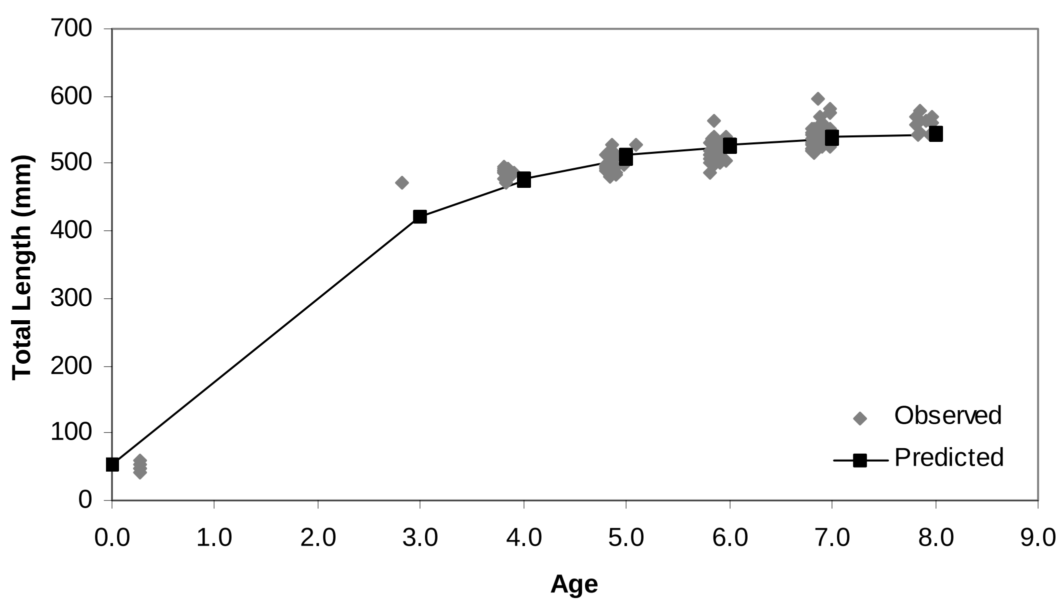
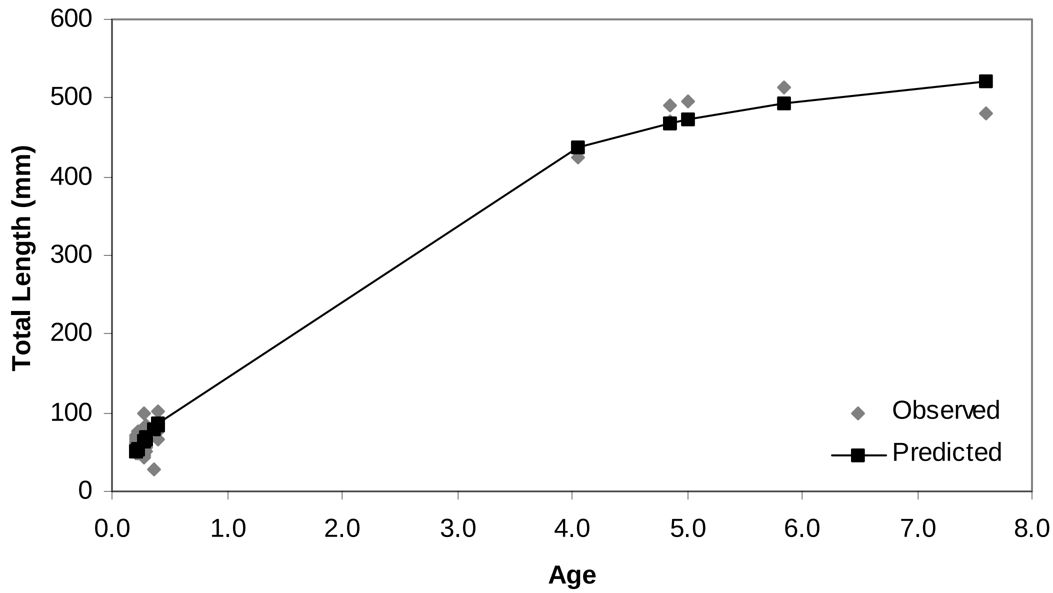


Figure 13.6 Von Bertalanffy growth curve using fractional ageing for (a) male and (b) female American shad from Neuse River.

(a)



(b)

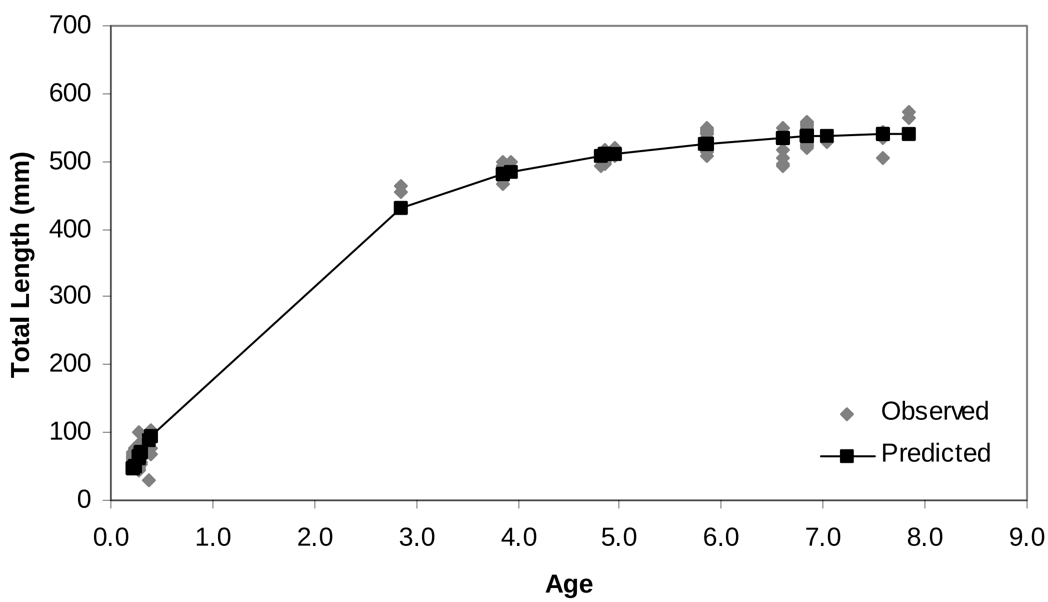


Figure 13.7 Von Bertalanffy growth curve using fractional ageing for male American shad from Cape Fear River.

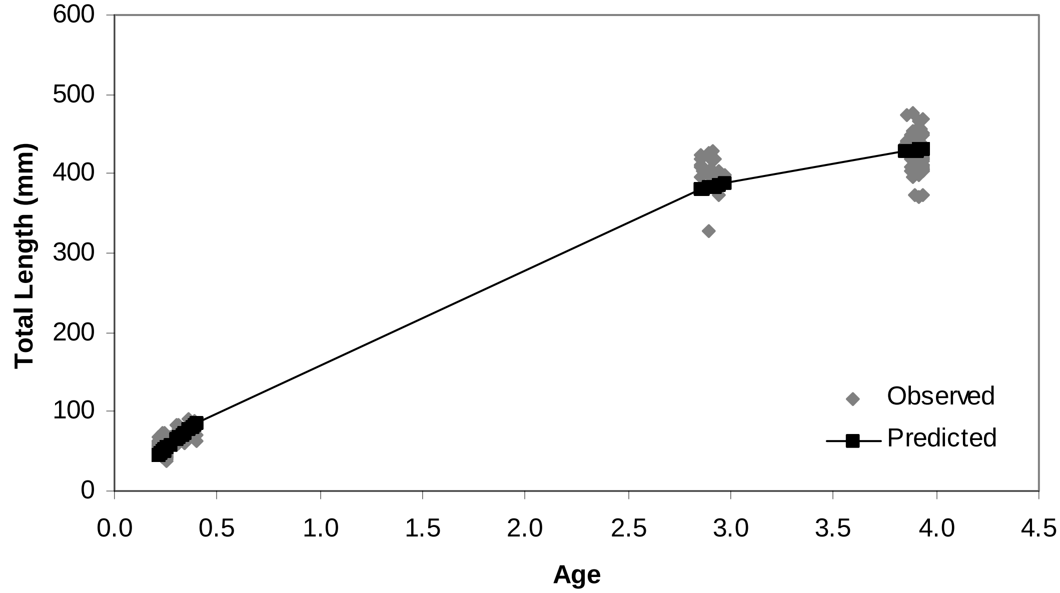


Figure 13.8 Von Bertalanffy growth curve using fractional ageing for female American shad from Cape Fear River.

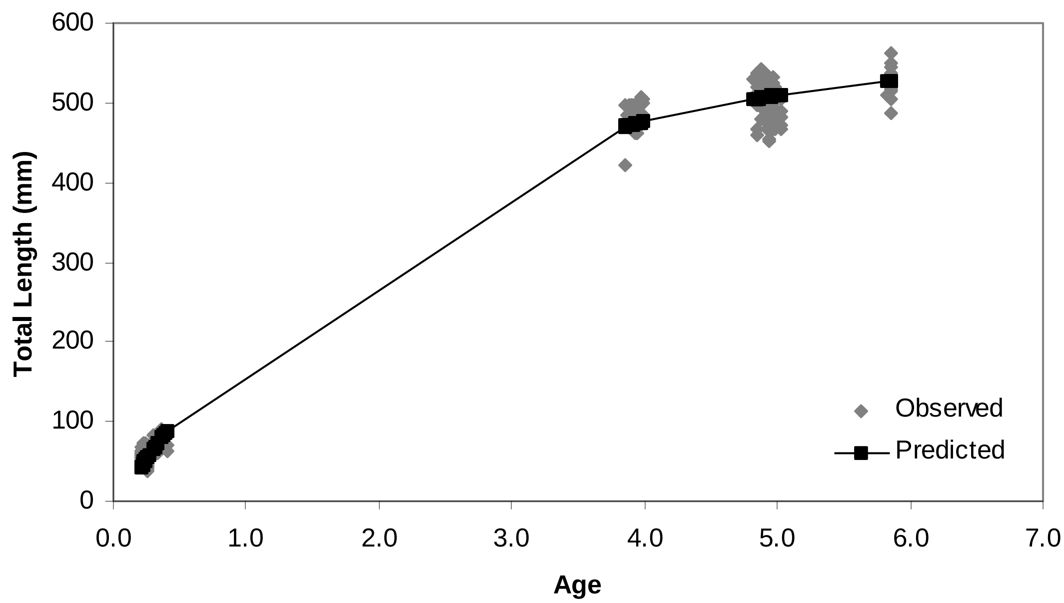


Figure 13.9 Statewide commercial landings (kg) of American shad in North Carolina, 1880-2005.

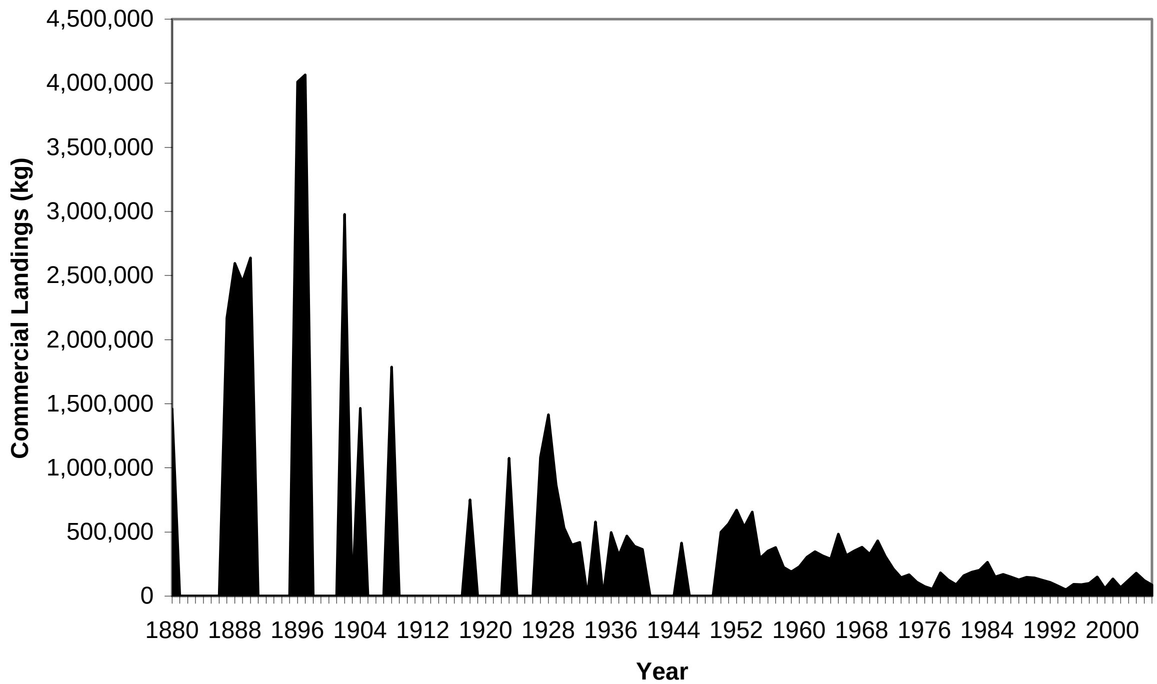


Figure 13.10 Regions used to describe the geographic distribution of Recreational Commercial Gear License (RCGL) trips.

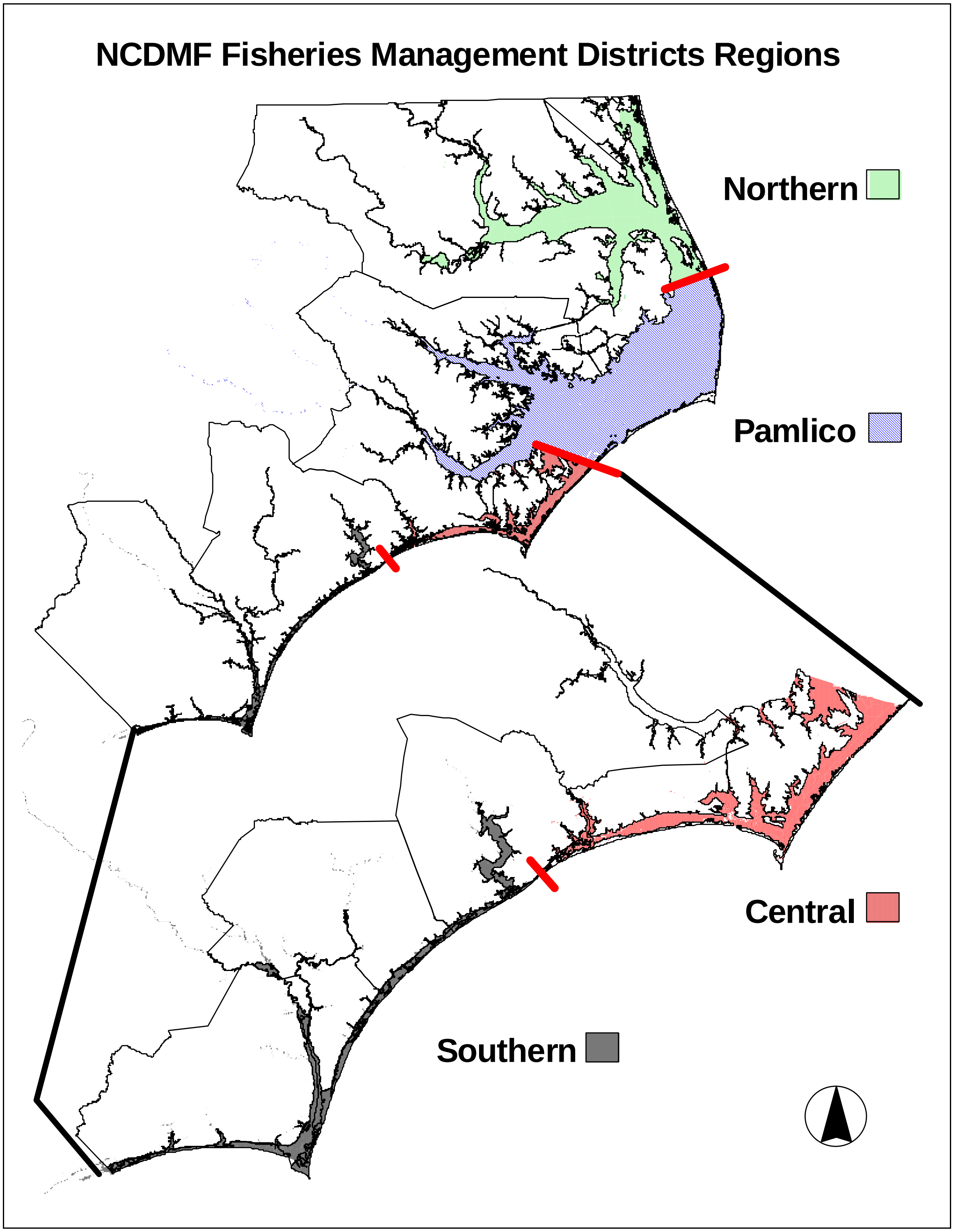


Figure 13.11 Alosine nursery area sampling sties in Albemarle Sound, 1972-2005.

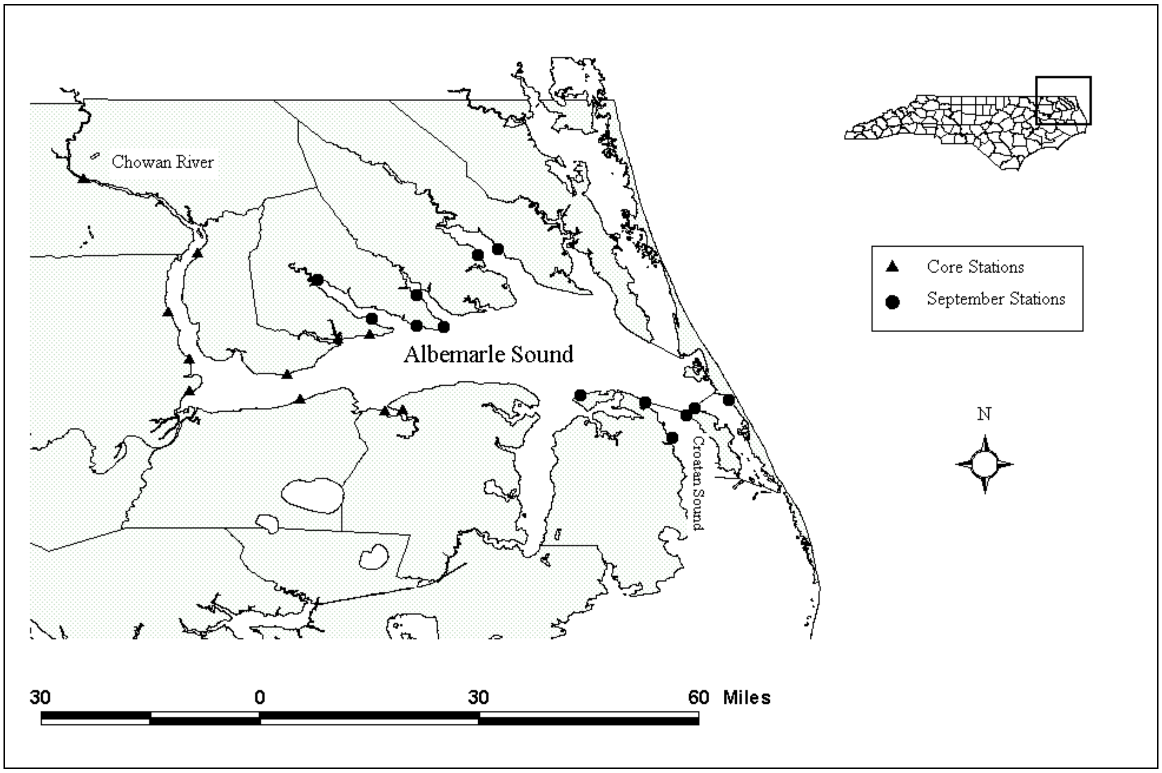


Figure 13.12 Commercial landings (kg) by gear type for Albemarle Sound, 1972-2005.

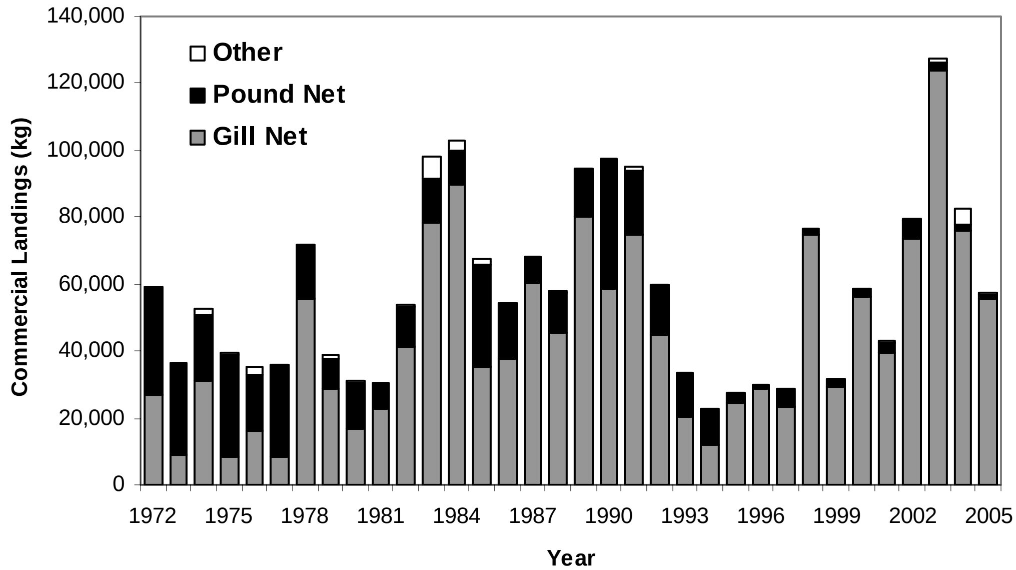


Figure 13.13 Commercial CPUE for directed shad trips, 1994-2005. Trends: Albemarle (+, Rsq=0.44, slope=7.49, p=0.02; Pamlico (-, Rsq=0.04, slope=-1.84, p=0.57); Neuse (+, Rsq=0.17, slope=4.45, p=0.19); Cape Fear (-, Rsq=0.10, slope=-2.11, p=0.33).

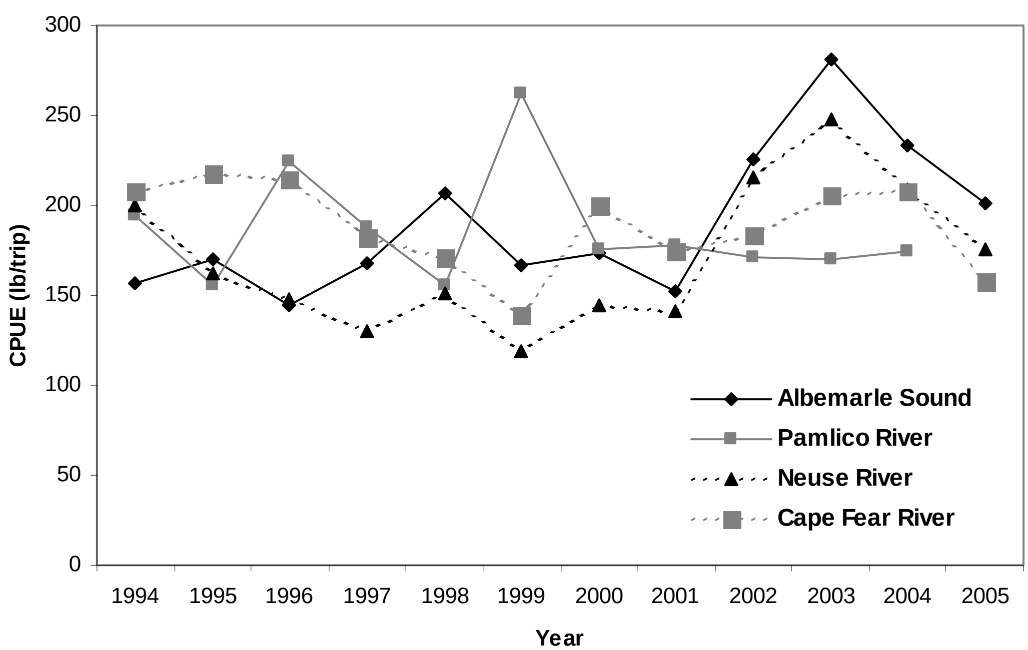


Figure 13.14 Commercial gill-net effort as number of trips.

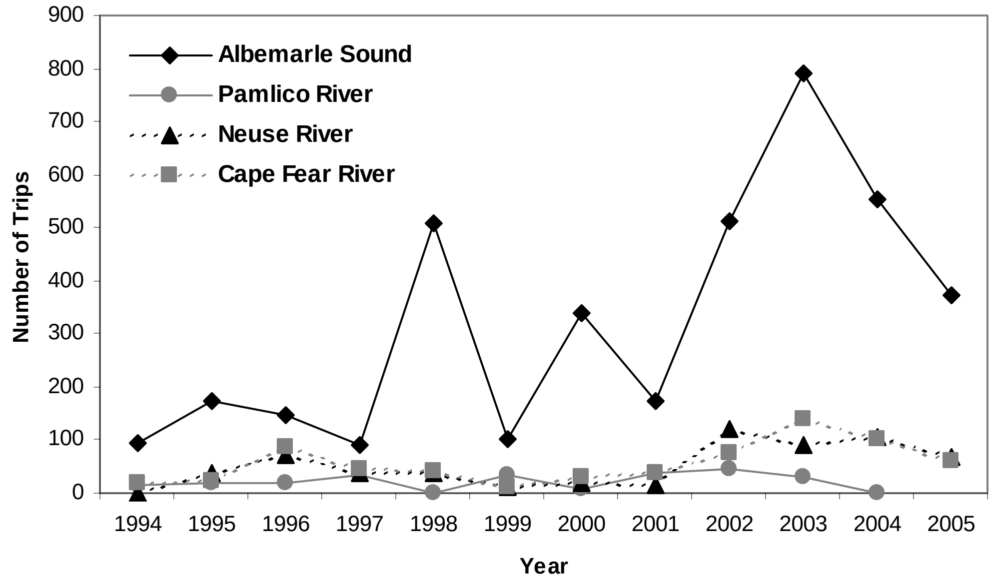


Figure 13.15 Mean total length (TL) and weight (Wgt) of male (M) and female (F) American shad in the Albemarle Sound commercial gill-net fishery.

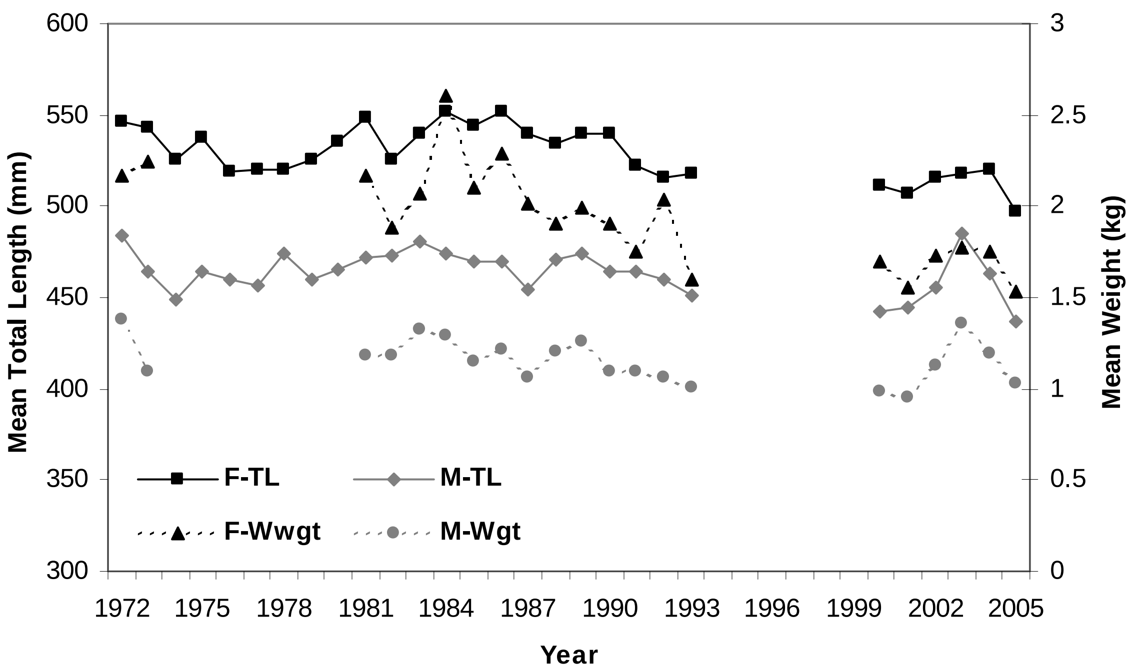
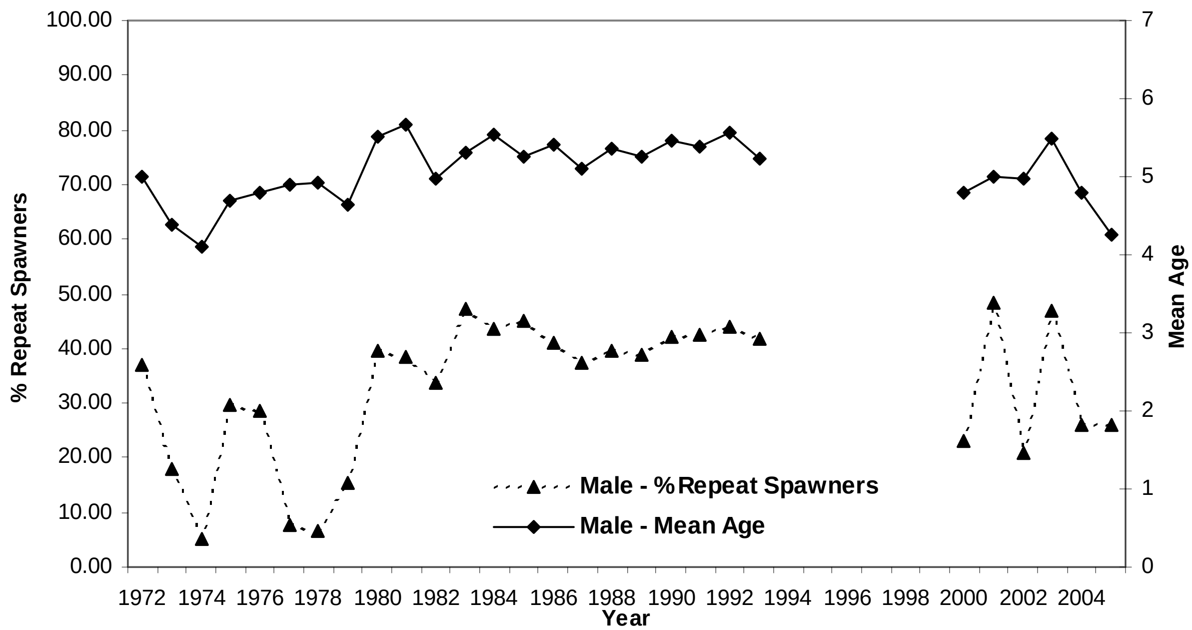


Figure 13.16 Mean age and percent repeat spawners of (a) male and (b) female American shad in the Albemarle Sound commercial gill net fishery, 1972-2005.

(a)



(b)

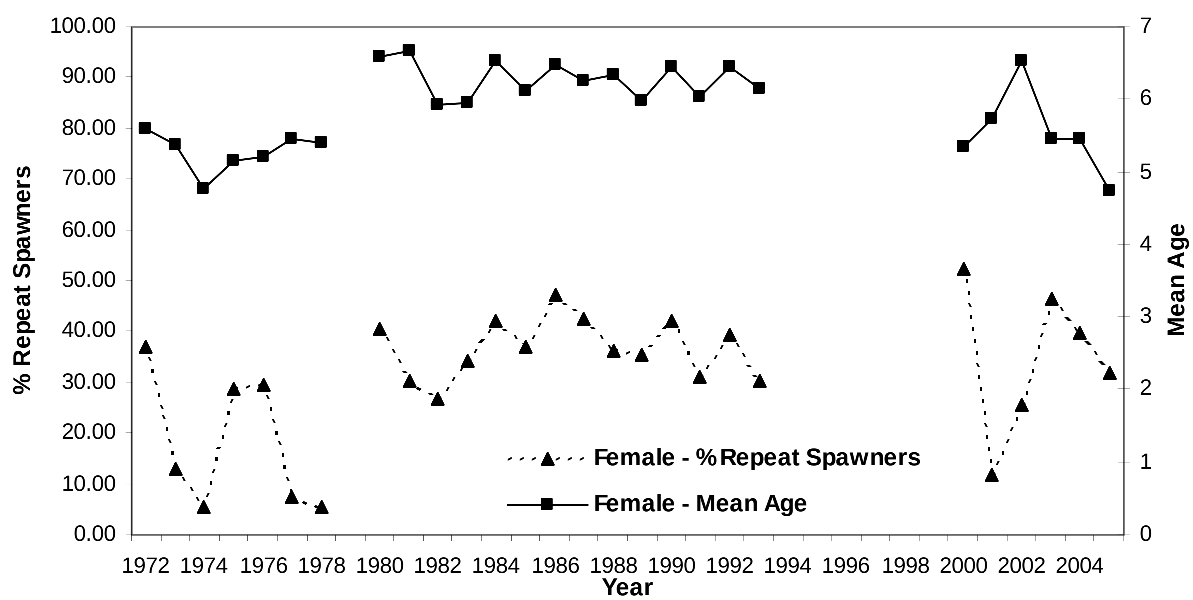
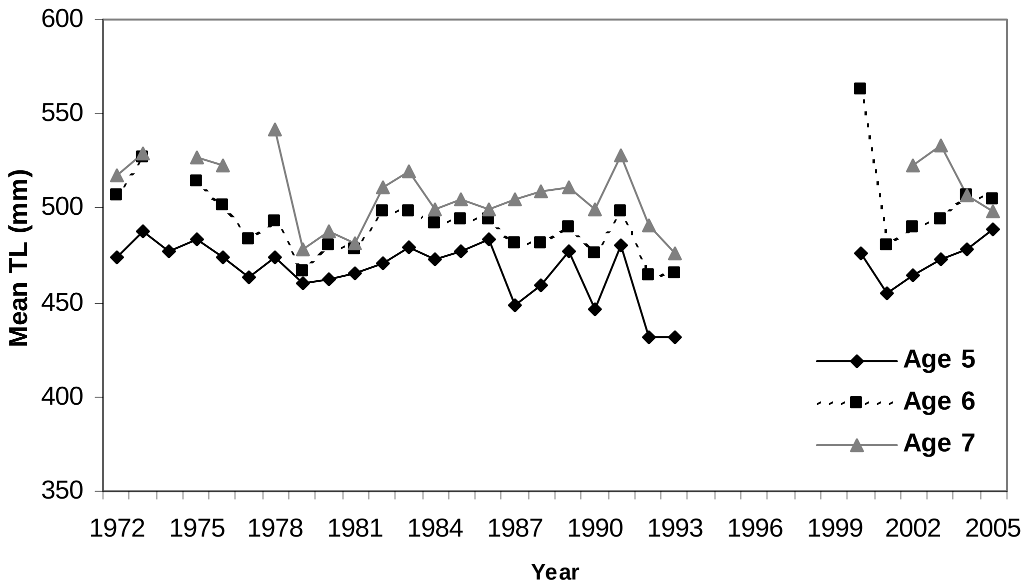


Figure 13.17 Mean (a) total length and (b) weight-at-age for male American shad caught in the commercial fishery in Albemarle Sound.

(a)



(b)

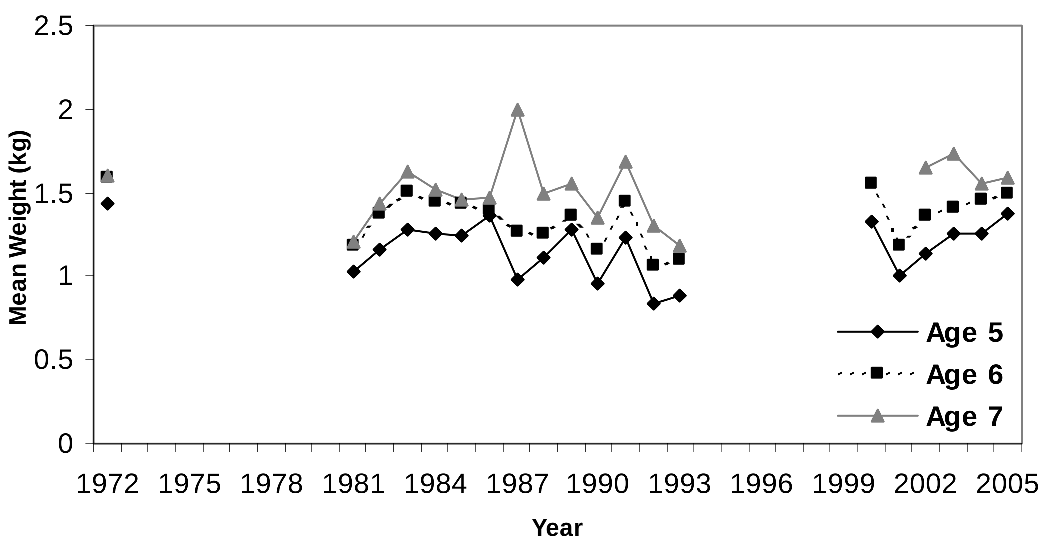
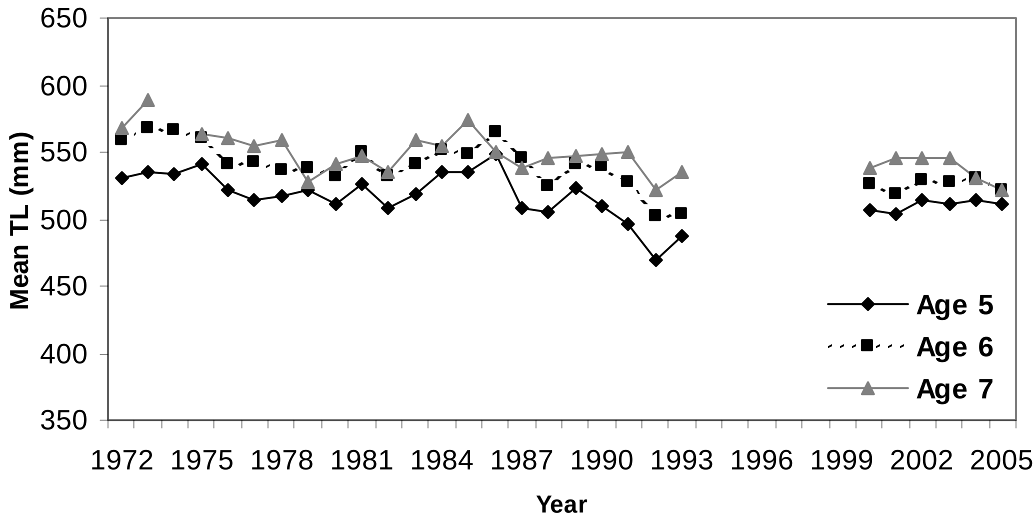


Figure 13.18 Mean (a) total length and (b) weight-at-age for female American shad caught in the commercial fishery in Albemarle Sound.

(a)



(b)

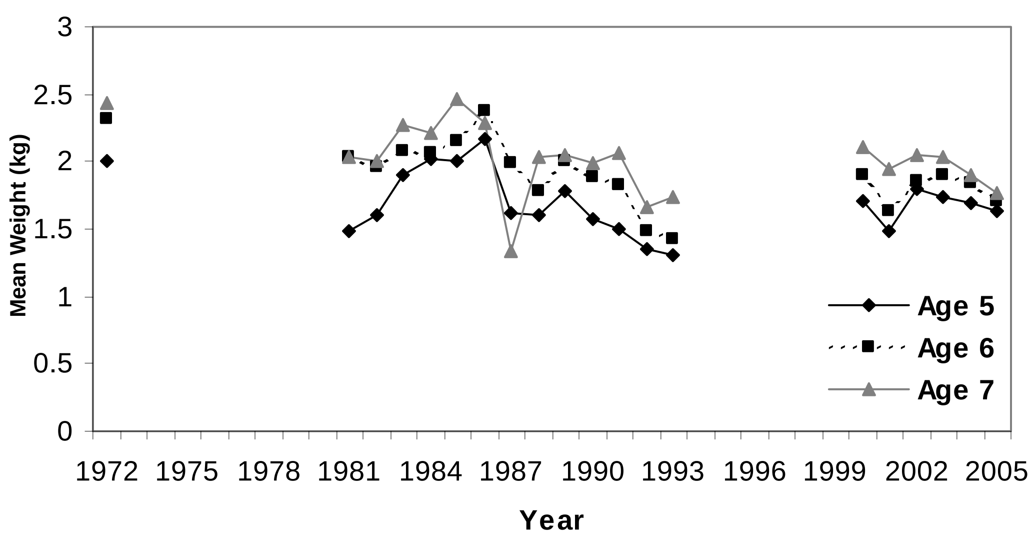
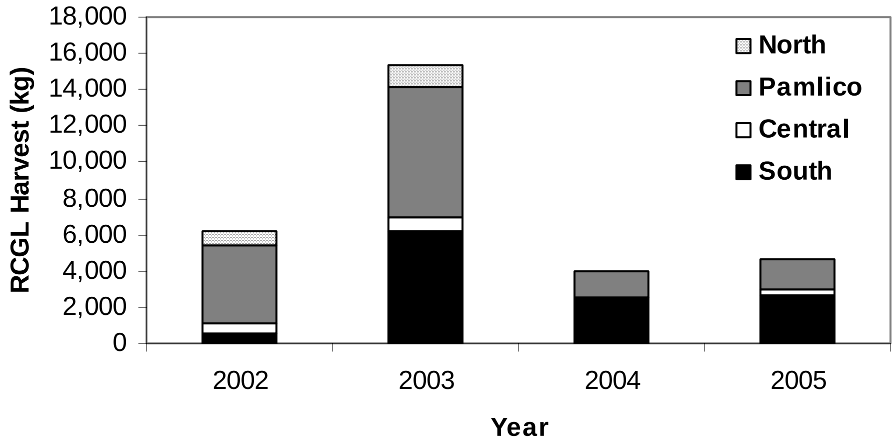


Figure 13.19 Recreational commercial gill-net license (a) harvest and (b) discards of American shad, 2002-2005.

(a)



(b)

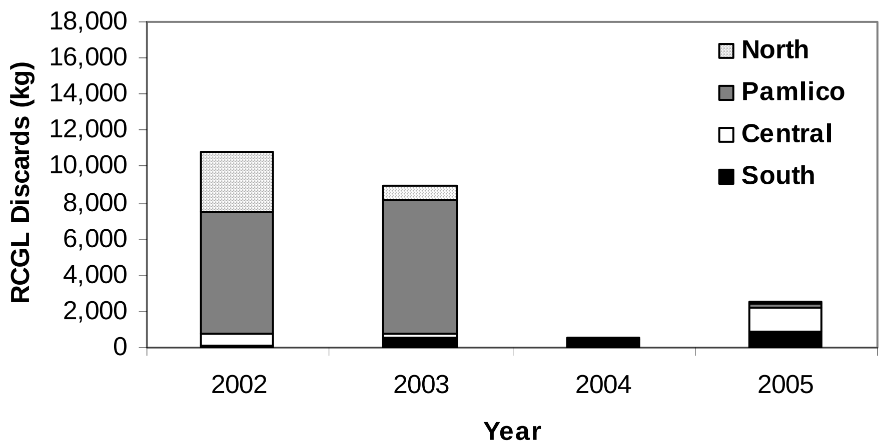


Figure 13.20 Gill net selectivity for American shad caught in fishery-independent gill-net survey in Albemarle Sound, 2000-2005.

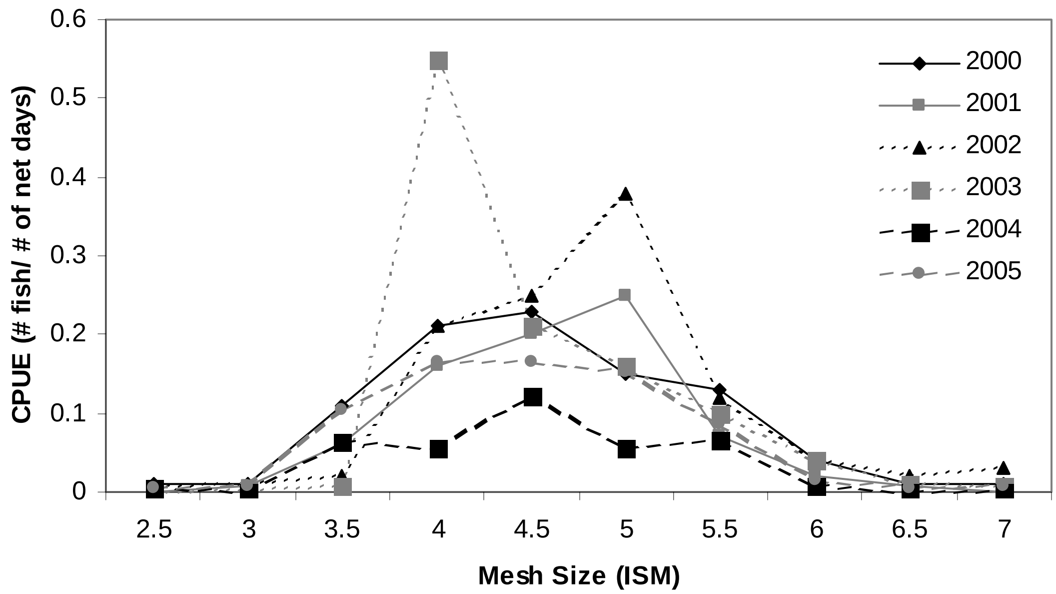


Figure 13.21 American shad fishery-independent (FI) gill net (GN) and electrofishing (EF) and fishery-dependent (FD) gill net CPUE from Albemarle Sound, 1991-2005. Trends: FI-GN Rsq=0.43, slope=0.005, p=0.01; FI-EF Rsq=0.30, slope=3.573, p=0.27; FD-GN Rsq=0.44, slope=7.49, p=0.02.

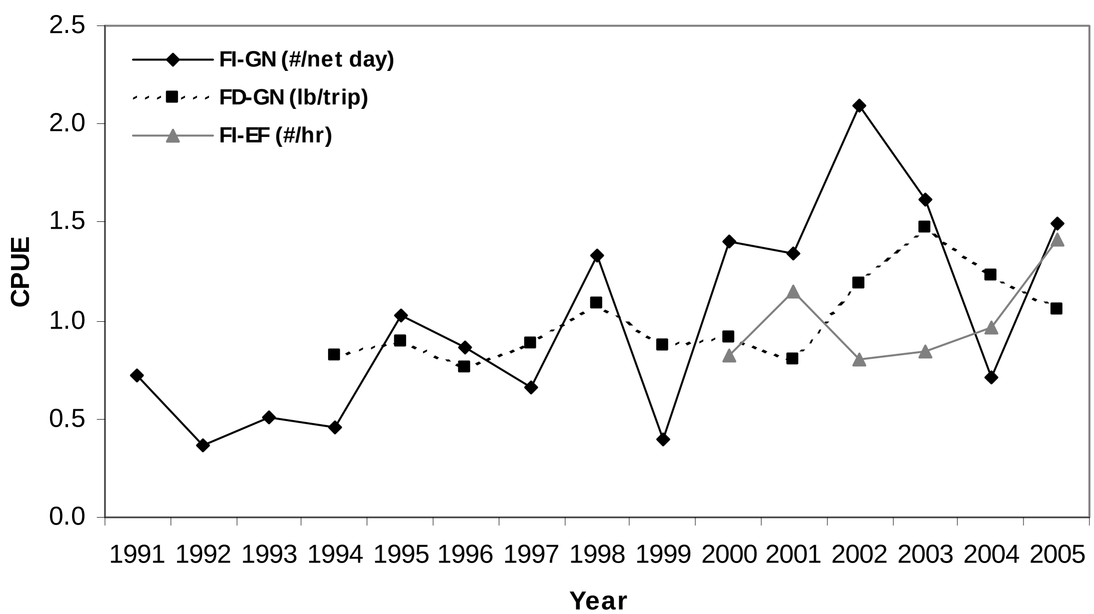


Figure 13.22 Mean total length of American shad caught by fishery-independent gill nets (FI GN) and fishery-dependent gill nets (FD GN) in Albemarle Sound and fishery-independent electrofishing (FI EF) in the Roanoke River for males (M) and Females (F), 2000-2005.

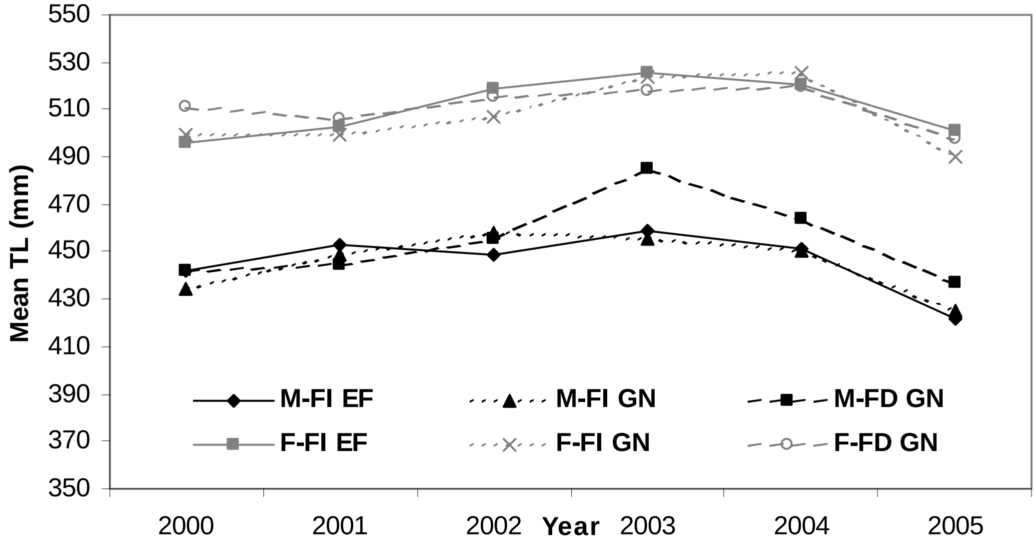


Figure 13.23 Sex ratios of American shad caught by fishery-independent gill nets (FI GN) and fishery-dependent gill nets (FD GN) in Albemarle Sound and fishery-independent electrofishing (FI EF) in the Roanoke River, 2000-2005.

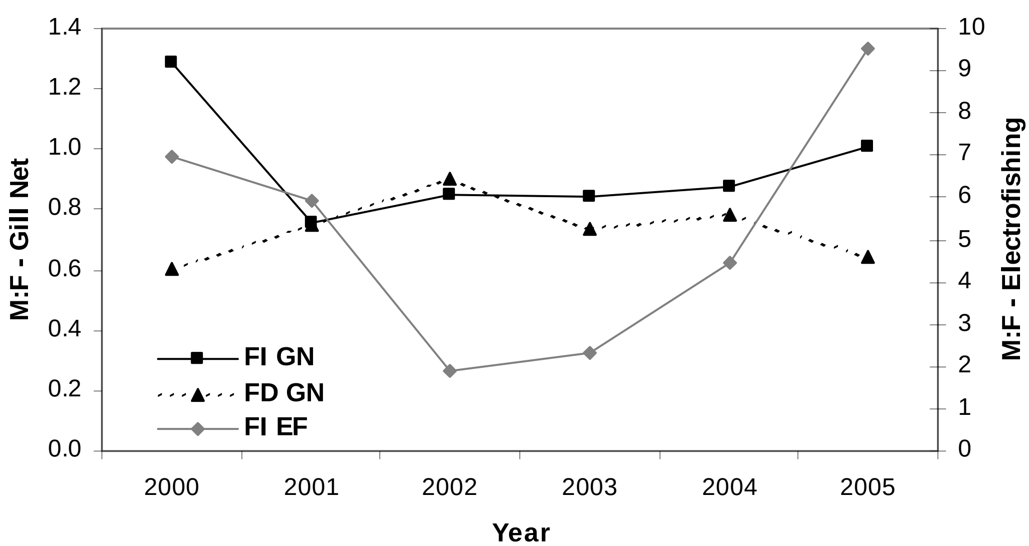
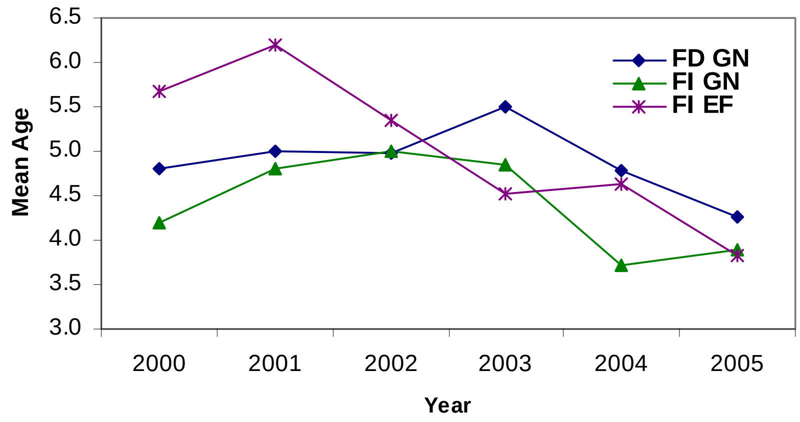
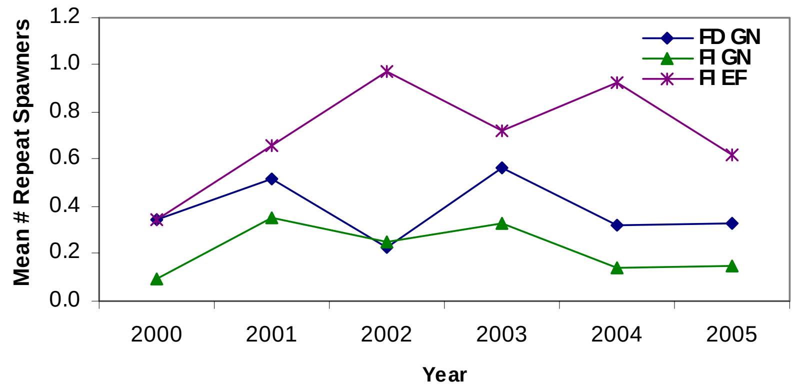


Figure 13.24 (a) Mean age, (b) mean number of repeat spawners, and (c) percent of repeat spawners for male American shad collected by fishery-dependent gill nets (FD GN) and fishery-independent gill nets (FI GN) from Albemarle Sound and fishery-independent electrofishing from the Roanoke River, 2000-2005.

(a)



(b)



(c)

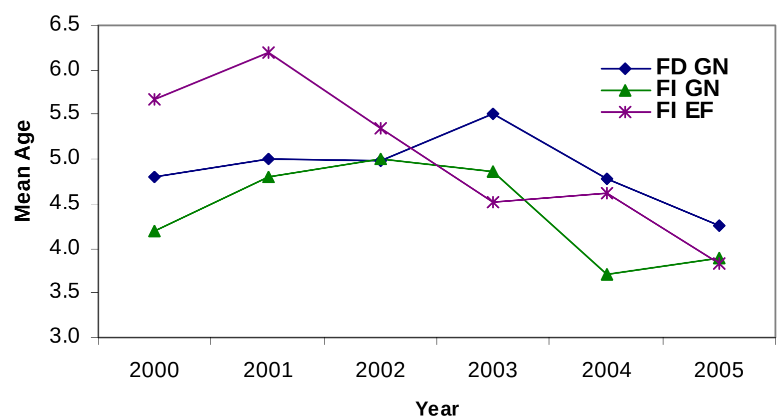
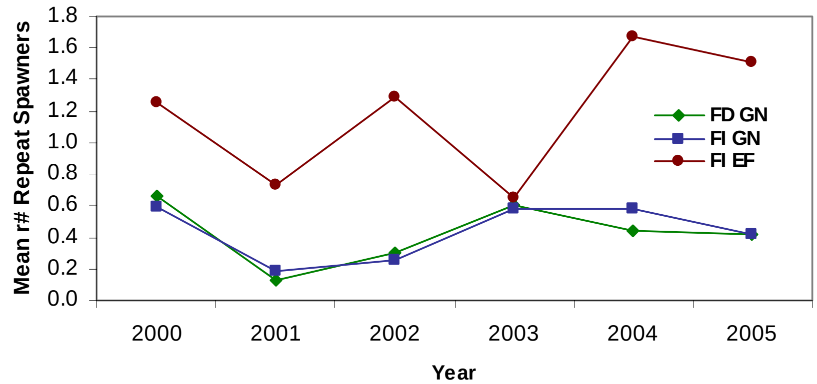
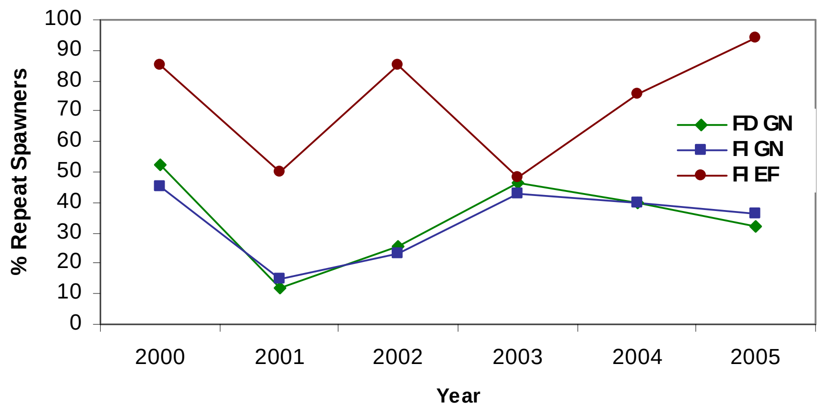


Figure 13.25 (a) Mean age, (b) mean number of repeat spawners, and (c) percent of repeat spawners for female American shad collected by fishery-dependent gill nets (FD GN) and fishery-independent gill nets (FI GN) from Albemarle Sound and fishery-independent electrofishing from the Roanoke River, 2000-2005.

(a)



(b)



(c)

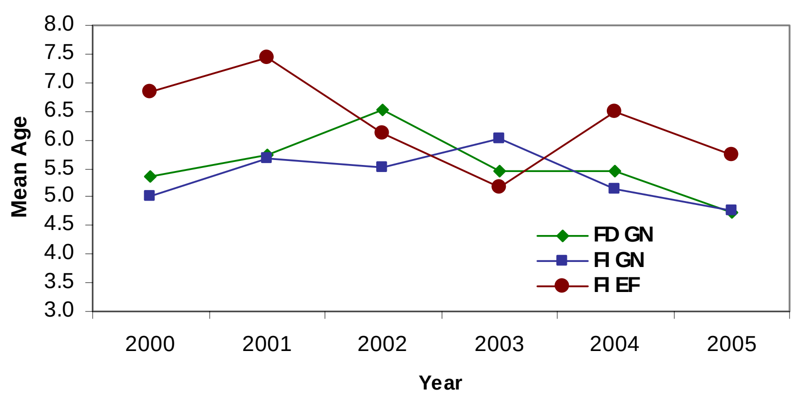
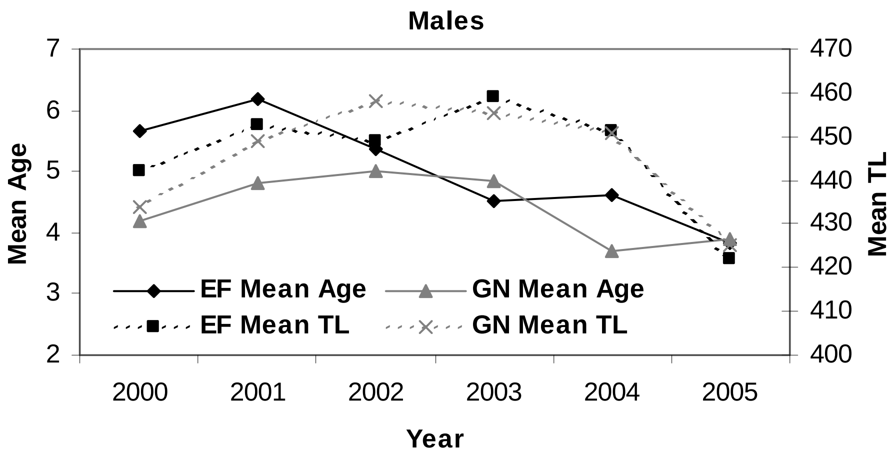


Figure 13.26 Mean age and mean TL for (a) male and (b) female American shad collected by the NCDMF fishery-independent gill-net survey (GN) in Albemarle Sound and the NCWRC electrofishing (EF) survey in the Roanoke River.

(a)



(b)

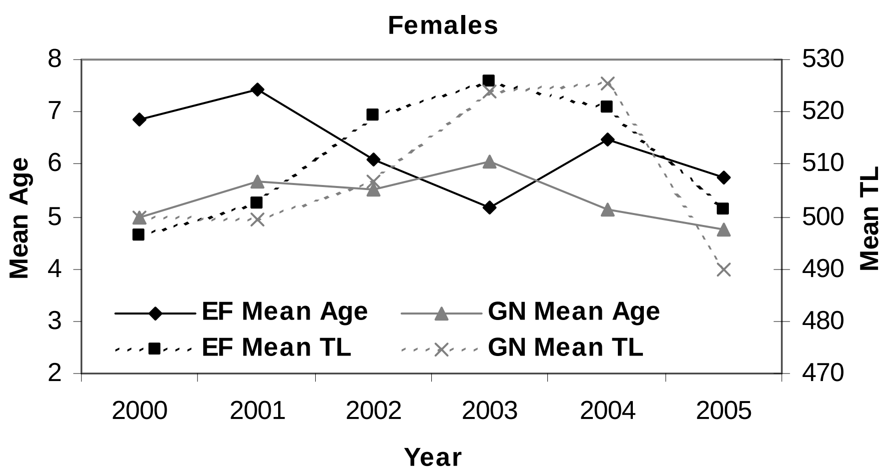
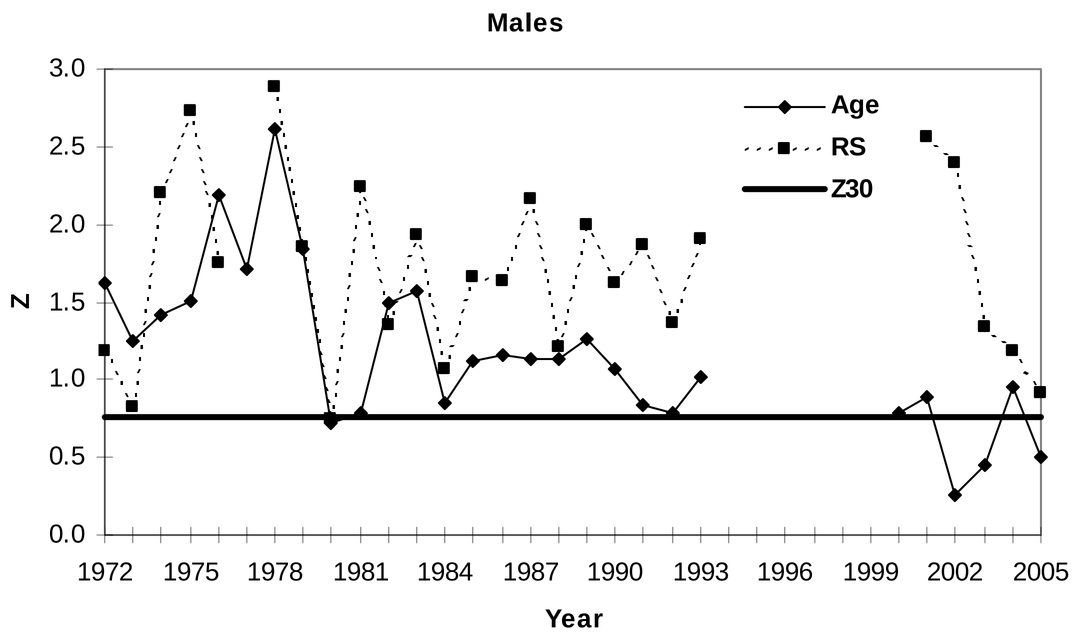


Figure 13.27 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the Albemarle Sound commercial gill-net fishery, 1972-2005.

(a)



(b)

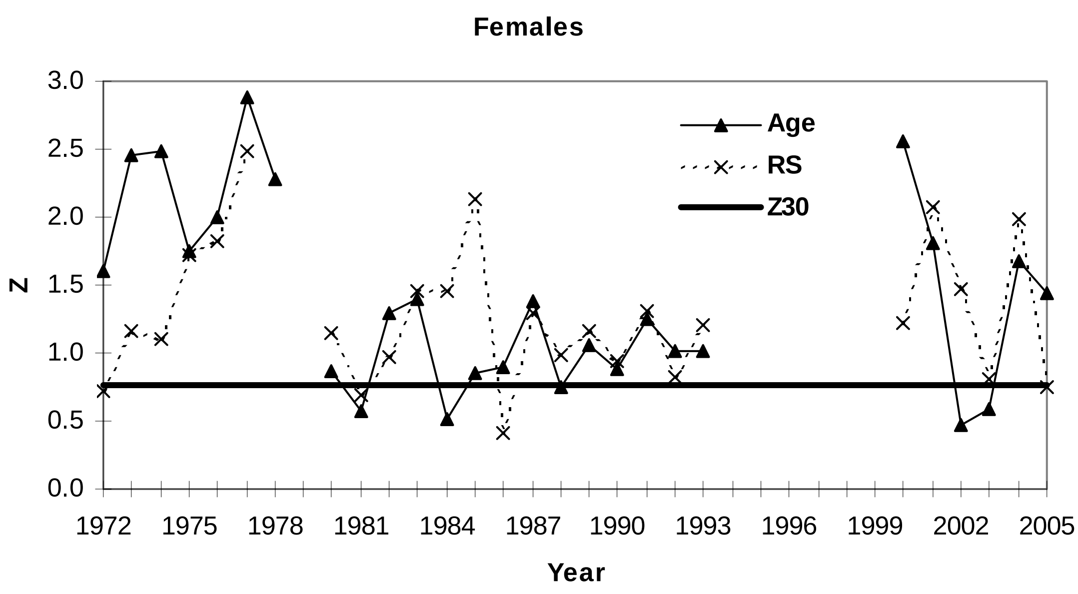
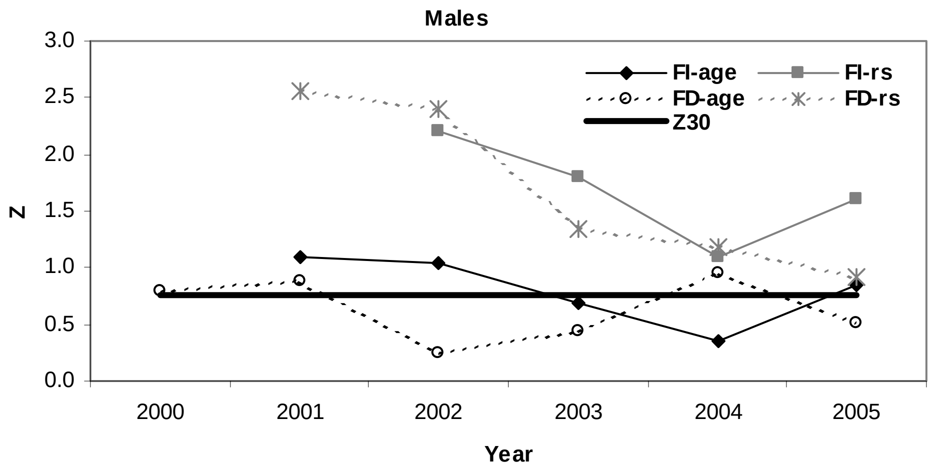


Figure 13.28 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the NCDMF fishery-independent (FI) and fishery-dependent (FD) gillnet surveys in Albemarle Sound using ages ad repeat spawning marks (rs), 2000-2005.

(a)



(b)

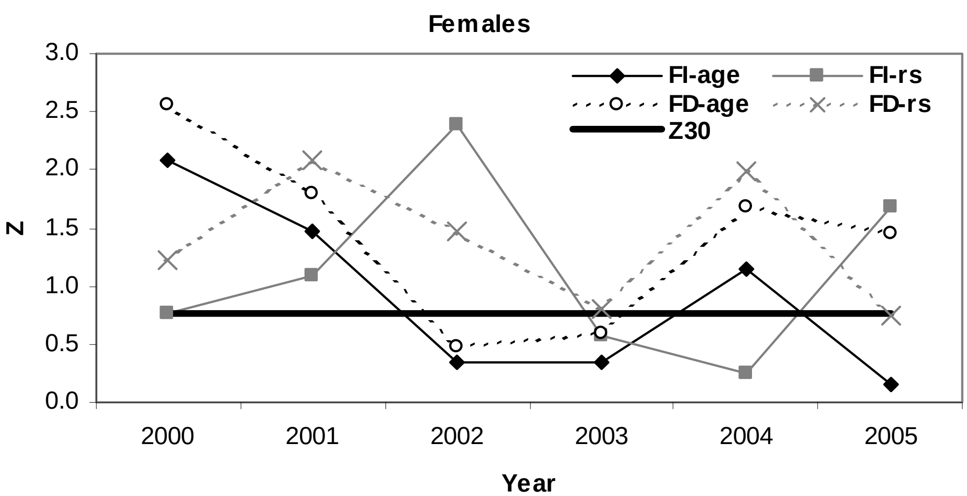


Figure 13.29 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the NCWRC fishery-independent (FI) electrofishing survey in the Roanoke River, 2000-2005.

(a)

(b)

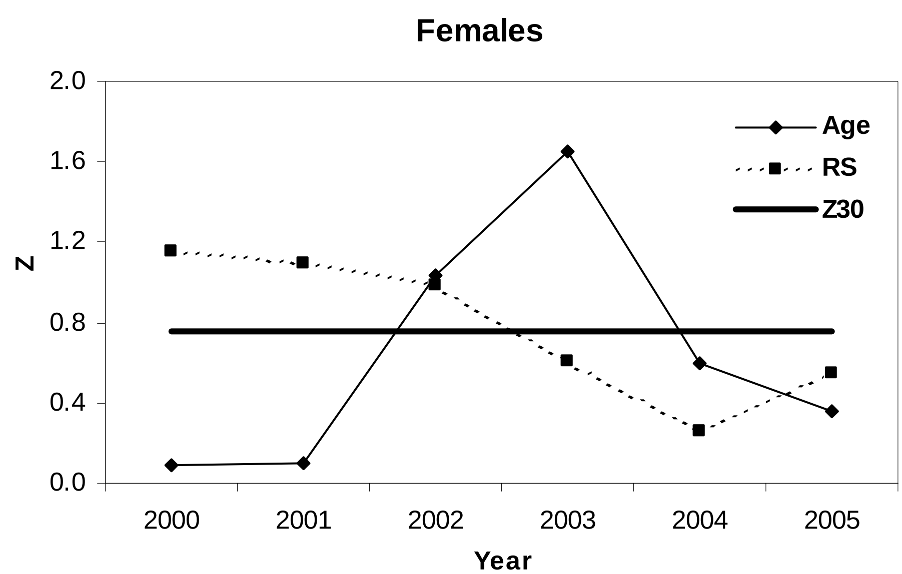


Figure 13.30 Commercial landings of American shad by gear type from Pamlico Sound, 1972-2005.

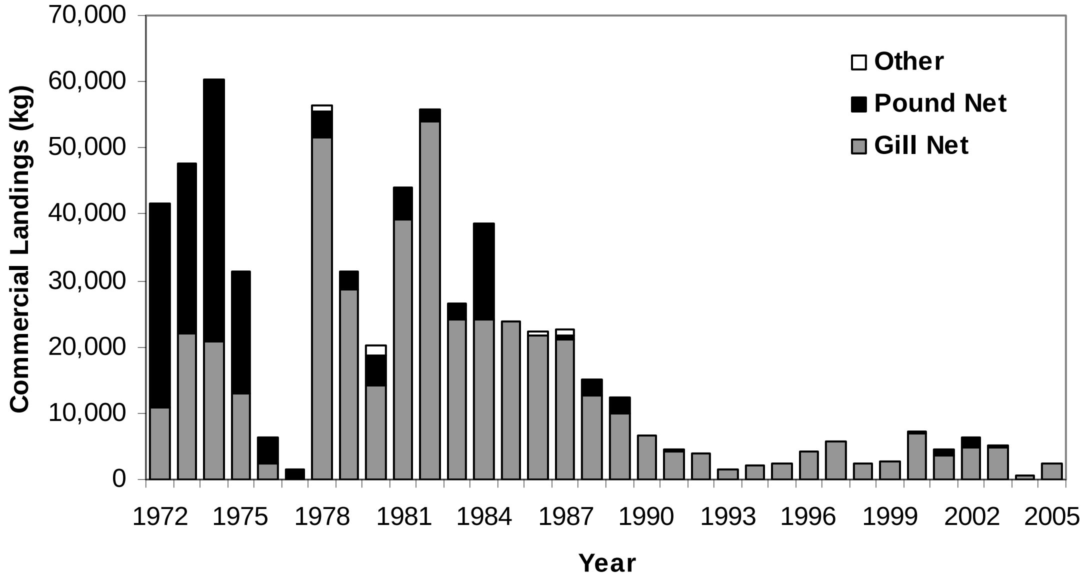


Figure 13.31 Commercial landings of American shad by gear type from Pamlico River, 1972-2005.

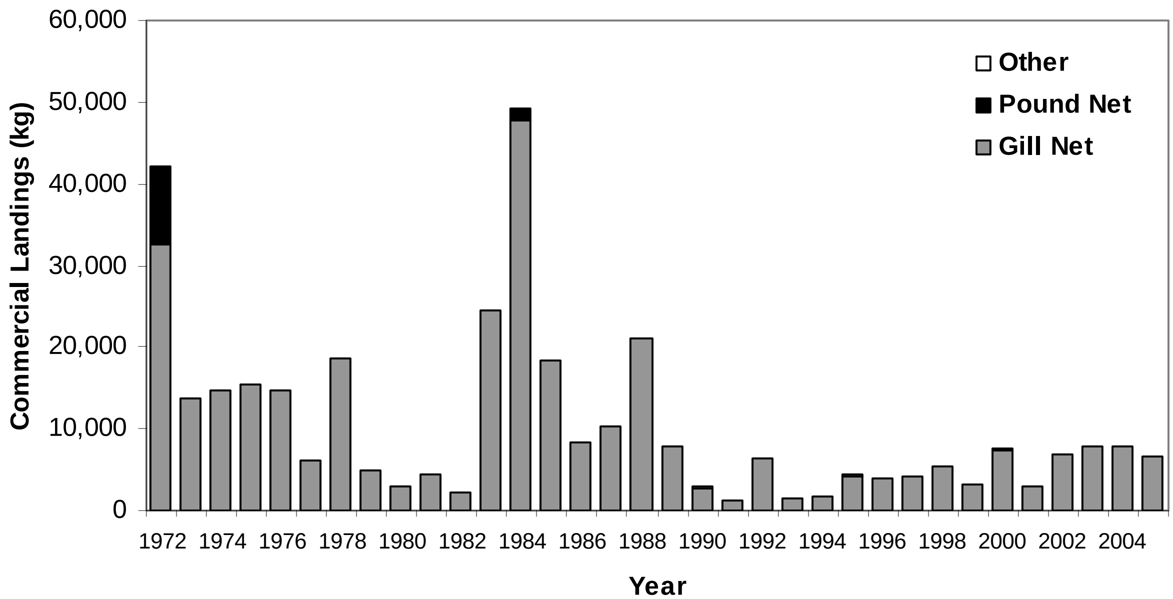
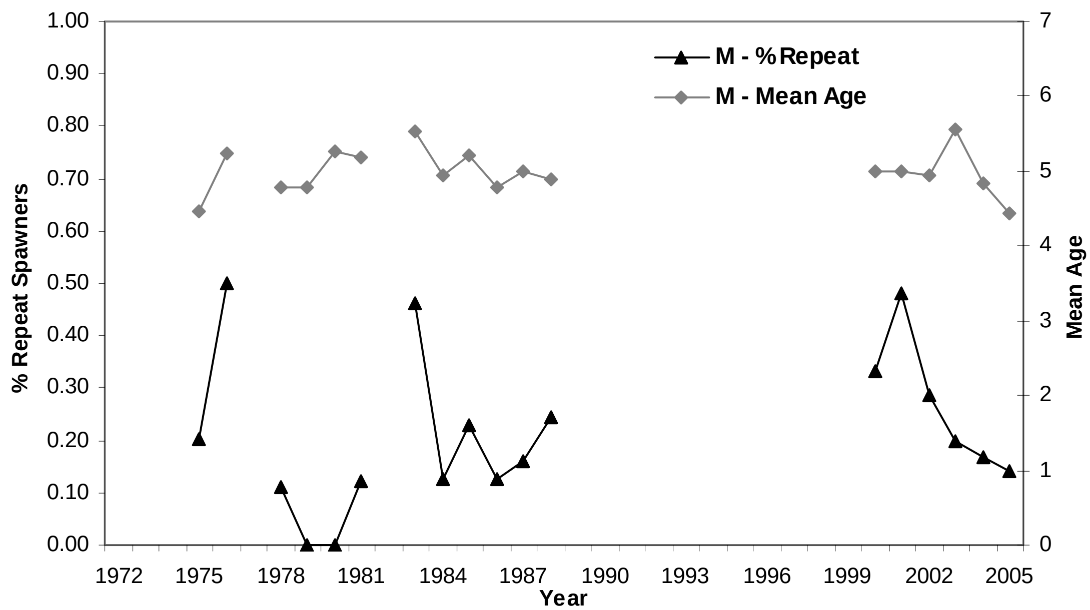


Figure 13.32 Mean age and percent of repeat spawners of (a) male and (b) female American shad from the commercial fishery in the Pamlico River, 1972-2005.

(a)



(b)

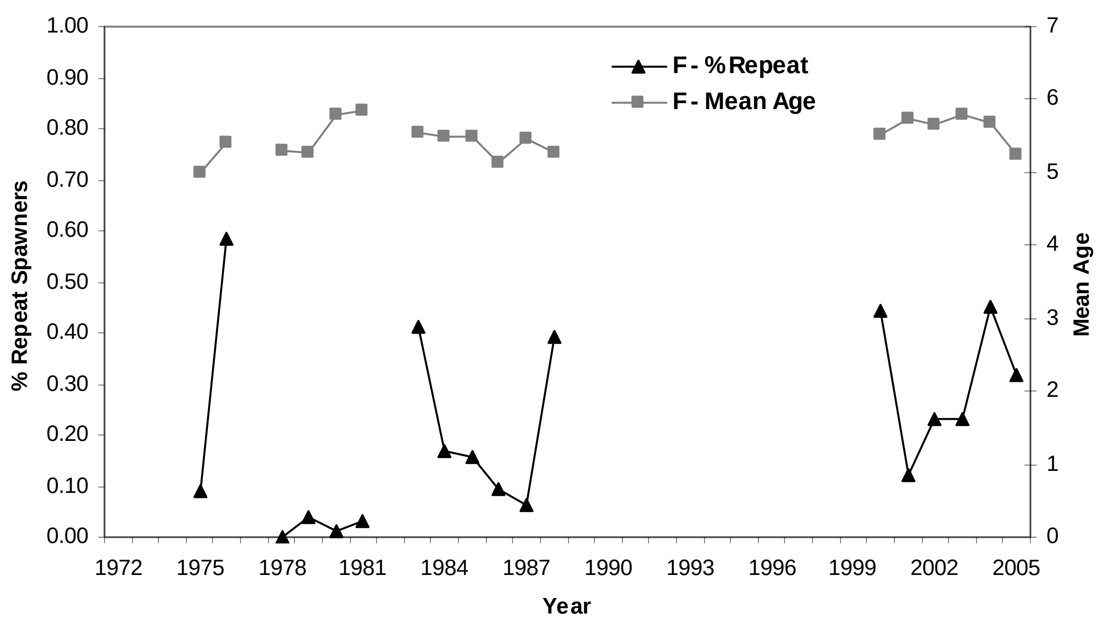
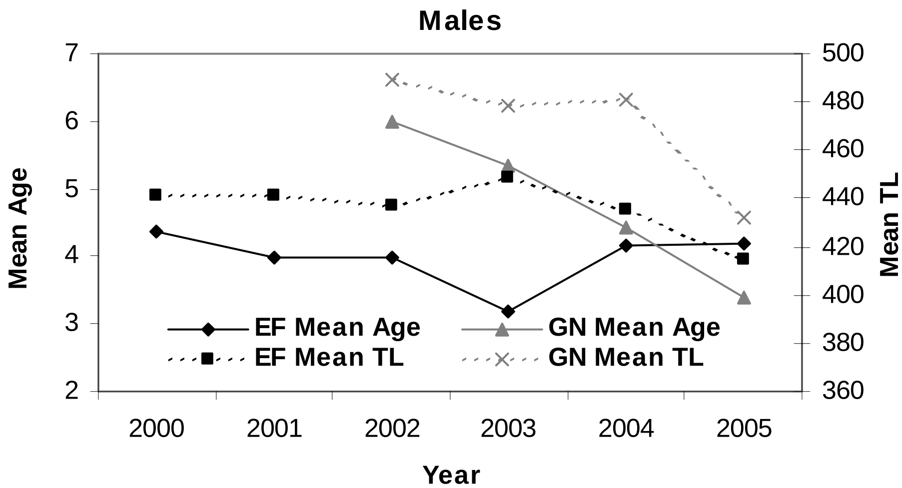


Figure 13.33 Mean age and total length (TL) of (a) male and (b) female American shad collected from the NCMF gill net (GN) survey in the Pamlico River and the NCWRC electrofishing (EF) survey in the Tar River, 2000-2005.

(a)



(b)

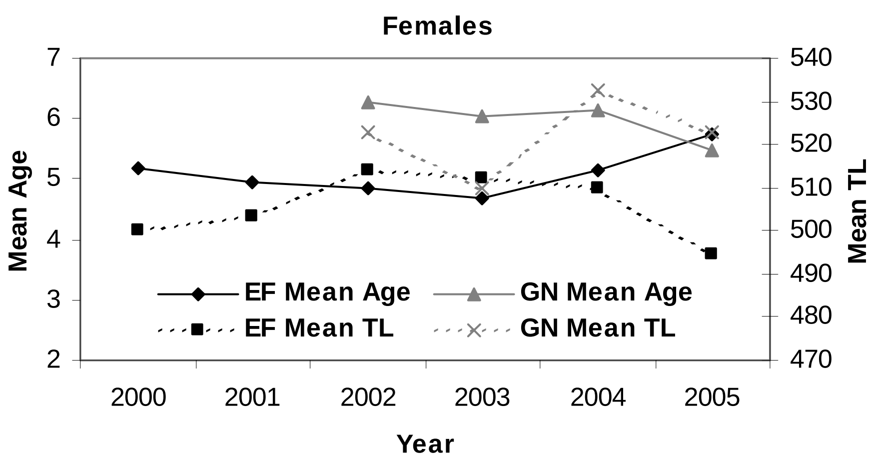
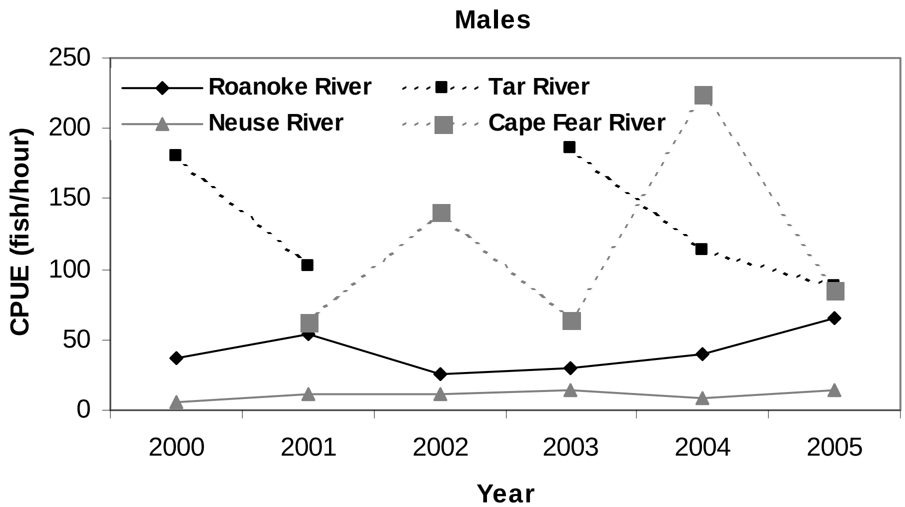


Figure 13.34 Annual CPUE of (a) male and (b) female American shad from NCWRC electrofishing surveys, 2000-2005.

(a)



(b)

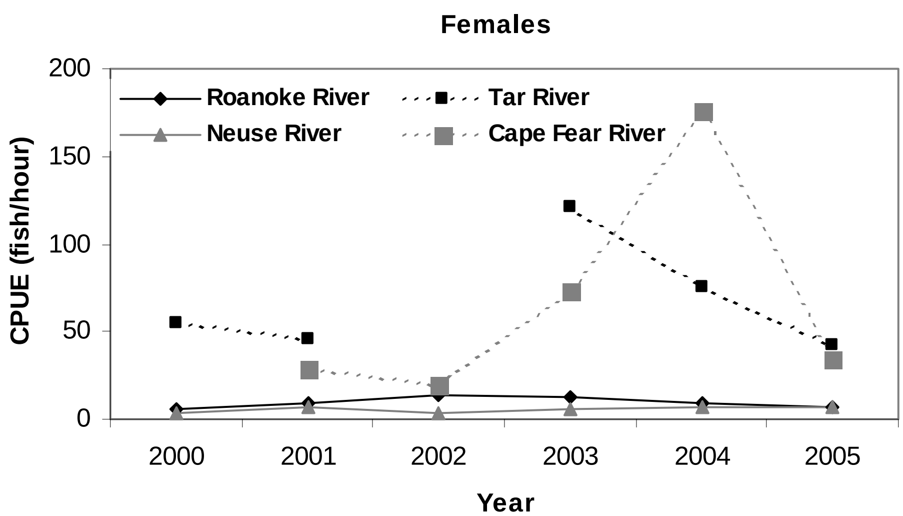
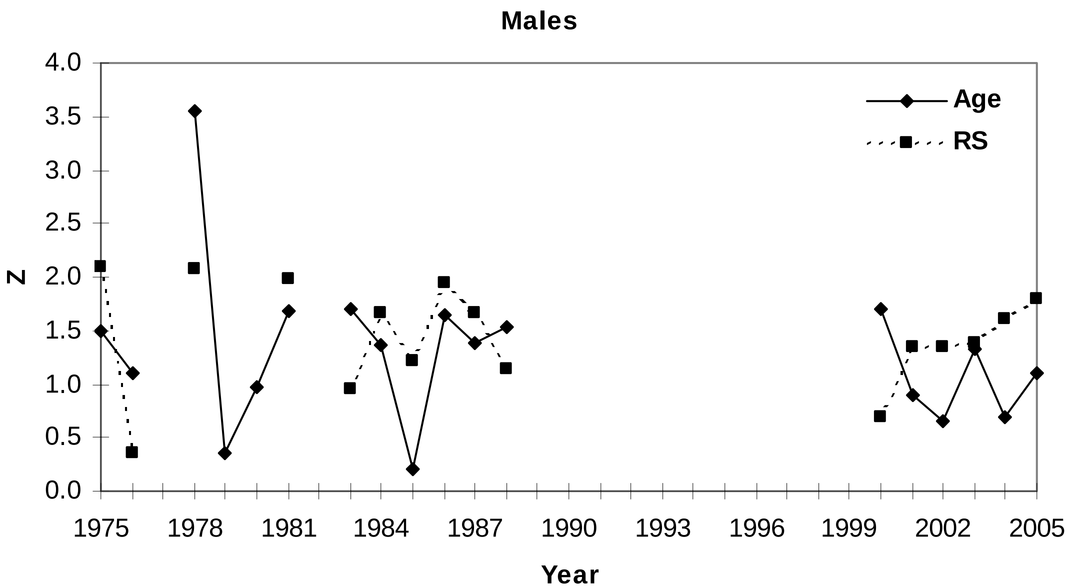


Figure 13.35 Total instantaneous mortality (Z) of (a) male and (b) female American shad in the commercial gill net fishery in the Pamlico River, 1975-2005.

(a)



(b)

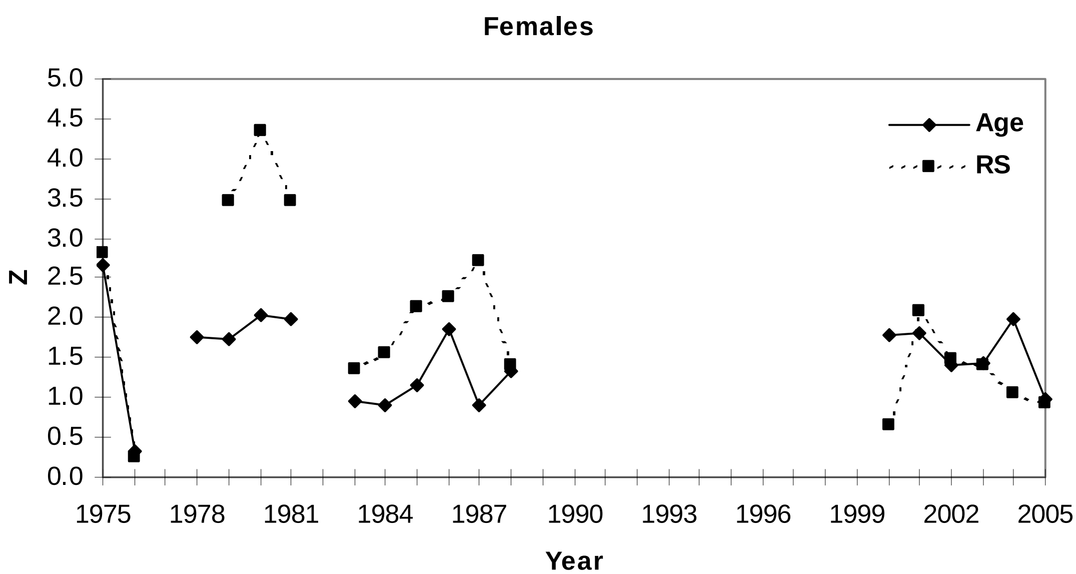
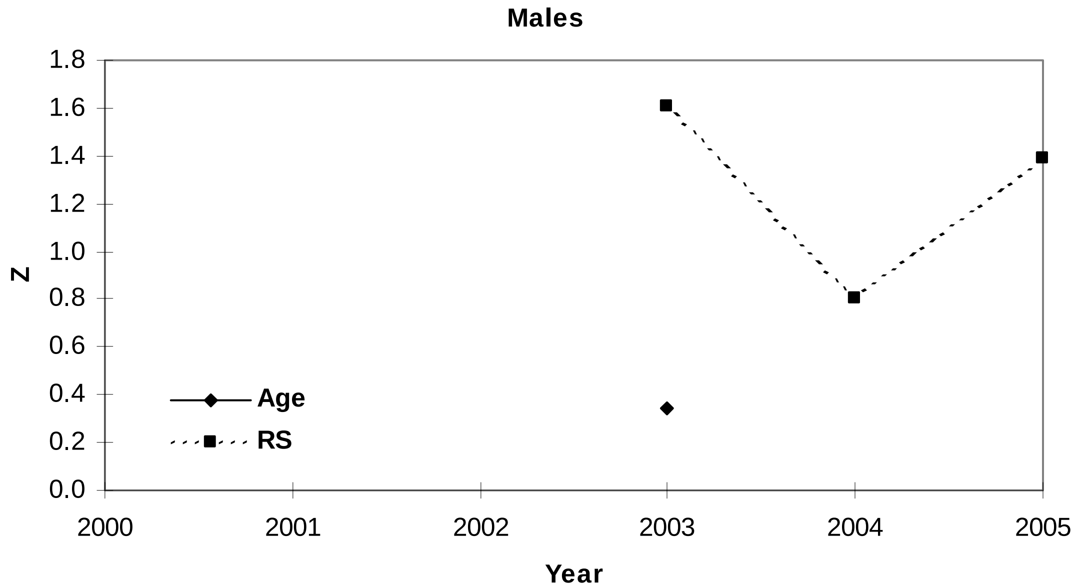


Figure 13.36 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the NCDMF fishery-independent gill-net survey in the Pamlico River using ages and repeat spawning marks (RS), 2000-2005.

(a)



(b)

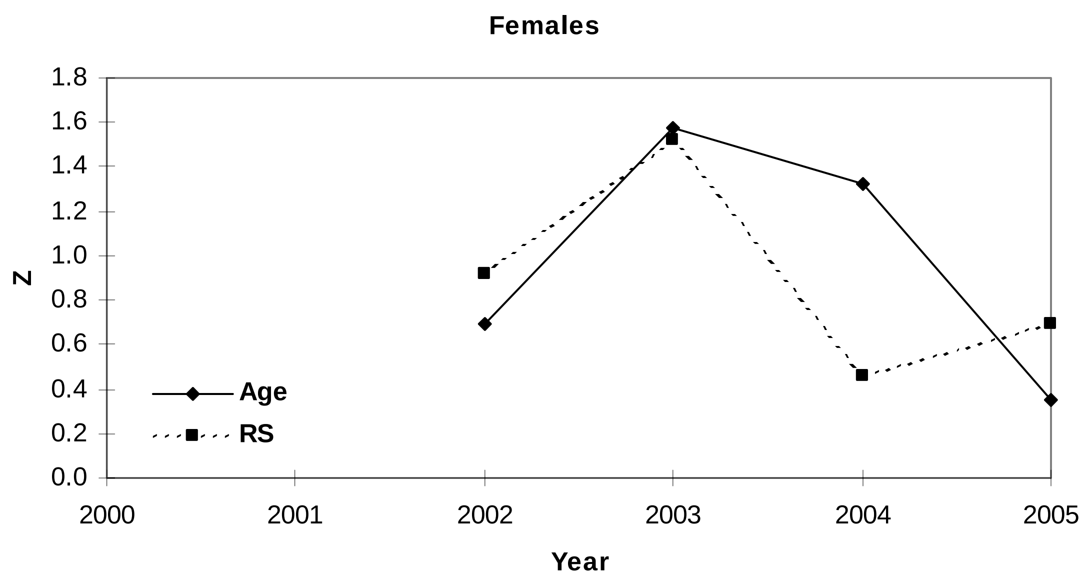
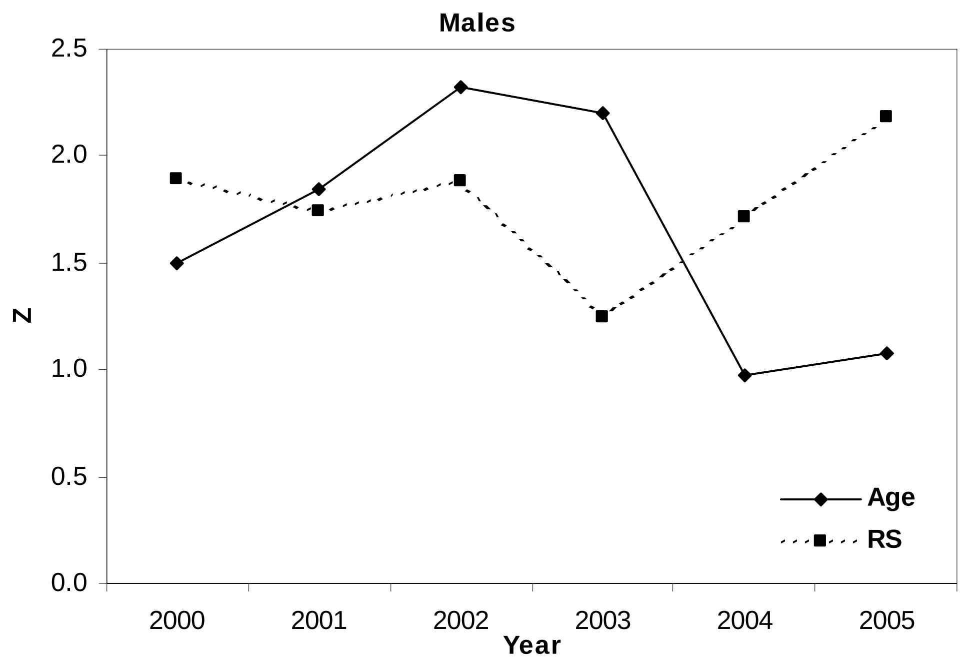


Figure 13.37 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the NCWRC fishery-independent electrofishing survey in the Tar River, 2000-2005.

(a)



(b)

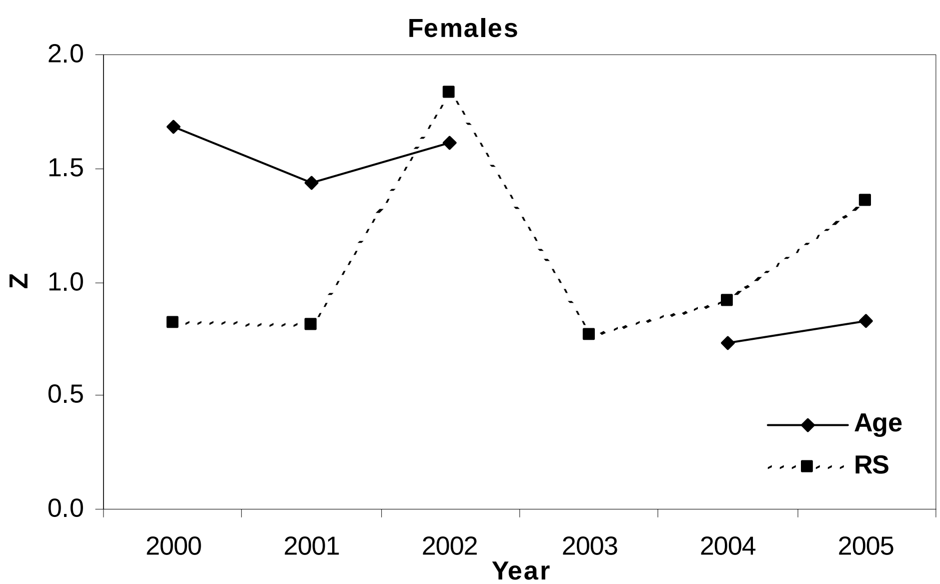


Figure 13.38 Commercial landing of American shad by gear type from the Neuse River, 1972-2005.

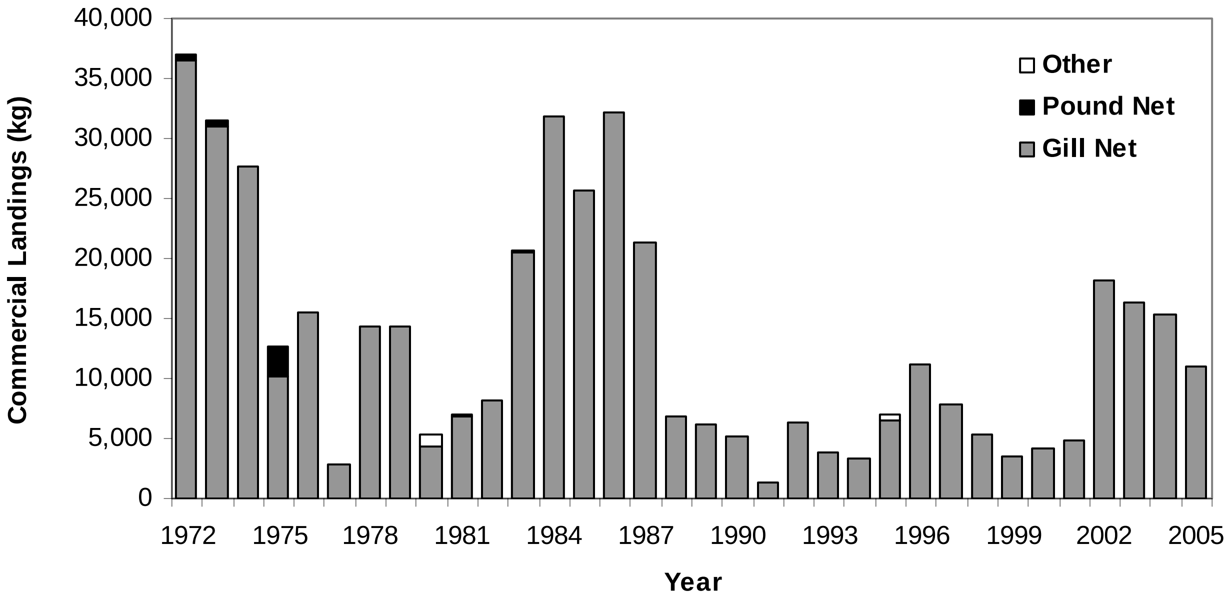


Figure 13.39 Mean age and mean total length (TL) of male and female American shad collected from the NCWRC fishery-independent electrofishing survey on the Neuse River, 2000-2005.

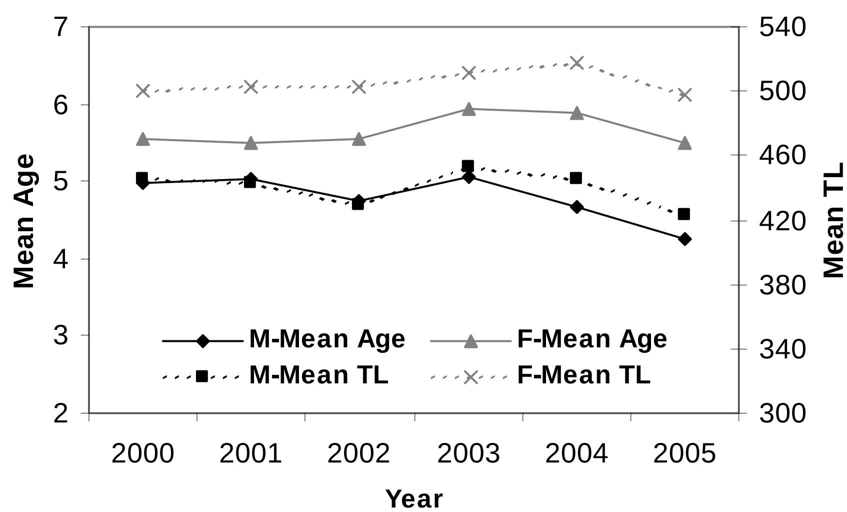
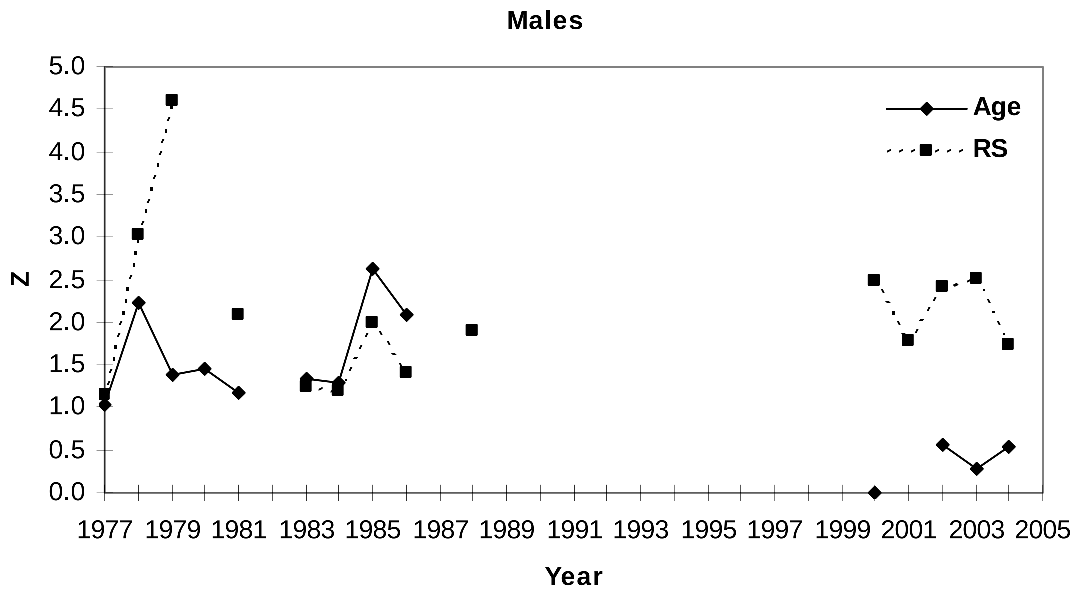


Figure 13.40 Total instantaneous mortality (Z) of (a) male and (b) female American shad in the commercial gill net fishery in the Neuse River, 1977-2005.

(a)



(b)

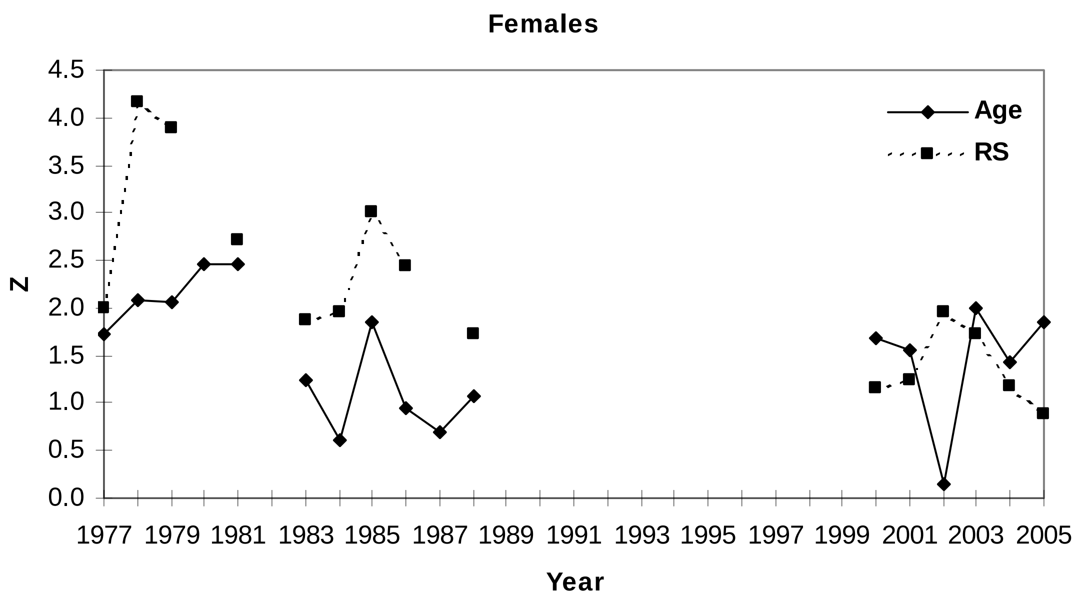
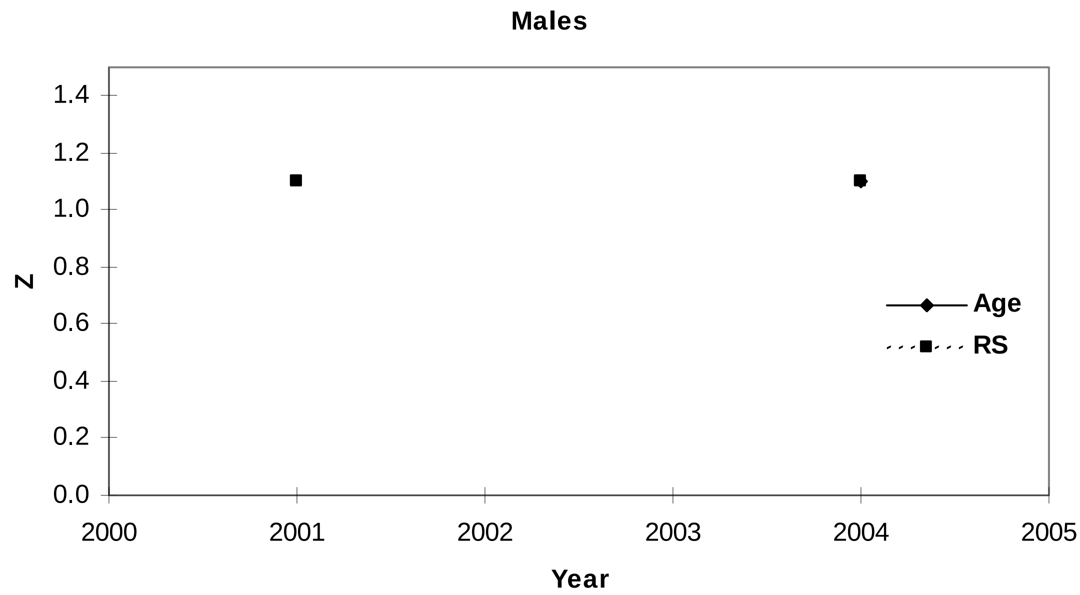


Figure 13.41 Total instantaneous mortality (Z) of (a) male and (b) female American shad caught in the NCDMF fishery-independent gill net survey in the Neuse River using ages and repeat spawning marks (RS), 2000-2005.

(a)



(b)

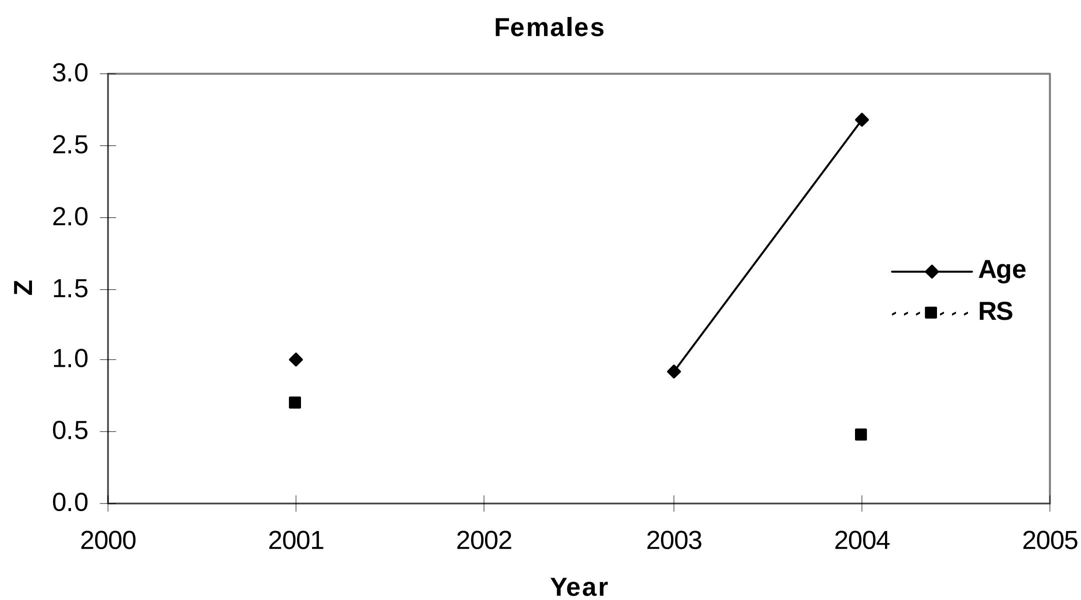


Figure 13.42 Total instantaneous mortality (Z) using ages of male and female American shad caught in the NCWRC fishery-independent electrofishing survey in the Neuse River, 2000-2005.

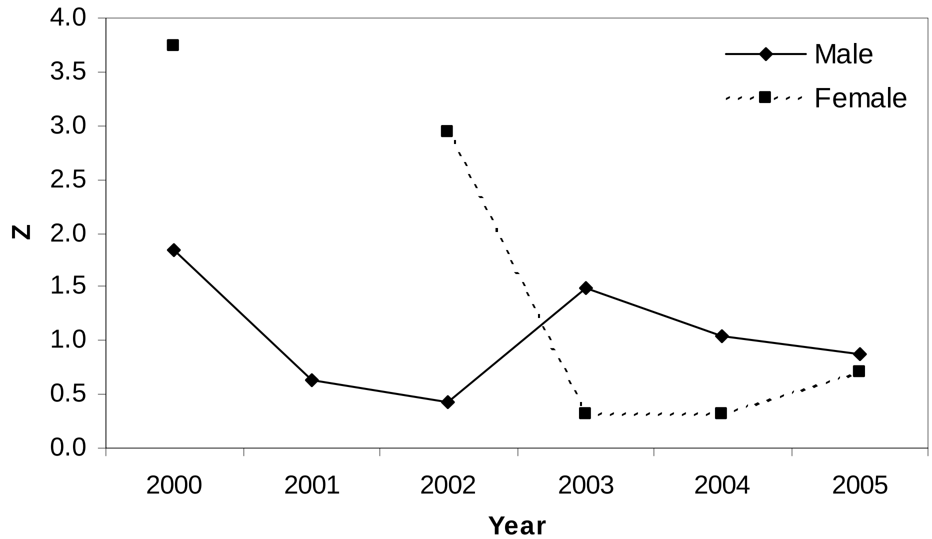


Figure 13.43 Commercial landings by gear type for Cape Fear River, 1972-2005.

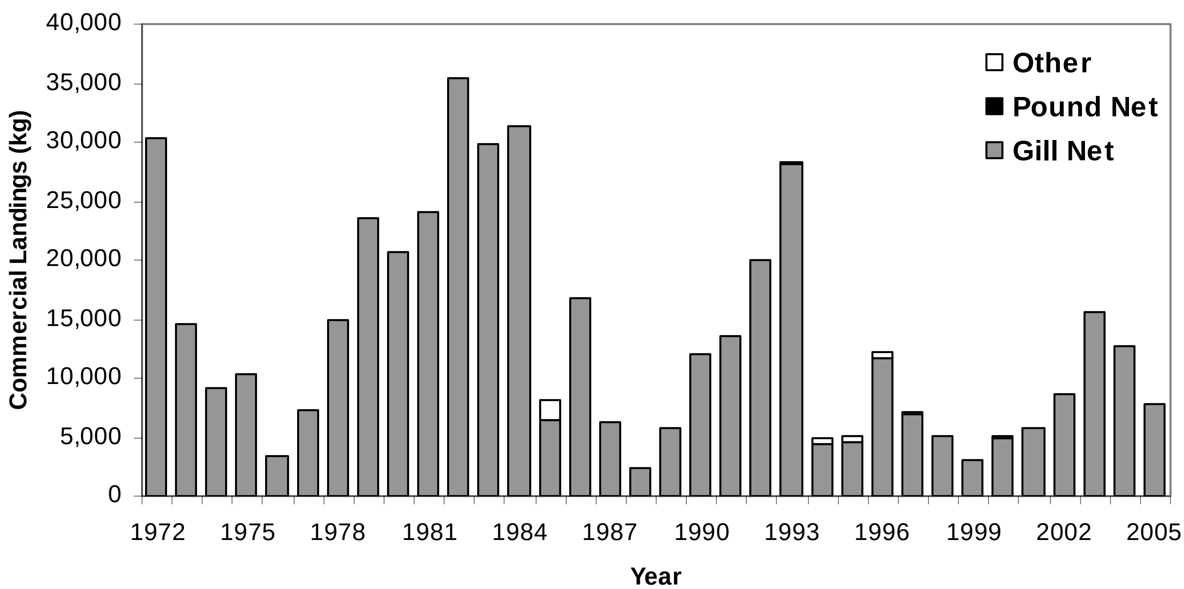
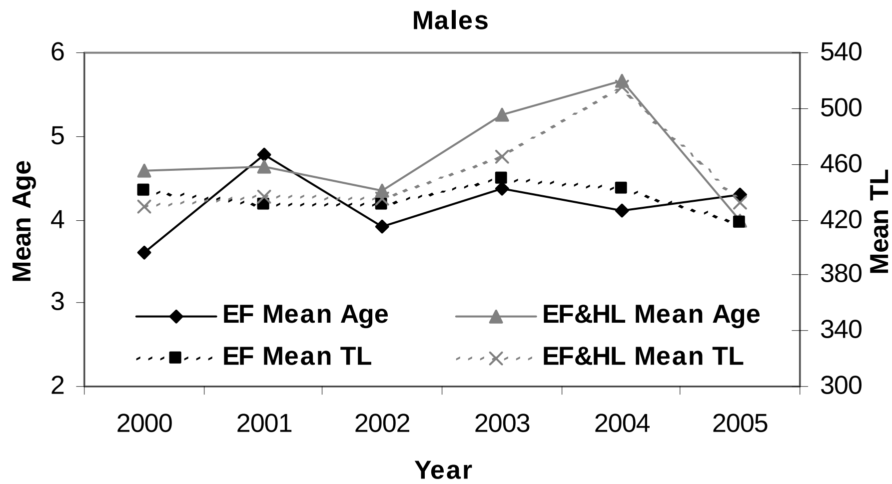


Figure 13.44 Mean age and mean total length (TL) of (a) male and (b) female American shad collected by the NCWRC electrofishing (EF) survey and the NCDMF electrofishing and hook and line (EF&HL) surveys on the Cape Fear River, 2000-2005.

(a)



(b)

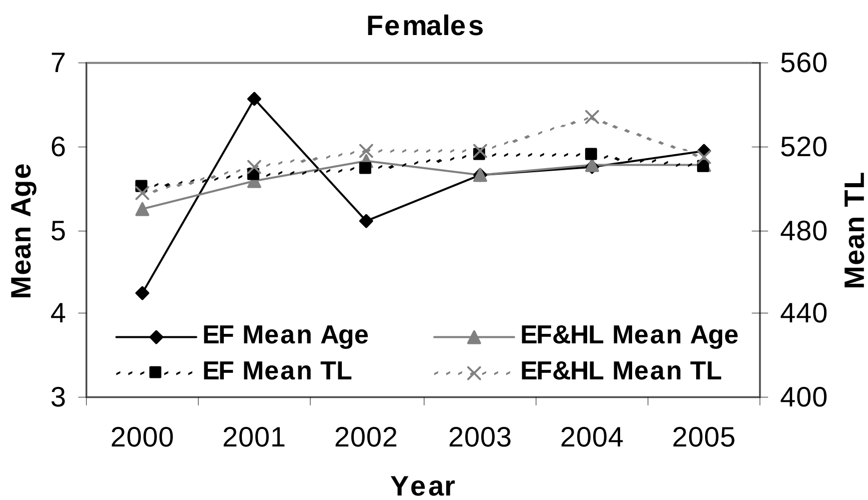
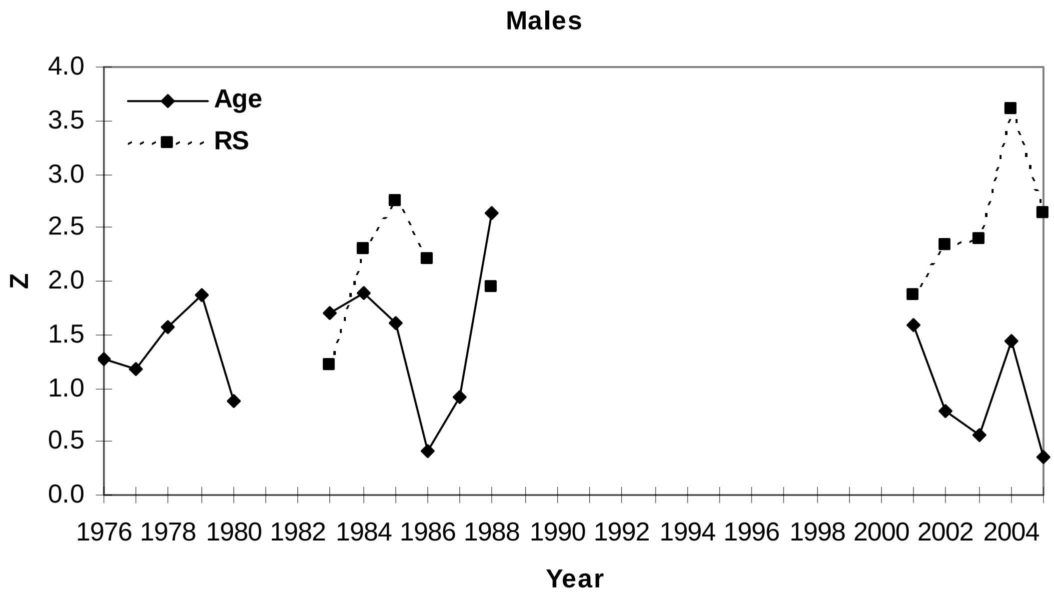


Figure 13.45 Total instantaneous mortality (Z) of (a) male and (b) female American shad in the commercial gill-net fishery in the Cape Fear River, 1975-2005.

(a)



(b)

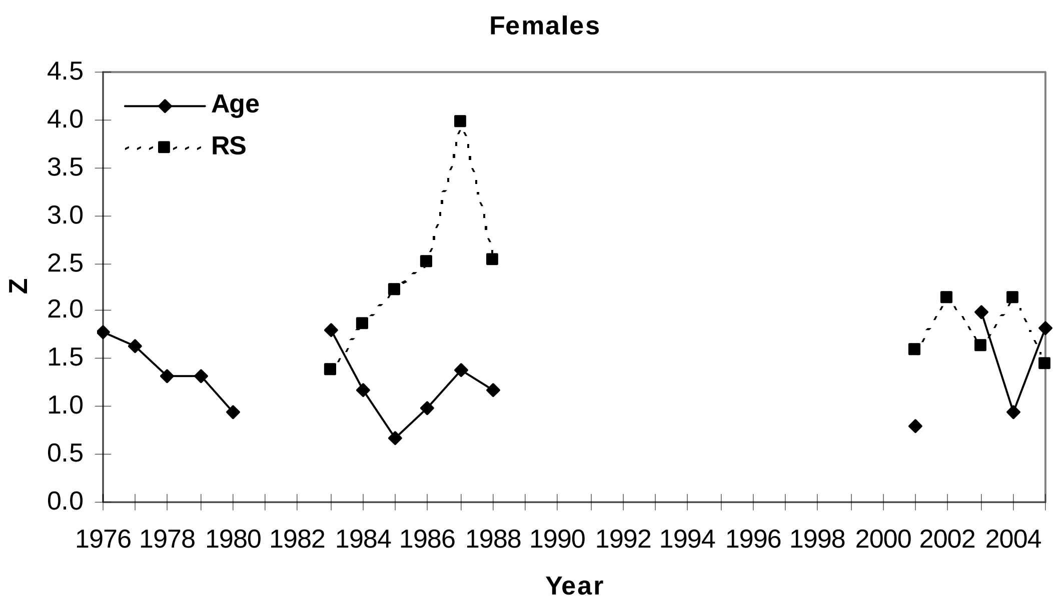
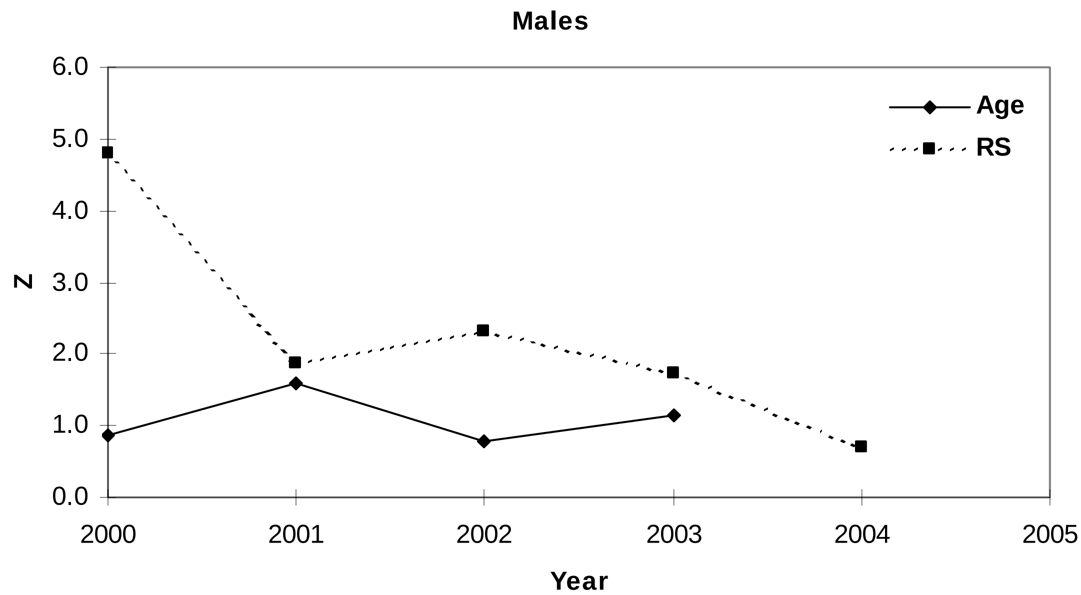


Figure 13.46 Total instantaneous mortality (Z) of (a) male and (b) female American shad in the NCDMF fishery-independent gill-net survey in the Cape Fear River using ages and repeat spawning marks (RS), 2000-2005.

(a)



(b)

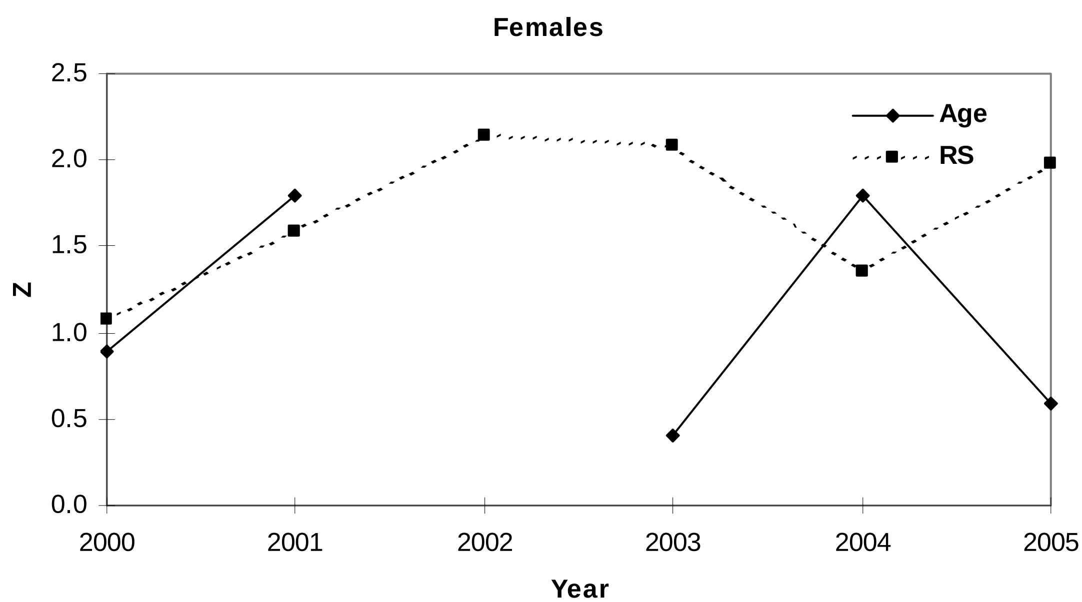
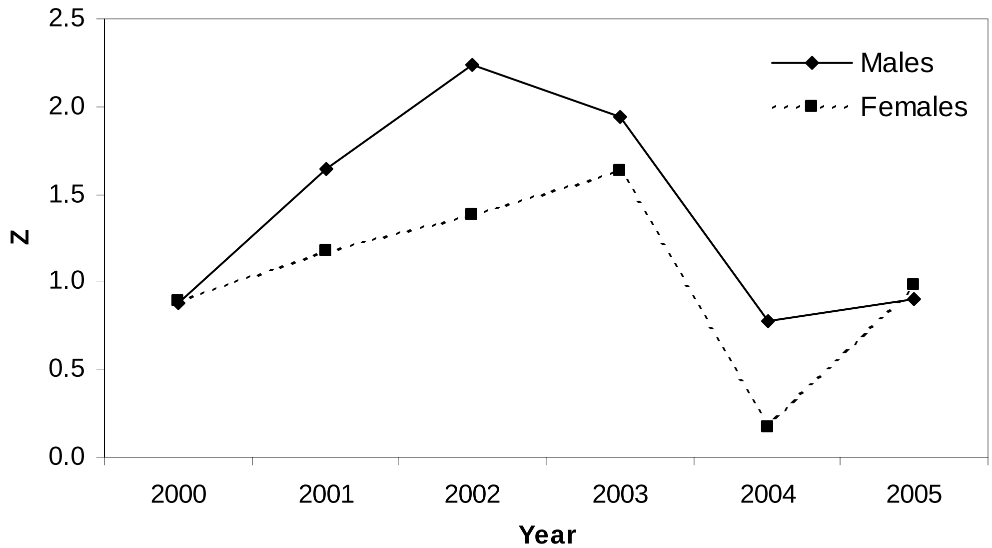


Figure 13.47 Total instantaneous mortality (Z) derived using ages of male and female American shad caught in the NCWRC fishery-independent electrofishing survey in the Cape Fear River, 2000-2005.



Section 14
Status of American Shad Stocks in South Carolina Rivers

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14.1 INTRODUCTION

American shad (*Alosa sapidissima*) are found in at least 19 rivers of South Carolina (Waccamaw, Great Pee Dee, Little Pee Dee, Lynches, Black, Sampit, Santee, Cooper, Wateree, Congaree, Broad, Wando, Ashley, Ashepoo, Combahee, Edisto, Coosawhatchie, and Savannah rivers, and Bull Creek). Many have historically supported a commercial fishery, a recreational fishery, or both, including the Winyah Bay system (primarily the Waccamaw and Pee Dee rivers), the Santee-Cooper system, Ashley, Edisto, Ashepoo, Combahee, Coosawhatchie, and Savannah rivers (Figure 14.1). It is possible that subpopulations exist within tributaries of the Winyah Bay (Waccamaw, Little Pee Dee, Great Pee Dee, Lynches, Black, and Sampit rivers).

Currently, commercial fisheries exist in Winyah Bay, Waccamaw River, Pee Dee, Black, Santee, Edisto, Combahee, and Savannah rivers, while the Lynches, Sampit, Ashepoo, Ashley, and Cooper rivers no longer support commercial fisheries. With the closure of the ocean-intercept fishery beginning in 2005, the Santee River and Winyah Bay complex comprise the largest commercial shad fisheries in South Carolina. Recreational fisheries exist in the Cooper, Savannah, Edisto, and Combahee rivers, as well as the Santee River Rediversion Canal.

Data for the assessment of American shad were available to assess trends in fishery and stock status for the following river systems in South Carolina: Winyah Bay and its major tributaries (i.e., Waccamaw and Great Pee Dee rivers), and Santee, Cooper, Edisto, Combahee, and Savannah rivers. Additional data for the Savannah River were provided by Georgia Department of Natural Resources (GADNR).

The South Carolina Department of Natural Resources (SCDNR) manages American shad populations and collects fishery-independent and dependent data for the major shad rivers. SCDNR has collected landings data by river system since 1979 and instituted mandatory catch and effort reporting in 1998. Mandatory reporting has not been fully implemented, as many licensed fishermen fish infrequently and provide incomplete, incorrect, or no effort data. SCDNR has worked successfully with several cooperating commercial American shad gill-net fishermen to collect commercial catch and effort data on several river systems since 1979. There are some gaps in these data, but they provide the broadest temporal and spatial view of American shad stocks in South Carolina. SCDNR has also conducted tag-return studies in the gill-net fisheries for several rivers, but these were not used to determine stock status, because there is no information available to determine if the assumptions of tag-return investigations were violated. These studies rotate among rivers and have run 2 to 5 years per river before changing to a different river. During these studies, SCDNR has collected biological information to support other studies (e.g., age, repeat spawning, length and weight data). In some systems, SCDNR has conducted creel surveys (Cooper River and Savannah River) and fish counts (Santee River).

This assessment primarily draws upon investigations conducted by the SCDNR's Marine Resources Division and Division of Wildlife and Freshwater Fisheries to provide a river-specific assessment of relative stock status for American shad. The general approach to this assessment was to (1) characterize fisheries by the magnitude and trend of landings data and note if the system still supports a viable fishery and (2) review supporting fishery-dependent and fishery-independent datasets and conduct analyses for each river system when applicable.

14.2 MANAGEMENT UNIT DEFINITION

South Carolina manages its shad fisheries using a combination of seasons, gear restrictions, and catch limits (Appendix I) implemented over several management units: Winyah Bay and Tributaries (Waccamaw, Great Pee Dee, Little Pee Dee, Lynches, Black and Sampit rivers); Santee River; Charleston Harbor (Wando, Cooper and Ashley rivers); Edisto River; Ashepoo River; Combahee River; Coosawhatchie River; Savannah River within South Carolina; ocean waters; and Lake Moultrie, Lake Marion, Diversion Canal, Intake Canal of Rediversion Canal and all tributaries and distributaries.

14.3 REGULATORY HISTORY

The first river-specific commercial regulations for American shad in South Carolina were enacted in 1993 for the Edisto River in response to SCDNR's studies that identified overfishing as a major contributor to a perceived trend of population decline [Act # 343 of the 1992 South Carolina General Assembly]. Beginning with the 1998 commercial shad netting season, all licensed fishermen are required to report their daily catch and effort to the SCDNR. In 2000, Act #245 of the 2000 South Carolina General Assembly was passed in response to the perceived status of shad populations in each of the state's river systems supporting an American shad fishery. This Act led to the closure of the commercial gill-net fishery on the Coosawhatchie River and a substantial reduction in potential gill-net fishery effort for other systems supporting small American shad stocks in South Carolina, including the Combahee, Ashepoo, and Ashley rivers (www.dnr.sc.gov).

Significant changes in shad and herring regulations became effective with the 2001 with the passage of the Marine Resources Act of 2000, which gave the SCDNR authority to implement a permit program for the State's shad and herring fisheries. All commercial shad and herring fishery license holders were issued permits that could be used to restrict the number of nets for taking shad in any body of water where the number of nets or fishermen must be limited to prevent congestion of nets or watercraft, or for conservation purposes. The number and conditions of permits can be controlled to designate areas, size and take limits, hours, type and amount of equipment, and catch reporting requirements, and enabled SCDNR to phase out the ocean-intercept fishery by 2005. In addition, a recreational aggregate creel limit of 10 American and hickory shad per person was implemented in all state waters, except for the Santee River in which a 20-fish creel limit was set.

14.4 ASSESSMENT HISTORY

Walburg (1956) conducted an early assessment of the American shad population on the Edisto River. Catch and effort (yard days) data were estimated from commercial fishermen via logbook reports and a creel survey was conducted to collect the same data from the hook-and-line recreational fishery. A tag-return study was conducted that estimated a 20 percent annual exploitation rate, which was combined with the catch and effort data to develop a population estimate of 55,053 (95% CI 28,000-100,000). Of 292 fish aged, most males were 3 to 4 years old (range 3 to 5) and most females were age 5 (range 4 to 6). No postspawning marks were reported, indicating that the shad sampled in the Edisto River were semelparous. Walburg and Nichols (1967) reported on the status of the U.S. Atlantic coast American shad fishery, see below.

The ASMFC Shad and River Herring Technical Committee conducted its first coastwide assessment in 1988 (Gibson *et al*. 1988) on 12 Atlantic coast rivers. The Savannah River was the only South Carolina river assessed. A second coastwide stock assessment was completed by the ASMFC in 1998. The Waccamaw-Pee Dee, Edisto, Santee, and Savannah Rivers were included in that assessment effort. The Santee River shad stock was found to be in a relatively healthy condition based on increases in both fish-lift counts and landings. The Waccamaw-Pee Dee, Edisto, and Savannah Rivers had experienced decreased landings since the middle to late 1980s. The decline in Edisto River shad landings were attributed to reduced commercial effort based on the results of tag-return data.

We decided not to repeat the approaches used in the last two assessments (Gibson *et al*. 1988; ASMFC 1999) because of recent uncertainties about data inputs and effects of these uncertainties in the calculation of stock recruitment characteristics, target fishing values, or current absolute values of fishing rates. In particular we were concerned about the tag-based estimators because of the host of necessary assumptions that appear to have been violated (see Section 14.9.4). We were reluctant to utilize the Thompson Bell, Shepherd stock-recruit, or the spawning biomass per recruit approaches to estimate target fishing rate because of the uncertainty about estimating M in semelparous stocks.

14.5 STOCK-SPECIFIC LIFE HISTORY

American shad returning to South Carolina rivers are generally believed to be semelparous. In annual compliance reports to the ASMFC, SCDNR reports that no repeat spawning marks have been observed in their sampling since 2001. Approximately 200 fish were sampled each year from both river and coastal ocean locations. SCDNR compliance reports note a low degree of repeat spawning in 1985 (3% for males and 2% for females) and Walburg (1956) did not record presence of spawning marks. There are no recent studies on the growth and fecundity of South Carolina shad.

14.6 HABITAT DESCRIPTION

14.6.1 Winyah Bay System

The Winyah Bay and its tributaries (Figure 14.1) constitute the northern most system that SCDNR monitors for American shad. Winyah Bay extends nearly 24 kilometers (km) inland and has six tributaries that have spawning runs of American shad (Sampit, Lynches, Pee Dee, Bull Creek, Black, and Waccamaw). From 1979 to 2005, shad had to bypass the Winyah Bay ocean-intercept fishery before entering their natal rivers to spawn. The Sampit is a small, tidal river that becomes unnavigable inland at about river kilometer (rkm) 64. The mouth of the Black River is near the junction of the Great Pee Dee River and upper Winyah Bay and has approximately 40 km of navigable waters. The downstream section of the Great Pee Dee River merges with the Black River and they diverge about 16 km upriver. The Pee Dee River continues until it merges with Bull Creek at river-kilometers (rkm) 96. The Little Pee Dee extends about 96 km to the North Carolina state line. The only dam is located on the Pee Dee River at Blewett Falls, North Carolina (320 km inland; Post *et al*. 2004). The Lynches River remains navigable for over 113 km after separating from the Great Pee Dee. Bull Creek extends 24 km and borders the

Waccamaw River to the south and the Great Pee Dee to the north. The Waccamaw River fishery began at rkm 0 and continued for 64 km upriver.

14.6.2 Santee-Cooper System

The Santee River was historically one of the longest river systems on the Atlantic coast and supported spawning stocks of American shad as far as 438 km inland to Great Falls on the Wateree River and up to 602 km up the Congaree River (Walburg and Nichols 1967; Figure 14.1). The Cooper River likely supported a small shad stock before the creation of the lakes and rerouting of the Santee River. The South Carolina Public Service Authority (SCPSA) initiated the Santee-Cooper Diversion Project in 1938. This project included the construction of the Santee Dam for flood control on Santee River at rkm 143, which created Lake Marion and the construction of Pinopolis Dam at rkm 77, which is a hydroelectric facility and navigation lock. Pinopolis Dam formed Lake Moultrie (Cooke and Leach 2003; Figure 14.1). With the increased flows resulting from the Diversion, the Cooper River likely attracted larger runs of anadromous species.

Increased flows from the Santee-Cooper Diversion Project to the Cooper River led to shoaling in Charleston Harbor[1]. The Cooper River Rediversion Project reduced shoaling in Charleston Harbor by diverting water back to the Santee River through a 15 km Rediversion Canal. The St. Stephen Dam was constructed 7 km up the Rediversion Canal to control the flow from Lake Moultrie to the Canal and has a hydroelectric facility and a fish-lift. The Rediversion Canal was completed in 1985 and approximately 75 percent of the Cooper River's flow was returned to the Santee River, increasing its flow from 63 cubic meters per second (cms) to 295 cms (Cooke and Leach 2003).

Initially, high or intermittent discharges from the St. Stephen Dam prevented fish from entering the lock. In the 1990s, the SCPSA implemented a flow agreement to improve the fish-lift function, and a series of modifications were completed from 1995 through 2000 that increased the efficiency of the fish-lift, but in low flow years, when water levels are not adequate for turbine operation, fish may bypass the Rediversion canal and use the Santee River proper. Pinopolis and St. Stephen Dams receive priority for releases to produce electricity from their hydroelectric facilities. This leads to minimal flow releases from the Santee dam. See Section 14.7.3 for information on upstream passage at St. Stephen fish-lift.

There have been no directed studies to determine turbine mortality on American shad at the St. Stephen Dam, although it is believed that turbine strike mortality is minimal, with anecdotal information indicating that passage is more problematic for larger fish. Turbine mortality studies may be conducted as part of the Federal Energy Regulatory Commission (FERC) relicensing process in the Santee-Cooper system. Blueback herring (*Alosa aestivalis*) were more affected by the pressure differential than by turbine strikes during their downstream migration through the facility (William McCord, SCDNR, pers. comm.).Above Lake Marion, several impediments to migrations exist on Santee River tributaries. On the Wateree River, the Wateree Dam is the first obstruction to fish passage.

14.6.3 ACE Basin (Edisto River, Combahee River, and Ashepoo River)

The lower portions of these systems comprise the ACE (Ashepoo-Combahee-Edisto) Basin National Estuarine Research Reserve (Figure 14.1). The Edisto River system drainage, which has no dams, is approximately 4,800 km^2 within the South Carolina Coastal Plain and is approximately 320 km long. At approximately rkm 180, the North and South Forks merge forming the Edisto River proper. Returning American shad reach at least rkm 161 in the North Edisto and at least rkm 193 in the South Edisto on

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[1] https://www.santeecooper.com/portal/page/portal/SanteeCooper/Environment/FercRelicensing/FieldStudies/anadromous.pdf

their spawning migration (Walburg and Nichols 1967). The system is tidally influenced 75 km upstream and the lower 50 km drains substantial areas of fresh, brackish and salt marsh. The watershed is similar to that of its smaller sister rivers, the Combahee and Ashepoo as all three of these rivers are connected in their lower 20 km before entering the Atlantic Ocean through St. Helena Sound. The Combahee River is a black-water river about 72 km long and is formed at the confluence of the Salkehatchie and Little Salkehatchie before draining into St. Helena Sound. There are no impoundments on the Combahee River and spawning shad reach rkm 137 near Walker, South Carolina (Walburg and Nichols 1967). The Ashepoo River is the smallest of the ACE Basin rivers and has no obstructions to shad migration. Shad reach rkm 80 on their annual spawning migration (Walburg and Nichols 1967).

An environmental factor that might have affected the American shad population in the ACE Basin was the increase in timber harvest in the 1980s possibly resulting in increased siltation from the flood plains to potential spawning habitat (Chris Thomason, SCDNR, personal communication).

14.6.4 Savannah River

The Savannah River, which is approximately 560 km long and is open to a shad gillnetting up to about rkm 322, but the first barrier to upstream migration is the New Savannah Bluff Lock and Dam (NSBLD) located at Augusta, Georgia (approximately rkm 301; Figure 14.1). The lock at NSBLD is designed for navigation and does not provide effective fish passage. During high flow periods, the river can rise above the NSBLD, which allows for some anadromous fish passage (Bailey *et al*. 2004). After NSBLD, there are several other dams on the Savannah River: Augusta Diversion Dam, Stevens Creek Dam, Strom Thurmond Dam, Richard B. Russell Dam, and Hartwell Dam. There are 43 km between NSBLD and the J. Strom Thurmond Dam. Water quality may be a problem in the Savannah as the dissolved oxygen in the lower Savannah can fall below 1.0 ppm (Billy McCord, SCDNR, personal communication). Walburg and Nichols (1967) reported that dealers noted oil pollutants causing an “oily flavor” of Savannah River shad.

14.7 RESTORATION PROGRAMS

14.7.1 Restoration Objectives

The U.S. Fish and Wildlife Service, the National Marine Fisheries Service (NMFS) and SCDNR developed a fish restoration plan for the Santee-Cooper River basin with proposed restoration targets (Anonymous 2001); however, river-specific goals were not established for other systems in South Carolina.

The proposed Santee-Cooper restoration goals were based on a target number of 50 fish per acre for currently available habitat and possible habitat if all upstream dams were equipped with effective fish passage. Effective fish passage at Santee-Cooper Project dams (Pinopolis, St. Stephen, and the Santee Dam) is identified as an essential requirement for restoration throughout the Basin. The plan identifies restoration priorities for upstream sub-systems of the Santee-Cooper reservoirs and main stem rivers including the Saluda River, Wateree-Catawba system, and Broad River. If all upstream dams were outfitted with adequate fish passage, the restoration target for the entire South Carolina portion of the Santee-Cooper Basin was estimated at 3.3 million American shad.

14.7.2 Hatchery Evaluations

A pilot study investigating the feasibility of American shad stock enhancement in South Carolina rivers through hatchery supplements to the wild stock was initiated in 2004, which led to attempted hormone induced tank spawn at the Bayless Striped Bass Hatchery. A total of 124 brood stock shad were implanted with time released spawning hormone during the 2005 season. The hormone-induced spawning was successful and resulted in an estimated 359,540 eggs with 70 percent viability or 246,760 yolk-sac larvae. Larvae were marked by immersion in oxytetracycline (OTC) and then stocked into the Wateree River. Future investigations should examine survival rates after captive first feeding and OTC mark retention and detection in the wild (Leach *et al*. 2005).

14.7.3 Fish Passage Efficiency

Pinopolis Dam

Fish passage counts at Pinopolis Dam serve primarily as an index of blueback herring passage and cannot be used as an index of American shad passage. Some hydroacoustic work indicates that blueback herring passage rates might be as high as 70 percent, but no measures for American shad are available.

There is evidence indicating that American shad enter the Pinopolis lock, but that they have difficulty exiting the lock. Telemetry studies indicate that 10 to 19 percent of acoustically tagged American shad that entered the lock did not pass upstream (NAI 2002; Isley 2002). Isley (2002) also reported that 54 percent of American shad required more than one lock operation to pass upstream. Timko *et al.* (2003) replicated Isley's study, noted that 17 percent of American shad entering the lock did not pass upstream and found that 45 percent did not exit the lock within 30 minutes.

St. Stephen Dam

Passage efficiency at St. Stephen is unknown but believed to be less than 100% during the years of this assessment. It varied over years as modifications to turbine operation and flow regimes were made to improve the attraction of fish to the lift, which is considered to have generally improved efficiency since 1990. Another possible confounding factor is that the Santee and Cooper River stocks may not be discrete units. If these stocks are not distinct, then American shad might select one river over the other dependent upon annual flow regimes.

Mortality of juvenile and adult American shad associated with cleaning and dewatering the fish-lift has decreased from the 1990s to recent years (e.g., 4,061 adult and 72,715 juvenile mortalities in 1999 to 129 adult and 200 juvenile mortalities in 2004; Cooke and Leach 1999, Leach and Cooke 2004). These reductions are attributed to improvements in the operational protocol and increasing the size of the floor grating to reduce impingement.

Santee Dam

There are no fish passage facilities on the Santee Dam on the Santee River.

The relative flow of the Santee River proper compared to that of the Rediversion Canal varies among years and can influence American shad migration and, therefore, the passage of shad through the St. Stephen fish-lock in a given year. The discharge of water from the St. Stephen Dam in moderate to high flow years provides an attractive flow to the Rediversion Canal for fish migrating up the Santee River. However, drought conditions, such as those experienced earlier this decade, reduce the availability of American shad at the St. Stephen fish-lift and fish may bypass the Rediversion Canal in those years.

Savannah River

New Savannah Bluff Lock and Dam are located at rkm 301 of the Savannah River. The dam was constructed in the 1930s as a commercial navigation lock. Currently, fish passage is possible by one of two methods: (1) fish pass freely at river flows greater than 453 cms when water levels above and below the dam are roughly equal and (2) in the navigation lock, which is operated 30 to 50 times a year between March 15 and June 15 to facilitate fish passage (Bailey *et al*. 2004). In dry years (i.e., when river flows do not reach 453 cms), lock operation is the only source of fish passage. There are no measures of efficacy for either method (Boltin 1999).

14.8 AGE

South Carolina DNR personnel age shad using Cating's method (Cating 1953). From 1979 to 1985, a single group of readers has read SCDNR samples, but there have been multiple shad ageing technicians with variable experience and training since then. The maximum age for American shad in South Carolina rivers recorded by SCDNR is age-6 (males) and age-7 (females).

Data from commercially harvested shad in the Waccamaw, Santee, and Edisto rivers were examined to evaluate whether the age of American shad has changed within these systems over time. Sampling levels for age and length are 200 fish per year in the Waccamaw and Santee rivers, and are taken from the first 20 fish caught on the river each day. Samples are collected throughout the season to better represent the commercial catch. From 1979 to 1985, SCDNR staff collected extensive biological information from the state's commercial shad fisheries. Beginning in 2000, SCDNR once again began monitoring commercial fisheries on individual rivers on a rotating basis (N. Santee – 2000 to 2002; Waccamaw – 2003 to 2005). Data for the Edisto River include SCDNR biological sampling from 1979 to 1985 and age data from Walburg's (1956) assessment efforts.

In the Waccamaw River, the maximum observed age decreased from age 6 (males) and age 7 (females) in 1979 to 1985 to age 5 (males) and age 6 (females) in 2003 to 2005. Although the maximum age and the range of ages appear to decrease in the Waccamaw River between the two sampling periods (Figure 14.2), length distributions (total length) appear similar between periods for both sexes (Figure 14.3). The dichotomy in changes in age and consistency in length between periods could be due to discrepancies in ageing methods, variability related to using different readers, changes in growth rate, or changes in catchability.

In the Santee River, the maximum observed age decreased from age 6 (males) and age 7 (females) in 1979 to 1985 to age 5 (males) and age 6 (females) in 2000 to 2003. Age and total length frequency distributions (Figures 14.4 and 14.5) indicate that younger and smaller fish were observed in the recent period. The change in age and length distributions could be influenced by the opening of the Rediversion Canal in 1985, as the increased flow to the Santee River has led to improved recruitment possibly attributable to increased shad attraction resultant from improved water quality and flow conditions in the river. Another explanation is that the decrease in age and length could be a function of increased fishing rate, as landings and the population increased after the completion of the Rediversion canal. Changes in gear selectivity are less likely as the same mesh size was employed in both periods (5.5"), but are not discountable. Similarity in direction of length and age change over time provides some support that shad ageing has been consistent over these periods, but does not provide support of the accuracy of ageing data.

American shad have been sampled opportunistically at the St. Stephen fish-lock since 1992 and have showed no trend in mean fork length through 2003 for both males and females (Leach and Cooke 2004; Figure 14.6).

In the Edisto River, age data were available for 1955 (Walburg 1956) and for 1979 to 1985, and the maximum observed ages for males (age 5) and females (age 6) did not change between the two periods. Age distributions for male and female shad between the two periods also appear similar (Figures 14.7 and 14.8). The percentage of female shad at each age was virtually the same, while the males were similar. No length data from Walburg (1956) were available to conduct comparisons between the two periods.

14.9 Fishery Description and Dependent Data

The commercial gill-net fishery targets female American shad. Catches early in the season are predominantly male, since they begin their upstream migration ahead of female shad; however, female shad comprise as much as 90 percent of the catch in the last several weeks of the season. Over the course of the season, females accounted for 65 to 75% of the annual American shad catch in South Carolina (Post *et al*. 2004).

14.9.1 Fishery Descriptions by River

Winyah Bay (Waccamaw, Pee Dee, Black)

The Winyah Bay complex has supported South Carolina's largest commercial shad fishery in the last few years. Fisheries were centered in the lower 64 km (40 miles) of the Waccamaw River. Both drift and anchored nets are used throughout this area. The concentrated amount of fishing effort within tidal freshwater and estuarine portions of the system complicates management of unit stocks or sub-stocks within the Waccamaw River. Drift nets were used in limited areas above the Winyah Bay, as winding channels, rapid currents, and water of variable depth with bottom obstructions are typical of most inland portion of these waterways.

The Winyah Bay extends nearly 24 km inland and is the point of access to spawning streams for American shad. Shad destined for the Sampit and Black Rivers had to avoid Winyah Bay fisheries from 1979 to 2005 before entering their natal rivers. The Sampit is a small, primarily tidal river that becomes unnavigable inland at about rkm 64. Shad gill-netting was sporadic and was generally limited to the first 16 km of the river above its confluence with the Winyah Bay.

The Black River branches from near the junction of the Great Pee Dee River and the upper Winyah Bay and extends inland with an additional 202 km or more of navigable waterway. Most American shad fishing occurs in the lower 97 km of Black River.

The Great Pee Dee River begins just below Highway 17 where it merges with the Black River. The rivers split about 16 km upriver and the Pee Dee River continues until it intercepts Bull Creek. Significant netting effort continues up to rkm 105, with activity less intensive farther upriver. Gillnetting extends upriver to at least rkm 240. The shad run continues beyond the North Carolina state line at about rkm 280 to Blewett Falls Dam located nearly 320 km from the Atlantic Ocean.

Fish migrating to the Little Pee Dee and Lynches Rivers must have successfully by-passed fisheries in the Great Pee Dee before entering their natal tributary streams at approximately rkm 72 and rkm 113, respectively. The Little Pee Dee extends about 97 rkm to the North Carolina state line. Shad fishery activity is generally restricted to the lower 32 km of the river. The Lynches River remains navigable for over 113 km beyond its departure from the Great Pee Dee, but the fishery is prosecuted in the lower 24 km.

Santee River

The Santee River was historically one of the largest watersheds on the Atlantic coast and supported spawning stocks of American shad as far as rkm 483. With the impoundment of the Santee-Cooper lakes in the late 1940s, this system was closed to anadromous fish migrations above rkm 121. This situation persisted through 1985, when the Santee-Cooper Rediversion Canal and fish-lift at St. Stephen Dam were completed. The fish-lift passes pre-spawning adult shad into the lakes and provides access to historical spawning grounds in portions of the Wateree and Congaree Rivers. Since completion of the Rediversion Project, the shad and river herring gill-net fisheries have been restricted to protect the Santee River striped bass population from incidental catches. The entire Rediversion Canal and Santee channel below Santee dam are closed to gill nets. Two sections downriver of the closed area remain open to commercial fishing. The upper of the two sections extending 48 km seaward of the closed area has had the open fishing period reduced by over 80 percent compared to what it was before rediversion. This section of river is open to commercial fishing from February 1 to April 30 Tuesdays and Thursdays 0700 to 1900 hours. The lower 48 km of the river remains open to shad fishing Monday noon through Saturday noon from February 1 through March 31. See Appendix I for additional details. The recreational fishery on the Rediversion Canal has reportedly increased in recent years; however, no data are available on it.

Cooper River

The Cooper River is navigable for approximately 80 km. It is largely tidal system and is impounded by the Pinopolis Dam at approximately rkm 88. The constructing of this dam was part of the original Santee-Cooper Project. The Cooper River likely supported a small shad stock before the creation of the lakes and rerouting of the Santee River. The increased flows effectively enlarged the watershed and most likely gradually produced higher levels of anadromous species.

Drift and set gill nets are not legal in open areas of this system. In the past 25 or more years, there has been limited and sporadic netting effort with both gear types in open portions of this area. High usage of these waterways by recreational, commercial, and military vessels makes gillnetting very difficult. In addition, many of the most suitable portions of the Cooper River are closed to gillnetting in order to protect striped bass.

Edisto River

The Edisto River is approximately 356 km long and is open to the shad gill-net fishery (both set and drift nets) for its entirety, and continues to support a gill-net fishery to approximately rkm 161. The Edisto River has supported commercial shad fishery for over 100 years and a recreational fishery since the late 1960s (Wade 1972; Walburg and Nichols 1967). Historically commercial fishery effort was concentrated between rkm 30 and 50, with gill netting, bow netting, and hook and line fishing occurring to rkm 170. Sporadic recreational netting extended into the North and South Forks for at least an additional 50 km. Current fisheries occur in the same areas, but at reduced levels of effort. Both set or anchored and drifting gill nets have been used in the commercial fishery for many years. Both historically and in recent years, there has been virtually no effort below rkm 32.

Set nets fished between rkm 30 and rkm 48 are typically fished only during flood and slack tide periods when currents are weakest. From rkm 48 to about rkm 161, relatively short set nets are typically fished in eddies or slow moving waters below creek entrances, below the mouths of oxbows lakes, or in deep holes along undercut banks on the outside of river bends.

A noteworthy shad fishery existed on the Edisto River in the vicinity of Willtown Landing that began after WWII and lasted through the early 1980s. There were at least 30 “Willtown netters” and they used both drift and set gill nets (William J. McCord, SCDNR, pers. comm.).

Combahee River

The Combahee River is approximately 72 km long and both drift and set gill nets are legal. Nearly all activity in the fishery occurs between about rkm 40 and rkm 80. There is a very small recreational hook and line fishery (trolling). Drift nets are rarely, if ever, used on the Combahee River due to its winding channels, rapid currents, varying water depths, and many bottom obstructions.

Savannah River

The Savannah River is open to commercial fishing with set and drift gill nets up to about rkm 322. There is a substantial recreational hook and line fishery below New Savannah Bluff Lock and Dam at Augusta, Georgia.

Drift nets are generally most prevalent in tidal portions of the river. Set nets are the principal gear used throughout the river. In the lower 40 km, which is strongly influenced by tides, set nets are fished only during flood and slack tide periods when currents are weakest. In areas above significant tidal influence (up to about rkm 306), set nets are fished in eddies or slow moving waters below creek entrances, below the mouths of oxbow lakes, or in deep holes along undercut banks on the outside of river bends.

14.9.2 Landings Data

South Carolina has monitored commercial fisheries for American shad within state waters since 1979. The NMFS landings data before 1979 were collected from major wholesale outlets located near the coast; therefore, it is likely that inland landings were not completely accounted for in these years, since many shad fishermen claim not to sell their catch and keep it for personal consumption. No landings were attributed to the South Carolina ocean-intercept fishery before 1979. SCDNR has landings by system since 1979 for the Atlantic Ocean (i.e., the ocean-intercept fishery), Winyah Bay, Waccamaw River, Pee Dee River, Black River, Santee River, Cooper River, Edisto River, Combahee River, and Savannah River (Table 14.1; Figure 14.9). Data collected since 1979 generally include inland landings and should be considered as a separate time series.

There are discrepancies between SCDNR and NMFS American shad landings. One reason for this is that NMFS uses dealer landings reports for their records; however, many shad fishermen claim not to sell their catch and keep it for personal consumption.

The Cooper River supports an active recreational fishery below the Pinopolis Dam tailrace in the late winter to early spring. SCDNR has conducted a creel survey from 2001 to 2005 to estimate exploitation and catch-per-effort in this recreational fishery. SCDNR also conducted sportfishing creel surveys on the Cooper and Santee Rivers from 1981 to 1982 and 1991 to 1993 in order to evaluate the impact of the Rediversion Canal on these rivers' recreational fisheries (Cooke and Chappelear 1994). These surveys examined the total recreational fisheries on each river for each study period. For the purpose of this assessment, the surveys can indicate changes in the magnitudes of each fishery; however, no shad-specific data are presented (Cooke and Chappelear 1994).

In discussions and resultant searches, raw catch and effort data provided by cooperating commercial gill-net fishermen were identified by SCDNR personnel. However, data are still on the original data entry sheets and no resources were available to input the data into electronic format before the shad stock assessment completion deadline. An important priority for future South Carolina shad stock assessment work will be to input this commercial catch and effort into a spreadsheet or database.

Recreational creel surveys were conducted on the Savannah River in the late 1990s by GADNR (1997) and SCDNR (1998 and 1999). Estimates of catch from these surveys varied from year to year largely due to dramatically different flow conditions, as 1998 was a "flood" year and 1999 a "drought" year. Catch estimates from each of these creel surveys are available in Boltin (1999); however, the year-to-year estimates were highly dependent on the impacts of the river flow on the recreational fishery. In 1997, no additional information on the flow was reported.

14.9.3 Catch-Per-Unit-Effort

Commercial American shad catches were sampled to collect biological data (e.g., length, weight, and age) by SCDNR from American shad fishermen at boat ramps from 1979 to 1985 for rivers with an active American shad fishery. During this time, SCDNR identified a group of “reliable” fishermen from which to collect catch and effort data. Voluntary catch records (data sheets) from these fishermen were used to develop fishery-dependent catch-per-unit-effort (CPUE) from 1979 to 2000. Starting in 1998, SCDNR instituted mandatory reporting for all commercial shad fishermen. In order to maintain consistency with previous years, mandatory reporting records from the “reliable” fishermen have been used to calculate CPUE for specific rivers since 2001. Every attempt has been made to use data from the same fishermen over time, but some difficulties were encountered (e.g., one or two fishermen did not fish for the season, fishermen changed their fishing gear, or fishermen may have left the fishery). Such events might have affected the CPUE estimates, but these problems were minimal and these data constitute the only available long-term CPUE series for South Carolina American shad fisheries. These records were separated by river and in some cases by specific regions of a river and by gear: Winyah Bay (drift nets); Waccamaw River (lower drift nets); Pee Dee River (Petersfield set nets); Santee River (upper set nets and lower set nets); Edisto River (Jacksonboro set nets, lower 24-hour set nets, and tide set nets); Combahee River (set nets); and Savannah River (lower set nets). Not all systems were monitored each year due to personnel limitations. Data collected from open-ocean waters, such as Charleston Harbor, were excluded, because river origin cannot be determined for shad collected from these areas.

No effort data were collected for American shad fisheries before 1979; thus, it was not possible to attribute stock fluctuations to changes in fishing effort, changes in spawning stock size, or other factors. License data are available, but are not useful as many shad fishermen participated on a part-time basis and the amount of gear deployed was not specified in records. In addition, approximately 80 percent of the licensed fishermen fished infrequently, precluding estimation of total effort and, therefore, CPUE (Ulrich *et al*. 1978).

The volunteer commercial CPUE gill net data were analyzed for female shad only, since females account for 65 to 75 percent of the annual American shad catch in South Carolina and provide the basis for management in the state. The standard unit of effort was calculated as fish per 92-meter net-hour. Because of differences in fishing power of the two gears, drift and set-net CPUE were calculated separately. Set gill nets with 14 cm stretch mesh were fished by all participating fishermen.

Even with mandatory catch and effort reporting in place for the American shad gill-net fishery, questions regarding the integrity of the reports, irregular or infrequent fishing by license holders, and year-to-year variability in river-wide records have not permitted successful development of total catch and effort statistics by river. The lack of comprehensive, dependable catch and effort resulting from incomplete implementation of mandatory catch and effort reporting by river leads to limitations when conducting stock assessment determinations for South Carolina’s American shad populations. The CPUE data collected from the “reliable” fishermen throughout the state are used to make general observations on changes in perceived stock status since 1979. Many variables, such as water temperature, water levels and flow rates, affect observed CPUE values and these parameters are highly variable between seasons and might have substantial impacts on catchability, and even effort, particularly in certain rivers. Linear regressions of CPUE against year were conducted to determine the significance of any trends in these data time series.

14.9.4 Tagging

South Carolina DNR has conducted tag-return studies on the Santee (1991,1992, 2000 to 2002), Edisto (1989, 1990, 1994 to 1999) and Waccamaw (2003 to 2005) rivers to estimate the in-river relative exploitation rate (RE) for pre-spawning female American shad. In this report, data for male American shad are also presented. In 1993 and 1999, SCDNR tagged fish on the Combahee River. Only 12 fish (5 males, 7 females) were tagged and no tags were returned in 1993 and 9 female shad were tagged with three returns in 1999. The poor capture success and low sample size for the Combahee River prevent the development of RE estimates. From 1986 to 1988, SCDNR tagged shad in the Atlantic Ocean (at North Jetty Winyah Bay) but these data are not used in this assessment because the data could not be used to calculate a river-specific RE rate. However, in the previous and current ASMFC stock assessments, these data, in conjunction with other tagging and mtDNA studies, are used to partition mixed-stock landings from the ocean-intercept fishery (ASMFC 1998).

Shad were tagged on the lower Edisto River near Jehossee Island seaward of the known contemporary shad fishery in order to prevent immediate recaptures. Tagging of fish seaward of the commercial fishery prevents immediate recaptures before shad resume natural movements. The netting area extended for about 500 meters upriver from rkm 28 (McCord 2000). Shad were tagged in the lower Santee River (1991, 1992, and 2001 to 2002) and the lower Waccamaw River (2003 to 2005) below shad fishery locations.

South Carolina DNR captures shad for tagging from late January through early May of each year with most tagging effort concentrated from late February through the end of April coinciding with the primary shad migration period. CPUE data are summarized (fish per 92 m net-hour) for the Edisto River (1994 to 1998), the Santee River (2000 to 2002) and the Waccamaw River (2003 to 2005) in McCord (2000) and Post *et al*. (2004), along with complete descriptions of the tagging programs. The short time series of these datasets do not permit any trend analysis, but, if continued on a regular rotating basis using the same methodology, they could provide a baseline for comparison with future CPUE estimates.

Shad were captured using 12.5 and 14.0 cm stretched-mesh monofilament drifting gill nets, 92 m long and 7.5 m deep. Fishing was conducted during low-flow periods of the tidal cycle to maximize catch rates. To minimize pre-tagging mortality or injury when possible, shad are removed as soon as they are caught. Typically, fishing gear was checked or retrieved within 30 minutes of being set.

Captured shad are held on board in a flow-through tank and most fish are transported and released approximately 200 m from the capture location in order to minimize immediate recapture of tagged shad. Only shad with actively moving opercula are tagged; the tags are cannula-implanted dart tags placed on the left side immediately below the dorsal fin. Tags are fluorescent orange and are printed with return address, reward notification and tag number. Public notification of the project included news releases before the season opening and posters posted at boat landings that outline the reward payment procedures (including payments for all returned tags) and the mechanics of the lottery drawing for two rewards each of $50 and $100. Rewards for individual tag returns depended on the project budget and the number of tag returns.

The in-river relative exploitation estimates from these studies should be considered lower bound estimates of exploitation rates because they do not account for tag loss, post tagging mortalities, “fall-back” of tagged shad, and non-reporting of recaptured shad (McCord 2000). *Fall back* describes fish that are tagged and then do not continue their migrations upriver (Hightower and Sparks 2003; Olney *et al*. 2006). In addition, the design of a high-reward component of tagging studies clearly distinguishes high-reward tags from low-reward tags. The purpose of conducting a high-reward study is to determine the difference in reporting rate between regular low-reward tags and high-reward tags that should be returned at a higher rate (approaching 100%). The lottery system, as used by SCDNR, based on a single batch of tags that did not distinguish differing reward levels does not achieve this goal. Therefore, the level of tag underreporting remains unknown. Given the concerns with the tagging data, these data are not used to evaluate stock status.

14.10 FISHERY-INDEPENDENT MONITORING

14.10.1 Winyah Bay

From 2003 to 2005, CPUE data were calculated for American shad captured by SCDNR for their tag-return studies. These data are not discussed in terms of stock status, since only three years of data exist.

14.10.2 Santee River

The Cooper River Rediversion Project was completed in 1985. The Rediversion set a maximum weekly average discharge (127 cms) from Pinopolis Dam and the difference of the flows were redirected back to the Santee River primarily via the St. Stephen Dam and Rediversion Canal. The St. Stephen fish lift is located approximately mid-way on the Rediversion Canal at rkm 92. Migratory fish are attracted to the fish lift by a variable attraction flow up to approximately 21 cms. Typically, fish lift operations occur on the hour during daylight periods and every 30 minutes as required when fish densities are high. Each morning a “clearing” operation is made to pass fish collected overnight.

Fish passage at the St. Stephen Dam was monitored by hydroacoustic sampling from 1986 to 1987, real-time human counts from 1988 to 1994, and time-lapse video recording from 1994 to 2005. Since the proportion of Santee River American shad that entered the Rediversion Canal and the efficiency of the fish lift both are unknown and appear to vary among years, fish passage at this facility can only be used to document general abundance trends.

In addition, fishery-independent CPUE data were collected from in the North Santee River when American shad were caught for tag-return studies in 2001 to 2002 using similar methods as described above for the Waccamaw River. These data are not discussed in terms of stock status, since only two years of data exist.

14.10.3 Cooper River

Pinopolis Dam is located approximately 77 km upstream from Charleston Harbor on the headwaters of Cooper River, South Carolina. A single-lift navigation lock, approximately 18.3 m wide by 73.2 m long, provides boat and fish passage between Cooper River and Lake Moultrie. An array of 11 upward facing, 235 KHz side-scan sonar transducers monitors fish passage. The transducers transmitted to a Bendix hydroacoustic biomass counter, which incorporates a conversion assuming an average swimming speed and mass of an adult blueback herring, 136 g. Counts are made in terms of these “herring units” and no species-specific counts are made. Therefore, these data are not used in this assessment.

14.10.4 Catawba-Wateree

Electrofishing has been conducted by Duke Power to sample diadromous fish at five locations on the Wateree River from its confluence with the Congaree River to its uppermost limit at the Wateree Dam tailrace to evaluate diadromous fish use of the Wateree River relative to the Federal Energy Regulatory Commission (FERC) relicensing of the Catawba-Wateree Hydro Project. Sampling was conducted throughout the 2004 and 2005 spawning season to document species presence and provide a measure of relative abundance (Coughlan *et al*. 2005). Due to the short time series, these data are not used in this assessment. However, if these investigations are continued they could provide information on the American shad population in upstream locations of the Santee-Cooper system.

14.10.5 Edisto River

Fishery-independent CPUE data were collected using 12.7 mm stretch mesh drift gill nets for the years 1994 to 1998 in the South Edisto River employing similar methods as the Waccamaw River (see above). These data are not discussed in terms of stock status, since only five years of data exist from 1994 to 1998.

14.10.6 Combahee River

Insufficient fishery-independent data have been collected for this stock.

14.10.7 Savannah River

No fishery-independent data have been collected for this stock.

14.10.8 Juvenile Surveys

Trawl sampling studies were conducted for juvenile American shad in the fall of 1985 in the Edisto River and Winyah Bay using 4.9 and 7.6 m otter trawls. Sampling in the Edisto River occurred from September through November with 32 trawls that caught two American shad. Winyah Bay sampling took place October and November. Nineteen trawls over five stations yielded three American shad. Data were also collected from another SCDNR trawl project in the Santee River where 15 juvenile American shad and 30 juvenile blueback herring were collected. These programs were discontinued after a single sampling season.

14.11 ASSESSMENT APPROACHES AND RESULTS

Available landings data indicate that most of South Carolina's American shad fisheries have declined over the past century, except for the Santee River fishery. Data are not available to quantitatively estimate abundance or to establish traditional biomass or fishing mortality levels. Evidence below is used to describe the trends in both fishery and stock status.

For a summary of data used in this assessment, please see Table 14.2.

14.11.1 Statewide Landings

Historical Landings

Historical commercial shad landings from NMFS[2] are available for South Carolina back to 1880 with the highest reported landings occurring in 1896 (304,819 kg; Figure 14.10). NMFS reporting agents compiled landings recorded before 1979. Landings data are available for 11 years between 1880 and 1926 with a range of 94,349 to 304,819 kg and a mean of 188,615 kg. Beginning in 1927, a continuous data stream of landings is available to the present, except for the 1940s (WWII). Landings generally declined from the

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[2] Statistics of the Fisheries of the (Middle-New England) Atlantic States. Division of Statistics and Methods of the Fishersies, United States Fish Commission. Obtained from NOAA Central Library Data Imageing Project: http://docs.lib.noaa.gov/rescue/cof/data_rescue_fish_commission_annual_reports.html

late 1800s throughout the twentieth century reaching a low in the 1970s, with annual landings averaging 16,477 kg from 1973 to 1976.

Walburg and Nichols (1967) report the status of the American shad on the U.S. Atlantic coast in 1960 compared to 1896 by river. In 1896, South Carolina landings were 304,593 kg primarily by gill nets (80%) and bow nets (17%) with shad fisheries existing in the Winyah Bay and tributaries (Waccamaw River, Pee Dee River, Lynches River, Black River, and Sampit River), Santee River, Cooper River, Edisto River, Ashepoo River, Combahee River and Savannah River (Table 14.3). South Carolina's most productive fisheries in 1896 in total landings were (1) the Waccamaw River, (2) the Savannah River (Georgia and South Carolina landings combined) and (3) the Edisto River. Landings from the Winyah Bay system totaled 202,922 kg in 1896 with most of the catch coming from the Waccamaw River 166,329 kg and the Pee Dee River 21,294 kg. The combined landings from Georgia and South Carolina for the Savannah River were 94,074 kg. Landings from the Edisto River were 58,732 kg (Walburg and Nichols 1967).

American shad landings from South Carolina were 128,291 kg in 1960 (Table 14.3). The most productive rivers that year were the Savannah River (74,671 kg), the Waccamaw River (48,264 kg) and the Santee River (24,610 kg; Walburg and Nichols 1967). The Sampit River no longer supported a commercial fishery. Comparatively, in 2005, total landings from South Carolina were only 92,194 kg, with Santee River (53,788 kg), Savannah River (Georgia and South Carolina combined, 9,773 kg), Waccamaw River (9,170 kg), and Winyah Bay (32,797 kg) producing the largest landings (Table 14.3).

Modern landings

From 1979 to the middle 1990s, ocean-intercept landings were typically greater than in-river landings. Ocean-intercept landings 1979 to 1995 were 1,404,065 kg and in-river landings were 1,083,228 kg. (Table 14.1; Figure 14.9). Since then, the ratio of ocean landings to in-river landings has declined, culminating with the ocean fishery closing in 2005 after a five-year phase out plan. Since 1979, statewide shad landings have undergone cyclic fluctuations. In 1979, total South Carolina shad landings were 89,577 kg, but they then rose to 243,801 kg in 1984 before declining to lows around 50,000 kg in 1993 to 1994. Since 1995, landings have fluctuated with peaks of approximately 250,000 kg in 1996 and 2000, and lows in 1999 of 85,996 kg and in 2005 of 92,194 kg.

With the onset of mandatory reporting in 1998, South Carolina shad fishermen were required to report effort and landings data. However, questions regarding the integrity of the reports, irregular or infrequent fishing by license holders, and year-to-year variability in river-wide records have not permitted successful development of total catch and effort statistics by river. In 2000, 2,727 commercial shad fishing trips were reported to SCDNR (Table 14.4). The number of reported trips generally decreased from 2000 to 2005 with 2,132 trips taken in 2005, the first year of the closure of the ocean-intercept fishery (Table 14.4). Nearly all fishermen (>95%) have submitted at least one monthly report since 2000, while only 60 to 70 percent report some catch (SCDNR records). It is likely that the ocean-intercept fishery closure in 2005 contributed to the decrease in landings from the 2004 amount of 170,212 kg. The total number of shad trips in South Carolina decreased from 2,384 in 2004 to 2,132 in 2005. Winyah Bay complex (including trips from Winyah Bay, Waccamaw River, Pee Dee River, and Black River) shad trips decreased from 1040 in 2004 to 998 in 2005. The decrease in Winyah Bay Complex trips was driven by a decrease in trips in Winyah Bay trips (144 to 106) and Waccamaw River trips (339 to 189), but buffered by an increase in trips in the Pee Dee River from 523 to 672 trips (Table 14.4).

With the closing of the ocean-intercept fishery in 2005, the Santee River and Winyah Bay now constitute the largest remaining commercial shad fisheries in South Carolina with Santee River landings comprising 58 percent and Winyah Bay landings 38 percent of the 2005 statewide total (Table 14.1; Figure 14.9). In

2005, shad trips in Winyah Bay complex and Santee River accounted for 49 percent and 27 percent of the total shad trips, respectively (Table 14.4).

14.11.2 Winyah Bay

Landings

Though the decline in total Winyah Bay landings and its major tributaries was discussed above, a few points should be noted regarding the lesser shad rivers of this system. As discussed previously, the Sampit River no longer supported a commercial shad fishery by 1960 nor were any landings reported in 2005. By 2005, no landings were reported from the Lynches River (1960 landings = 13,428 kg) and the Black River only yielded 192 kg (1960 landings = 5,168 kg).

Winyah Bay landings averaged 37,695 kg a year since 1979, highlighted by a period of below average landings from 1987 to 2000 (Table 14.1; Figure 14.9). The highest landings of the time series were in 1981 when 114,104 kg of shad was landed. Recent peaks in landings came in 2002 and 2004 with 85,502 kg and 77,167 kg of shad landed, respectively. Landings in 2005 were below average for the time series at 32,797 kg, which is likely attributable to shifting effort from Winyah Bay to the Santee River. There is no apparent trend in landings from this system since 1979.

Catch and effort

Data from the volunteer fishermen in the drift gill-net fishery in Winyah Bay produced a continuous dataset from 1981 through 1997 (Table 14.5; Figure 14.11). Fish moving through the lowermost portion of this complex system may be bound for any Winyah Bay tributary, so these CPUE records are used to reflect abundance trends in this system. The CPUE fluctuated without trend throughout the time series ($P = 0.39$, slope = 0.06, and $r^2 = 0.05$; Table 14.6). No data were collected from 1998 through 2000. The cooperating fishermen who provided drift net catches for this area switched to set nets beginning in 2001, precluding direct comparison of recent CPUE data with earlier data. Interpretation of the set-net time series will require additional years of data to determine whether the increase in CPUE in 2004 is a real increase.

CPUE data from volunteer commercial fishermen in the drift gill-net fishery in the lower Waccamaw River increased significantly from 1979 to 1997 ($P < 0.001$, slope = 0.095, and $r^2 = 0.48$; Tables 14.6 and 14.7; Figure 14.12). No data were collected in 1998 and 1999. Peaks in the time series occurred from 2000 to 2002. The catch rates in 2003 and 2004 are similar to those observed in the late 1990s. Flood conditions in these years may have negatively affected catch rates associated with changes in availability and catchability that do not reflect increases in real abundance (Post *et al*. 2004).

CPUE data are available for the Pee Dee River set gill-net fishery from 1979 to 1999, but have fluctuated with trend ($P = 0.58$, slope = -0.006, and $r^2 = 0.017$). CPUE peaked in 1996 and 1997, before decreasing to the lowest two consecutive years in the time series (Tables 14.6 and 14.8; Figure 14.13).

Tagging

Lower bound relative exploitation rates from tag-return studies conducted in the Waccamaw River from 2003 to 2005 are presented in Table 14.9.

14.11.3 Santee River

Landings

The Santee River stands alone as the only South Carolina river that has experienced a consistent increase in shad harvest over the last 100 years. Walberg and Nichols (1967) reported a Santee shad harvest of 15,183 kg in 1896, which increased to 24,610 kg in 1960. Since 1979, Santee River commercial shad harvest has averaged 42,260 kg a year, with 53,788 kg landed in 2005. Note that the "modern" landings include "before and after" Rediversion landings, where annual harvest averaged 2,482 kg a year before the Rediversion canal was completed in 1985.

The Santee River shad landings averaged only 2,554 kg from 1979 to 1985; however, since the completion of the Rediversion Canal in 1985 the shad run and, concurrently, landings have risen to an average of 91,286 kg a year since 1995 (Table 14.1; Figure 14.9). In 2005, Santee River shad landings were 53,901 kg, the lowest since 1995. Annual fishing effort has averaged 710 trips since 1999 and the number of trips in 2005 dropped to 577 from 696 in 2004 (Table 14.4).

Catch and Effort

Records for both the lower drift gill-net fishery are available from 1980 to 2003 (no data available for 2000; Table 14.10; Figure 14.14) and for the upper set gill-net fishery from 1979, 1980, 1985, and 1992 to 2005 (Table 14.11; Figure 14.15). CPUE has increased significantly in the lower drift gill-net fishery (P = 0.004, slope = 0.049, and r^2 = 0.329), while the creasing CPUE trend was not significant in the upper set gill-net fishery ((P = 0.137, slope = 0.16, and r^2 = 0.175; Table 14.6). Interestingly, data from the lower set gill-net fishery consistently increases over the whole time series including the years before completion of the Rediversion canal.

Creel Survey

A recreational creel survey conducted by SCDNR in the Santee River before and after completion of the Rediversion Canal showed that effort increased by 52.1 percent in the post-Rediversion survey, while landings increased by 77.5 percent from the earlier period (Cooke and Chappelear 1994; Table 14.12).

Tagging

Lower bound exploitation rates from tag-return studies on the Santee River are reported in Table 14.9.

Fish Passage

From 2001 to 2005, annual American shad passage decreased compared to the previous six years (Table 14.13; Figure 14.16). Counts peaked from 1995 through 2000 ranging from 306,493 to 592,321 shad passed per year. Since 2001, annual counts averaged 193,161 shad and in 2005 a total 215,438 shad were passed through the fish-lift.

Alternate Relative Exploitation of American Shad on the Santee River

Relative exploitation of American shad on the Santee River, South Carolina was estimated using commercial gill-net landings data and fish-lift counts from the St. Stephen fish-lift (Table 14.14; Figure 14.17). Landings data and population size estimates (in numbers) were used in order to calculate relative exploitation rates. These relative exploitation rates ***were not used*** in evaluating stock status, because of the unknown extent of underreporting in the commercial fishery, the unknown impact of the recreational fishery, and unknown fish passage the St. Stephen fish-lift. However, the Stock Assessment Subcommittee thought it might provide insight into potentially deleterious exploitation trends.

Count data from the Stephen fish-lift are available since 1988, but Santee River commercial gill-net landings in numbers by sex are only available since 1998; however, Santee River landings by weight are available to 1988. The ratio of male to female American shad in pounds landed was calculated for the period 1999 to 2005 (males = 7%, females = 93%). This ratio was applied to the commercial gill-net landings from 1988 to 1998 to partition the landings between male and female. To convert the estimate to numbers, the landings of male and female shad were divided by the average weight of male (1.36 kg) and female (1.81 kg) shad South Carolina Department of Natural Resources to convert landings in weight to number. Numbers of shad estimated for the period 1999 to 2005 were compared to the actual numbers reported in Table 14.14 for comparison. Actual numbers landed by sex were used in this analysis.

A minimum population bound was calculated by summing landings and fishway counts in numbers for each year. This is considered a minimum bound because landings are known to be underreported and do not include recreational removals from the Rediversion Canal fishery, which can be significant at times. Additionally, fish passage at the St. Stephen fish-lift is known to be less than 100 percent. Relative exploitation rates were then calculated by dividing the catch by the minimum population bound for the year. Sex-specific estimates of relative exploitation were not developed, because counts from the St. Stephen fish-lift are not collected by sex.

In 1988 and 1989, relative exploitation estimates were the highest in the time series while biomass was at its nadir (Table 14.14; Figure 14.17). This might partially explain catch increases in the lower set nets, if shad were more “catchable” those two years. Relative exploitation rates decreased to time series lows in 1990, since then both exploitation and the minimum population bound increased through 2000. From 2001 to 2005, commercial gill-net landings and fish-lift counts have decreased (i.e., the minimum population bound), while relative exploitation rates remained near 2000 levels. Sensitivity analyses to evaluate the impacts of underreported landings, fish-lift counts and catch composition indicate similar trends for each scenario presented, only differing in the magnitude of the results.

14.11.4 Cooper River

Landings

Historically, the Cooper River has not supported a large commercial fishery, with only 823 kg landed in 1896 and 2,859 kg landed in 1960. Commercial landings reported from the Cooper River have been intermittent since 1979, with only seven years of data reported for the time series (Table 14.3). The Cooper River supports an active recreational fishery below the Pinopolis Dam tailrace in the late winter to early spring. Landings have been reported sporadically, with a high of 1294.1 kg in 1984 and a minimum reported value of 5 kg in 2004.

Creel Survey

In the 2001 to 2005 American shad fishing seasons in the Cooper River Tailrace Canal, 1,862 surveys were conducted (mean = 372/y) over a total of 203 survey dates (mean = 41 d/y; Table 14.15; Figure 14.18). Creel clerks were on duty an average of six hours per day. Annual estimates of the shad catch (in numbers) from 2001 to 2005 are 3,864, 3,199, 6,856, 5,529 and 14,629 (Leach and Cooke 2004). Catch-per-man-hour (CPMH) averaged 0.96 and ranged from 0.59 in 2002 to 1.60 in 2005. CPMH increased slightly during the five-year period. A 10 fish per day creel limit has been in effect for the duration of this study. Twenty-two percent of the catch was released in 2005. A recreational creel survey conducted by SCDNR in the Cooper River before (1981 to 1982) and after (1991 to 1993) completion of the

Rediversion Canal showed that, although effort increased slightly in the post-Rediversion survey, landings of all fish decreased over 50 percent from the earlier period (Cooke and Chappelear 1994; Table 14.12). The combined effort on the Santee River and Cooper River increased 27.6 percent while landings decreased 20.6 percent (Table 14.12).

14.11.5 Edisto River

Landings

The magnitude of the Edisto River commercial fishery has consistently declined over the last century. In 1896, landings were 58,732 kg, but they dropped to 15,145 kg in 1960. From 1979 to 2005, Edisto River commercial shad landings averaged 2,934 kg a year. Landings in the Edisto River have been below the time series average (2,934 kg) for 13 of the last 15 years (Table 14.1; Figure 14.9). The lowest landings in the time series occurred from 1994 to 1997 when annual landings ranged between 354 kg and 1,132 kg. Since 2000, landings have averaged 2,211 kg a year with 1,686 kg landed in 2005. This assessment does not account for the unknown recreational harvest.

Catch and Effort

Data are available from 1980 through 2004 for the lower Edisto River set gill-net fishery (no data are available for 1996 and 2002). The annual CPUE for the lower Edisto River set gill-net fishery has declined significantly (P = 0.04, slope = -0.035, and r^2 = 0.186; Tables 14.6 and 14.16; Figure 14.19). The time series of CPUE data for the Edisto River tide set nets is disjointed from 1979 to 2004, and there is a negative, but not significant, trend in the time series with low CPUE values in 2003 (1.39 fish /92 m net-hr) and 2004 (0.94 fish/92 m net-hr; P = 0.169, slope = -0.062, and r^2 = 0.097; Tables 14.6 and 14.17; Figure 14.20). The time series for the Jacksonboro set net runs from 1980 to 1993, 1995 to 1997, and 2000, and declined significantly (P = 0.041, slope = -0.04, and r^2 = 0.184; Tables 14.6 and 14.18; Figure 14.21). From 1980 to 1992, CPUE ranged between 0.9 and 1.92 fish per 92-m net-hour. In 1993, CPUE decreased to 0.55 fish per 92 m net-hour, before peaking in 1995 (3.11 fish/ 92 m net-hr) and 1996 (2.58 fish/92 m net-hr) and reached a low in 2000.

Tagging

Lower bound estimates of relative exploitation for the Edisto River are presented in Table 14.9.

14.11.6 Combahee

Landings

In 1896, 6,419 kg of shad were harvested on the Combahee River; landings dropped to 878 kg in 1960 (Walberg and Nichols 1967). The Combahee has supported a small fishery that has landed an average of 715 kg shad per year since 1979 (Table 14.1; Figure 14.9). Landings varied from 702 kg up to 2,081 kg a year from 1979 to 1985, before declining sharply in 1986 and 1987. A slight upturn in landings in 1987 (1,216 kg) preceded another decline in the early 1990s. No landings were reported from 1994 through 1997. Since 1998, landings have been below the time series average, but have been stable. There have been an average of 59 trips per year since 1998 and 38 commercial shad trips were made on the Combahee in 2005.

Catch and Effort

CPUE data for the Combahee River do not show a significant trend (P = 0.683, slope = 0.012, r^2 = 0.019;Tables 14.6 and 14.19; Figure 14.22).

Tagging

Lower bound estimates of relative exploitation for the Combahee River are presented in Table 14.9.

14.11.7 Savannah River

Landings

Landings have decreased by an order of magnitude from 1896 (94,074 kg) and 1960 (74,671 kg) to 2005 (9,773 kg) in the Savannah River (Walberg and Nichols 1967; Table 14.3). The Savannah River has supported the third largest commercial river-specific shad fishery in South Carolina since 1979 (Table 14.1; Figures 14.9 and 14.23). Fishermen from both Georgia and South Carolina catch shad in the Savannah River; therefore, each state has shad landings data for this river (Table 14.20; Figure 14.23). SCDNR data goes back to 1979, while GA DNR landings go back to 1964, but data are not available for shad from 1983 to 1988. Georgia landings data from 1967 are unusually low compared to other years of data from the 1960s. From 1964 to 1979, annual landings in Georgia average approximately 30,000 kg. South Carolina shad landings were stable from 1979 to 1987 averaging 16,689 kg per year, but have decreased since then with landings not exceeding 10,000 kg since 1997 and have reached a time series low of 1,150 kg in 2002. Savannah River shad landings for South Carolina in 2005 were 3,407 kg. For the years where landings data are available from both states (1979-2005, except 1983 to 1988), Georgia landings have accounted for 71 percent of the total (449,699 kg) amount of Savannah River shad landings. Georgia's Savannah River annual landings since 2000 averaged 3,957 kg, with a low of 1,732 kg in 2002 and a high of 6,380 kg in 2005.

Peak observed landings for the Savannah River occurred in 1980 at 61,729 kg, before trending downward to time series lows in 2002 and 2003. However, if Georgia's proportion of the Savannah River American shad landings from 1983 to 1988 was similar to the preceding four years and following five years, then it is possible that the combined interstate commercial landings for those years were of similar magnitude or even much greater and landings would have peaked in 1984 and then declined.

South Carolina Catch and Effort

The CPUE time series for the Savannah River lower set-net fishery did not show a significant trend (P = 0.632, slope = -0.010, r^2 = 0.011; Tables 14.6 and 14.21; Figure 14.24).

Georgia Effort and CPUE

From 1989 to 1998, an average of 214.1 drift gill net trips were taken per year. Since 1999, the average has dropped to 66.7 trips per year, which is difficult to interpret since the decrease in trips corresponds with the implementation of mandatory reporting. It could be a true decline in effort, which could be supported by the consistently lower but stable landings from 2000 through 2005 (Table 14.22). Another possible explanation could be that the number of partial trips reported as single trips could have decreased since implementation of the trip ticket system.

The number of reported set gill net trips has fluctuated over the time series and interpretation of any trend is difficult because of possible variable reporting rates. Estimates of CPUE did not show a significant trend from 2000 to 2005 (P = 0.137, slope = -6.7, r^2 = 0.46; Tables 14.6 and 14.23).

Tagging

In 1986, 6 males and 12 females were tagged in the Savannah River at the New Augusta Lock and Dam, but none were recaptured.

Creel Survey

The creel survey by Boltin (1999) provides a snapshot of estimated recreational catch for 1999 and cites earlier catch estimates from creel surveys conducted by GADNR (1997) and SCDNR (1998). The estimated catch decreased in each year, but (1) methods were not available for each year and (2) in both 1998 and 1999, extreme conditions were cited as reducing recreational effort substantially on the Savannah River. The total number of shad caught in the 1999 survey was 3,645 shad compared to the reports of 6,664 and 34,895 shad caught in 1997 and 1998. Effort data are available only for the 1999 survey.

14.12 BENCHMARKS

No benchmarks were calculated for any South Carolina American shad stock.

14.13 CONCLUSIONS AND RECOMMENDATIONS

14.13.1 Conclusions

Winyah Bay

When considering the status of American shad in Winyah Bay, signals of the mixed stock within the Bay may be driven by the contributions of the larger shad fisheries (and populations) in the Waccamaw River and Pee Dee River, potentially masking decreases in smaller components of the Winyah Bay shad fishery tributaries (e.g., Lynches, Sampit, and Black Rivers). That is, even with no effort in the smaller tributaries rebuilding American shad populations in these rivers may be hindered by fisheries prosecuted in Winyah Bay.

Evidence indicates that some fishermen had devised strategies by which nets could be weighted down and practically anchored, but fished as drifting gear (2001 to 2004). This practice may have resulted in increased catches, but such net designs were clarified as illegal after 2004. Increased participation, based on the expectation of high catch rates, in the lower Santee River over the past 5 to 10 years has drawn several past participants away from the lower Winyah Bay watershed. Additional data are needed before contemporary changes in stock status can be estimated (Post *et al*. 2005). Data for 2000 though 2002 suggest an extreme increase of catch rates in comparison to previous years. High catch rates in 2003 to 2004 drove the price down resulting in many fishermen not fishing thus lower catches. In addition, the fisherman from whom the records were taken only fished a portion of the season in 2004 (Post *et al*. 2004).

Data suggest that, overall, Winyah Bay shad stocks have remained stable or increased slightly since the late 1970s, but these trends cannot be substantiated for the status of the smaller tributaries. Landings have been stable, size distribution has been stable, the ocean-intercept fishery was closed in 2005, and there was no decline in CPUE. In fact, there has been some increase in CPUE. However, we do not know current survival rates, current abundance, or how current abundance compares to habitat carrying capacity.

Santee River

The Santee River American shad spawning run appears to have increased since the completion of the Rediversion canal (Table 14.6). However, the large decrease in American shad counts at the St. Stephen fish-lift since 2000 is a cause for concern. Decreases could indicate a reduction in stock size or a reduction in the proportion of fish entering the Rediversion canal and the lift. Moreover, age and size distribution of shad in the Santee declined since the diversion, which could indicate increased mortality. If annual exploitation rates are increasing, then there could be cause to closely monitor this American shad stock, especially if effort is redirected to the Santee River from the closure of the ocean-intercept fishery.

Cooper River

The Pinopolis Lock and Dam creel survey provides a short time series of harvest and catch rate estimates (2001 to 2005) and provides evidence that the river has supported the current level recreational harvest; however, additional years of the survey will be need to confirm these observations. Increased catch may indicate growing popularity of the fishery. Total catch was derived from the highest daily boat count multiplied by the average catch of surveyed parties, which underestimates effort because boats left and entered the fishery throughout the day. A previous study of the Cooper River Tailrace Canal fishery indicated severely declining CPUE following Rediversion reaching as low as 0.8 fish per day (Low 1987), compared to the average of 4.2 fish per day in the recent creel survey. The method used in the Cooper River creel survey (2001 to 2005) to estimate total landings is believed to underestimate landings in the fishery, and landings may be as much as twice that reported here (Leach and Cooke 2004).

Fish counts at the Pinopolis lock, do not provide an index of shad passage, and records total fish passage in terms of “herring units.” Species-specific verification of passage rates and efficiency would permit monitoring of trends in passage rates (i.e., an index of abundance) and allow for estimates of absolute abundance if sampling could be conducted over the entire migratory period without confounding post-spawning.

Edisto River

Recent estimates of commercial CPUE have declined in all three available time series, significantly for two of them, and landings have been below the time series (1979 to 2005) average for 13 of the last 15 years. Given the low landings and declining commercial set gill net CPUE, harvesting Edisto River American shad could prolong the recovery of this stock.

Combahee River

This relatively small river is perceived to have undergone significant American shad stock declines over the past 25 years. The Ashepoo River, an even smaller sister river to the Combahee and Edisto, has apparently followed a similar trend in stock status and is no longer known to support a gill-net fishery. No CPUE data are available for the Ashepoo, and the commercial set net CPUE for the Combahee River American shad showed no significant trend since 1993 (Table 14.6). Continued harvest of American shad on the Combahee River could reduce the chance of recovery of spawning run and prolong the perceived depleted status of shad on this river.

Savannah River

Over the past century, the magnitude of shad landings from the Savannah River has declined by an order of magnitude. The commercial set net CPUE data available since 1979 indicates some stability in the current level of exploitation at harvest levels much reduced compared to historical levels (Table 14.6).

Status of Other Rivers

Given the lack of information on the viability of the status of shad stocks of the Lynches River, Black River, Sampit River, Bull Creek, Wateree River, Catawba River, Wando River, Ashley River, Ashepoo River, and Coosawhatchie River is unknown. Since these stocks are perceived as small, removals from these stocks could prolong or prevent successful rebuilding of these stocks. The danger is that there could be loss of genetic diversity or even extirpation of these presumed small stocks in these unmonitored rivers.

14.13.2 Research Recommendations

Research recommendations should be prioritized based on the assumed magnitude of the American shad run and fisheries of a river. Comprehensive monitoring of the shad runs from two or three of South Carolina's major shad rivers to collect reliable data on age composition and relative abundance could be used to guide management for the whole state, as trends in market factors and alternative fisheries probably apply statewide. However, the danger in adopting such a strategy is that there could be loss of genetic diversity in the small or unmonitored rivers.

Commercial Landings and Effort

- Continue and improve compliance with mandatory catch and effort reporting from commercial fishery for all American shad fisheries prosecuted in South Carolina waters.
- Continue the "volunteer CPUE" series to compare with CPUE series developed from comprehensive mandatory reporting database.
- Convert volunteer commercial catch and effort from field reports into digital format so raw data are available for future analysis.
- Collect age, length, weight, and spawning history information from shad caught in commercial fisheries in the Santee River, Winyah Bay system, Savannah River, and Edisto River.
- Conduct an age validation study of American shad from South Carolina rivers (especially, Santee River, Winyah Bay system, Savannah River, and Edisto River).

Tagging

- Continued monitoring of river systems (Santee River, Waccamaw River and Edisto River) on rotating basis (yearly rather than a three year schedule).
- Improvements to tagging design (e.g., develop high-reward design, telemetry studies to get estimates of fall back, double tagging study to estimate tag loss, and tag-mortality study) to improve relative exploitation estimates.
- Conduct tagging studies for duration of shad migration and continue to collect effort information from sampling collections (e.g., soak time, net length, and mesh size) to permit development of CPUE calculations.

Creel Surveys

- Continue to conduct creel surveys in rivers with notable recreational fisheries (Savannah River and Cooper River). If necessary, conduct creel surveys on a rotating basis.

Fish Passage

- Develop species specific upstream and downstream passage efficiency at all rivers with priority given to Santee-Cooper system dams
- Develop species-specific counts at Pinopolis fish-lock on the Cooper River.

Juvenile Abundance Index

- Develop a reliable index of juvenile abundance.

General

- Collect environmental covariates (tidal stage, flood stage, flow rate, water temperature, cloud cover, water clarity, annual precipitation, etc.) to aid development of CPUE indices

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Table 14.1 Reported annual South Carolina American shad landings (kg) by water area, 1979-1997. Beginning with the 1998 season, landings were taken from mandatory catch and effort reports.

Year	Winyah Bay Complex	Santee River	Cooper River	Edisto River	Combahee River	Savannah River (SC)	Total In-river	Ocean-Intercept	Statewide All Waters
1979	28920.9	4315.5	NR	5284.1	1709.1	11390.0	51619.5	37958.2	89577.7
1980	30185.0	2010.5	NR	3202.7	803.6	16289.5	52491.4	70487.3	122978.6
1981	114104.5	1827.3	NR	4126.4	2080.9	12797.3	134936.4	67978.2	202914.5
1982	44322.7	4093.6	NR	3137.7	1520.5	16626.4	69700.9	111402.7	181103.6
1983	38870.9	664.5	NR	3820.9	1446.4	12390.9	57193.6	93419.1	150612.7
1984	21181.4	1982.7	1294.1	4037.7	701.8	35991.4	65189.1	178611.8	243800.9
1985	76837.7	2983.6	NR	5981.4	1545.0	17890.0	105237.7	62525.0	167762.7
1986	82027.3	16286.8	NR	4803.6	304.5	13044.1	116466.4	102467.7	218934.1
1987	36415.0	4636.4	NR	2713.6	131.4	13780.9	57677.3	163462.3	221139.5
1988	24676.8	13869.5	181.4	3114.1	546.8	8131.8	50520.5	117453.2	167973.6
1989	35418.2	5617.7	NR	5379.5	1215.9	6266.4	53897.7	103744.1	157641.8
1990	11026.8	4250.5	NR	5625.5	342.7	7723.6	28969.1	73351.8	102320.9
1991	20026.4	21127.3	NR	2183.2	250.0	2544.5	46131.4	65569.1	111700.5
1992	28022.7	24072.7	NR	2560.9	118.2	7016.4	61790.9	49593.6	111384.5
1993	4037.3	15153.6	NR	1628.2	34.5	1730.5	22584.1	29516.4	52100.5
1994	6129.5	13975.9	NR	488.6	NR	2246.8	22840.9	32685.9	55526.8
1995	12973.6	48706.4	NR	1132.3	NR	6861.8	69674.1	60145.9	129820.0
1996	9275.5	126952.7	NR	1032.7	NR	8479.5	145740.5	100929.1	246669.5
1997	17024.5	80195.5	126.4	353.6	NR	6827.7	104527.7	51507.3	156035.0
1998	12238.2	150188.6	170.9	3603.6	573.6	2876.4	169651.4	28193.6	197845.0
1999	8889.5	65531.4	NR	1739.1	831.8	4409.5	81401.4	4595.5	85996.8
2000	37331.8	162386.8	NR	3340.9	667.3	2873.2	206600.0	47243.6	253843.6
2001	57288.2	83265.0	NR	1525.5	127.7	3379.5	145585.9	41391.4	186977.3
2002	85501.8	77650.9	NR	2038.6	401.8	1150.0	166743.2	46711.4	213454.5
2003	65074.1	69701.4	NR	1874.1	304.1	1842.7	138796.4	15011.4	153807.7
2004	77167.3	85662.3	5.0	2800.0	392.3	4185.0	170211.8	20886.4	191098.2
2005	32796.8	53901.4	NR	1686.4	402.7	3407.3	92194.5	0.0	92194.5

Table 14.2 Summary of available data sets for the South Carolina American shad stock assessment.

River	Commercial Landings	Commercial Effort*	Commercial CPUE*	Recreational Landings	Recreational Effort	Recreational CPUE	Fishery Independent Surveys	Tag-Return	Fish Passage Counts	Biological Data
Waccamaw River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	2003-2005	2003-2005	na	1979-1985
Pee Dee River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	1979-1985
Bull Creek				na	na	na	na	na	na	1979-1982
Lynches River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	
Black River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	
Sampit River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	
Winyah Bay	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	

* Note mandatory catch and effort reporting ahs been in place in the South Carolina shad fishery since 1998; however, concerns regarding incomplete and inaccurate reporting preclude the development comprehensive catch-effort database.

** Creel surveys conducted in 1997 and 1998 were reported in Boltin (1999), but were not published.

*** Creel surveys were conducted in the Santee River and Cooper River before (1981-1982) and after (1991-1993) completion of the Rediversion canal to investigate the impact of the project on recreational fisheries in these rivers and no shad specific data were presented in these reports (Cooke and Chappelear 1994).

**** Pinopolis counts reflect blueback herring/anadromous

Table 14.2(cont.) Summary of available data sets for the South Carolina American shad stock assessment.

River	Commercial Landings	Commercial Effort*	Commercial CPUE*	Recreational Landings	Recreational Effort	Recreational CPUE	Fishery Independent Surveys	Tag-Return	Fish Passage Counts	Biological Data
Santee River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	1981-1982,1991-1993***	1981-1982,1991-1993***	1981-1982,1991-1993***	1991,1992, 2001-2002	1991,1992, 2001-2002	1988-2005	1979-1982,1984,1985, 1991,1992,2000-2002
Cooper River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	, 1981-1982,1991-1993***, 2001-2005	, 1981-1982,1991-1993***, 2001-2006	, 1981-1982,1991-1993***, 2001-2007	na	na	1975-1997, 1999-2005****	1984
Edisto River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	1994-1998	1989-1990, 1994-1998	na	1979-1985, 1989,1990,1994-1998
Ashepoo River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	na	na	
Combahee River	1896,1967,1979-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	na	na	na	na	1999	na	1993 & 1999
Savannah River	1896,1967,1979-2005; GA - 1964-1982, 1989-2005	1979-2005 - volunteer; 1998-2005 mandatory	1979-2005 - volunteer; 1998-2005 mandatory	1999**	na	na	na	na	na	1979-1985

* Note mandatory catch and effort reporting ahs been in place in the South Carolina shad fishery since 1998; however, concerns regarding incomplete and inaccurate reporting preclude the development comprehensive catch-effort database.
** Creel surveys conducted in 1997 and 1998 were reported in Boltin (1999), but were not published.
*** Creel surveys were conducted in the Santee River and Cooper River before (1981-1982) and after (1991-1993) completion of the Rediversion canal to investigate the impact of the project on recreational fisheries in these rivers and no shad specific data were presented in these reports (Cooke and Chappelear 1994).
**** Pinopolis counts reflect blueback herring/anadromous

Table 14.3 Historical American shad landings snapshots from South Carolina rivers from 1896, 1960 and 2005 (Walberg and Nichols 1967). Landings for the Savannah River include both Georgia and South Carolina data.

Year\River	**Savannah River**	**Combahee River**	**Ashepoo River**	**Edisto River**	**Cooper River**	**Santee River**	**Waccamaw River**	**Pee Dee River**	**Lynches River**	**Black River**	**Sampit River**	**Winyah Bay**
1896	94074	6419	14292	58732	823	15183	166329	21294	1703	12100	1495	202922
1960	74671	878	227	15145	2859	24610	48264	17469	13428	5168	0	84328
2005	9773	402	0	1683	0	53788	9170	8933	0	192	0	32797

Table 14.4 Reported commercial tips for American shad by river and total trips from 1999 to 2005.

Year	**Atlantic Ocean**	**Black River**	**Combahee River**	**Cooper River**	**Edisto River**	**Pee Dee River**	**Santee River**	**Savannah River**	**Waccamaw River**	**Winyah Bay**	**Grand Total**
1999	60	21	86		311	264	850	211	159	24	**1986**
2000	87	36	89	0	725	472	903	145	211	59	**2727**
2001	104	44	37	0	572	531	727	153	213	100	**2481**
2002	112	40	42	0	473	554	676	51	237	103	**2288**
2003	56	74	76	26	520	581	538	35	202	137	**2245**
2004	66	34	42	26	422	523	696	92	339	144	**2384**
2005	0	31	38		450	672	577	69	189	106	**2132**

Table 14.5 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Winyah Bay drift gill-net fishery (1979-1997) from voluntary reports and set gill-net fishery (2001-2004) subset from mandatory reports. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality.

Year	January	February	March	April	Season
1979	closed				
1980	closed				
1981	closed	1.450	3.739	5.222	2.706
1982	closed	2.692	7.438	2.476	5.380
1983	closed	2.347	3.250	4.417	2.922
1984	closed	2.154	4.929		3.598
1985	closed	3.503	6.998	9.576	5.470
1986	closed	3.477	6.410		4.619
1987	closed	2.112	6.046	2.625	4.355
1988	closed	1.598	5.933	3.500	4.058
1989	closed	2.518	7.143		4.772
1990	closed	2.588	5.289	5.833	4.215
1991	closed	3.252	5.954		5.113
1992	closed	2.111	4		3.070
1993	closed	1.745	3.100		2.535
1994	closed	2.174	3.176		2.923
1995	closed	8.993	5.450	3.917	6.508
1996	closed	6.286	9.031	4.600	7.389
1997	closed	3.215	5.750		3.597
1998					
1999					
2000					
2001					1.38
2002					1.31
2003					1.33
2004					3.65
2005					

Table 14.6 Summary of commercial catch-per-unit-effort indices for American shad in South Carolina coastal systems and rivers.

System	Data Set	Gear	Years	Mixed Stock*	Slope	Slope Positive or Negative	*P*-value	R-square	Conclusion
Winyah Bay		Drift Gill Net	1981-1997	Yes	0.060	Positive	0.390	0.050	No significant trend in data set
Waccamaw River		Drift Gill Net	1979-1997, 2000-2005	No	0.095	Positive	<0.001	0.476	Significant positive slope
Pee Dee River		Set Gill Net	1979-1988, 1990-1999	No	-0.006	Negative	0.580	0.017	No significant trend in data set
Santee River	Upper Santee	Set Gill Net	1979-1980, 1986, 1992-2005	No	0.160	Positive	0.137	0.175	No significant trend in data set
	Lower Santee	Drift Gill Net	1980-1999, 2001-2003	No	0.049	Positive	0.004	0.329	Significant positive slope
Edisto River	Lower	Set Gill Net	1980-1995, 1997-2001, 2003, 2004	No	-0.035	Negative	0.040	0.186	Significant negative slope
	Tide Set Net	Set Gill Net	1979-1982, 1985, 1986, 1988-1994, 1996, 1997, 1999-2004	No	-0.062	Negative	0.169	0.097	No significant trend in data set
	Jacksonboro	Set Gill Net	1980-1993, 1995-1997, 2000-2005	No	-0.040	Negative	0.041	0.184	Significant negative slope
Combahee River		Set Gill Net	1989, 1993-2002, 2004**	No	0.012	Positive	0.683	0.019	No significant trend in data set
Savannah River		Set Gill Net	1980, 1982-1997, 1999-2005	No	-0.010	Negative	0.632	0.011	No significant trend in data set
		GADNR Drift Gill Net	2000 - 2005	No	-6.700	Negative	0.137	0.460	No significant trend in data set

* Mixed stock - shad caught in Winyah Bay could be bound for any of its tributaries or perhaps to other river systems.
** Trend for 1993 to 2004

Table 14.7 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Waccamaw River Drift Net fishery from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality.

Year	**January**	**February**	**March**	**April**	**Season**
1979	closed	1.364	1.447	0.786	1.280
1980	closed	0.362	1.846	2.626	1.209
1981	closed	0.815	1.318	1.005	1.012
1982	closed	0.750	1.636	1.426	1.285
1983	closed	0.569	1.275		1.066
1984	closed	0.424	1.392	1.621	0.936
1985	closed	1.305	2.909	6.076	2.483
1986	closed	1.236	1.331		1.271
1987	closed	1.053	2.399	2.404	2.071
1988	closed	0.772	2.083	2.306	1.648
1989	closed	0.964	1.690		1.547
1990	closed	0.670	1.514	3.566	1.132
1991	closed	1.209	2.002		1.519
1992	closed	0.904	1.179	1.336	1.132
1993	closed	0.939	1.762	2.075	1.555
1994	closed	0.666	1.317	0.375	1.051
1995	closed	2.210	2.849	2.470	2.592
1996	closed	1.827	2.533	4.018	2.363
1997	closed	2.093	2.409		2.266
1998					
1999					
2000	closed	4.272	4.447	3.075	3.934
2001					4.753
2002					4.857
2003					2.123
2004					2.5
2005					2.699

Table 14.8 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Pee Dee River (Petersfield set net fishery) from voluntary reporting from 1979-2000. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality.

Year	January	February	March	April	Season
1979	closed	0.064	0.510	0.914	0.466
1980	closed	0.052	0.618	1.631	0.690
1981	closed	0.082	0.302	0.761	0.320
1982	closed	0.111	0.861		0.427
1983	closed	0.037	0.387		0.164
1984	closed	0.072	3.017	4.310	1.271
1985	closed	0.221	0.577		0.443
1986	closed	0.071	0.316	0.777	0.267
1987	closed	0.162	0.690	1.341	0.640
1988	closed	0.189	0.556	1.018	0.452
1989	closed				
1990	closed	0.283	0.709	1.238	0.626
1991	closed	0.343	0.617		0.383
1992	closed	0.125	0.293	0.497	0.236
1993	closed	0.118	0.374	0.311	0.282
1994	closed	0.232	0.451	0.708	0.442
1995	closed	0.275	0.665		0.371
1996	closed	0.290	1.581	1.311	0.926
1997	closed	0.768	0.973	0.724	0.836
1998	closed	0.090	0.390		0.171
1999	closed	0.071		0.135	0.110
2000	closed				

Table 14.9 Tag-return data from several South Carolina rivers from 1989 to 2005 for American shad including numbers tagged, relative return location, and in-river exploitation rate.

River System	Years	Number Tagged		Returns Within River		Returns Outside River		Minimum Relative Exploitation Rates	
		Female	Male	Female	Male	Female	Male	Female	Male
Edisto River	1989	82	7	35	0	5	0	48.6	0
	1990	95	11	41	3	2	0	45.6	30
	Total	**177**	**18**	**76**	**3**	**7**	**0**	**46.9**	**18.8**
Santee River	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 River	1993	7	5	0	0	0	0	ID	ID
Edisto River	1994	43	4	12	0	0	0	27.9	ID
	1995	210	42	34	4	0	1	16.2	11.8
	1996	213	25	23	1	0	0	10.8	4
	1997	139	6	19	0	1	0	14.4	0
	1998	133	12	6	1	0	0	4.5	7.8
Combahee River	1999	9	0	3	0	0	0	ID	ID
	Total	**738**	**89**	**94**	**6**	**1**	**1**	**12.9**	**7.9**
Santee River	2001	317	1610	13	125	0	0	4.1	7.8
	2002	1027	1052	10	25	0	0	1.0	2.4
	Total	1344	2662	23	150	0	0	1.7	5.6
Waccamaw River	2003	601	469	19	32	0	0	3.2	6.8
	2004	251	577	9	67	0	0	3.6	11.6
	2005	443	121	41	6	0	0	9.3	5.0
	Total	**1295**	**1167**	**69**	**105**	**0**	**0**	**5.3**	**9.0**

Table 14.10 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Santee River drift net fishery (lower) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality. Note: no data were available for 2004 and 2005.

Year	January	February	March	April	Season
1979	closed				
1980	closed	0.032	0.075		0.052
1981	closed	0.190	0.232	0.300	0.246
1982	closed		0.547	0.334	0.436
1983	closed	0.319			0.319
1984	closed		0.739		0.739
1985	closed	0.271	0.762	1.053	0.707
1986	closed	0.572	1.084	1.500	0.829
1987	closed	0.382	0.482	0.421	0.429
1988	closed	0.367	0.321	0.476	0.378
1989	closed	0.745	0.679	0.608	0.664
1990	closed	0.671	0.972	1.778	0.868
1991	closed	1.071	1.286	1.097	1.163
1992	closed	1.25	1.096	0.809	1.101
1993	closed	0.336	0.371	0.342	0.350
1994	closed	0.552	1.716	1.475	1.221
1995	closed	1.145	3.753	2.225	2.494
1996	closed	1.125	1.478	1.194	1.276
1997	closed	0.655	1.021	1.114	0.882
1998	closed		0.500		0.500
1999	closed	0.370	1.020		0.747
2000	closed				
2001	closed	1.58	1.85		1.737
2002					0.44
2003					2.07
2004					
2005					

Table 14.11 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Santee River set net fishery (upper) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2003. Catch and effort data from February, March and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality.

Year	**January**	**February**	**March**	**April**	**Season**
1979	closed	0.152	1.877	3.658	2.061
1980	closed	0.130	0.128	4.375	0.290
1981	closed				
1982	closed				
1983	closed				
1984	closed				
1985	closed	1.167	9.444	10.526	4.435
1986	closed				
1987	closed				
1988	closed				
1989	closed				
1990	closed				
1991	closed				
1992	closed	1.943	3.513	2.69	2.915
1993	closed	0.696	2.236	1.170	1.387
1994	closed	0.933	2.531	1.662	1.850
1995	closed	0.939	4.780	2.444	2.922
1996	closed	1.957	8.480	8.417	5.574
1997	closed	2.641	5.982	1.714	3.490
1998	closed	2.180	7.750	3.760	4.980
1999	closed	1.360	1.690	1.550	1.510
2000	closed	2.050	5.620	7.6	3.520
2001					4.064
2002					2.611
2003					7.195
2004					4.074
2005					3.554

Table 14.12 Results (total effort and landings) from SCDNR pre-Rediversion and post-Rediversion recreational creel surveys on the Cooper and Santee rivers. Data are presented on a per annum basis (i.e., 1991-93 data are annual averages for that period). The survey examined recreational fisheries on these rivers in total and no shad specific data were presented.

Period	**Cooper River**		**Santee River**		**Combined**	
	Effort (hrs)	**Landings (kg)**	**Effort (hrs)**	**Landings (kg)**	**Effort (hrs)**	**Landings (kg)**
1981-2	185,762	129,596	155,924	45,004	341,686	174,600
1991-3	198,934	58,736	237,086	79,861	436,020	138,597
Percent Change	7.1%	-54.7%	52.1%	77.5%	27.6%	-20.6%

Table 14.13 Annual total number of American shad passed at St. Stephen fish lock, 1986-2005. Counts make by: hydroacoustic gear, 1986,1987; real time counts, 1988-1994; and counts from vide recordings 1995-2005.

Year	**American Shad**
1988	10000
1989	27000
1990	81000
1991	176000
1992	147000
1993	159000
1994	212000
1995	445000
1996	477047
1997	387755
1998	543681
1999	306493
2000	592321
2001	165875
2002	140398
2003	298902
2004	145201
2005	215428

Table 14.14 Development of relative exploitation rates of American shad on the Santee River based on commercial gill-net landings and counts from fish counts at the St. Stephen fish lock. Percent difference is calculated as the difference in landings (numbers) and estimated landings (numbers) divided by landings in numbers. Relative exploitation rates are estimated for sexes combined since lift counts are not sex specific. Relative exploitation rates are based on the estimated numbers landed before 1999 and based on numbers landed by sex since mandatory reporting began in 1999.

Year	St. Stephen Fish Lock	Estimated Numbers		Numbers Landed		Percent Difference		Minimum Population Estimate	Relative Exploitation Rate (sexes combined)
	Numbers Passed	Males	Females	Males	Females	Males	Females		
1988	10,000	888	7,096					17,983	0.44
1989	27,000	359	2,874					30,234	0.11
1990	81,000	272	2,175					83,447	0.03
1991	176,000	1,352	10,809					188,161	0.06
1992	147,000	1,540	12,316					160,856	0.09
1993	159,000	970	7,753					167,722	0.05
1994	212,000	894	7,150					220,044	0.04
1995	445,000	3,117	24,918					473,035	0.06
1996	477,047	8,124	64,950					550,120	0.13
1997	387,755	5,132	41,028					433,915	0.11
1998	543,681	9,611	76,837					630,129	0.14
1999	306,493	4,193	33,526	4,535	30,469	7.53	-10.03	341,497	0.10
2000	592,321	10,391	83,078	7,796	84,440	-33.29	1.61	684,557	0.13
2001	165,875	5,328	42,599	3,785	43,430	-40.77	1.91	213,090	0.22
2002	140,398	4,969	39,727	7,774	37,849	36.08	-4.96	186,021	0.25
2003	298,902	4,460	35,660	6,601	34,210	32.43	-4.24	339,713	0.12
2004	145,201	5,481	43,825	4,018	44,603	-36.42	1.74	193,822	0.25
2005	215,428	3,449	27,576	1,505	28,705	-129.18	3.93	245,638	0.12

Table 14.15 Cooper River Rediversion Canal American shad sport fishing creel survey summary results, 2001-2005. Results include summarized details of survey effort, catch, and catch-per-effort. CPPD = catch per party day (fish/d), CPMD = catch per man day (details of survey effort, catch, and catch-per-effort. CPPD = catch per party day (fish/d), CPMD = catch per man day (fish/angler d-1), CPMH = fish per angler hour (fish/angler h-1). CPMH = fish per angler hour (fish/angler h-1).

Year	**Start Date**	**End Date**	**Days**	**N Surveys**	**Mean Time Surveyed (h/d)**	**Total Time Surveyed (h)**	**Catch (surveys)**	**Catch (total)**	**Mean CPPD**	**Mean CPMD**	**Mean CPMH**	**Economic Value ($)**	**Value/fish ($)**
2001	28-Feb	13-Mar	34	251	7.2	245	1518	3864	6.6	3.4	0.066	$19,241.00	$12.68
2002	28-Feb	5-Apr	37	303	4.2	156	1508	3199	4.9	2.8	0.59	$18,377.00	$12.19
2003	19-Feb	6-Apr	47	425	6.5	306	3421	6856	8.8	4.6	1.01	$35,863.00	$10.48
2004	16-Feb	15-Apr	31	285	4.5	139	2128	5529	7.3	4.2	0.96	$8,810.00	$4.14
2005	21-Feb	15-Apr	54	598	7.4	401	6663	14629	11.2	5.8	1.6	$17,890.00	$2.68

Table 14.16 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Edisto River set net fishery (lower 24-hour) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

Year	January	February	March	April	Season
1979	closed				
1980	closed	0.350	0.580	0.600	0.533
1981	closed	0.500	1.250	0.770	0.926
1982	closed	0.240	0.900	0.370	0.530
1983	closed	0.270	0.540	0.460	0.453
1984	closed	0.340	0.890	1.560	0.759
1985	closed	0.940	2.500	1.650	1.871
1986	closed	0.820	1.060	0.840	0.968
1987	closed		4.170	1.360	2.111
1988	closed	1.330	1.140	0.560	0.957
1989	closed	0.410	1.470	1.860	1.454
1990	closed	0.890	1.680	1.330	1.516
1991	closed	0.780	0.870	1.090	0.895
1992	closed	1.57	1.56	1.14	1.364
1993	0.222	0.593	1.590	1.433	1.228
1994		0.716	0.579	0.503	0.567
1995		0.458	2.021	1.889	1.630
1996					
1997	0.000	0.466	0.242	0.206	0.327
1998		0.104	0.758	0.851	0.471
1999	0.004	0.032	0.182	0.134	0.102
2000	0.039	0.458	0.792	0.502	0.608
2001					0.0776
2002					
2003					0.154
2004					0.102
2005					

Table 14.17 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Edisto River set net fishery (tide) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

Year	**January**	**February**	**March**	**April**	**Season**
1979	closed	1.459	2.772	1.157	1.702
1980	closed	2.128	2.138	0.559	2.081
1981	closed	1.451	4.773	2.757	3.181
1982	closed	1.108	5.061	2.500	2.568
1983	closed				
1984	closed				
1985	closed	2.298	5.174		4.002
1986	closed	0.648	2.251	2.819	1.889
1987	closed				
1988	closed	4.182	5.527	5.600	5.171
1989	closed	4.583	9.796	7.391	7.642
1990	closed	1.483	2.398	1.378	1.930
1991	closed	1.910	2.730	2.696	2.601
1992	closed	0.615	2.586	2.321	2.214
1993	0.00	0.000	2.424	closed	1.600
1994	0.00	0.396	3.124	closed	2.524
1995				closed	
1996	0.00	0.714	2.125	closed	1.560
1997	1.00	0.800	0.375	closed	0.400
1998					
1999	did not fish	0.910	2.790		2.531
2000	did not fish	2.310	3.100		2.739
2001					1.01
2002					2.898
2003					1.389
2004					0.938
2005					

Table 14.18 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Edisto River set net fishery (Jacksonboro 24-hr) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

Year	January	February	March	April	Season
1979	closed				
1980	closed	0.650	1.740	1.270	1.247
1981	closed	0.670	1.490	0.910	1.044
1982	closed	0.900	1.890	1.550	1.443
1983	closed	0.620	1.220	0.770	0.908
1984	closed	1.000	2.810	1.470	1.814
1985	closed	1.010	2.790	1.910	1.919
1986	closed	0.800	1.890	1.400	1.360
1987	closed	1.090	1.930	1.300	1.469
1988	closed	0.520	1.640	0.810	1.058
1989	closed	0.680	1.300	1.200	1.028
1990	closed	0.670	1.370	0.810	0.986
1991	closed	0.700	1.630	1.080	1.158
1992	closed	0.65	1.34	0.86	0.990
1993	0.063	0.489	0.701		0.545
1994					
1995		2.713	3.241		3.113
1996	0.741	1.307	3.494		2.577
1997	0.449	1.071	1.534		1.090
1998					
1999					
2000	0.07	0.250	0.570	0.46	0.353
2001					0.330
2002					0.661
2003					0.261
2004					0.125
2005					0.275

Table 14.19 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Combahee River set net fishery from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

Year	January	February	March	April	Season
1979	closed	no data	no data	no data	
1980	closed	no data	no data	no data	
1981	closed	no data	no data	no data	
1982	closed	no data	no data	no data	
1983	closed	no data	no data	no data	
1984	closed	no data	no data	no data	
1985	closed	no data	no data	no data	
1986	closed	no data	no data	no data	
1987	closed	no data	no data	no data	
1988	closed	no data	no data	no data	
1989	closed	2.361	2.708	1.389	2.153
1990	closed	no data	no data	no data	
1991	closed	no data	no data	no data	
1992	closed	no data	no data	no data	
1993	closed	0.053	0.522	0.133	0.182
1994	closed	0.031	0.222	2.000	0.143
1995	closed	0.256	0.829	1.250	0.462
1996	closed	0.775	1.111	2.381	0.941
1997	closed	0.258	0.611	0.556	0.442
1998	closed	0.894	1.110		1.037
1999	closed	0.122	0.639		0.337
2000	closed	0.863	0.635		0.795
2001					0.432
2002					0.278
2003					
2004					0.417
2005					0.272

Table 14.20 Total Savannah River American shad landings (kg) for Georgia and South Carolina combined. Georgia landings data are available from 1962 to 1982 and from 1989 to 2005. South Carolina data are available from 1979 to 2005. Interpolated landings for Georgia from 1983 to 1988 (in bold) were calculated by applying a ratio of the average SC:GA Savannah River American shad landings from 1979 to 1983 and 1989 to 1993.

Year	Georgia	South Carolina	Total
1964	33091		
1965	47182		
1966	27227		
1967	318		
1968	24182		
1969	53909		
1970	43682		
1971	25636		
1972	25500		
1973	34000		
1974	26318		
1975	20455		
1976	6364		
1977	20864		
1978	38241		
1979	46369	11390	57759
1980	45440	16290	61729
1981	26382	12797	39180
1982	31304	16626	47930
1983	**35266**	12391	47657
1984	**102437**	35991	138428
1985	**50918**	17890	68808
1986	**37125**	13044	50170
1987	**39223**	13781	53003
1988	**23144**	8132	31276
1989	17892	6266	24158
1990	14593	7724	22317
1991	18839	2545	21383
1992	19272	7016	26289
1993	7828	1730	9559
1994	9913	2247	12160
1995	18404	6862	25265
1996	14890	8480	23369
1997	11704	6828	18532
1998	7212	2876	10088
1999	4993	4410	9403
2000	4667	2873	7540
2001	5762	3380	9141
2002	1732	1150	2882
2003	1784	1843	3626
2004	3417	4185	7602
2005	6380	3407	9787

Table 14.21 Commercial catch-per-unit-effort (fish per 92-m net-hr) of American shad in the Savannah River set net fishery (lower) from voluntary reporting from 1979 to 2000 and by sub-setting mandatory reporting data from 2001 to 2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

Year	**January**	**February**	**March**	**April**	**Season**
1979	no data	no data	no data	no data	
1980	0.375	0.250	no data	no data	0.292
1981	no data	no data	no data	no data	
1982	0.208	0.689	1.330	no data	1.028
1983	0.208	0.458	1.330	no data	1.019
1984	no data	2.746	3.438	3.864	3.189
1985	1.707	2.773	2.994	no data	2.670
1986	0.583	1.587	1.746	no data	1.583
1987	0.878	1.293	1.639	1.273	1.378
1988	0.555	0.619	0.670	0.545	0.628
1989	no data	1.137	2.030	no data	1.654
1990	0.799	1.805	1.719	no data	1.674
1991	no data	1.506	1.718	1.446	1.607
1992	no data	1.275	1.388	no data	1.331
1993	no data	1.208	1.369	1.682	1.309
1994	no data	1.115	1.283	1.614	1.222
1995	no data	1.946	2.781	1.845	2.384
1996	no data	1.803	2.467	no data	2.101
1997	0.804	1.459	1.743	1.565	1.551
1998					
1999	no data	0.570	0.270	no data	0.457
2000	no data		0.780	no data	0.533
2001					0.947
2002					0.63
2003					2.216
2004					1.502
2005					1.319

Table 14.22 Commercial drift gill-net trips targeting American shad on the Savannah River, Georgia from 1989 to 2005. Before 2000, the number of reported trips included single trips, as well as, partial and multiple trips reported as single trips. Since 2000, compliance and trips level reporting have improved (Bold face type).

Year	**Drift Gill Net**
1989	175
1990	276
1991	275
1992	223
1993	189
1994	149
1995	331
1996	188
1997	179
1998	156
1999	81
2000	**93**
2001	**79**
2002	**42**
2003	**57**
2004	**60**
2005	**69**

Table 14.23 Commercial catch-per-unit-effort (kg/trip) of American shad in the Savannah River from Georgia Department of Natural Resources mandatory catch and effort reporting records from 2000 to 2005.

Year	**CPUE (kg/trip)**
2000	108.0
2001	101.6
2002	64.8
2003	66.8
2004	72.4
2005	78.2

Figure 14.1	Map of major South Carolina drainage basins and river systems with American shad with first barriers to upstream migration shown.

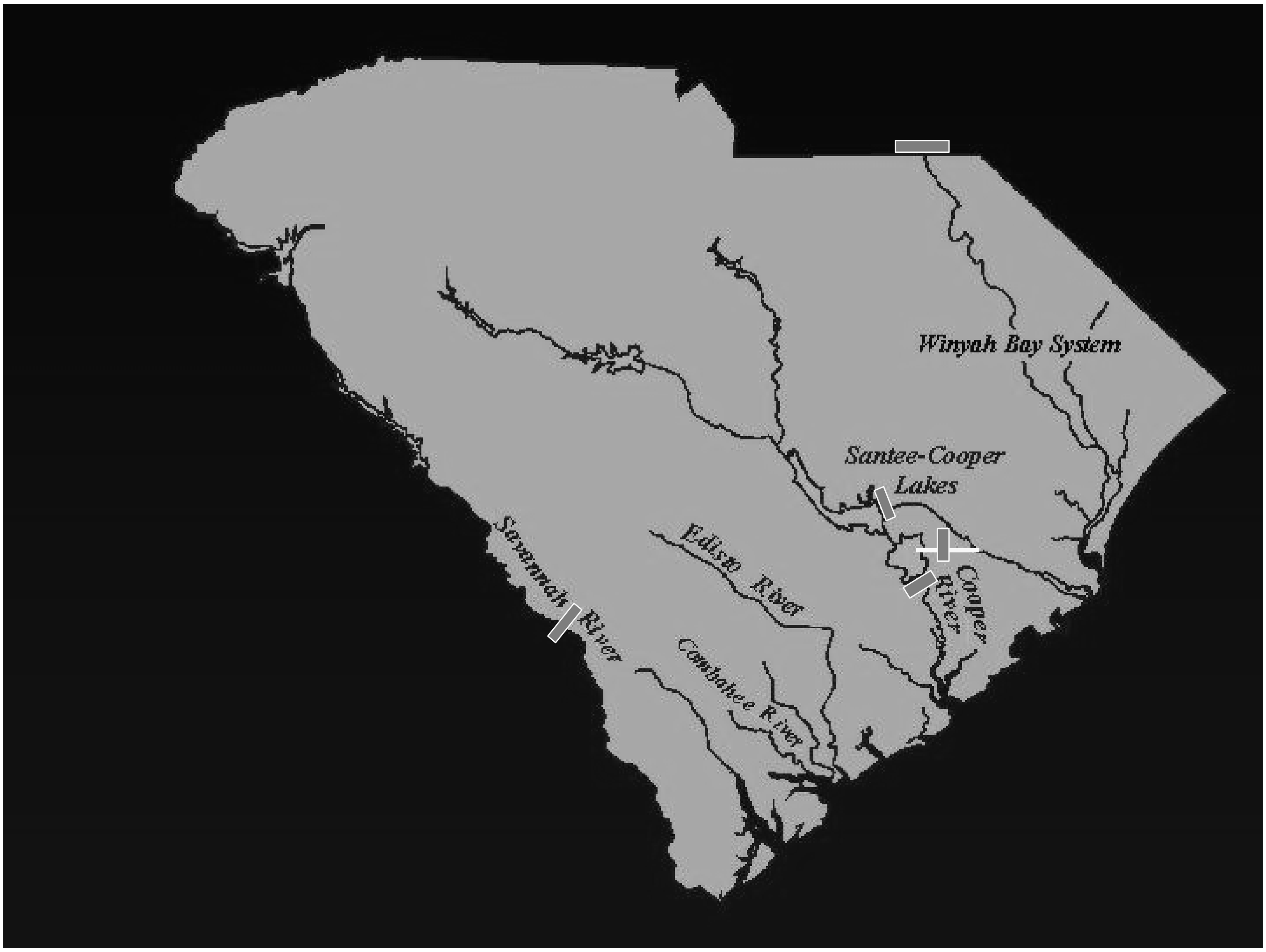


Figure 14.2 Age distribution of male (a) and female (b) American shad sampled in the Waccamaw River, South Carolina using gill nets in two periods, 1979 to 1985 (primary y-axis) and 2003 to 2005 (secondary y-axis). Ages were determined from scales using Cating's (1953) method.

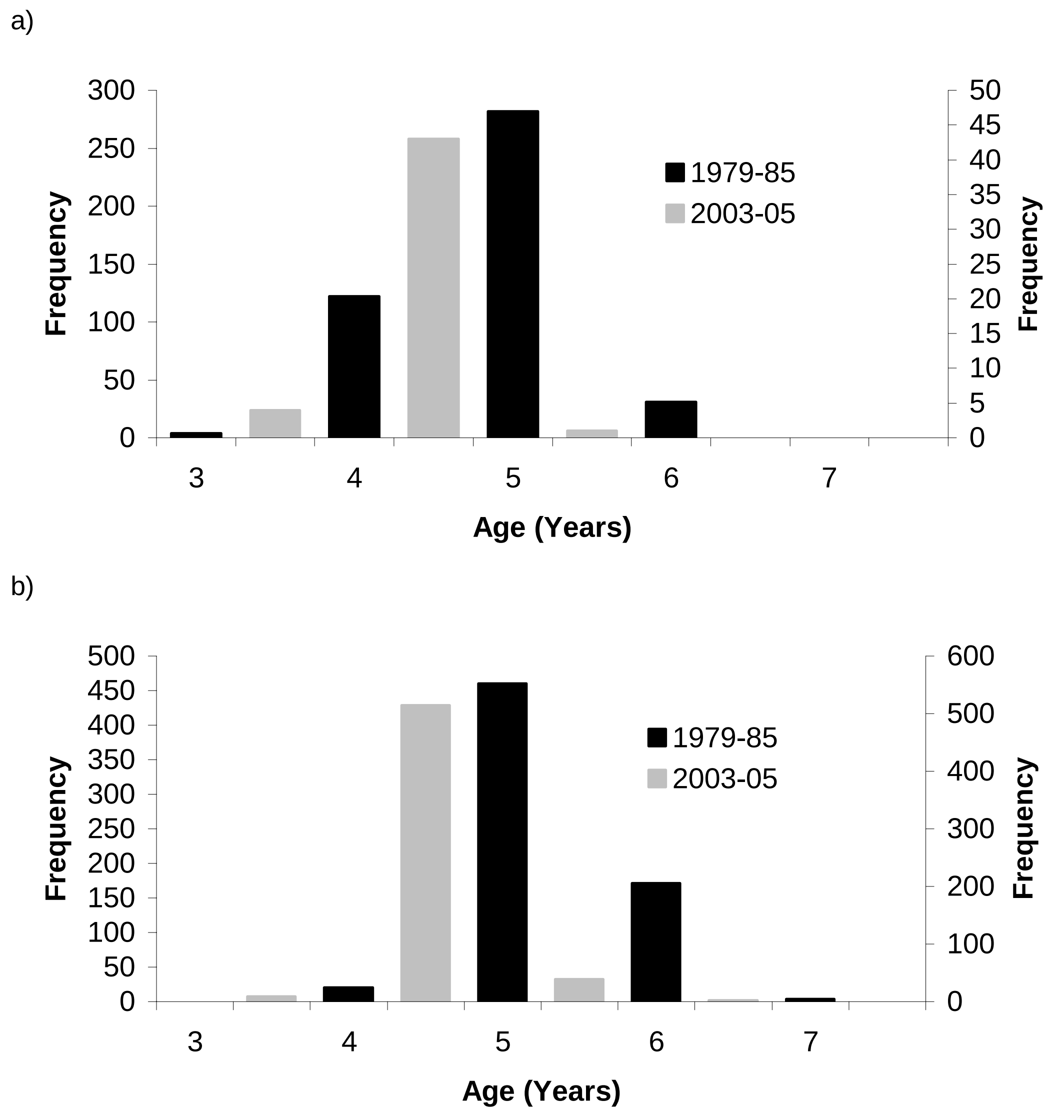
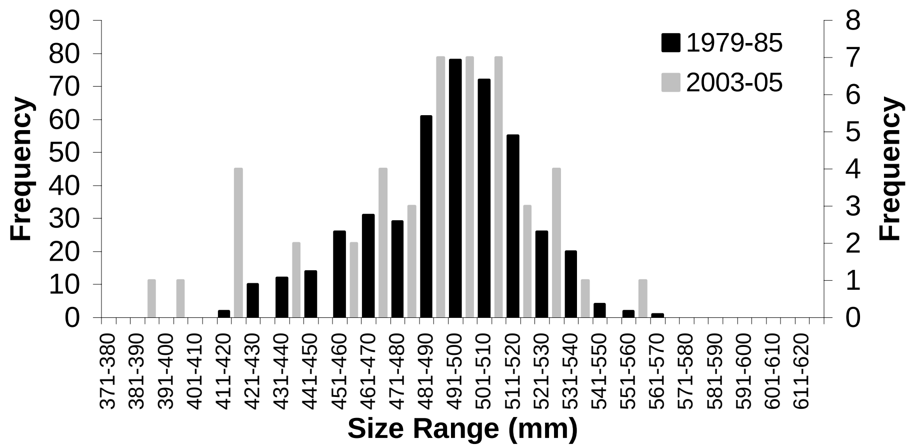


Figure 14.3 Length (total length) distribution of male (a) and female (b) American shad sampled in the Waccamaw River, South Carolina using gill nets in two periods, 1979-1985 (primary y-axis) and 2003-2005 (secondary y-axis).

a)



b)

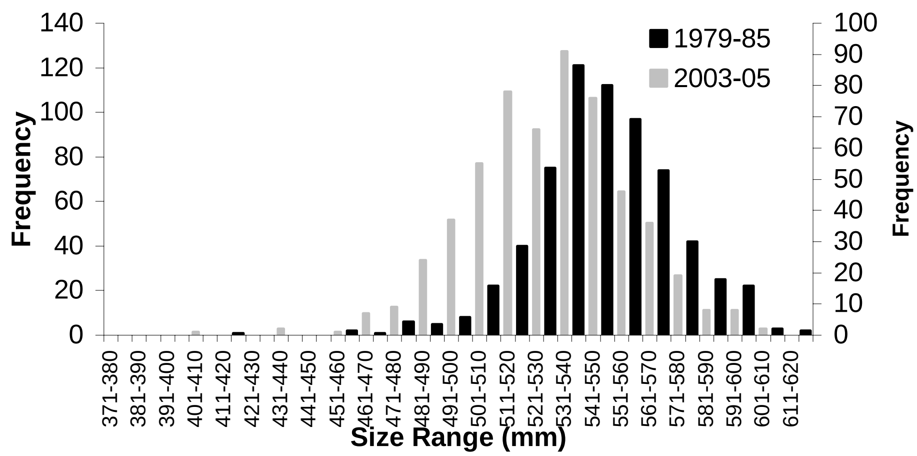
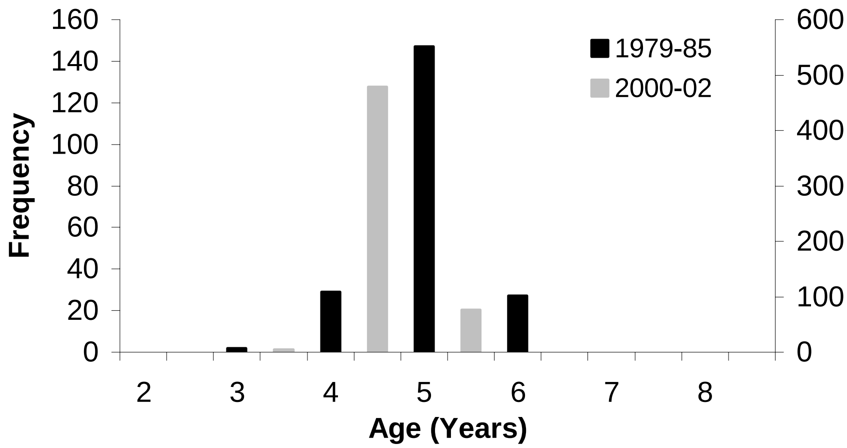


Figure 14.4 Age distribution of male (a) and female (b) American shad sampled in the N. Santee River, South Carolina using gill nets in two periods, 1979-1985 (primary y-axis) and 2000-2002 (secondary y-axis). Ages were determined from scales using Cating's (1953) method.

a)



b)

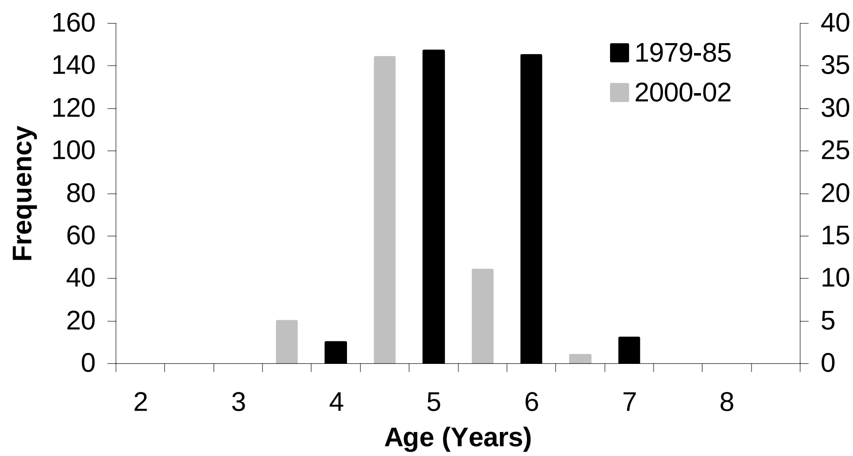
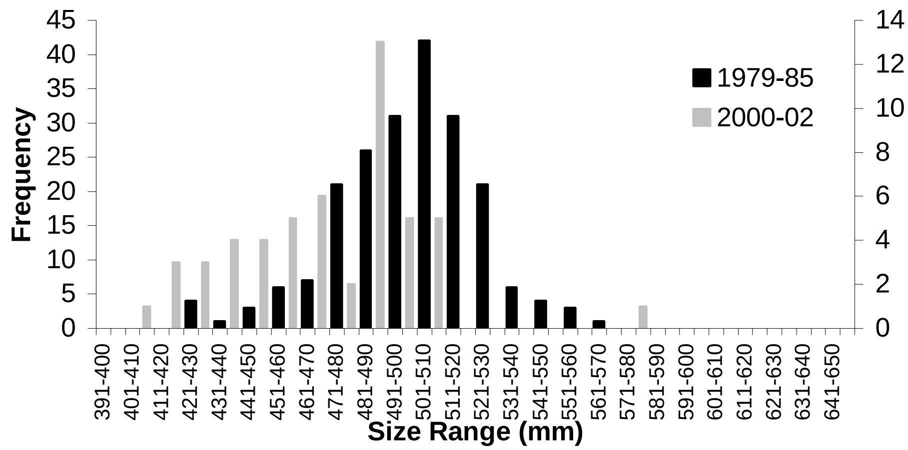


Figure 14.5 Length (total length) distribution of male (a) and female (b) American shad sampled in the N. Santee River, South Carolina using gill nets in two periods, 1979-1985 (primary y-axis) and 2000-2002 (secondary y-axis).

a)



b)

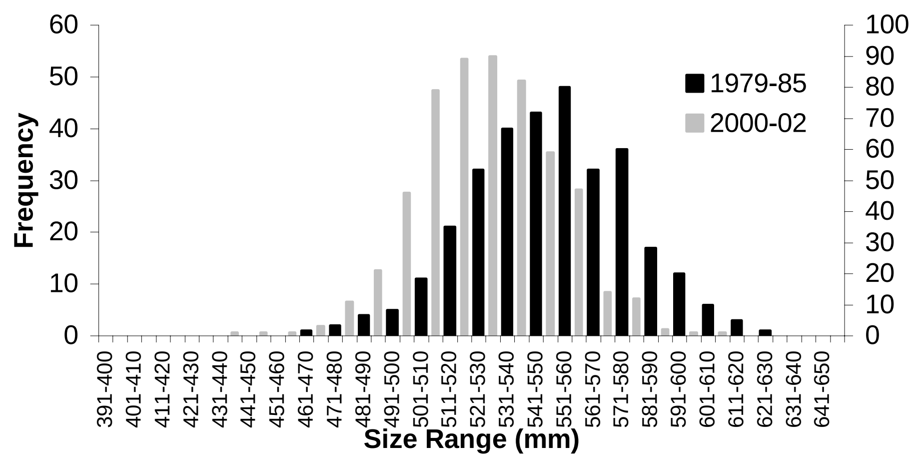


Figure 14.6 Mean annual fork length (mm) of male and female American shad sampled from the St. Stephen fish lock, Santee River commercial fishery, Santee River recreational fishery, and Cooper River recreational fishery.

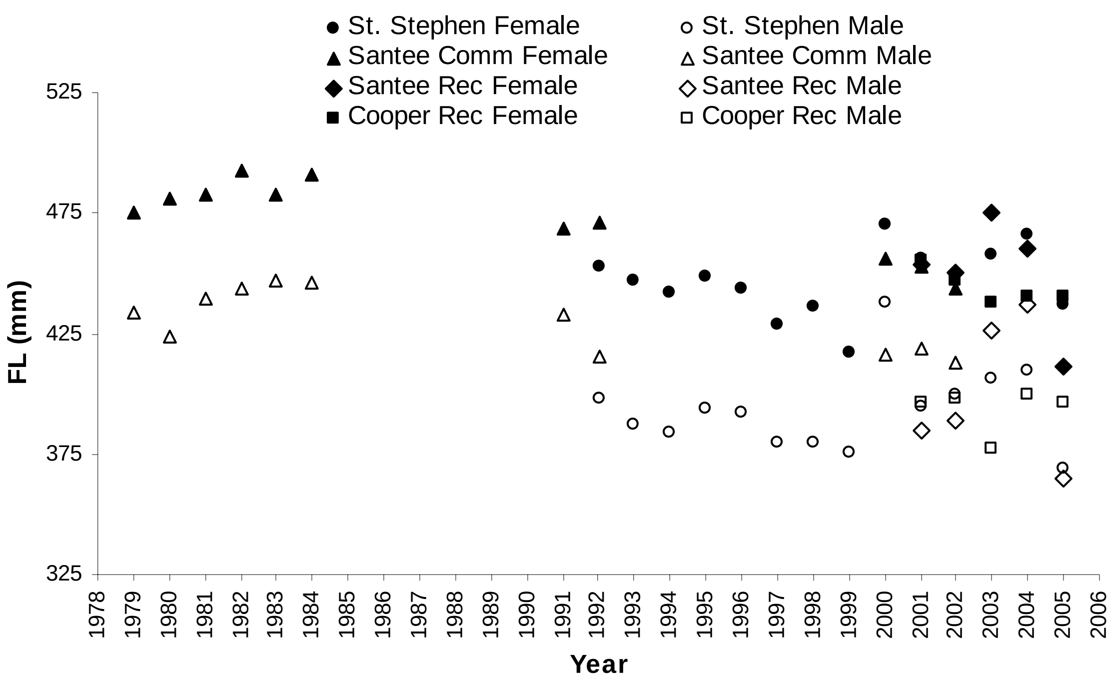
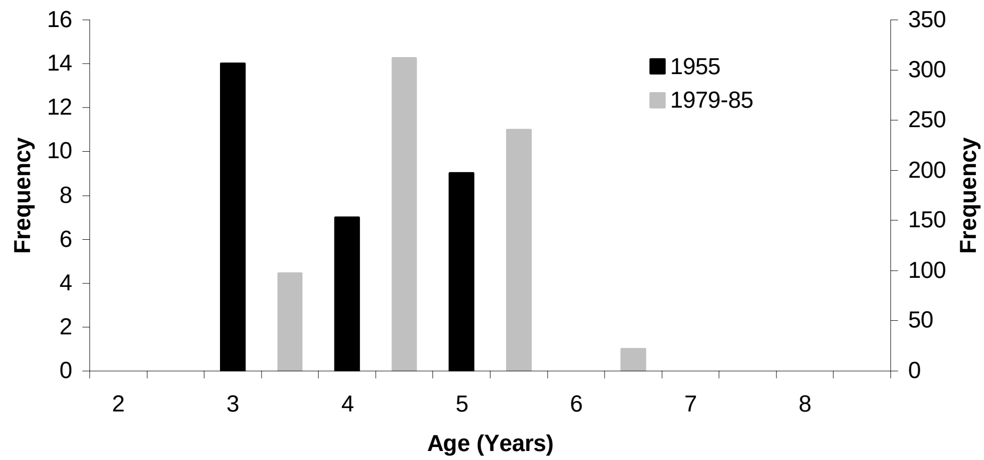


Figure 14.7 Age distribution of male (a) and female (b) American shad sampled in the Edisto River, South Carolina using gill nets in two periods, 1955 (primary y-axis) and 1979-1985 (secondary y-axis). Ages were determined from scales using Cating's (1953) method.

a)



b)

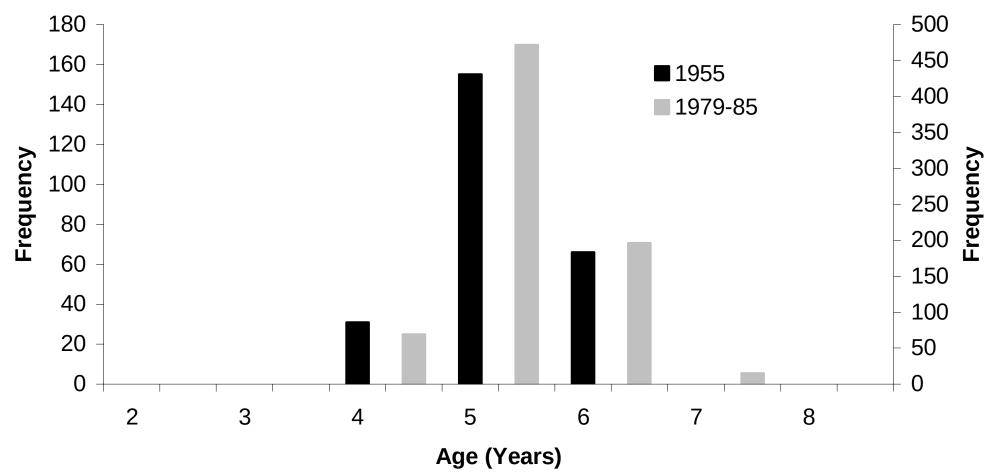
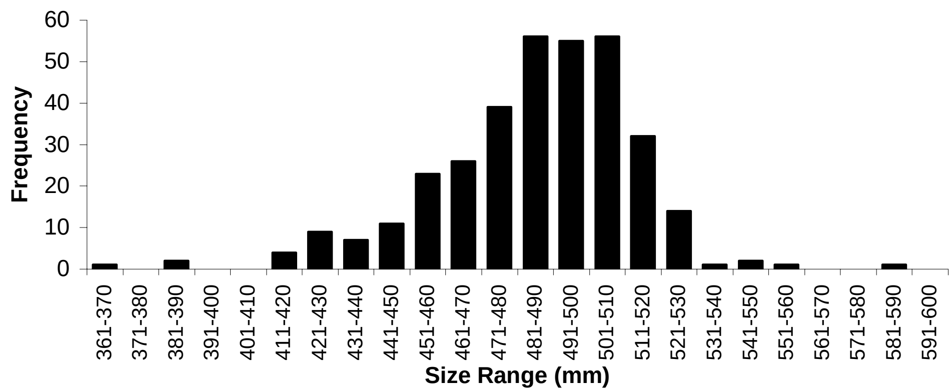


Figure 14.8 Length distribution of male (a) and female (b) American shad sampled in the Edisto River, South Carolina using gill nets from1979-1985. Note different scales on x- and y-axes.

a)



b)

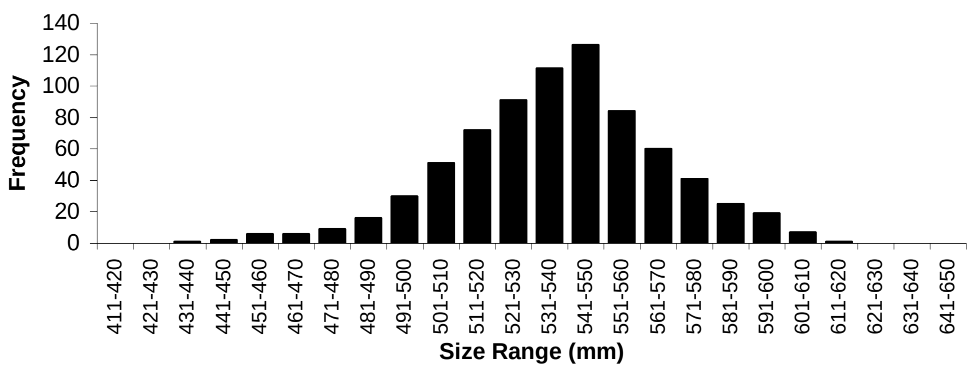


Figure 14.9 Reported annual South Carolina American shad landings (kg) by water area from 1979 to 1997. Beginning with the 1998 season, landings were taken from mandatory catch and effort reports.

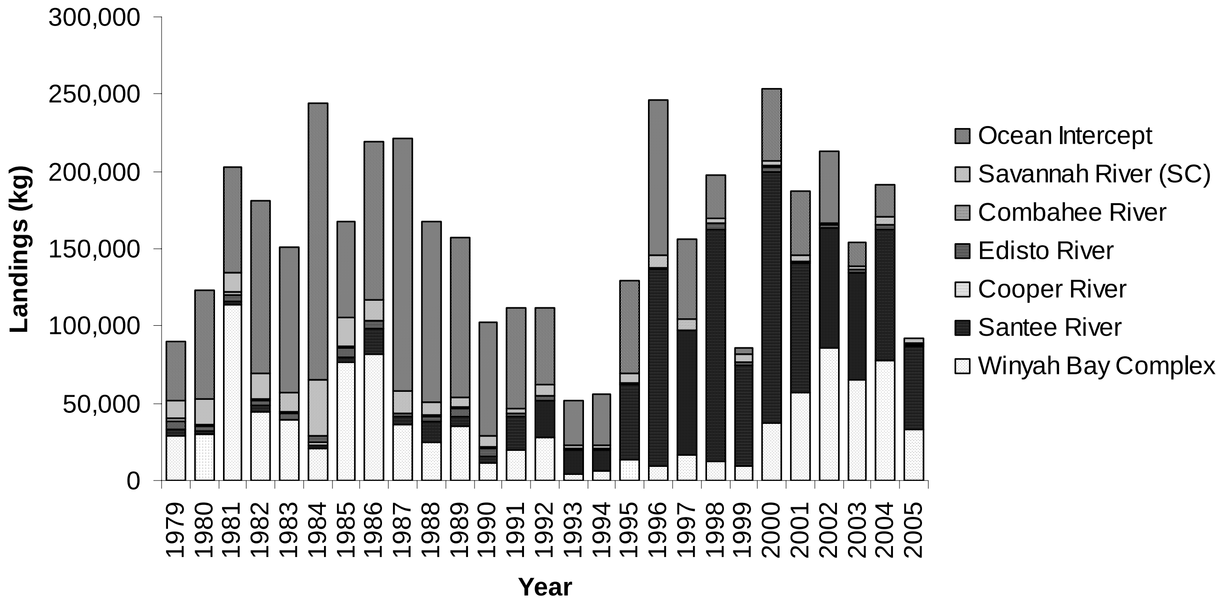


Figure 14.10 Historical landings of American shad in South Carolina. Landings from before 1979 are from: Statistics of the Fisheries of the [Middle-New England] Atlantic States. Division of Statistics and Methods of the Fisheries, United States Fish Commission. Obtained from NOAA Central Library Data Imaging Project (docs.lib.noaa.gov). Landings after 1979 are from South Carolina Department of Natural Resources.

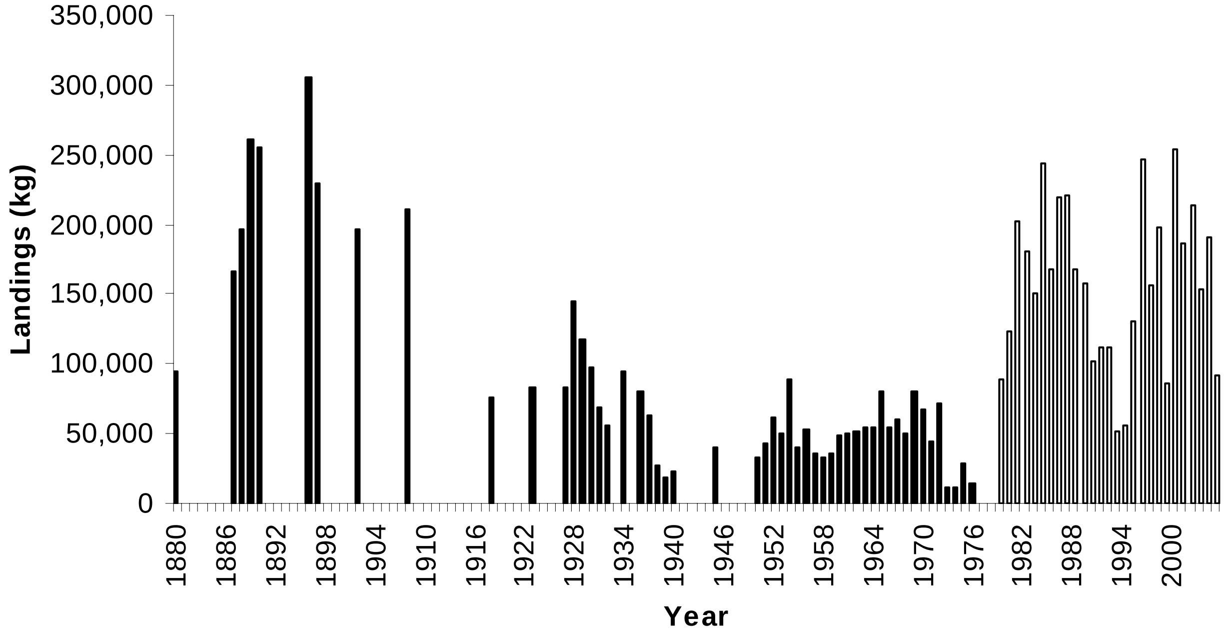


Figure 14.11 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Winyah Bay drift gill-net fishery (1979 to 1997) and set gill-net fishery (2001 to 2004). Catch and effort data from February, March, and April were used to develop season totals.

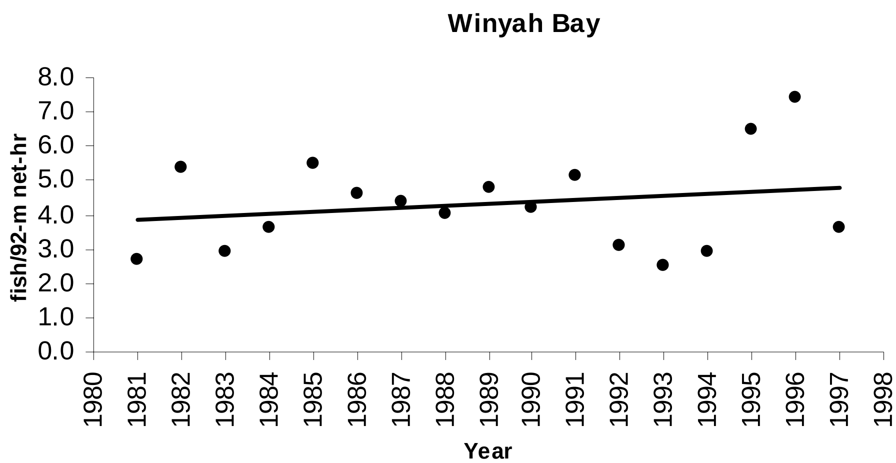


Figure 14.12 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Waccamaw River Drift Net fishery from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

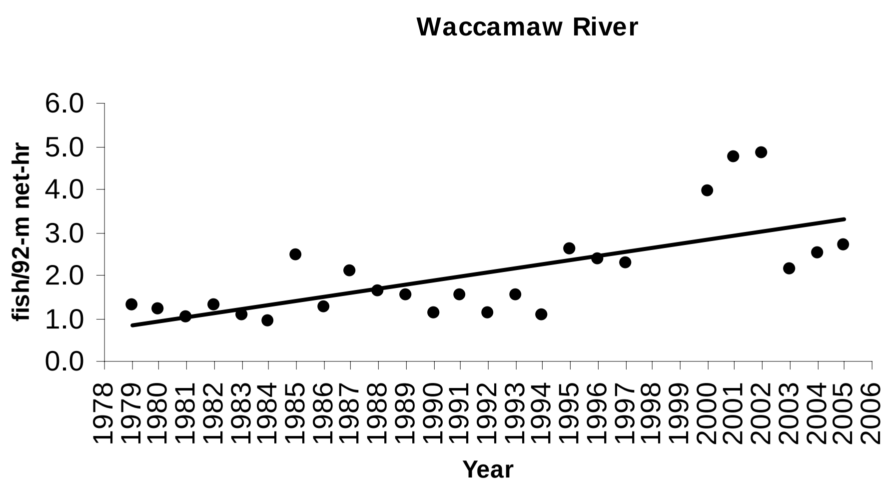


Figure 14.13 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Pee Dee River (Petersfield set net fishery) from voluntary reporting from 1979-2000. Catch and effort data from February, March, and April were used to develop season totals.

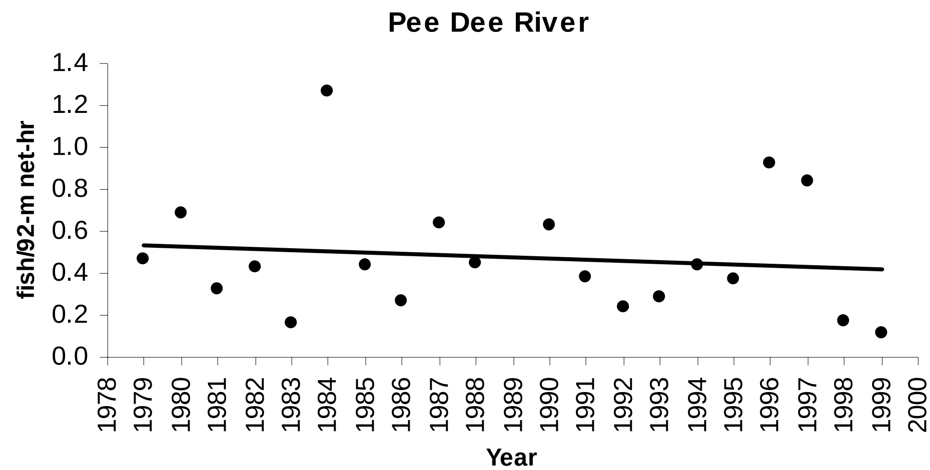


Figure 14.14 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Santee River drift net fishery (lower) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

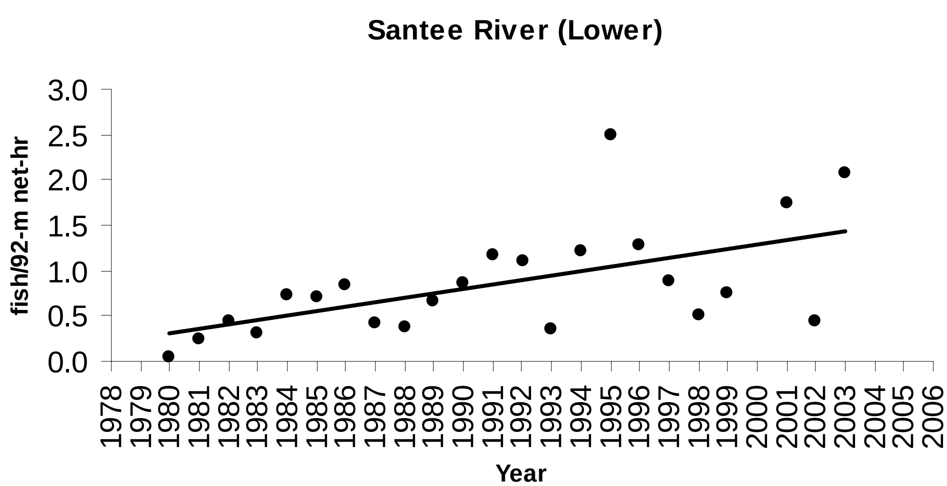


Figure 14.15 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Santee River set net fishery (upper) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

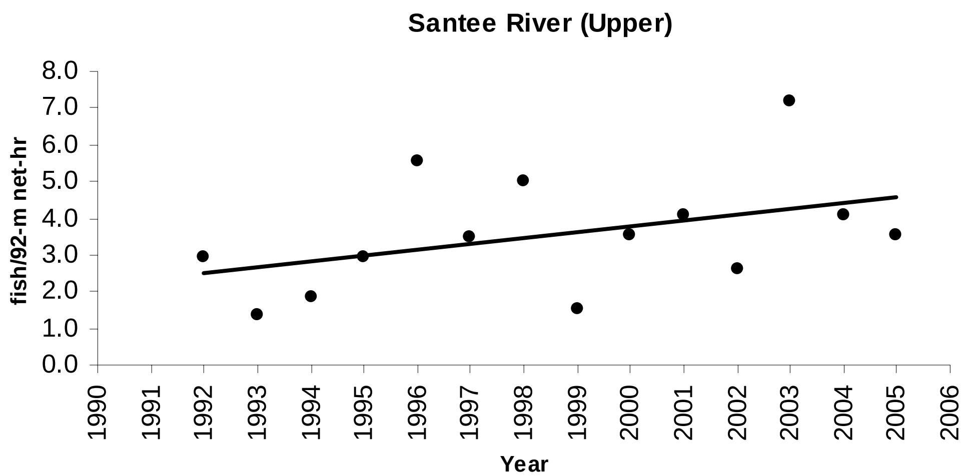


Figure 14.16 Annual total number of American shad passes at St. Stephen fish lock, 1986-2005. Counts made by: real time counts, 1988-1994, and counts from video recordings 1995-2005.

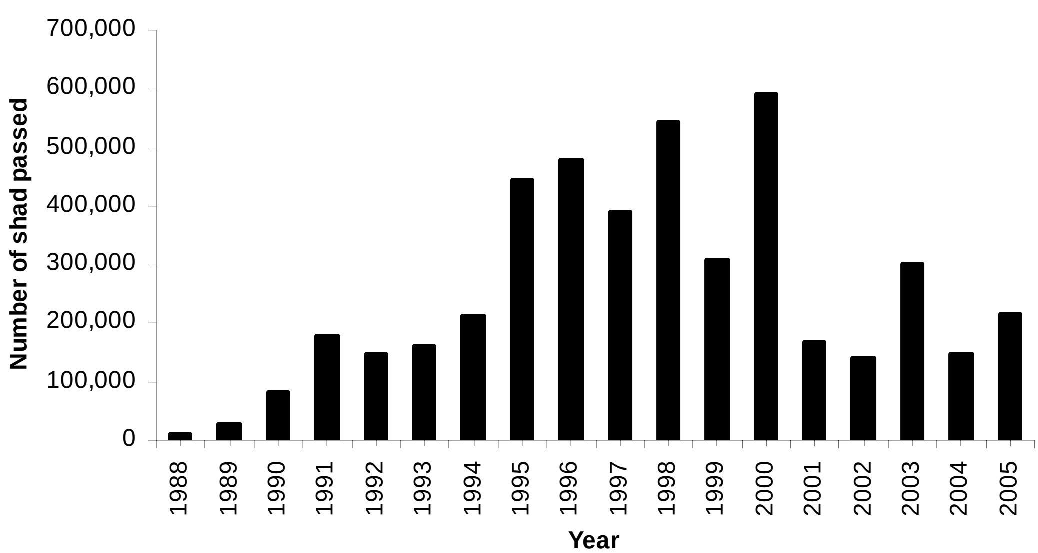


Figure 14.17 The bars indicate the numbers of fish passed at St. Stephens fish lock and the minimum population bound (estimate) for American shad on the Santee River, South Carolina, with corresponding population sizes on primary y-axis. Relative exploitation rates of buck, roes and total (both sexes) as scatter plots with lines on secondary y-axis.

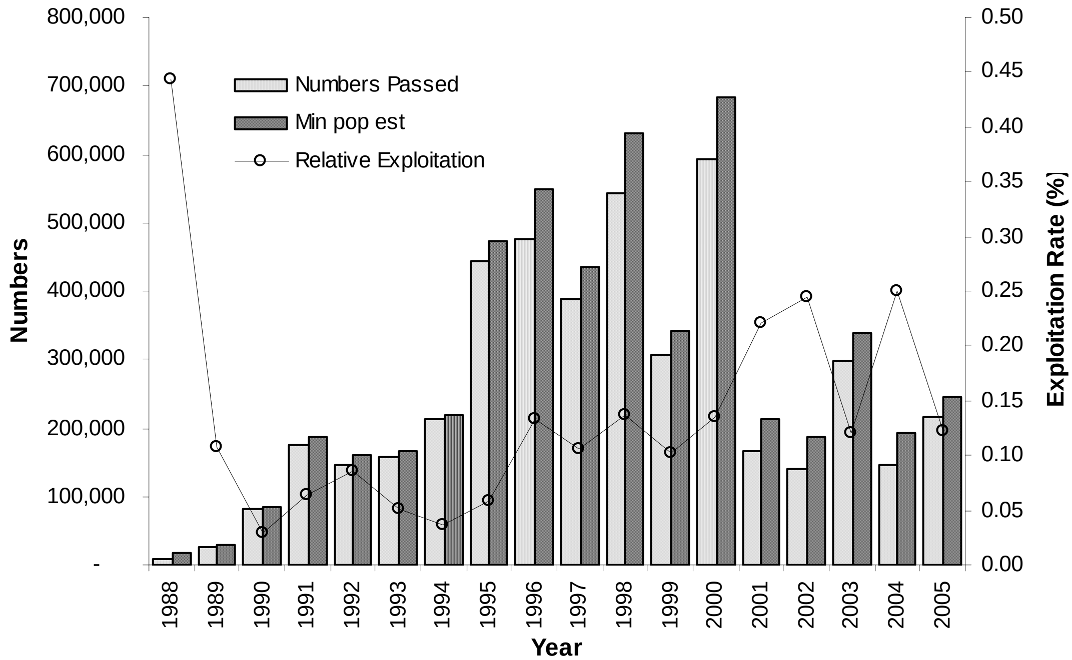


Figure 14.18 Catch-per-unit-effort from the Cooper River creel survey conducted in Pinopolis Dam Tailrace to characterize the American shad recreational fishery. CPPD = catch per party day (fish /d); CPMD = catch per man day (details of survey effort, catch, and catch-per-effort); and CPMH = fish per angler hour (fish / angler h-1).

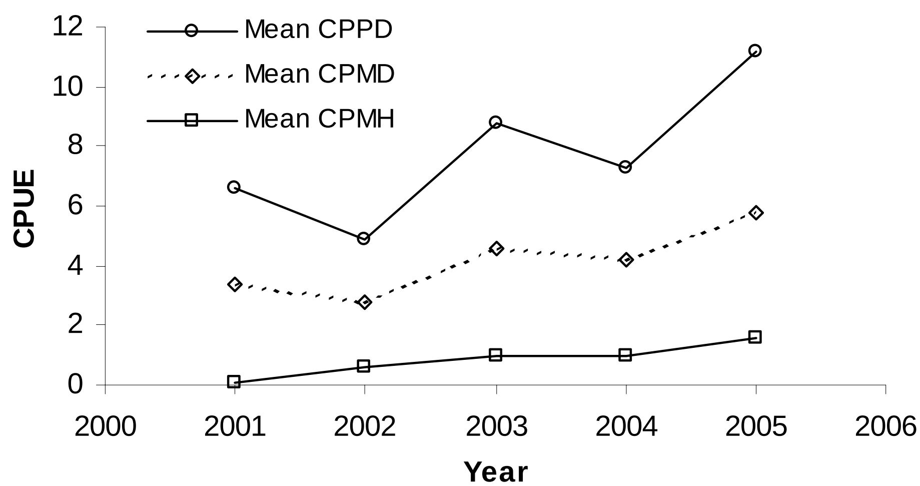


Figure 14.19 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Edisto River set net fishery (lower 24-hour) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

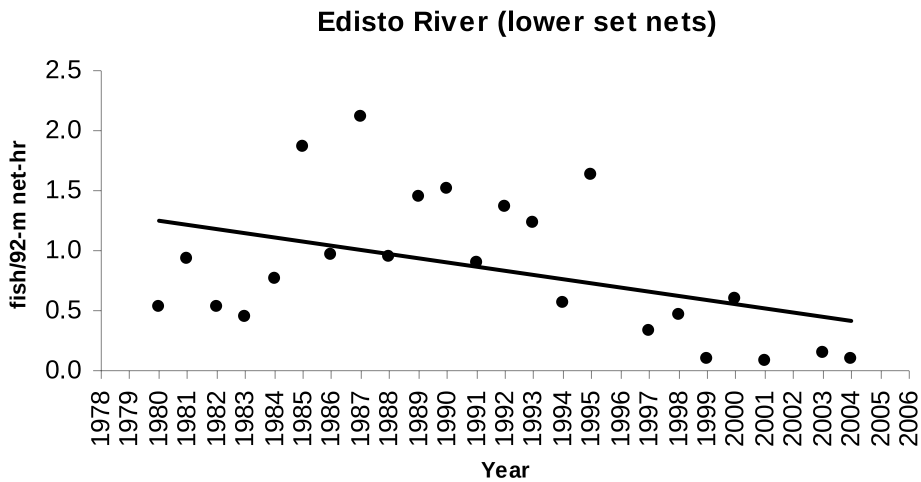


Figure 14.20 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Edisto River set net fishery (tide) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

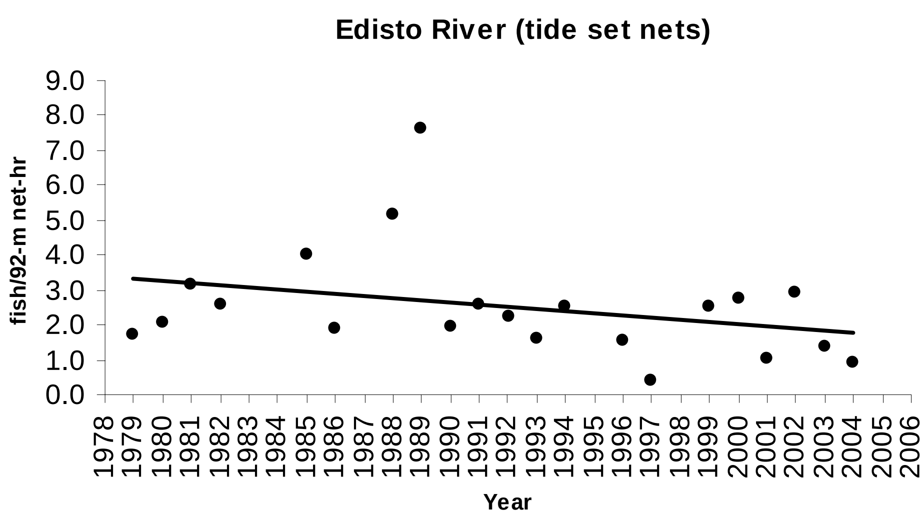


Figure 14.21 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Edisto River set net fishery (Jacksonboro 24-hr) from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals. Catch and effort data are not presented to maintain confidentiality of those data.

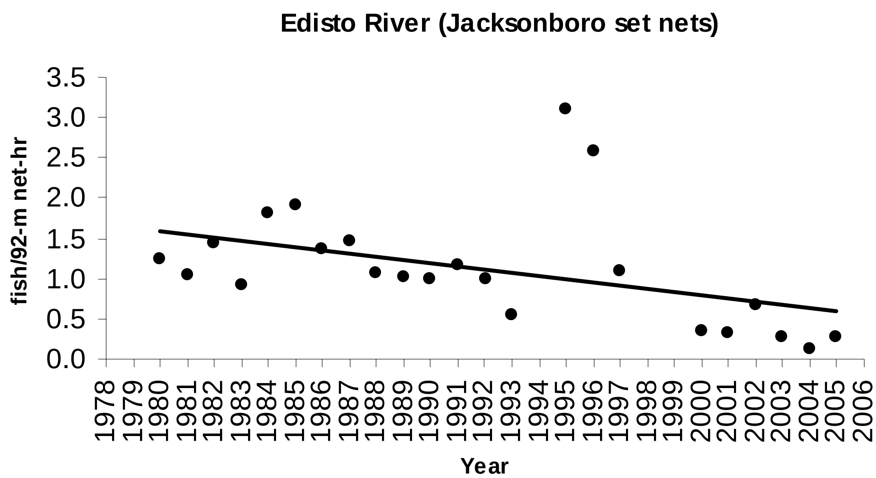


Figure 14.22 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Combahee River set net fishery from voluntary reporting from 1979-2000 and by sub-setting mandatory reporting data from 2001-2004. Catch and effort data from February, March, and April were used to develop season totals.

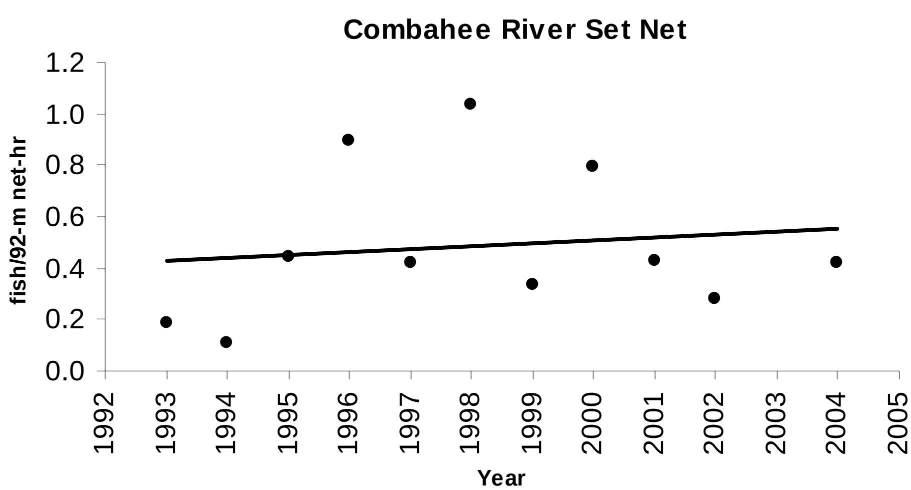


Figure 14.23 Total Savannah River American shad landings (Georgia and South Carolina combined). Georgia landings data are available from 1962 to 1982 and from 1989 to 2005. South Carolina data are available from 1979 to 2005. Interpolated landings for Georgia were calculated by applying a ratio of the average SC:GA Savannah River American shad landings from 1979-1983 and 1989-1993.

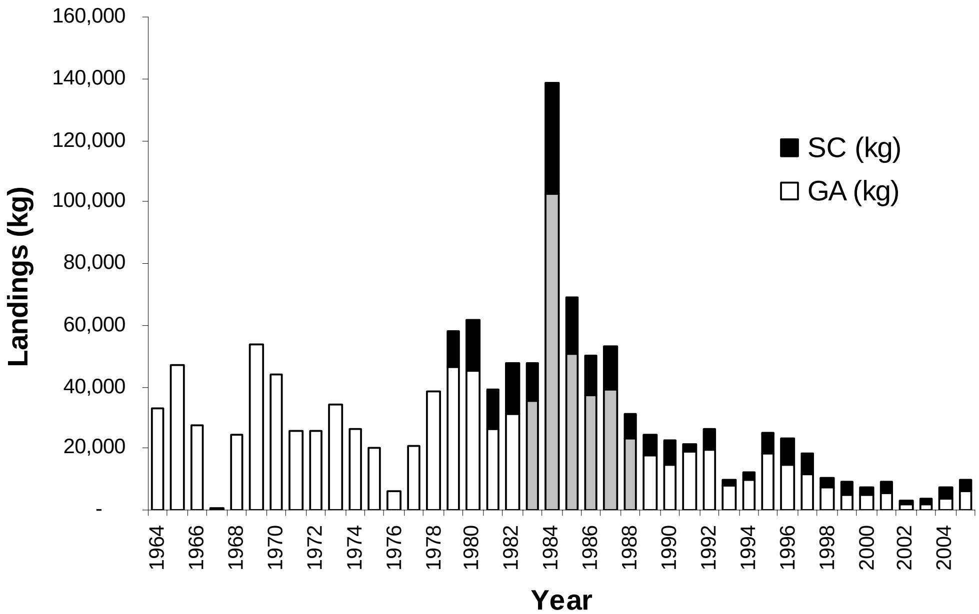
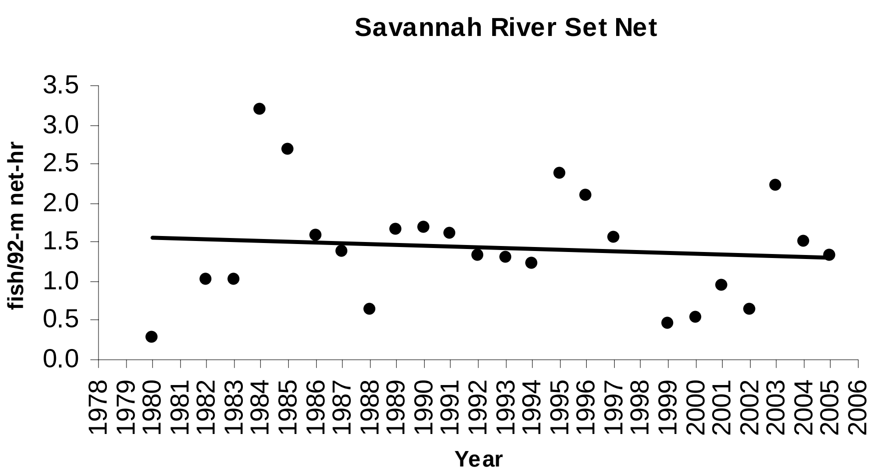


Figure 14.24 Commercial catch-per-unit-effort (fish/92 m net-hr) of American shad in the Savannah River set net fishery (lower) from voluntary reporting from 1979 to 2000 and by sub-setting mandatory reporting data from 2001 to 2004. Catch and effort data from February, March, and April were used to develop season totals.



Appendix I. Summary of 2001 South Carolina Shad Laws by Water or Fishery Area (from Table 1, South Carolina Annual Report for the 2005 Fisheries to the ASMFC for Compliance to Amendment 1 of the Interstate Management Plan for Shad & River Herring).

A. Winyah Bay and Tributaries (includes Waccamaw, Great Pee Dee, Little Pee Dee, Lynches, Black and Sampit Rivers)

1) Pee Dee River and tributaries above Hwy. 701, Waccamaw River and tributaries above entrance of Big Bull Creek, and Black River above Co. Rd. 179

Open Season	Feb. 1 - Apr. 30
Weekly Open Period	Mon. Noon - Sat. Noon
Special Provisions	None
Gear Restrictions	As specified in general provisions
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Remainder of Winyah Bay system including Big Bull Creek and Sampit River

Open Season	Feb. 1 – Apr. 15
Weekly Open Period	Mon. Noon - Sat. Noon
Special Provisions	Drift gill nets measuring not more 300 yards in length may be used between the Waccamaw River mouth and Butler Island
Gear Restrictions	As specified in general provisions
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

B. Santee River

1) Rediversion Canal

Open Season	None - hook & line only
Hook & Line Gear	No season; 20-fish aggregate creel limit for American and hickory shad

2) Wilson Dam seaward to Hwy. 52

Open Season	None - hook & line only
Hook & Line Gear	No season; 20-fish aggregate creel limit for American and hickory shad

3) Hwy. 52 bridge seaward to Hwy. 41 bridge

Open Season	Feb. 1 - Apr. 30
Weekly Open Period	Tues. & Thurs., 7:00 AM - 7:00 PM
Gear Restrictions	None
Hook & Line Gear	No season; 20-fish aggregate creel limit for American and hickory shad

4) Hwy. 41 bridge seaward

Open Season	Feb. 1 – Mar. 31
Weekly Open Period	Mon. Noon - Sat. Noon
Gear Restrictions	None
Hook & Line Gear	No season; 20-fish aggregate creel limit for American and hickory shad

C. Charleston Harbor; Wando, Cooper & Ashley Rivers

1) Tailrace Canal from Wadboo Ck. to Pinopolis Dam

Open Season	None - hook & line only
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Cooper River from Wadboo Ck. to Hwy. 17

Open Season	None - hook & line only
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

3) Ashley River to confluence with Popper Dam Ck. entrance

Open Season	Feb. 1 - Mar. 31
Weekly Open Period	Wed. Noon - Sat. Noon
Gear Restrictions	Drift gill nets only
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

4) Remainder of Charleston Harbor system

Open Season	Feb. 1 - Mar. 31
Weekly Open Period	Wed. Noon - Sat. Noon

Gear Restrictions	Drift gill nets only
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

D. Edisto River

1) Above U.S. Hwy. 17 bridge

Open Season	Jan. 15 - Apr. 15
Weekly Open Period	Tues. Noon - Sat. Noon
Gear Restrictions	5.5" minimum stretched mesh except minimum 4.5" allowed above Hwy. 15 (beginning in 2003, 5" minimum)
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Seaward of U.S. Hwy. 17

Open Season	Jan. 15 - Mar. 31
Weekly Open Period	Wed. Noon - Fri. Midnight
Special Provisions	None
Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

E. Ashepoo River

1) Above U.S. Hwy. 17 bridge

Open Season	Feb. 1 - Mar. 31
Weekly Open Period	Fri. Noon - Sat. Noon
Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Seaward of U.S. Hwy. 17

Open Season	Feb. 1 - Mar. 31
Weekly Open Period	Fri. Noon - Sat. Noon

Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

F. Combahee River

1) All tributaries except main stems of Salkehatchie Rivers

Open Season	None
Weekly Open Period	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Remainder of Combahee River, including main stem of Salkehatchie River

Open Season	Jan. 15 - Mar. 31
Weekly Open Period	Set Nets: Tues. Noon – Fri. Noon Drift Nets: Mon. Noon – Sat. Noon
Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

G. Coosawhatchie River and all tributaries and distributaries

Open Season	None
Weekly Open Period	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

H. Savannah River within South Carolina jurisdiction

1) Above (inland of) U.S. Hwy. I-95 bridge

Open Season	Jan. 1 - Apr. 15
Weekly Open Period	Wed. 7:00 AM - Sat. 7:00 PM
Special Provisions	No open season from confluence of Spirit Creek to New Savannah Bluff Lock & Dam; all tributaries closed
Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

2) Main river seaward of U.S. Hwy. I-95 bridge

Open Season	Jan. 1 - Mar. 31
Weekly Open Period	Wed. 7:00 AM – Sat. 7:00 PM
Special Provisions	Nets prohibited in Savannah's Back River & north channel downriver from New Savannah Cut
Gear Restrictions	None
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

I. Ocean Waters

Open Season	Feb. 1 – Mar. 31
Weekly Open Period	Tues. 7:00 AM - Sat. 7:00 PM
Special Provisions	No nets within 3 miles of designated Winyah Bay entrance area; no nets within 1500 ft. of a public fishing pier or man-made jetty equipped with a fishing walkway
Gear Restrictions	Drift nets only – see general provisions
Hook & Line Gear	No season; 10-fish aggregate creel for American and hickory shad

J. Lake Moultrie, Lake Marion, Diversion Canal, Intake Canal of Rediversion Canal and all tributaries and distributaries thereto

Open Season	None
Weekly Open Period	None
Gear Restrictions	Cast net, lift net, and hook & line only
Special Provisions	Daily limit of 250 pounds of herring and shad combined for cast and lift nets
Hook & Line Gear	No season; 10-fish aggregate creel for American and Hickory shad

K. General provisions

1) Gill net marking/identification

a) Atlantic Ocean	20" minimum diameter international orange buoys on each end of all nets; one such buoy must bear name and license number of owner; nets longer than 100 yards must have international orange buoy at least 10” in diameter along float line every 300 ft. The total length of nets may not exceed 2000 yards per licensee.

b) All inland saltwaters	20" minimum diameter international orange buoys on each end of all nets; one such buoy must bear name and license number of owner; nets longer than 100 yards must have international orange buoy at least 10" in diameter along float line every 300 ft. Individual nets may not exceed 300 yards in length.
c) All freshwaters	6" minimum diameter international orange buoys on each end of all nets; one such buoy must bear name and license number of owner; nets longer than 100 yards must have international orange buoy at least 6" in diameter along float line every 300 ft. Individual nets may not exceed 200 yards in length.

2) Fishing gill nets near the mouth or confluence of tributaries

a) All waters	No net may be used within 75 ft. of the confluence of any tributary.

Section 15
Status of American Shad Stocks in Georgia Rivers

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15.1 INTRODUCTION

The Georgia Department of Natural Resources (GADNR) manages American shad (*Alosa sapidissima*) by river system. The Altamaha, Ogeechee, and Savannah rivers all support commercial American shad fisheries (Figure 15.1a and 15.1b). There are small shad runs in the Satilla and St. Marys rivers but no commercial landings have been reported from these rivers since the 1980s (Figure 15.1a). A law prohibiting the use of nets within Florida waters restricts fishing in the St. Marys River, which forms the border between Georgia and Florida. This law and the narrow width of the river, combined with the relatively small shad run, have essentially closed the commercial fishery on the St. Marys River. In addition to collecting commercial landings data, GADNR actively monitors American shad fisheries on the Altamaha and Ogeechee rivers. Monitoring of the Savannah River American shad stock was assigned to South Carolina by the Atlantic States Marine Fisheries Commission (ASMFC).

According to commercial landings reported to the Coastal Resources Division (CRD) of GADNR, the Altamaha River has the largest commercial shad harvest in Georgia followed by the Savannah River and then the Ogeechee River. Shad landings from the Savannah River in this section of the assessment include only Georgia landings. For the full assessment of the Savannah River, please see the South Carolina section (Section 14). Recreational fisheries for American shad exist on both the Savannah and Ogeechee rivers. Historically, the Ogeechee River had the largest recreational fishery in the state; however, in recent years the recreational fishery on the Savannah River, according to anecdotal evidence, has become larger than that on the Ogeechee River (D. Harrison, pers. comm.). The primary location of the Savannah River recreational fishery is immediately below the New Savannah Bluff Lock and Dam.

15.2 MANAGEMENT UNIT DEFINITION

The American shad management units for Georgia are the Altamaha River, the Ogeechee River, the Savannah River, the Satilla River, and the St. Marys River.

15.3 REGULATORY HISTORY

Commercial set and drift gill-net fisheries are conducted in the Altamaha, Ogeechee, and Savannah rivers. Under Georgia law, nets can only be fished in the flowing waters within the banks of the stream channels. Mesh size and lead length restrictions have been implemented to reduce harvest. Closed seasons and days during the commercial season allows additional escapement of spawning fish (Table 15.1). In 1960, the commercial season extended from January 1 to April 1, except for the St. Marys River while the season was December 15 to April 15 (Walburg and Nichols 1967). No commercial fishing was permitted on weekends from sundown Friday to sunrise Monday. Recreational fishing was allowed seven days a week and the creel limit was eight fish (Walburg and Nichols 1967). Prior to 1980, a shad license was required to fish commercially for American shad and hickory shad (*A. mediocris*) in Georgia (Table 15.2; Figure 15.2), since then commercial shad fishing has been covered under a general commercial fishing license.

A decrease in shad landings from the commercial and recreational fishery on the Ogeechee River led to reduction in commercial fishing days from 4 to 2 days per week and a reduction in the recreational bag limit from 8 fish to 2 fish per day in 1987 (GADNR 1995). The creel limit was revoked in 1993 and, beginning in 1995, the weekly openings for commercial fishing had to be on consecutive days (GADNR 1995).

Set gill nets were banned in the lower Savannah River beginning in 1990 to protect striped bass, which had the effect of affording American shad protection from reduced netting effort in the lower Savannah. Recreational fisheries currently exist in the Ogeechee and Savannah rivers, with a creel limit in both rivers of eight fish per angler. Shad are infrequently caught as bycatch in Altamaha River recreational fishery.

Today the commercial shad season for both American and hickory shad is open from January 1 to March 31. Each week, the Savannah River is open to commercial fishing from Tuesday through Friday below the Interstate-95 bridge and Wednesday through Saturday above the bridge. The Ogeechee River is open only Friday and Saturday. The Altamaha, Satilla, and St. Marys rivers are open Monday through Friday below the saltwater demarcation line and Tuesday through Saturday above the line. In 2004 and 2005, the commercial shad season above the Interstate-95 bridge on the portion of the Savannah River was extended to April 15 to match the South Carolina commercial shad season for this section of river. There is no commercial shad fishing on the St. Marys River due to the Florida net ban enacted in 1995.

Set and drift gill nets (≥11.4 cm mesh) are the only legal commercial gear for American shad in Georgia. Gill nets must be set in flowing water and not in areas such as sloughs and oxbow lakes. Set nets must be less than 30.5 m long and set at least 183 m apart with one end secure to the stream bank and the other buoyed and clearly visible to boaters. Drift nets must be fished at least 91 m apart and no longer than 305 m long. Both gears must allow half the width of the river or stream to be open to the passage of fish and have a permanent tag labeled with fisherman’s name, address, and commercial fishing license number. All sturgeon, catfish, and non-shad gamefish must be immediately released.

15.4 ASSESSMENT HISTORY

There have been several studies investigating the shad fisheries and populations in Georgia. Sykes (1956) surveyed the commercial and recreational fisheries on the Ogeechee River in 1954 to develop estimates of total catch, standardized fishing effort, exploitation, “run” or population size, escapement, and age composition of the commercial catch. The run size was estimated by dividing the total catch by an exploitation rate calculated from a tag-return study. Escapement was estimated by subtracting the catch from the population estimate. Catch-per-unit-effort (CPUE) estimates were developed for each portion of the river, accounting for different gear efficiency at upriver and down-river locations.

Walburg and Nichols (1967) summarized American shad fisheries for all Georgia rivers in terms of amount of gear and landings in 1960 and provided a comparison to records from 1896 by river and gear. The report also described trends in production between 1896 and 1960, reporting on factors that might have explained observed trends in landings over that period. The impact of pollution was noted as affecting the “taste and odor” of shad on the Altamaha River and causing fish to have “oily flavor” in the Savannah River. Landings increased from 50,322 kg in 1896 to 230,615 kg in 1960; however, this change is more likely representative of changes in the transportation infrastructure's ability to support a commercial shad fishery. Godwin (1968) conducted a study on the Altamaha River similar to Sykes (1956) work on the Ogeechee River and extended the work of Walburg and Nichols (1967) on the Altamaha River shad fishery to include 1967 and 1968 data (e.g., landings, effort and gear). Godwin's (1968) work also included a tagging study that was used to derive a run size estimate in each year, characterize the commercial catch age composition, and delimit the spawning area in the Altamaha River. This study also identified the impact of the "inland" shad fishermen, whose landings and effort were not previously documented in existing databases that only tracked coastal shad landings.

A 1979 study by GADNR (Hardisky and Smith 1980) examined the accuracy of existing fishery data collection techniques in order to estimate the magnitude of underreported landings in Georgia shad rivers, including the Savannah, Ogeechee, Altamaha, and the St. Marys rivers. Before this study, landings data in Georgia were collected by National Marine Fisheries Service (NMFS) port agents in coastal areas and did not account for upriver landings. GADNR staff worked with commercial fishermen and dealers to conduct a comprehensive survey of the entire fishery by using trip level logbooks kept by cooperative dealers, telephone interviews with fishermen, and personal interviews with fishermen. NMFS commercial landings records of American shad were found to account for only 43 percent of the commercial harvest estimated by Hardisky and Smith (1980). In addition, a concurrent recreational mail survey identified the recreational fishery as a significant contributor to the Georgia shad harvest and indicated that the magnitude of recreational harvest exceeded the commercial harvest. The possible contribution to conservation of shad due to market dynamics within the coastwide commercial shad season was discussed. The price per pound of shad decreased drastically at the end of the Georgia shad run, as did landings and effort. These changes were concurrent with increases in shad landings in rivers to the north, which was proposed as possibly affording "late running" shad protection from harvest. No estimate of the portion of American shad runs in Georgia afforded this protection was made. Essig (1983) continued the characterization of the Georgia's commercial shad fisheries through 1982.

A decade-long study (1982 to 1992) of the population dynamics and commercial fishery of Altamaha River American shad was conducted by GADNR (Michaels 1984, 1990, 1993) and examined exploitation rates, catch, effort, population, age composition, and juvenile abundance of American shad over the entire range of the fishery. Commercial catch fluctuated over this period but had a decreasing trend primarily due to a decreasing contribution to the catch by drift gill nets. Population estimates, calculated as catch divided by relative minimum exploitation rates from a tag-return study, declined from 1982 to 1992. Catch-per-unit-effort estimates ranged from approximately 12 to 28 shad per standardized fishery unit day with peaks in 1985 and 1988 (Table 15.3; Figure 15.3). A standardized fishery unit day was defined as one 91.4-m long drift gill net fished for 4 hours in the lower Altamaha River. There was no trend in relative minimum exploitation rates of female shad derived from the tag-return study from 1982 to 1992, but an increase in the catchability coefficient with decreasing population size was noted.

This study also found that the commercial landings reported to GADNR were far below actual landings and a regression analysis was conducted to compare the reported coastal drift gill-net landings of American shad in the Altamaha to the study's commercial creel survey estimates of American shad landings. The relationship between the GADNR commercial creel survey landings and coastal drift-net landings was reported to have an asymptotic relationship. This approach has been used since 1992 to adjust the reported coastal landings from the Altamaha River to an estimate of total landings for the Altamaha River and is used in the annual population estimate reported by GADNR (Michaels 1984 and 1993).

No biological basis was provided for the selecting an asymptotic regression that provides no real improvement in fit compared to a linear regression (r^2=0.803 vs. r^2 = 0.801). No work has been done to determine if the relationship remains accurate in the years since completion of the study in 1992. It is important to note that in many recent years (5 of the last 7), the coastal drift-net landings of Altamaha River American shad have decreased to levels below the minimum observed from 1982 to 1992. Thus, the expansion from reported coastal drift gill-net landings to the adjusted Altamaha landings uses a regression relationship with no biological rationale, has not been verified in over a decade, and extrapolates data beyond the range of the regression. Another variable factor to consider is that reported coastal drift gill-net landings used to predict the "adjusted" landings is that they are estimated by proportionally allocating landings from unknown drift-net landings in the Altamaha River and unknown river landings each year to the known coastal drift-net landings, which varies from year to year.

In 1988, Gibson *et al*. assessed selected Atlantic coast rivers for the ASMFC, including the Altamaha and Savannah rivers in Georgia. An assessment for the Ogeechee River was planned, but the available data for the assessment were considered unreliable. The assessment used a Shepherd stock-recruitment model to estimate F_{msy} and MSY using long-term commercial CPUE, age composition, and mortality data. Historical F rates were estimated for the Altamaha River by multiplying a catchability coefficient, q, times total annual effort estimate, E_t. Estimates of q were obtained from

$$q = \frac{R_t}{(M_t * E_t)},$$

where R_t equals recaptures in year t and M_t equals the number of marked fish from Georgia DNR tag-return studies in year t. To get total annual fishing effort, E_t, the number of days fished was converted to equivalent fishing effort units by scaling the days fished using the long-term average CPUE (no information on the scalar or data used were provided in Gibson *et al*. 1988). An estimate of q for the Savannah River was obtained from a surplus production model (Jenson 1986 in Gibson *et al.* 1988), but the catch and effort series was not reported in Gibson *et al*. (1988). The Savannah River was the only system in the Gibson *et al*. (1988) assessment where a surplus production model was used to estimate q.

Both the Altamaha and Savannah rivers had relatively poor fits to the Shepherd stock-recruitment model ($r^2 = 0.224$ and $r^2 = 0.223$, respectively). F_{msy} was estimated at 0.550 (a 42.3% annual harvest rate) for the Altamaha River and at 1.120 (a 67.4% annual harvest rate) for the Savannah. The historical F for the Altamaha (0.573) indicated that overfishing had occurred. The Savannah River stock was fished below its F_{msy}, with a historical F of 0.416. A linear multiple regression model was developed using latitude and flow variation as independent variables to estimate F_{msy} and F rates for rivers where suitable data were not available (e.g., Ogeechee River, $F_{msy} = 1.062$, $F = 0.966$).

A second coastwide stock assessment for the years 1982 to 1997 was conducted in 1998, and the Altamaha River was the only Georgia river assessed (ASMFC 1999). In-river fishing mortality rate (F_r) estimates were developed by converting annual relative minimum exploitation rates from tag-return studies conducted in the Altamaha to instantaneous rates. Population estimates were also available from the tag-return study. Estimates of fishing mortality from the coastal ocean-intercept fishery (F_c) were developed based on the Georgia ocean-intercept fishery catches attributed to the Altamaha from coastal South Carolina tag-return studies. F_c was estimated as a log ratio of the coastal landings from the Altamaha (numbers) to the population size estimate plus the coastal landings. In 1996, estimates of stock abundance in the Altamaha River reached a time series high of 285,000 fish. Ocean-intercept landings constituted a relatively minor portion of the total Altamaha harvest and overall fishing mortality ($F_r = 0.36$ and $F_c = 0.03$). Total F ($F_t = F_r + F_c = 0.39$) was below the recommended overfishing reference point of F_{30} (0.48).

We decided not to repeat the approaches used in the last two assessments (Gibson *et al*. 1988; ASMFC 1999) because of recent uncertainties about data inputs and effects of these uncertainties in the calculation of stock recruitment characteristics, target fishing values, or current absolute values of fishing rates. In particular we were concerned about the tag-based estimators because of the host of necessary assumptions that appear to have been violated (see Section 15.10). We were reluctant to utilize the Thompson Bell, Shepherd stock-recruit, or spawning stock biomass-per-recruit approaches to estimate target fishing rate because of the uncertainty about estimating M for semelparous stocks. Finally, known and potentially variable underreporting of both ocean and river landings and stock composition of ocean landings deterred us from using landings to estimate current exploitation rates and population estimates.

15.5 STOCK-SPECIFIC LIFE HISTORY

GADNR has collected age data since completion of the previous coastwide stock assessment. Scale samples for ageing are taken from shad captured during tagging studies in the lower Altamaha River and scale samples are obtained from fish (≤20) captured in the Ogeechee River by commercial fishermen. GADNR does not sample shad from the Satilla, St, Marys, or Savannah rivers.

Age and spawning mark data are available from shad collected on the Altamaha from 1967 to 1968 (Georgia Fish and Game Commission—predecessor to GADNR), 1982 to 1991 (GADNR), and 2000 to 2005 (GADNR; Table 15.4). There are no records of repeat spawning marks in 1,311 male specimens and 2,452 female specimens examined for all years. The youngest fish observed in gill-net collections conducted by GADNR for tag-return studies are ages 2 to 4 for males and ages 3 to 4 for females. The oldest fish observed in these collections are ages 6 to 8 for males and ages 7 to 9 for females. Four to six year old shad dominate the spawning runs in the Georgia. GADNR reports that the average weight of males captured in their gill-net sampling ranged from 0.81 to 1.14 kg from 1994 through 2005 and females averaged 1.31 to 1.74 kg over the same period (Table 15.4). Depending on weather conditions, adult shad normally enter Georgia rivers from early January to the middle of April. There has been no trend in the average size of fish captured over time. In the Altamaha River, female shad carry 273,700 to 486,700 eggs, depending on the size and age of the fish (Vaughn 1967). GADNR does not routinely collect genetic samples from shad ascending coastal rivers, but has periodically collected samples for universities. Between 2000 and 2005, sampling of the Ogeechee River American shad commercial harvest showed that the harvest included females aged 2 through 8 (n = 111) and males aged 2 through 4 (n = 6); none of the fish had repeat spawning marks.

15.6 HABITAT DESCRIPTIONS

15.6.1 Altamaha River

The Altamaha River is Georgia's largest watershed, draining 37,192 square kilometers. The Altamaha is formed by the confluence of the Oconee and Ocmulgee rivers and flows for 240 km to the Atlantic Ocean (Figure 15.1a and 15.1.b). The Altamaha River is free of dams for the entire length of the river; however, dams are located on both of its major tributaries. Historically, American shad are known to have reached Cedar Shoals (near Porterdale, Georgia) on the Yellow River (approximately rkm 634), and the City of Athens, Georgia (approximately rkm 560), both in the Ocmulgee drainage (Alice Lawrence, pers. comm.). In recent years, American shad have been documented immediately below the farthest downstream dams on both the Ocmulgee River (~rkm 547) and Oconee River (~rkm 451). Neither dam currently has dedicated fish passage. The only major point source of pollution on the Altamaha is a pulp mill located at Doctortown, Georgia approximately 80 km upstream from the river mouth. Walburg and Nichols (1967) noted that shad were abundant in the Altamaha River in the late 1800s, but the transportation infrastructure was lacking to supply more than local markets. Shad are reported to spawn at least 90 to 95 km upstream and in each of the major tributaries when water temperature is between 12.3 and 22°C (Walburg and Nichols 1967; Godwin 1968; Godwin and Adams 1969).

The main stem of the Altamaha River has a large commercial fishery for American shad throughout the entire river but has no directed recreational fishery. Commercial set nets have been observed in the Ocmulgee River up to just below Abbeville, Georgia. In this area, the gear is probably being used to catch shad for personal consumption and not sold through a fish dealer. A small recreational fishery has developed below Juliette Dam near Macon, Georgia. There has been very little commercial or recreational activity observed or reported from the Oconee River.

15.6.2 Ogeechee River

The Ogeechee River rises out of the east-central piedmont and flows southeasterly for approximately 564 km to the Atlantic Ocean (Figure 15.1a). Recently, GADNR has documented American shad approximately 270 rkm upstream on the Ogeechee River. There are no barriers to upstream migration on the entire length of the Ogeechee River. During the late 1800s, shad harvest from the Ogeechee River was higher than from any other Georgia River (Walburg and Nichols 1967; Hardisky and Smith 1980). Currently the Ogeechee ranks third in commercial harvest of American shad in Georgia. A small sport fishery exists on the river, and both fisheries operate in the lower Ogeechee River. Sykes (1956) reported that the major shad spawning grounds on the Ogeechee River are between Kings Ferry, Georgia (~rkm 30) and Midville, Georgia (rkm 200).

15.6.3 Savannah River

Please see the South Carolina section (Section 14) for the Savannah River assessment.

15.6.4 Satilla River

The Satilla River rises out of the coastal plain south of Fitzgerald, Georgia and flows southeasterly 328 km to the Atlantic Ocean (Figure 15.1a). The river drains approximately 9,143 square kilometers of land. The average discharge rate of the Satilla River near Waycross, Georgia over a 52-year period was 29 cubic meters per second (cms) with extremes of 1104 cms and 0.2 cms (USGS 1990). There are no barriers to upstream migration the entire length of the Satilla River. Walburg and Nichols (1967) reported that American shad spawn near Owens Ferry (rkm 64) on the Satilla River. There are no current commercial or recreational fisheries for American shad on the Satilla River.

15.6.5 St. Marys River

The St. Marys River originates in the southeastern portion of the Okefenokee Swamp and flows 239 km to the Atlantic Ocean, draining approximately 3,900 square kilometers of land (Figure 15.1a). The average discharge rate of the St. Marys River near MacClenny, Florida over a 63-year period was 19 cms with extremes of 796 cms and 0.3 cms (USGS 1990). There are no barriers to upstream migration the entire length of the St. Marys River. Walburg and Nichols (1967) reported ripe females caught near Traders Hill and Folkstan, Georgia (~rkm 90). There are no current commercial or recreational fisheries on the St. Marys River.

15.7 RESTORATION PROGRAMS

The GADNR is developing a plan for American and hickory shads within the Altamaha River Basin with specific goals and strategies for the restoration and management that are congruent with the goals of the ASMFC Interstate Fisheries Management Plan for Shad and River Herring (GADNR 2006). The restoration plan is being developed based on the assumption that the Altamaha River American shad population pre-exploitation and pre-dam construction was much larger than today's population. Specific goals include restoration of historical American shad distribution in the basin where feasible, enhancement of the spawning population of American shad in the basin, and management for sustainable recreational and commercial fisheries. The plan recommends maintaining current monitoring efforts, such as tag-return studies and creel surveys, and regulations. It also requests improved monitoring efforts in other areas (e.g., observer coverage of set gill-net fishery to get better estimates of bycatch). Overall the plan calls to maximize "participation and harvest within recreational and commercial fisheries that is conducive to restoration objectives." Proposed measures of success are based on a population density of 50 shad per acre of available habitat upriver of present-day dams.

15.7.1 Hatchery Evaluations

There are no current hatchery based restoration efforts for American shad in Georgia, but proposed restoration objectives for hatchery programs include determining appropriate stocking rates for the Altamaha basin and developing both husbandry techniques and facilities to meet stocking recommendations. A stocking level of 3,000,000 American shad fry is proposed based on a return rate of 1 adult shad per 372 fry stocked from a Susquehanna River study and a desire to stock approximately 25 percent of the restoration target of 50 shad per acre. Based on the available habitat above the East Juliette Hydroelectric Dam (660 acres), the restoration goal for this stretch of river would be 33,000 adult fish.

15.7.2 Fish Passage Efficiency

The proposed annual fish passage goal on the Altamaha is to pass sufficient numbers of shad to populate upstream habitat with 50 fish per acre. If migrating populations cannot meet the 50 fish per acre goal, then fish passage facilities should pass 80 to 90 percent of all fish that migrate to the tailrace.

15.8 AGE

American shad are aged using the scale methodology developed by Cating (1953). No validation of scale annuli has been conducted on shad from Georgia rivers.

15.9 FISHERY DESCRIPTIONS

15.9.1 Commercial Fisheries

In Georgia, dealers are required to report commercial harvest of shad. The CRD receives dealer reports and tabulates the total commercial landings for Georgia. Landings are reported by sex, river, and gear for American shad. NMFS port agents collected commercial shad landings until 1978, when GADNR assumed this responsibility (Michaels 1993). GADNR recognized that NMFS port agent coverage focused on dealers operating in coastal and lower river locations, and that it did not account for the landings of fishermen operating in upriver locations, resulting in significant underreporting. GADNR conducted several studies to characterize the state's commercial shad fishery, as well as to determine the extent of underreporting (Hardisky and Smith 1980; Essig 1983; Michaels 1984, 1990, and 1993). Additionally, these studies identified that drift gill nets were the predominant means of shad harvest in the coastal and downriver locations, while set gill nets were most commonly employed in inland and upriver locations. Essig (1983) noted that market saturation, which was attributed to shad entering the markets from points north, occurred during the latter portions of the Georgia shad run resulting in depressed prices, possibly providing some conservation benefit to late spawning shad. Historically, Georgia has had no ocean-intercept fishery.

Currently, dealers are required to report commercial harvest of shad to the CRD. Commercial fishing effort for shad has been collected by the CRD via a trip ticket system beginning in 2000 that collects data from fishermen each time they sell their catch. These individual trip forms are then submitted to CRD and tabulated. Effort estimates include the number of fishing trips from both drift and set gill nets by river. Before the trip tickets were implemented, catch and effort data were required, but were not always able to be collected due to difficulties in enforcement. In some cases trip level data can be linked to the harvester, but in many cases only daily or weekly summaries were available.

Before 1979, commercial shad fisherman were required to hold a shad license, which was applicable for both American shad and hickory shad, but no other effort data were collected. GADNR trip level records begin in 1989; however, these data do not necessarily correspond to a single trip as “trips” could be partial trips, full trips, or combined trips before 2000 and GADNR does not consider trip level data before 2000 as an accurate measure of a trip. In order to meet coastwide commercial catch and effort data reporting standards set by the Atlantic Coastal Cooperative Statistics Program, trip ticket reporting was implemented in 2000 that included information on gear quantity, soak time, and number of sets. Reporting of these factors has improved in recent years (since 2004), which should permit more specific estimates of effort and CPUE in future years. Upriver effort and landings sampling estimates remain troublesome to quantify and have not been examined since 1992 (Michaels 1993).

15.9.2 Bycatch Losses

Commercial shrimp trawling is the only commercial fishery in Georgia to which shad are vulnerable. Since commercial shrimp fishermen are required to use bycatch reduction devices in their nets, shad are rarely caught in commercial shrimp trawling off the Georgia coast (Ottley *et al*. 1998; Gaddis *et al*. 2001; Page *et al*. 2004).

15.9.3 Recreational Fisheries

Harvest of both American and hickory shad in the Ogeechee River is estimated through an access creel survey conducted once every five years.

15.10 FISHERY-INDPENDENT SURVEYS

15.10.1 Tagging Studies

Relative minimum exploitation rates and population estimates have been estimated using tag-return methodology on an annual basis since 1982. GADNR collects American shad for its tag- return program from the Altamaha River by utilizing drift gill nets with a mesh sizes from 11.4 to 13.3 cm (mostly between 11.4 and 12.7 cm). Six to eight tagging locations from rkm 17 to rkm 37 have been used since the early 1990s, when use of tagging sites in Altamaha Sound ended. American shad are sampled at least once a week during the entire shad season (January 1 to March 31), and are tagged with a standard T-bar floy tag. Tide, river flow, and capture success dictate allocation of the sampling effort. Tagging is conducted on the weekends (when the Altamaha River commercial fishery is closed) to avoid interference with commercial fishermen and to ensure that tagged fish have at least 12 hours to disperse before the fishery reopens. The gear utilized during GADNR sampling efforts is essentially the same gear used by commercial fishermen. A reward system is utilized to encourage commercial fishermen to return the tags. The rewards are $4, $10, or $100 per tag, with the values randomly assigned.

Relative minimum exploitation rates for the Altamaha River population were estimated as the ratio of the number of recaptured tags to the number of tags released. GADNR estimates population size by dividing the adjusted Altamaha River American shad landings in numbers, by the exploitation rate estimates. Landings in numbers are estimated by converting the adjusted Altamaha River American shad landings from weight to numbers by dividing by an annual average weight.

There are several assumptions used when developing exploitation estimates from the tag-return study: (1) there is no post-tagging loss of tags; (2) there is no tag mortality; (3) all recovered tags are reported; (4) age and size distribution of tagged fish mimics that of the populations; (5) tagged fish randomly mix with untagged fish; and (6) all tagged fish continue upriver and do not stop their migrations after tagging. Violations of assumptions 1, 2, 3, and 6 would artificially decrease estimates of exploitation and increase estimates of population size. If tagged fish were a subset of the population, exploitation estimates would be biased higher if the tagged subset were the fished subset and biased lower if it was not. Violation of assumption 5 could bias exploitation estimates in either direction depending on whether tagged fish were more or less vulnerable to harvest than the untagged fish. None of these assumptions have been tested for the GADNR tagging study. However, we suspect that assumptions 1, 2, 3, and 6 are violated to some degree; thus, estimated relative minimum exploitation rates are biased. The following studies support our argument. Leggett (1976) indicated that there was a 3 percent tag loss in American shad tagged in the Connecticut River. Olney *et al*. (2006) and Hightower and Sparks (2003) show that some acoustically tagged American shad on the York River, Virginia and the Roanoke River, North Carolina may delay or abandon their migration entirely.

In addition, the reward component of the tag-return program is a lottery program rather than a high-reward study. The purpose of conducting a high-reward study is to determine the difference in reporting rate between regular low-reward tags and high-reward tags that should be returned at a higher rate (approaching 100%). The reward program should be well advertised and reward tags should be easily differentiated from regular tags. The GADNR lottery system, which is based on a single batch of tags that does not distinguish differing reward levels, does not achieve this goal. Given the concerns with the tagging data, these data and estimates were only used to corroborate trends from the other indicators of fishery and stock condition for the Altamaha River.

Use of exploitation estimates and landings data to estimate population size requires satisfying all of the assumptions of exploitation rate estimation, as well as the assumption that landings are reported accurately. Since we know that substantial underreporting occurs and that underreporting varies among years (see Section 15.11.2), we know that this last assumption is also violated. Underreporting would bias population estimates lower in proportion to the level of underreporting. Given the uncertainties of all of the assumptions involved in population estimates, we decided not to use them in this assessment. Please see Appendix I for discussions and simulations addressing tag-return assumptions.

Complete records of catch and effort were retained for the GADNR gill-net tagging collections, which permitted examination of the data to develop an index using the “area under the curve” (AUC) from 1986 to 2005 as described by Wilhite *et al*. (2003) and Olney *et al*. (in this volume), which accounts for the magnitude and duration of the annual spawning migration.

15.10.2 Juvenile Abundance Index Data

A juvenile survey was conducted from 1982 to 1991 in the Altamaha River (Table 15.6; Figure 15.4), but was discontinued because the juvenile abundance index did not relate to recruitment to the adult spawning stock based on a regression of returning spawners (year t+5) and the juvenile survey catch rates, nor did it relate to the parent stock that produced it. Independent validation in this assessment (as per Section 12) of this juvenile abundance index in this assessment was not possible as the fishery-independent CPUE AUC was not age-specific and the overlap between the two indices was only 5 years. A juvenile survey was conducted from 1982 to 1985 on the Ogeechee River.

15.11 ASSESSMENT AND RESULTS

15.11.1 Statewide Commercial Fishery Summary

Historical records of American shad landings in Georgia date back to 1880[1] (114,307 kg; Figure 15.5). Landings increased to 466,754 kg by 1902 and reached a time series high of 604,643 kg in 1908, before decreasing to 45,814 kg in 1918. The fishery rebounded by 1929 with landings of 214,099 kg. Over the next thirty years, landings fluctuated between 30,000 kg and 180,000 kg. In the 1960s, landings reached a second peak of consistently high landings, sustaining average annual harvests of nearly 200,000 kg. The shift from multifilament to more effective monofilament mesh in gill nets around 1960 might have contributed to the increased landings during that decade. Since the 1970s, landings have consistently declined to current low levels. An all-time low of 11,579 kg of American shad was landed in 2002 and 18,071 kg were landed in 2005. No information is available to determine whether historical fluctuations (pre-1980s) in landings were attributed to changes in effort, catchability, or abundance of American shad in Georgia rivers. When comparing the historical total American shad landings for Georgia (e.g., Figure 15.5) to the total landings based on the landings presented by river (Table 15.6; Figure 15.6) note that the landings reported in Figure 15.5 include landings from "unknown" river and that GADNR has no river-specific data for the Savannah River or the Ogeechee River from 1983 to 1988.

A comparison of the commercial shad license data from 1953 to 1979 with landings data over the same time period yields interesting trends (Figure 15.7). From 1953 to the early 1960s, landings and the number of licenses increased. Landings jumped from around 100,000 kg a year in the early to mid-1950s to 241,950 kg in 1960 and 239,138 kg in 1962. Licenses increased from 290 in 1953 to 1,187 in 1963. The number of annual licenses averaged approximately 1,000 per year for the rest of the time series (note that no data are available from 1973 to 1975). In contrast, landings were high throughout the 1960s peaking at 280,189 kg in 1969 before experience a rapid decline to 42,049 kg in 1976. Landings rebounded to 121,509 kg by 1979. Landings by river are reported in Table 15.7 and Figure 15.6. Note that licenses are a coarse estimate of effort.

From 1989 to 2005, there have been a total of 1,005 set net trips reported in Georgia waters compared to 5,206 drift set net trips (6,211 total reported trips; Table 15.8). The number of reported set net trips has been cyclic since 1989. Generally, the number of reported trips increased through the late 1990s and then dropped before peaking again in 2004 and 2005. Total annual drift net trips for American shad have been stable with a brief spike in trips in 1999 and 2000.

15.11.2 Altamaha River

Landings data for the Altamaha River are available from 1962 to 2005 (Table 15.7; Figure 15.6). From 1962 to 1973, unadjusted reported landings from the Altamaha River averaged 188,624 kg. The Altamaha River (unadjusted landings) accounted for 64 percent of all reported in-river shad landings since 1962 and has produced the highest river-specific landings in all but six years in that period.

Reported unadjusted landings peaked in 1968 at 213,963 kg and then declined steadily to the early 1980s. From 1983 to 1988 landings average 122,150 kg, before declining to an average of 44,675 kg from 1989

[1] Annual reports of the United States Fish Commission 1871 to 1940. Statistics of the Fisheries of the (Middle-New England) Atlantic States. Division of Statistics and Methods of the Fisheries, United States Fish Commission. Obtained from NOAA Central Library Data Imaging Project:
http://docs.lib.noaa.gov/rescue/cof/data_rescue_fish_commission_annual_reports.html

to 1994. Landings increased briefly from 1995 to 1998, averaging 106,646 kg annually, and then declined to a mean of 30,535 kg a year from 1999 to 2005. Landings in 2005 were 25,653 kg.

Results from the roving commercial survey conducted from 1982 to 1991 indicated that annual shad drift-net landings from the Altamaha River were greatly underreported (see Section 15.4; Table 15.3; Figure 15.3). Landings data adjusted for underreported drift gill-net landings in 1965 to 1967 and from 1982 through 2005 are also reported in Table 15.7. Renewing efforts to determine accuracy of reporting would be helpful to determine the contemporary accuracy of reported landings.

Relative minimum exploitation rates for male shad were consistently lower than those for females and rates for both sexes consistently decreased over the duration of the program (Table 15.9). From 1982 to 1990, relative minimum exploitation rates averaged 51.2% annually for females and 27.3% for males. Since 2000, average relative minimum exploitation rates fell to 28.2% for females and 7.4% for males.

Catch-per-unit-effort data are available for the GADNR gill-net tagging collections since 1982, but data were insufficient for calculating an AUC index from 1982 to 1985 (Table 15.10; Figure 15.8). The AUC approach had low values from 1986 to 1994, before peaking from 1993 to 1998 (range: 1.40 to 3.05). In recent years the AUC estimates have decreased, averaging 1.13, with a peak of 2.52 in 2003. Over this period the American shad season length varied from 56 to 103 days and sampling occurred from a minimum of 9 days in 1997 to a maximum of 25 days in 1988.

Although the AUC indices fluctuated radically between some years, we felt that it provided a usable index of change in abundance over time. Plots of seasonal CPUE values by day suggested that sampling encompassed maximum period of abundance in most years (Appendix II, Figures AII.1a to AII.1t). Frequency distributions of CPUE suggested data distributions that were not skewed and often were relatively symmetrical (Appendix II, Figures AII.2a to AII.2t). Finally, plots of annual AUC indices on sample season length showed no obvious relationship suggesting that the variable season length did not seriously affect annual AUC estimates (Appendix II, Figure AII.3). We feel that the interannual fluctuations were likely affected by environmental conditions that might have altered capture efficiency among years.

The number of reported commercial gill-net trips on the Altamaha River has increased dramatically since 1989. Before 1998 fewer than 100 trips were reported annually and the annual average number of trips was 13.2 per year for set gill nets and 34.2 per year for drift gill nets. Since then the number of reported trips has averaged 40.5 per year for set gill nets and 253.3 for drift gill nets (Table 15.11). From 1989 to 1994, the number of reported set gill-net trips was less than 15 per year; therefore, given the uncertainty in reporting, it is difficult to assess any trends in effort over this period. Since 2000, CPUE peaked in the drift gill-net fishery in 2004 before declining in 2005 (Table 15.12; Figure 15.9). Possible confounding factors include incomplete record keeping by commercial fishermen (e.g., might not detail changes in gear or sites during a specified trip) and unknown variability of underreporting rates of catch and effort data over time.

15.11.3 Ogeechee River

A total of 94,689 kg of shad was harvested from the Ogeechee River in 1896, all of which was harvested using drift gill nets (Walburg and Nichols 1967). Modern records of American shad landings for the Ogeechee River begin in 1960 (21,620 kg; Table 15.7; Figure 15.6). Landings declined to 5,942 kg by 1965, rebounded to 59,512 kg in 1967, and declined again to 15,604 kg in 1968. From 1969 to 1975, landings averaged 22,680 kg with a peak of 60,510 kg in 1973, and fell to an average of 11,298 kg from 1977 to 1982. No landings were collected by GADNR on the Ogeechee River from 1983 and 1988.

Landings averaged 1,483 kg per year from 1989 to 1997, with a low of 122 kg in 1992. Since 1998, landings averaged 268 kg annually, with lows of 17 kg in 2003 and 69 kg in 2005.

Due to the low number of annual trips for both set (0 to 21) and drift (0 to 46) gill-net fisheries and the issues related to trip reporting prior to 2000, little information can be drawn from these data except that the number of trips peaked on the Ogeechee River in 1995 and 1996 before improved trip level reporting was implemented (Table 15.13). Since 1989, there were seven years where no set gill-net landings were reported and two years where no drift gill-net landings were reported.

Harvest of both American and hickory shad in the Ogeechee River was estimated through an access creel survey conducted in 1996, 2000, and 2005 (Table 15.14). In 1996, the estimated harvest was 1,239 fish, weighing 1,421 kg, with effort equaling 2,604 hours. Harvest of American shad in 2000 was estimated to be 295 fish, weighing 382 kg, caught in 1,193 hours. During the 2005 survey the estimated harvest was 442 fish, weighing a total of 379.9 kg, and overall effort was estimated to be 1,754 hours.

15.11.4 Savannah River

Please see the South Carolina chapter (Section 14) for the Savannah River assessment.

15.11.5 Satilla River

Walburg and Nichols (1967) reported 2,536 kg of American shad were taken in 1896 and 10,067 kg taken in 1960. Since 1962, American shad landings have been reported in only 6 years, with the last report from 1982, for a total harvest of 40,410 kg. Reported landings ranged between 1,588 kg in 1982 and 13,018 kg in 1969.

15.11.6 St. Marys River

Walburg and Nichols (1967) reported that total removals (Florida and Georgia) of American shad from the St. Marys River were 13,059 kg in 1896 and 10,893 kg in 1960. No landings have been reported from the St. Marys since 1989 (272 kg); the Florida net ban has effectively ended commercial gillnetting in the St. Marys River. Since 1962, American shad landings have been reported in 11 years for a combined harvest of 27,183 kg, with a peak of 15,876 kg in 1979 and a low of 45 kg in 1979.

15.12 BENCHMARKS

No benchmarks were developed for American shad in Georgia rivers.

15.13 CONCLUSIONS AND RECOMMENDATIONS

Overall, shad landings are much reduced compared to historical data, with no landings data available from either the St. Marys River or the Satilla since the 1980s. Participation in the commercial shad fisheries of Georgia appears to be waning based on GADNR personnel's observations and communications with commercial shad fishermen. Trends in effort are difficult to ascertain as dependable trip level reporting has only been in place since 2000. Georgia's American shad populations may show signs of recovery in upcoming years due to the closure of the commercial ocean-intercept fishery.

If current or future monitoring programs do not see a recovery or see evidence of continued declines and there is evidence of declining participation (i.e., effort), then effort should not be increased on any river system. Some studies referred to in this stock assessment suggest that annual fluctuations of environmental factors, especially river flow, influence the strength of American shad spawning runs.

Studies to investigate this observation should be conducted to determine the extent of environmental variability on shad spawning runs.

15.13.1 Conclusions

Altamaha River

The Altamaha River has been the major source of shad landings in Georgia since 1960 (Walburg and Nichols 1967); however, since then landings have steadily decreased and are currently at all-time low levels. Landings since 2000 are an order of magnitude lower than in the 1960s, but effort data are not of sufficient quality or duration to provide insight into potential causes of the decline. From 1995 through 1998, landings ranged from 94,274 kg to 121,811 kg, before declining to the current low levels. The lone CPUE series spanning sufficient time to provide insight on recent population trends was from the GADNR tag-return study collections, which was used to develop an area under the curve estimate of the seasonal catch in numbers per ft net-hour. This index only provides a view of the stock for the last two decades. A rise in the area under the curve index begins in 1989 and peaks in the mid to late 1990s before decreasing to low levels since 1999 (Table 15.15). Other indices are of short duration (recent commercial drift gill-net CPUE) or were terminated in the early 1990s (roving commercial gill-net survey; Table 15.15). Commercial effort records (number of trips) are available since 1989, but are not considered reliable before 2000,with the increase in trips after mandatory reporting caused by changes in reporting rates and not increased effort.

In summary, the Altamaha River American shad fishery and stock appear to be at depressed levels compared to 1960s and earlier. The AUC index indicates a brief increase in the stock from 1995 through 1998, before decreasing to current low levels (Table 15.15; Figure 15.10).

Ogeechee River

Commercial landings of Ogeechee River American shad have fallen to nearly nothing in the river that once yielded Georgia's greatest American shad harvest (Walburg and Nichols 1967). Landings since 1998 have averaged 268 kg per year (lows of 17 kg in 2003 and 69 kg in 2005) compared to an annual average of 22,680 kg from 1969 to 1975 and 94,689 kg in 1896. Commercial effort (i.e., reported trips) in the Ogeechee River has been low. Since 1989, there have never been more than 67 (1995) trips reported (drift and set gill nets combined) and from 2002 to 2005 there have been 7, 2, 5, and 3 trips per year (both drift and set nets combined). The Ogeechee River recreational creel survey indicates a decrease in the number harvested from 1996 (1,239 fish) to 2000 and 2005 (295 and 442 fish, respectively; Table 15.14).

Fishing rate increases are not warranted until usable indicators of stock status can be developed to guide further management activities.

Savannah River

Please see South Carolina chapter (Section 14) for conclusions on Savannah River stock status.

Satilla River and St. Marys River

No recent data exist to evaluate stock status. We recommend that some form of monitoring these rivers be conducted to characterize shad spawning runs and that would document whether these stocks can sustain or increase their current population levels and provide insight as to whether or not these stocks are depleted to a level where they are at risk of extirpation. Until monitoring is in place, fishing on these stocks is not recommended.

15.13.2 Research Recommendations

1. Develop stock-specific age validation studies.
2. Develop of reliable estimates of natural mortality for Georgia's American shad stocks.
3. Evaluate the use of historical spawning sites of American shad in the Altamaha Basin.
4. Study fish passage efficiency.
5. Improve tagging program design in order to develop accurate estimates of exploitation. Such changes would be to use a true high reward study design and to conduct tagging mortality, fall back, and tag retention studies.
6. Maintain and continue to improve commercial catch and effort reporting to aid stock status determination for all Georgia rivers.
7. Perform a fishery-independent survey on the Ogeechee River.
8. Develop of reference points for Georgia American shad stocks.
9. Investigate development of juvenile surveys using gears other than trawl, such as push nets or beach seines.
10. Investigate influence of environmental factors on American shad spawning run strength.

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Table 15.1 Summary of commercial and recreational American shad regulations in Georgia waters. In addition, the first impoundment, if applicable, is noted and the status of each fishery.

River	Impoundments (first)	Season	Commercial Gear Restrictions	Commercial Active Fishery	Recreational Creel Limits	Recreational Active Fishery
Altamaha River	On tributaries - Ocmulgee River (rkm 547) and Oconee River (rkm 451)	January 1 to March 31 Monday - Friday	Set and drift gill nets; minimum mesh size 4.5"	Yes	8 fish/day (American shad, hickory shad, or both)	No
Savannah River	Yes - first at rkm 301	January 1 to March 31	Set and drift gill nets; minimum mesh size 4.5"	Yes	8 fish/day (American shad, hickory shad, or both)	Yes
Below I-95 bridge		Tuesday – Friday				
Above I-95 bridge		Wednesday - Saturday				
Ogeechee River	None	January 1 to March 31 Friday and Saturday	Set and drift gill nets; minimum mesh size 4.5"	Yes	8 fish/day (American shad, hickory shad, or both)	Yes
St. Marys River	None	January 1 to March 31 Monday - Friday	Set and drift gill nets; minimum mesh size 4.5"	No	8 fish/day (American shad, hickory shad, or both)	No
Satilla River	None	January 1 to March 31 Monday – Friday	Set and drift gill nets; minimum mesh size 4.5"	No	8 fish/day (American shad, hickory shad, or both)	No

Table 15.2 Number of commercial shad licenses (American and hickory) in Georgia, 1953-1979. The shad license was abolished in 1979. After 1979, only a general commercial fishing license was required. No data are available from 1973 to 1975.

Year	Statewide Shad License Sales
1953	299
1954	447
1955	353
1956	353
1957	481
1958	329
1959	439
1960	600
1961	769
1962	832
1963	1187
1964	1015
1965	613
1966	1115
1967	935
1968	981
1969	1027
1970	1035
1971	830
1972	1083
1973	no data
1974	no data
1975	no data
1976	925
1977	975
1978	1106
1979	1194

Table 15.3 Results from the Georgia Department of Natural Resources roving commercial survey conducted from 1982 to 1991, which surveyed the entire Altamaha River American shad fishery, compared to the coastal drift net landings reported for the same period. One SFU Day = one drift gill net, 91.4 m long, fished for 4 hours in the lower river.

Year	**Creel Survey Effort (Net hours)**	**Creel Survey Harvest (Numbers)**	**Creel Survey Harvest (kg)**	**Creel Survey (kg/net hour)**	**Creel Survey (Fish/SFU day)**	**Coastal Drift Net Landings (kg)**
1982	93,655	55,260	97,588	1.04	12.3	74,496
1983	133,188	78,035	133,189	1.00	15.3	141,306
1984	190,648	69,081	120,028	0.63	14.7	119,306
1985	186,487	93,749	162,638	0.87	26.8	
1986	18,052	41,876	7,844	0.43	22.5	89,023
1987	186,671	63,765	113,152	0.61	18.8	160,210
1988	170,897	54,532	91,964	0.54	26.1	78,170
1989	143,827	51,396	92,156	0.64	15.6	81,385
1990	166,383	31,932	59,047	0.35	15.7	41,488
1991	131,753	29,506	51,711	0.39	13.6	32,933

Table 15.4 Age records of male and female American shad collected in Georgia Department of Natural Resources annual gill-net collections for its tag-return project.

Male	Year																
Age\Year	1967	1968	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2000	2001	2002	2003	2004	2005
2													1					
3	27	34				12	1	2	3	4			55	1	3	8	10	1
4	101	134	2	2	5	58	12	18	17	15	4	8	40	34	29	33	42	8
5	90	83	2	7	1	28	18	19	15	32	8	9	12	21	40	38	24	13
6	2	7				2	2	6	1	6		2	10	11	22	13	13	3
7	2							1					3	4	5	6		2
8															1	2		

Female	Year																	
Age\Year	1967	1968	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	2000	2001	2002	2003	2004	2005
2																		
3	4	2							2				39		3		1	
4	169	115	4	3	2	16	4	15	24	9	14	21	31	47	13	12	15	5
5	412	279	15	31	5	50	18	45	50	64	55	54	25	35	40	32	45	39
6	87	33	9	22	4	27	25	30	26	24	29	24	10	25	33	38	26	51
7	4	3	1	4	1	7	5	10	6	3	2	1	3	14	7	16	12	5
8	2	1												8	4	6	1	
9															1	2		

Table 15.5 Number of fish and total weight of American shad samples collected from commercial fish buyers used to calculate the average weight of male and female American shad harvested from the Altamaha River, Georgia, 1994-2005.

Year	Female			Male		
	Number	Total Wt. (kg)	Mean Wt. (kg)	Number	Total Wt. (kg)	Mean Wt. (kg)
1994	4364	6402.1	1.47	347	334.4	0.96
1995	7111	11191.7	1.57	738	771.3	1.05
1996	9137	13744.1	1.50	910	903.1	0.99
1997	6899	9979.2	1.45	526	498.1	0.95
1998	1324	1973.2	1.49	267	280.1	1.05
1999	1552	2131.9	1.37	166	134.8	0.81
2000	2214	3606.1	1.63	145	157.4	1.09
2001	686	1043.3	1.52	84	93.0	1.11
2002	831	1360.8	1.64	363	339.3	0.93
2003	600	1043.3	1.74	298	308.0	1.03
2004	228	386.3	1.69	128	145.6	1.14
2005	2875	4347.3	1.51	193	179.6	0.93

Table 15.6 Catch-per-unit-effort (number/1000m^3) of juvenile American shad in the Altamaha River and Ogeechee River, Georgia. Estimates of percent standard error standard error and were only available for the Altamaha River data series.

Year	Altamaha River		Ogeechee River
	CPUE	**%S.E.**	**CPUE**
1982	9.7	31.4	1.4
1983	1.9	18.1	2.5
1984	15.9	21.0	2.1
1985	1.1	22.0	0.9
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	

Table 15.7 Directed commercial gill-net (set and drift) landings (kg) of American shad in Georgia, including total harvest and harvest by river system, 1962-2005. Total landings are for the river-specific landings reported below and include unadjusted Altamaha River landings. Landings not attributed to a river (i.e., unknown landings) are not included.

Year	Total Landings	Altamaha River Unadjusted	Altamaha River Adjusted	Savannah River	Ogeechee River	Satilla River	St. Marys River
1962	239,134	166,108			58,650	10,977	3,402
1963	150,275	111,948			29,303	7,348	1,678
1964	142,428	93,215		33,022	13,699	1,588	907
1965	170,687	117,664	72,036	47,084	5,942		
1966	175,041	114,216	114,276	27,171	33,657		
1967	151,545	83,372	105,114	318	59,512		8,346
1968	258,003	213,963		24,132	15,604		4,309
1969	280,184	184,933		53,797	28,032	13,018	408
1970	241,084	156,673		43,591	40,824		
1971	190,509	109,726		25,583	55,203		
1972	155,967	70,013		25,447	60,510		
1973	108,629	34,876		33,929	39,826		
1974	73,314	24,916		26,263	22,136		
1975	82,512	39,421		20,412	22,680		
1976	42,051	25,994		6,350	9,662		45
1977	53,496	23,242		20,820	9,435		
1978	107,932	59,377		38,161	10,396		
1979	121,507	43,791		46,272	15,571		15,876
1980	85,497	30,901		45,345	7,892		1,361
1981	88,824	45,211		26,327	13,915	3,372	
1982	145,744	41,430	97,607	31,239	12,216	4,107	578
1983	133,212	65,302	133,214				
1984	120,049	61,124	120,051				
1985	0	50,986					
1986	78,457	44,231	78,459				
1987	113,171	87,758	113,173				
1988	91,980	39,559	91,981				
1989	112,539	38,893	92,173	17,855	2,241		272
1990	77,445	20,903	59,058	14,563	3,826		
1991	71,002	16,778	51,721	18,799	483		
1992	85,009	22,772	65,657	19,232	122		
1993	65,183	18,983	57,096	7,812	277		
1994	77,153	21,887	66,834	9,892	428		
1995	119,406	55,253	97,918	18,365	3,124		
1996	120,781	50,750	104,136	14,859	1,789		
1997	106,484	42,763	93,748	11,680	1,058		
1998	148,540	44,733	95,636	52,557	350		
1999	50,752	14,383	45,328	4,983	442		
2000	66,029	18,730	60,939	4,657	434		
2001	60,704	18,150	54,604	5,750	351		
2002	30,813	8,491	28,734	1,729	351		
2003	38,798	11,916	37,002	1,780	17		
2004	29,416	13,648	25,873	3,410	134		
2005	41,529	11,636	35,095	6,366	69		

Table 15.8 Total commercial set and drift gill-net trips targeting American shad in Georgia, 1989-2005. Before 2000, the number of reported trips included single trips, as well as, partial and multiple trips reported as single trips. Since 2000, compliance and trips level reporting have improved.

Year	**Set Gill Net**	**Drift Gill Net**	**Total**
1989	68	225	293
1990	21	297	318
1991	9	296	305
1992	23	258	281
1993	31	259	290
1994	63	191	254
1995	49	433	482
1996	70	244	314
1997	95	227	322
1998	111	243	354
1999	77	585	662
2000	43	570	613
2001	27	337	364
2002	60	234	294
2003	37	332	369
2004	114	171	285
2005	107	304	411

Table 15.9 Estimated exploitation rates of American shad by sex and sexes combined from the Altamaha River, Georgia, based on tag-return studies conducted by Georgia Department of Natural Resources, 1967-2005.

Year	**Male**	**Female**	**Combined**
1967			48.7
1968			43.3
1982	34	64.2	52.1
1983	18.4	47.2	32.3
1984	17.2	49.6	35.4
1985	25.2	48.4	43.6
1986	33.9	55.2	51.7
1987	27.7	48.3	46.5
1988	20	44.8	42.5
1989	39.7	56.6	53.3
1990	30	46.5	45.3
1991	10	41.7	39.3
1992	10	39.7	37.9
1993	4.8	30.7	26.4
1994	8	35.7	25.9
1995	20.3	48.6	33.3
1996	17.2	35.6	26.4
1997	11.2	33.2	25
1998	14.7	35.8	29
1999	4	25.8	23.2
2000	12	39	27
2001	8.3	37.7	30.8
2002	12.7	29.1	23.5
2003	10.4	24.1	17.7
2004	9.3	16.6	13.7
2005	7.4	22.6	20.3

Table 15.10 Fishery-independent catch-per-unit-effort (CPUE – number caught per foot-hour) of American shad developed from GADNR gill-net tagging data for the area under the curve for number of fish caught per ft hour of net over a shad spawning season on the Altamaha River, 1986-2005. Season length, number of days sampled and total effort of GADNR tagging efforts are also presented as is the Commercial gill net CPUE from the Altamaha River, Georgia.

Year	**Season Length**	**Days Sampled**	**Total Effort**	**CPUE (AUC)**	**Commercial CPUE**
1986	78	20	30204	0.77	
1987	56	14	23604	0.70	
1988	78	25	42621	0.84	
1989	77	22	26241	0.92	711.88
1990	76	20	31131	0.61	960.17
1991	96	22	31095	1.02	998.66
1992	90	18	25329	0.90	649.52
1993	80	19	23988	1.40	282.56
1994	83	23	28464	1.99	421.80
1995	79	12	17163	2.37	710.91
1996	103	15	19212	3.05	781.10
1997	60	9	16689	1.46	470.89
1998	77	11	12777	2.75	335.63
1999	77	20	26976	0.96	25.64
2000	87	19	28323	1.48	42.06
2001	78	19	26538	0.75	40.86
2002	78	16	31560	0.77	41.10
2003	64	13	20667	2.52	50.62
2004	77	16	17868	0.71	76.05
2005	86	15	25554	0.56	48.79

Table 15.11 Commercial set, drift, and total gill-net trips targeting American shad on the Altamaha River, Georgia, 1989-2005. Before 2000, the number of reported trips included single trips, as well as partial and multiple trips reported as single trips. Since 2000, compliance and trip level reporting have improved. Exact values may not be reported due to data confidentiality.

Year	Altamaha River		
	Set Gill Net	Drift Gill Net	Total
1989	<15	33	37
1990	<15	<15	<15
1991	<15	<15	<15
1992	<15	16	21
1993	<15	52	61
1994	<15	29	32
1995	<15	55	68
1996	<15	30	44
1997	30	33	63
1998	56	79	135
1999	34	498	532
2000	<15	465	479
2001	<15	258	272
2002	40	185	225
2003	36	273	309
2004	84	107	191
2005	55	232	287

Table 15.12 Set and drift gill-net catch-per-unit-effort (kg/trip) on the Altamaha River, Georgia of American shad, 2000-2005.

Year	Set Gill Net (kg/trip)	Drift Gill Net (kg/trip)
2000	67.1	88.7
2001	141.9	73.8
2002	90.9	79.6
2003	165.3	74.0
2004	185.3	126.5
2005	96.7	87.0

Table 15.13 Commercial set, drift, and total gill-net trips targeting American shad on the Ogeechee River, Georgia, 1989-2005. Before 2000, the number of reported trips included single trips, as well as partial and multiple trips reported as single trips. Since 2000, compliance and trip level reporting have improved. Exact values may not be reported due to data confidentiality.

Year	Set Gill Net	Drift Gill Net	Total
1989		<15	<15
1990	<15	<15	<15
1991	<15	<15	<15
1992	<15		<15
1993		16	16
1994		<15	<15
1995	21	46	67
1996	<15	24	38
1997	20	15	35
1998	<15	<15	17
1999	<15	<15	<15
2000	<15	<15	<15
2001			
2002		<15	<15
2003		<15	<15
2004	<15	<15	<15
2005		<15	<15

Table 15.14 Harvest estimates of American shad from the Ogeechee River recreational creel survey conducted in 1996, 2000, and 2005.

Year	Harvest No.	Harvest Wt (kg)
1996	1,239	1,421
2000	295	382
2005	442	380

Table 15.15 Summary of trend indices for American shad on the Altamaha River Georgia. A nonlinear (quadratic) regression was conducted on the Area Under Curve index, and a linear regression was fit to both the Roving Commercial Creel Net Survey and the Commercial Drift Net CPUE.

System	Index	Gears	Years	Slope	P-value	R-square	Conclusion
Altamaha River	Area Under Curve	Drift Gill Net	1986 to 2005	a= -0.014, b= 0.323, c= -0.018	a= 0.012, b= 0.009, c= 0.971	0.338	Nonlinear trend: Increases to mid-1990s and then declines to present
	Roving Commercial Creel Survey	Set and Drift Gill Net	1982 to 1991	0.080	0.899	0.002	Non-significant positive slope and poor fit
	Commercial CPUE	Drift Gill Net	2000 to 2005	4.107	0.446	0.151	Non-significant positive slope and poor fit

Figure 15.1a Map of southeastern river systems, including Georgia shad river systems.

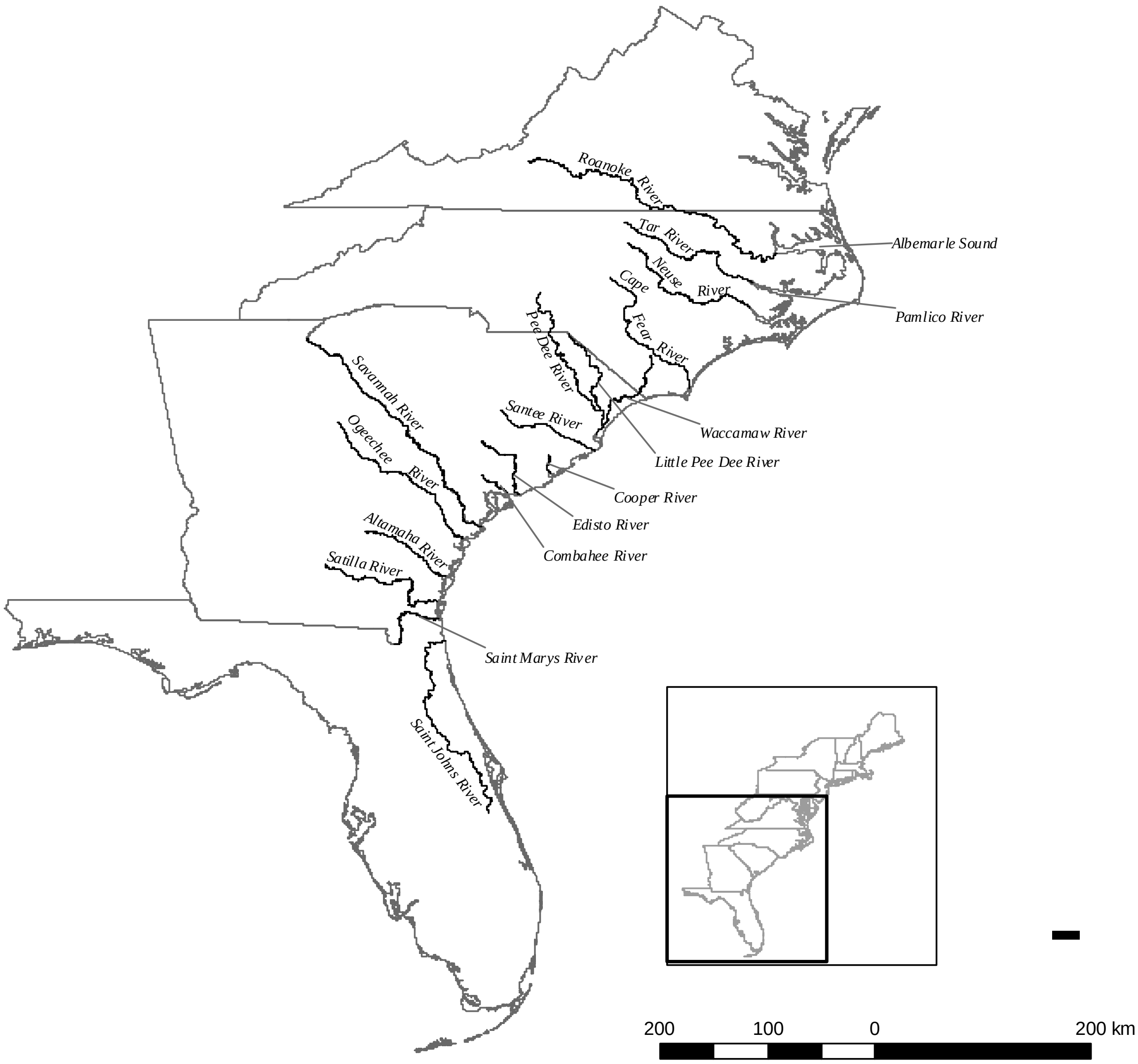


Figure 15.1b Map of Altamaha River, GA with dam locations identified with black circles.

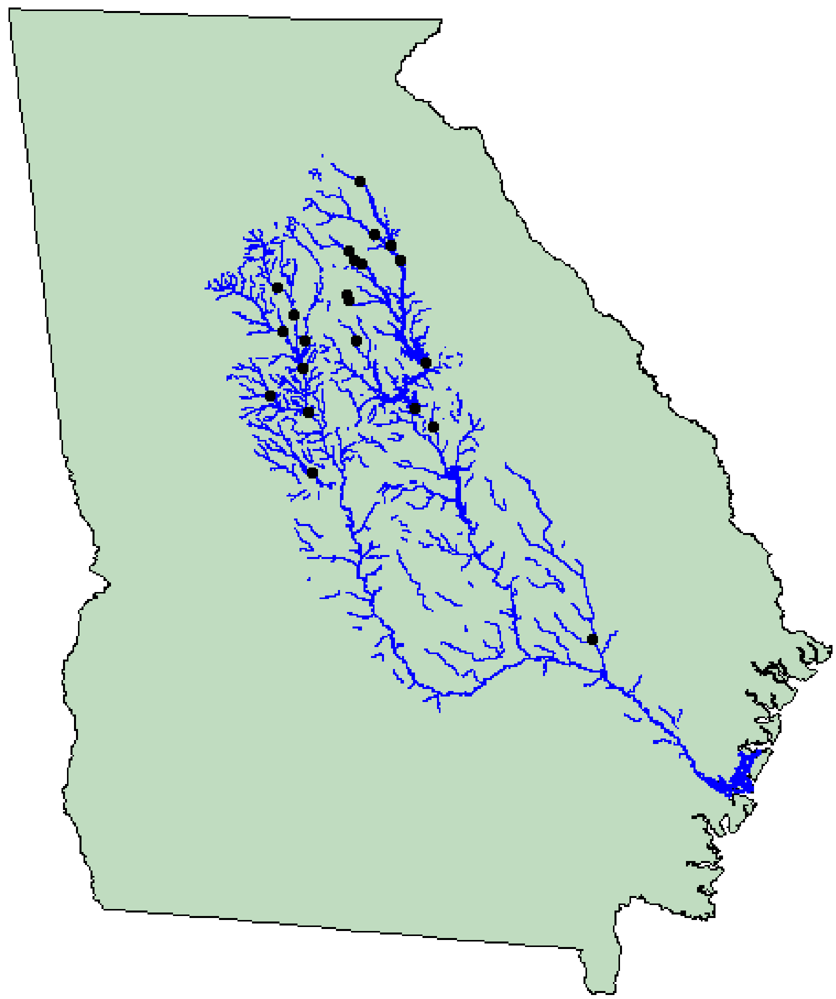


Figure 15.2 Number of commercial shad licenses (American and hickory) in Georgia from 1953 to 1979. The shad license was abolished in 1979. After 1979, only a general commercial fishing license was required. No data are available from 1973 to 1975.

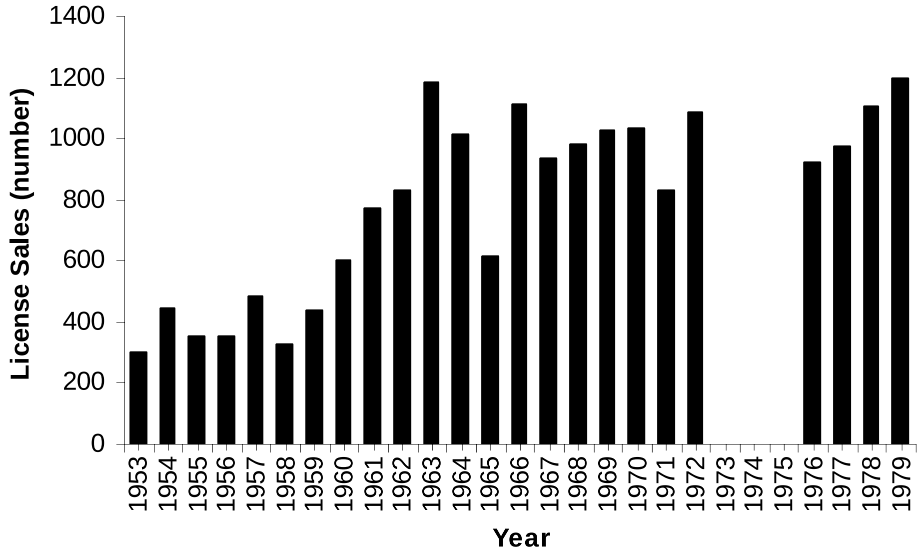


Figure 15. 3 Results from the roving commercial gill-net survey conducted, 1982-1991 investigating underreporting annual American shad drift and set net landings from the Altamaha River, Georgia. CPUE = fish/SFU Day. One SFU Day = one drift gill net, 91.4 m long, fished for 4 hours in the lower river.

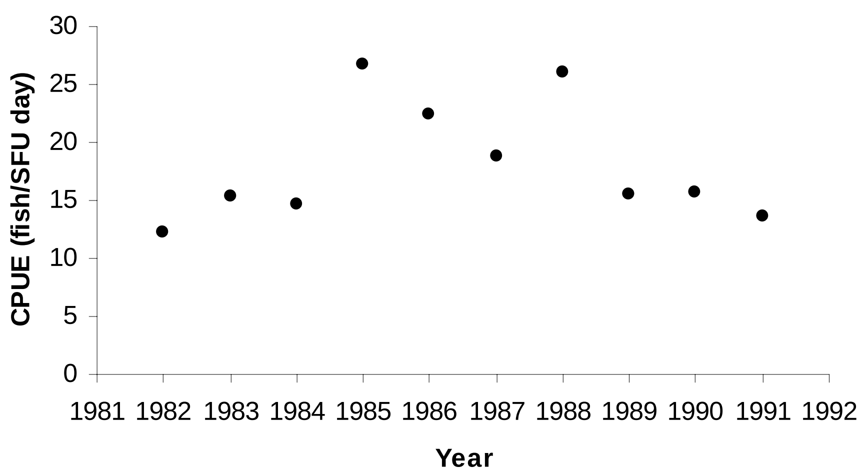


Figure 15.4 Catch-per-unit-effort (number/1000m^3) of juvenile American shad in the Altamaha River and Ogeechee River, Georgia. Error bars indicate percent standard error and are only available for the Altamaha River data series.

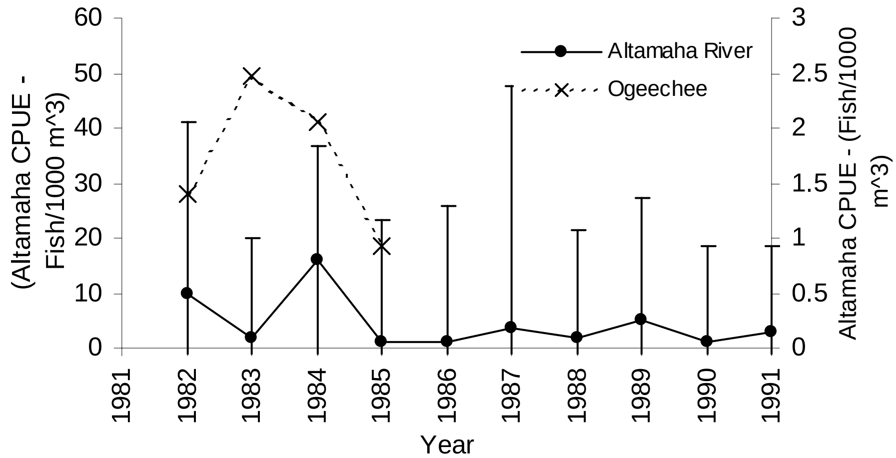


Figure 15.5 Historical landings of American shad in Georgia (Data from National Marine Fisheries Service).

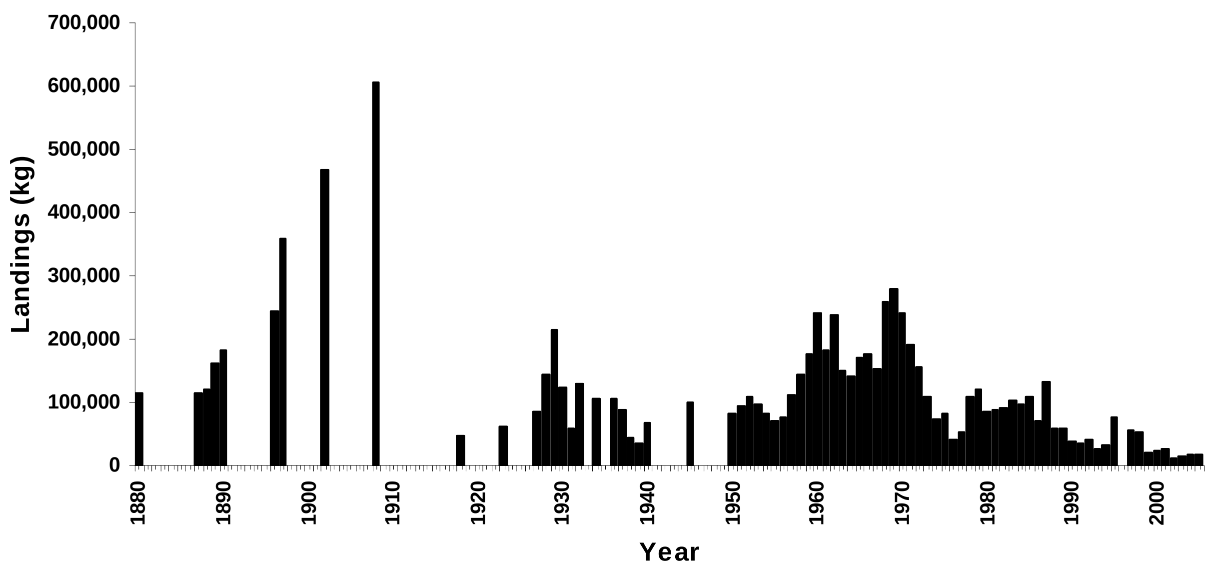


Figure 15.6 Stacked bar chart of directed commercial gill-net (set and drift) landings (kg) of American shad Georgia by river system. From 1983 to 1988, river-specific landings are available for the Altamaha River only.

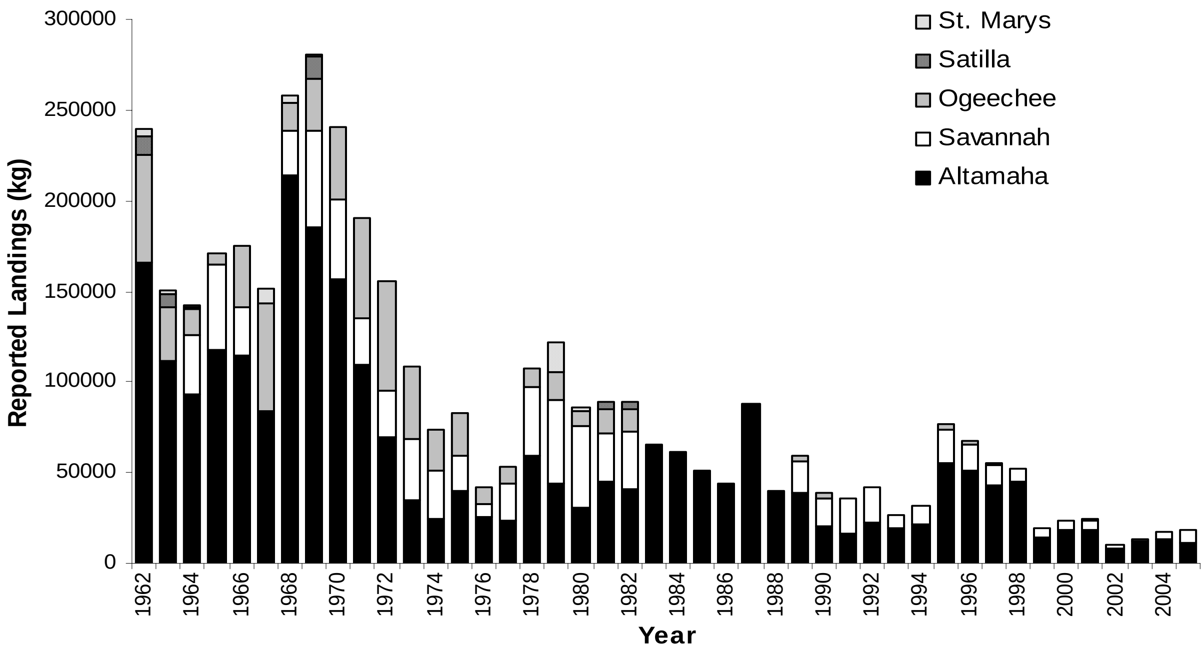


Figure 15.7 Number of commercial shad licenses (used for both American and hickory shad) in Georgia from 1953 to 1979 (line) with total American shad from Georgia landings over the same time period (bars). The shad license was abolished in 1979 and no license data are available from 1973 to 1975.

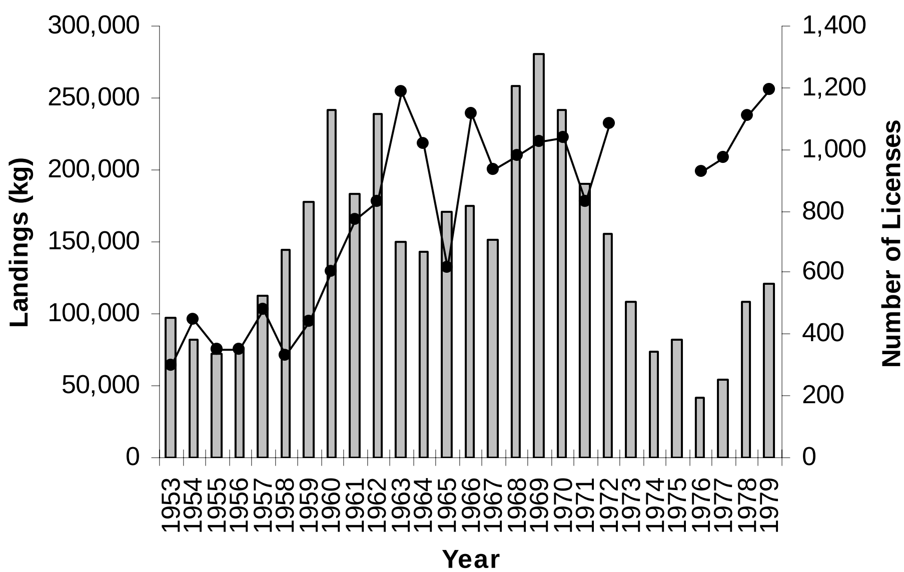


Figure 15.8 Fishery-independent index for American shad developed from GADNR gill-net tagging data for the area under the curve for number of fish caught per foot-hour of net over a shad spawning season on the Altamaha River, 1986-2005.

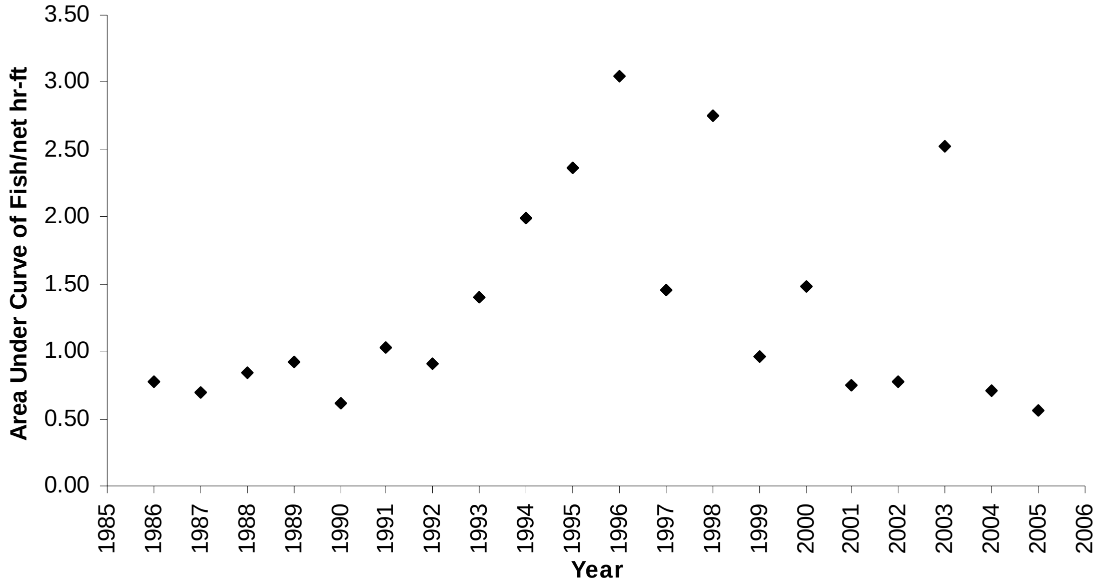


Figure 15.9 Drift gill-net catch-per-unit-effort (kg/trip) on the Altamaha River, Georgia of American shad from 2000 to 2005.

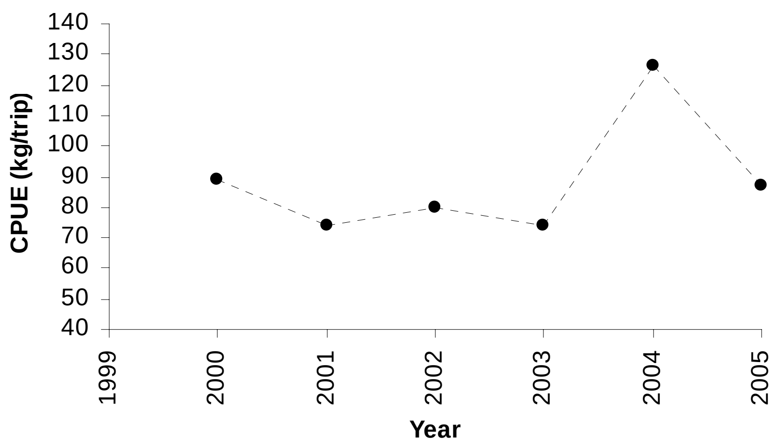
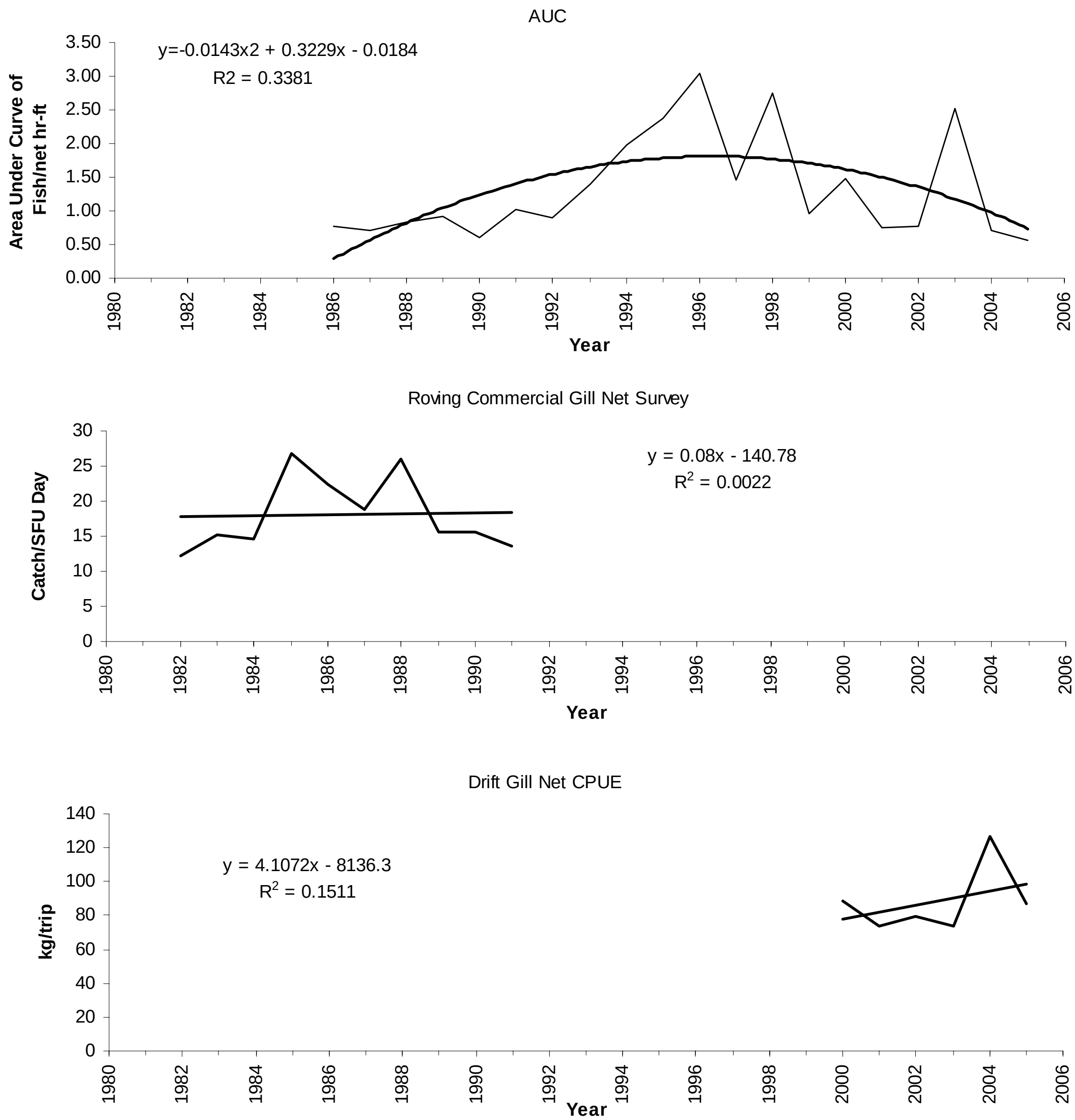


Figure 15.10 Altamaha River American shad area under the curve (fish per net-hr) index developed from GADNR gill net tag-return CPUE data from 1986 to 2005, CPUE (catch/SFU day) from GADNR roving commercial creel survey (Michaels *et al*. 1984, 1990, and 1993) from 1982 to 1991, and commercial CPUE from the Altamaha River commercial drift net fishery from 2000 to 2005.



APPENDIX I

Tagging Program Simulation Model

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Introduction

This simulation model was created to explore the effects of violating assumptions of the Lincoln-Peterson (L-P) mark-recapture model. Model parameters (e.g., annual fishing mortality rate, initial population size) may be set by users in top section of code.

Model description:

- Tracks male and female abundance at age. Initial population size for each sex is distributed evenly among adult age classes.
- In each time step, the population undergoes (1) transition to next age class and death of terminal-aged fish, (2) fishing mortality, (3) spawning of surviving adults, then (4) natural mortality.
- Recruitment is balanced between a replacement factor (*Hprop*) and natural mortality of young-of-year (age-0).
- No density dependent growth (allows examination of estimator performance across a range of potential population sizes).
- Simulates ideal tagging program where:
    - Recapture rate is proportional to annual fishing mortality (H).
    - Total adult population size before fishing was estimated separately for males and females using an unbiased L-P method and then summed across sexes.
    - No violations of L-P assumptions were made.
    - Same number marked of each sex annually (default is average number marked in Altamaha River, Georgia from 1998 to 2005).
- Simulates violations of L-P assumptions using bias-corrected L-P method Note: I selected a few scenarios that may be applicable to the Georgia shad assessment. Additional simulations can be programmed as needed.
    1. sim1: tagging loss/failure to report tags/post-tagging mortality from 5-50% by 5% increments.
    2. sim2: combining male and female data in same L-P estimator when selectivities are different.
    3. sim3: combination of problems; sim2 with ~20% tagging loss.

Discussion of model simulations:

1. Tag loss between marking and recapture has a similar effect on the population estimate as underreporting of recaptured fish or post-tagging mortality. Tag loss violates the L-P assumption that “animals do not lose marks between sampling periods” (Krebs 1999). Underreporting of recaptured fish violates the assumption that “all marks are reported upon discovery in the second sample” and tagging mortality violates the assumption that “marking individuals does not affect their catchability.” All these problems typically result in overestimation of population size (Figure AI.1).

Also, note that with small sample size (# marked) and unknown rates of tag loss/mortality, population estimate uncertainty will be high. For example, Krebs (1999) provides a general rule of thumb for determining sample sizes: to achieve accuracy of ±50% with alpha=5%, the minimum number marked should be close to 1,000 for a population of 100,000 individuals; contrast that with the ~200 individuals marked per year in the Altamaha River, Georgia and the population estimate of ~122,000 in 2005.

2. Males and females may not be targeted equally by the GA shad tagging protocol or the fishery (Figures AI.2 and AI.3). Note that the number of males marked and recaptured is often much lower than the number of females marked. Such differences in potential for individuals to be marked (e.g., due to fishing gear selectivity) are a violation of the assumption of equal catchability in the first sample (Krebs 1999). Therefore, tagging data for males and females should not be combined in the same estimator. Doing so will result in underestimation of population size (Figure AI.4).

3. When multiple assumptions are violated, however, the result is more difficult to intuit. In this scenario, data from both sexes with different selectivities were combined and there was a 20% loss of marked individuals/tags. The total population estimate was generally smaller than the true population size (Figure AI.5).

Literature Cited

Krebs, C. J. 1999. Ecological methodology, 2nd edition. Benjamin Cummings, Menlo Park, California.

Figure AI.1 Performance of Lincoln-Peterson model compared to true population size with different rates of tagging loss/underreporting/post-tagging mortality of marked fish (square = 5%, circle =25%, diamond = 50% loss).

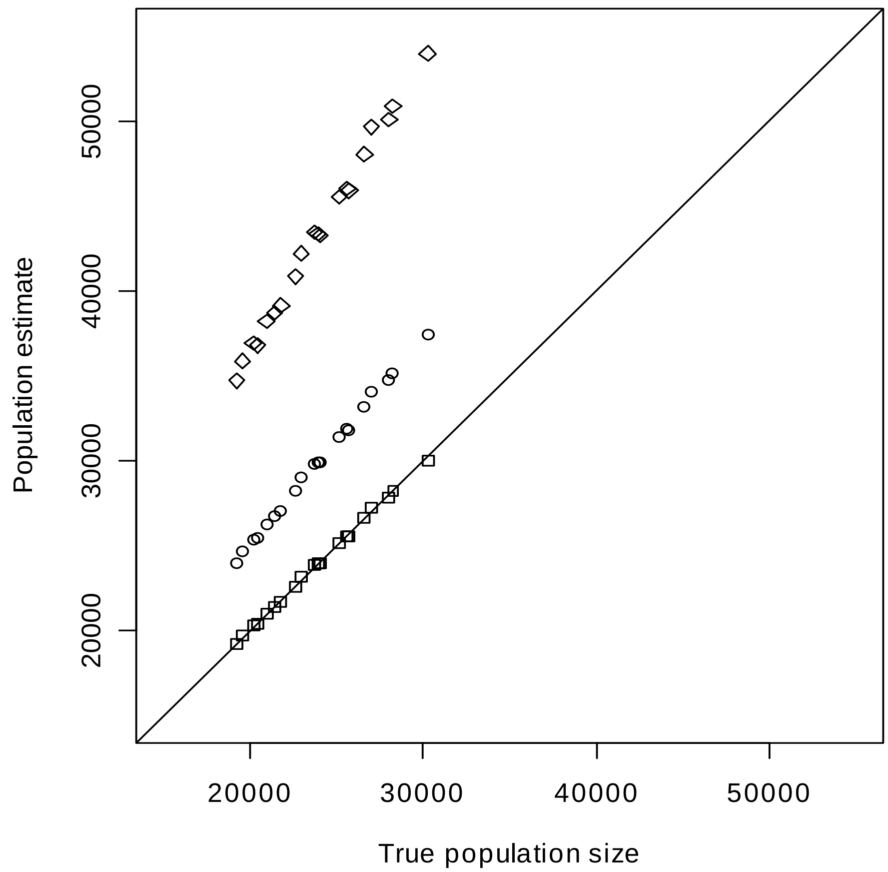


Figure AI.2 Number of fish marked on the Altamaha River, Georgia from 1998-2005.

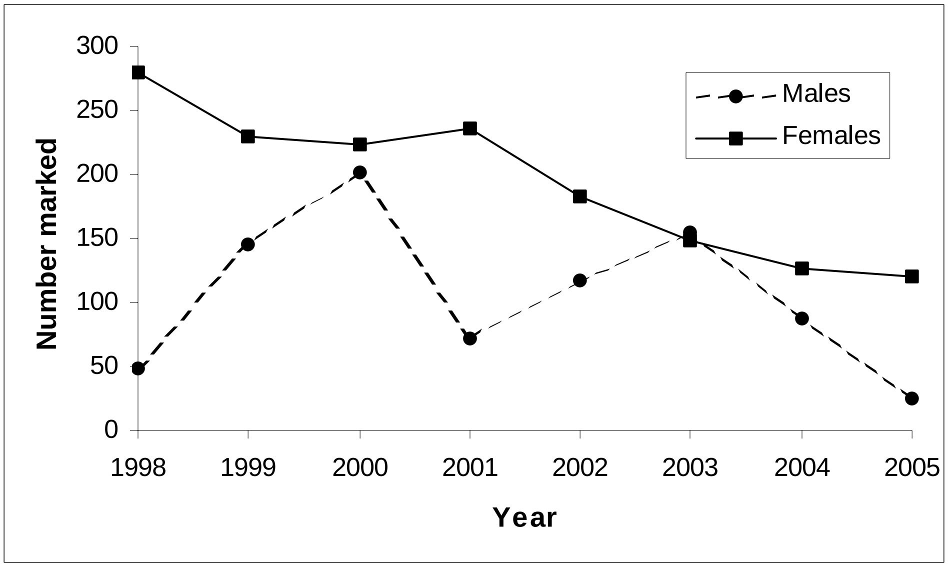


Figure AI.3 Number of fish recaptured on the Altamaha River, Georgia from 1998-2005.

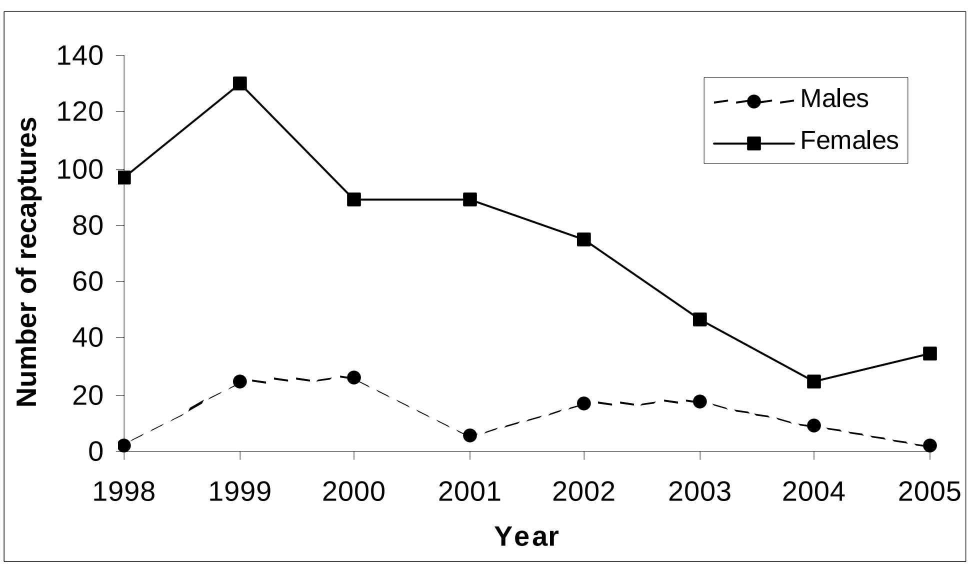


Figure AI.4 Performance of Lincoln-Peterson model compared to true population size when mark-recapture data for males and females with different selectivities are combined in the same estimator.

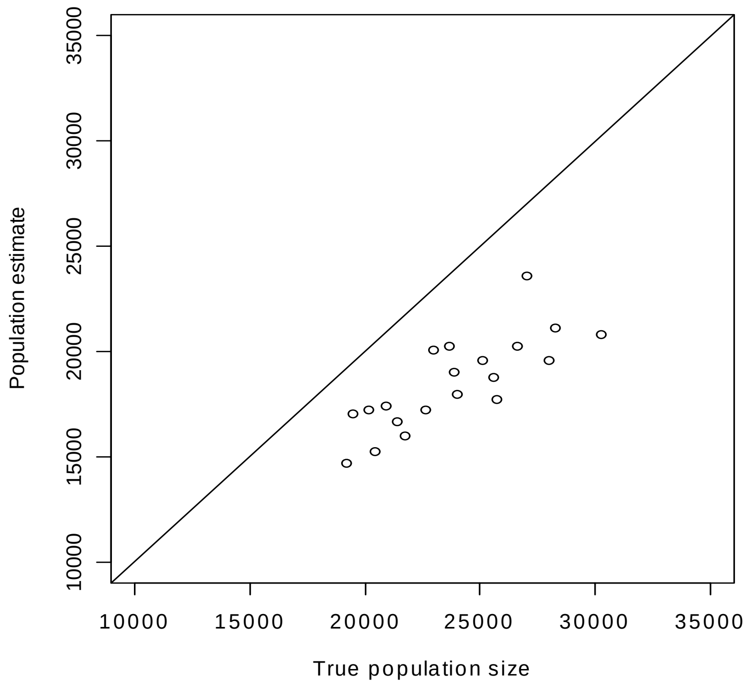
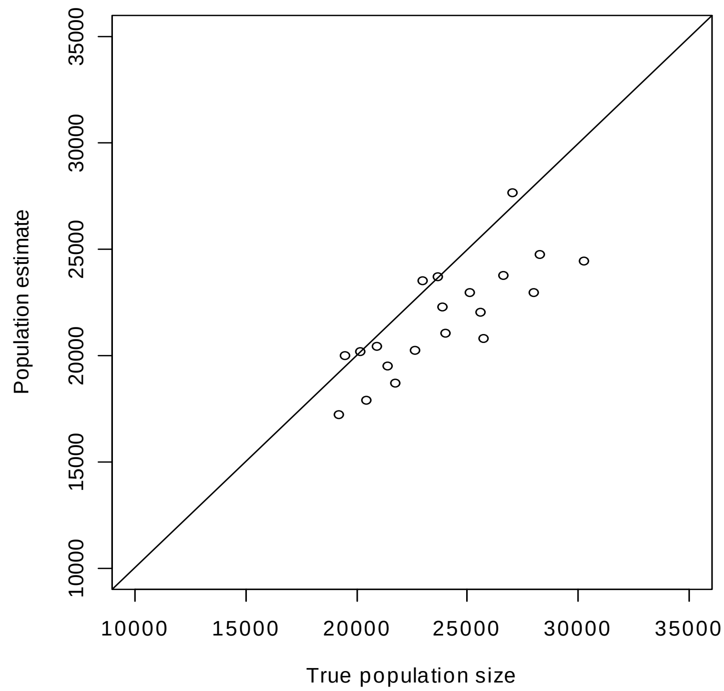


Figure AI.5 Performance of Lincoln-Peterson model compared to true population size when mark-recapture data for males and females with different selectivities are combined in the same estimator and there is a 20% loss of marked individuals/tags.



APPENDIX II

Supporting Analyses for Area Under the Curve Calculations

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Analyses were conducted to support the use of the area under the curve (AUC) of daily catch rates from the Georgia Department of Natural Resources (GADNR) tag-return sampling versus time of year as an index of American shad abundance. Plots of daily CPUE values against Julian day suggested that sampling encompassed the maximum period of abundance in most years (Figures AII.1a-1t). Frequency distributions of CPUE suggested data distributions that were not skewed and often were relatively symmetrical (Figures AII.2a-2t). Finally, plotting the annual AUC index against sample season length showed no obvious relationship suggesting that the variable season length did not seriously affect annual AUC estimates (Figure AII.3).

Figure AII.1 Daily catch-per-unit-effort of American shad against Julian day for 1986 through 2005 for GADNR tag-return collection sampling.

Figure 1a - 1986

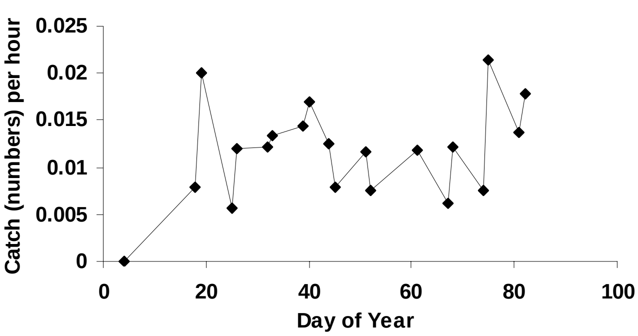


Figure 1b - 1987

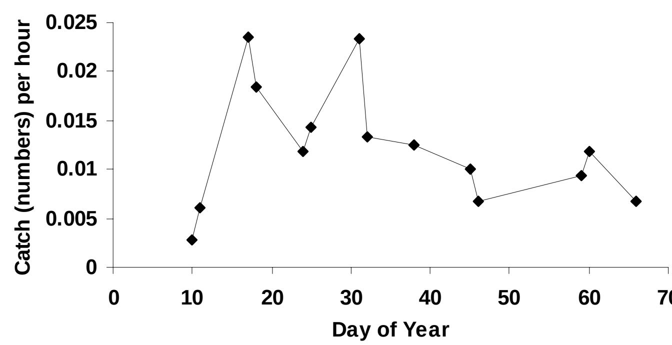


Figure 1c - 1988

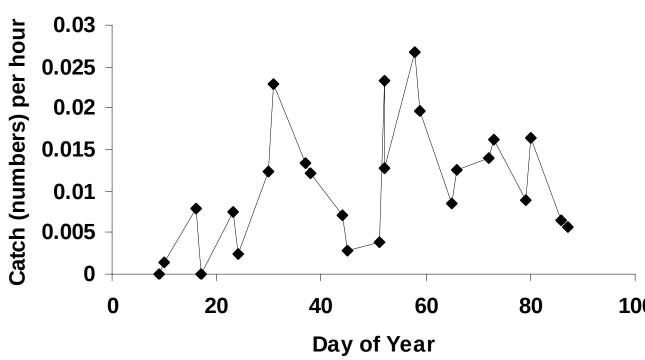


Figure 1d - 1989

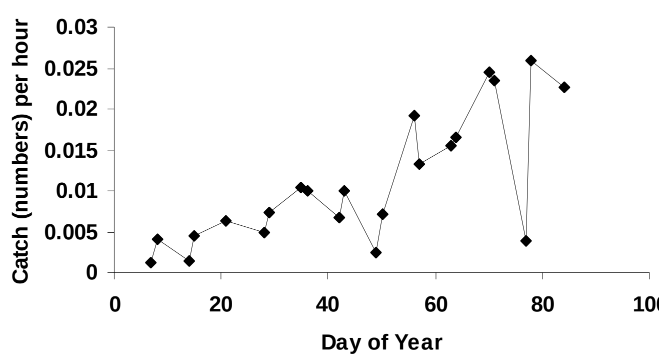


Figure AII.1 (cont.) Daily catch-per-unit-effort of American shad against Julian day for 1986 through 2005 for GADNR tag-return collection sampling.

Figure 1e - 1990

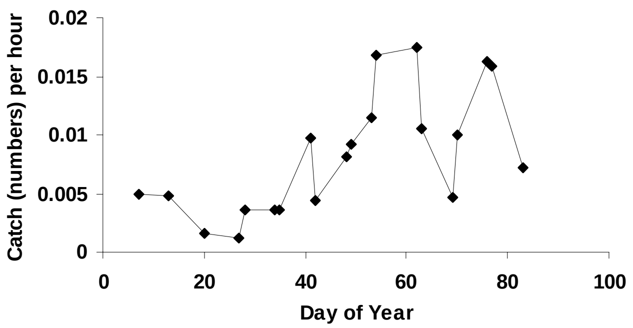


Figure 1f - 1991

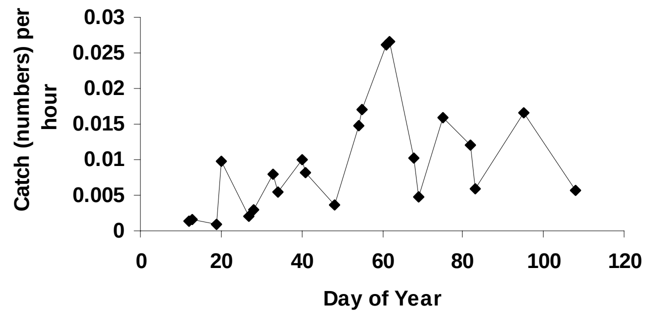


Figure 1g - 1992

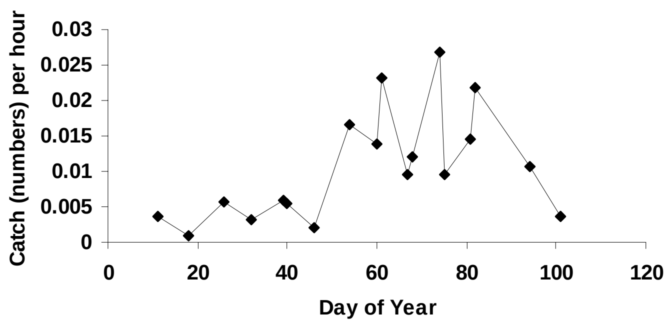


Figure 1h - 1993

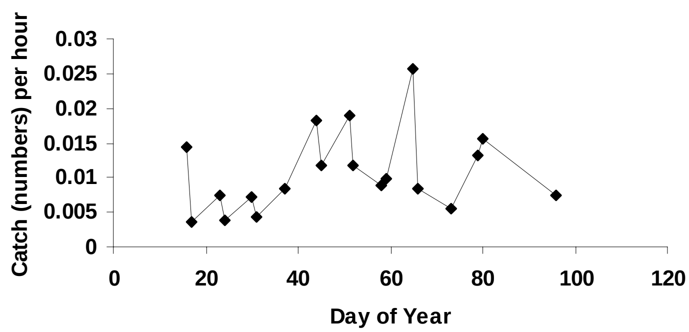


Figure 1i - 1994

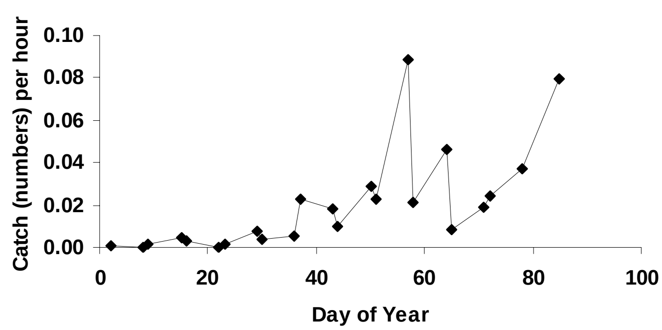


Figure 1j - 1995

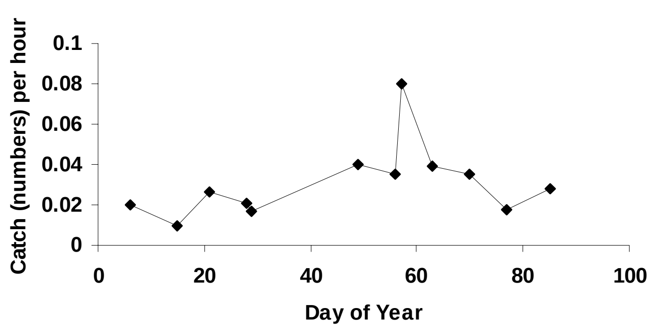


Figure 1k - 1996

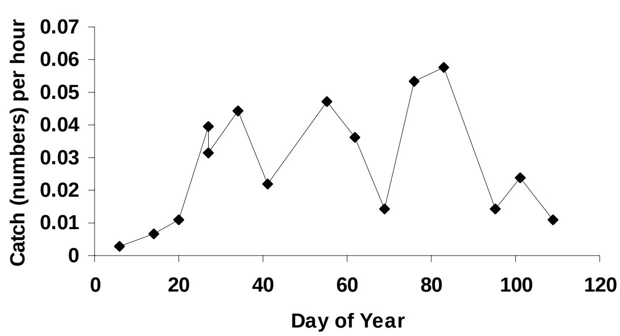


Figure 1l - 1997

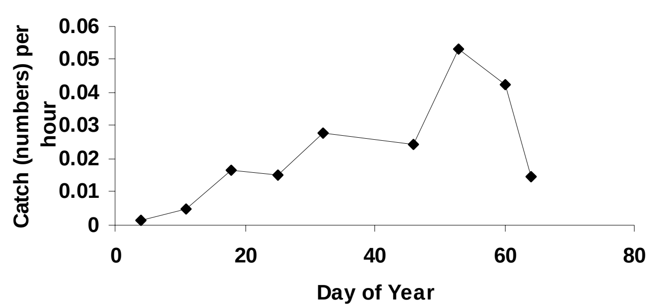
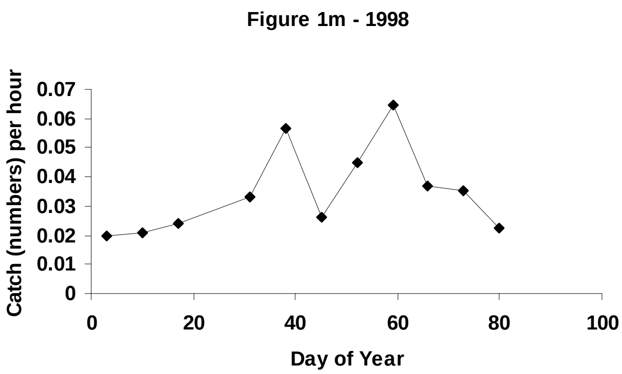
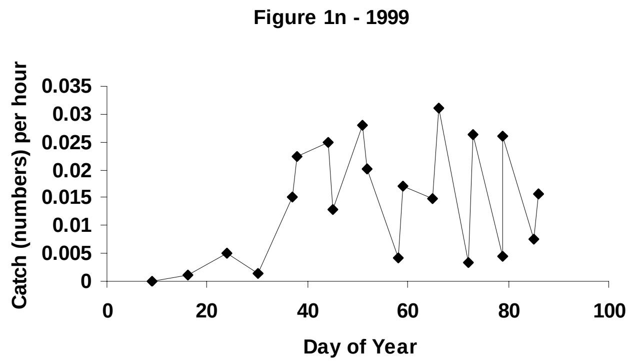
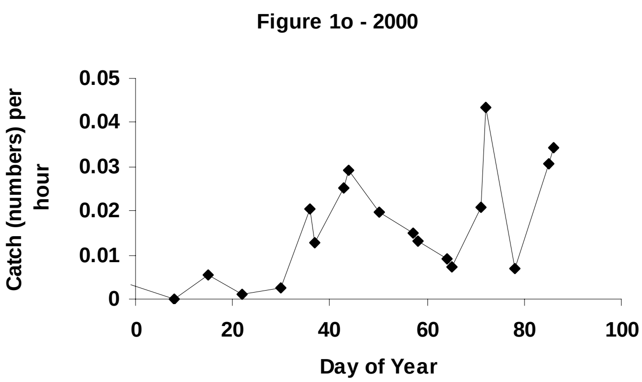
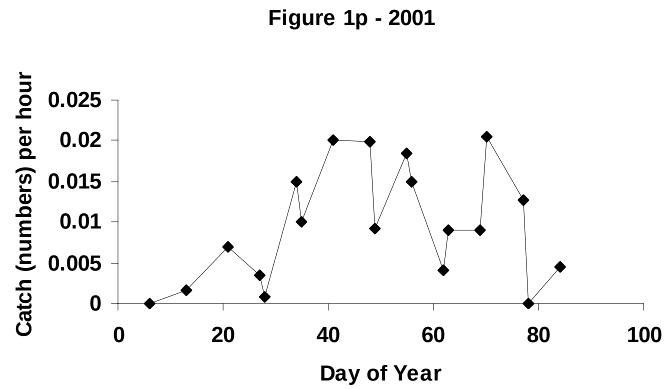


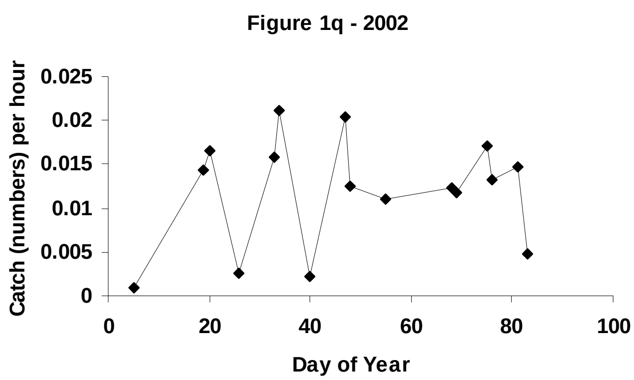
Figure AII.1 (cont.) Daily catch-per-unit-effort of American shad against Julian day for 1986 through 2005 for GADNR tag-return collection sampling.

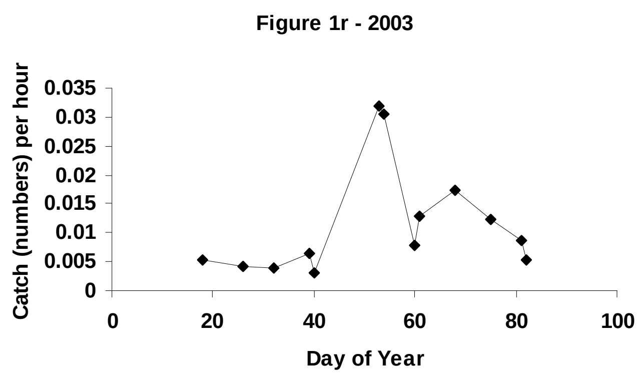


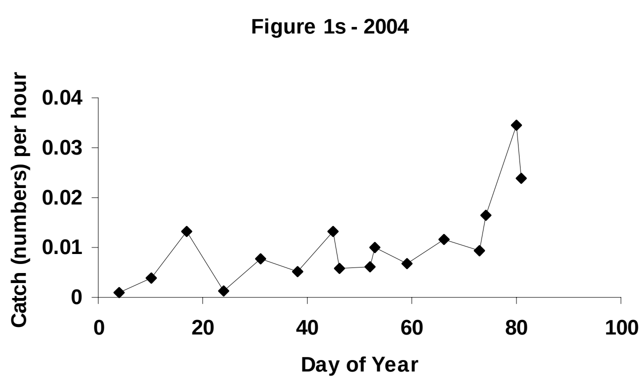


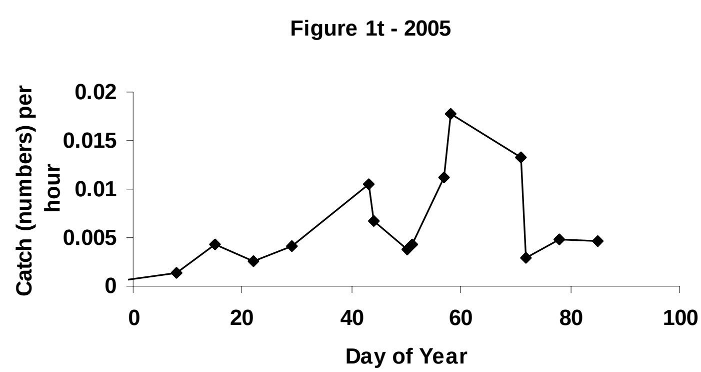












Figures AII.2 Frequency distributions of CPUE of American shad for 1986 through 2005 from GADNR tag-return collection sampling.

Figure 2a - 1986

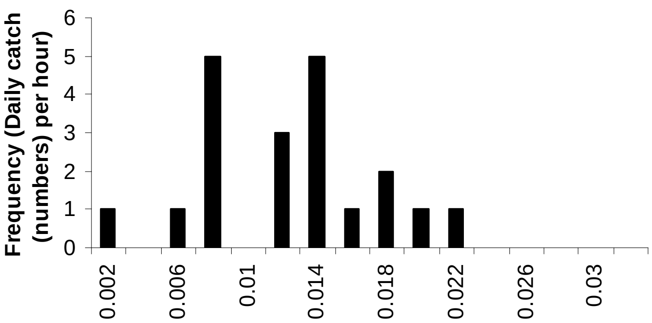


Figure 2b - 1987

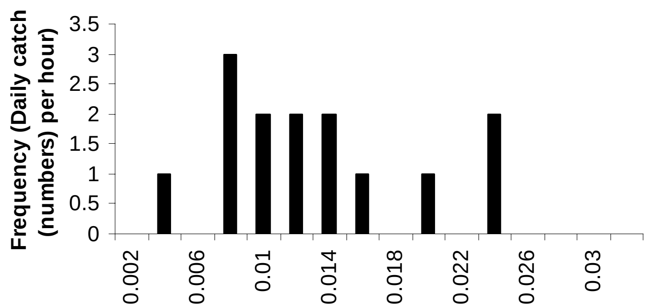


Figure 2c - 1988

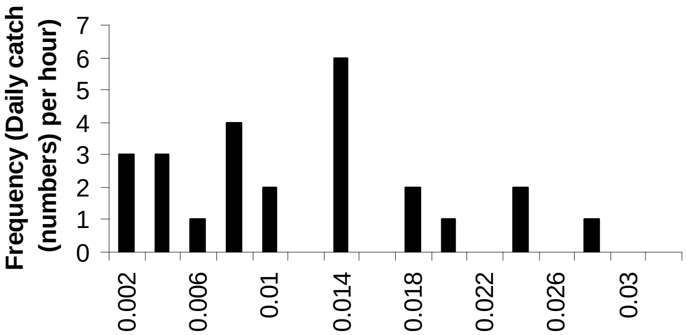


Figure 2d - 1989

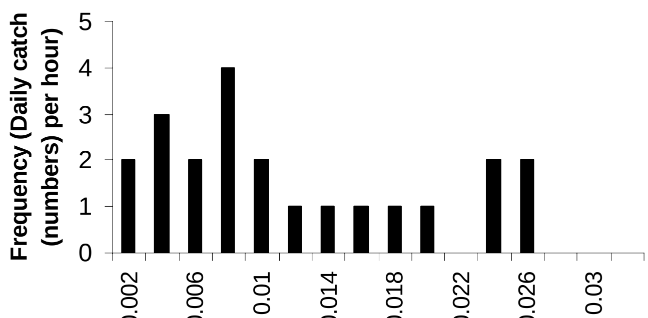


Figure 2e - 1990

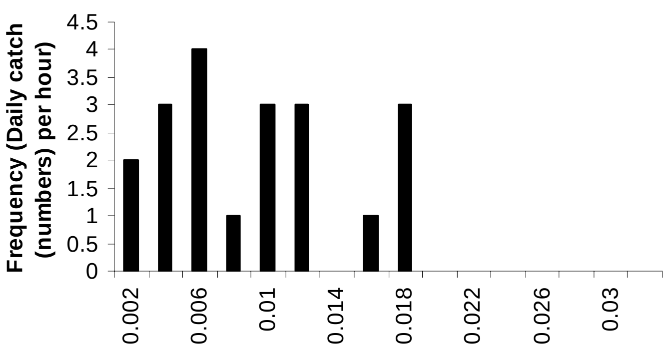


Figure 2f - 1991

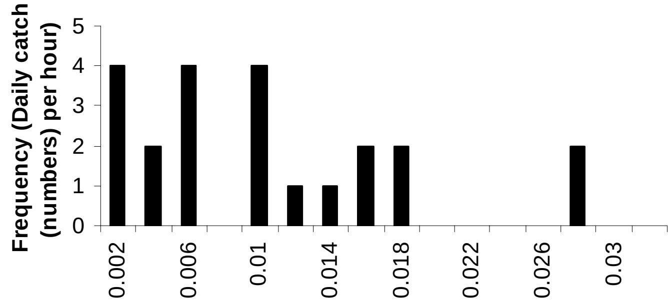


Figure 2g - 1992

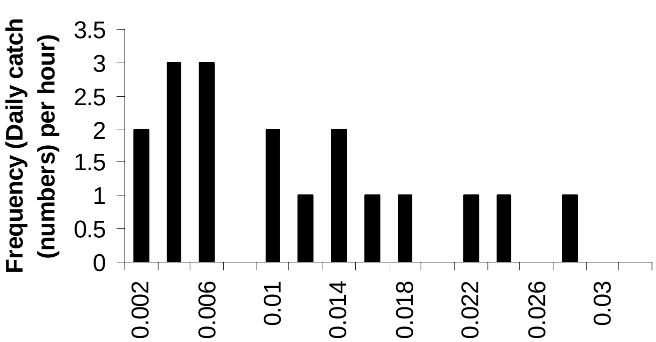
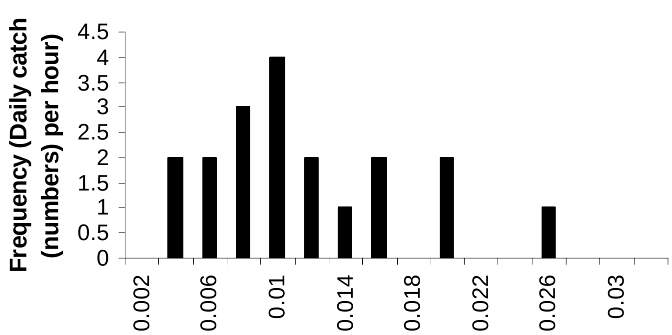


Figure 2h - 1993



Figures AII.2 (cont.) Frequency distributions of CPUE of American shad for 1986 through 2005 from GADNR tag-return collection sampling.

Figure 2i - 1994

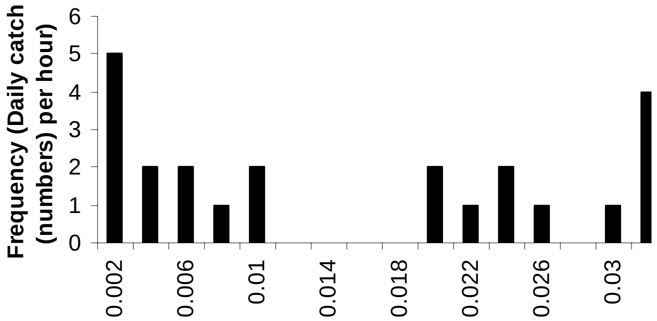


Figure 2j - 1995

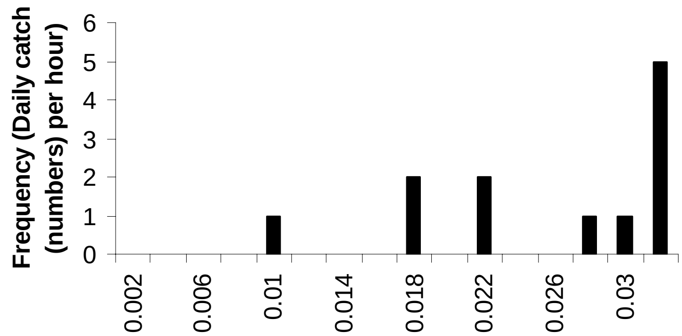


Figure 2k - 1996

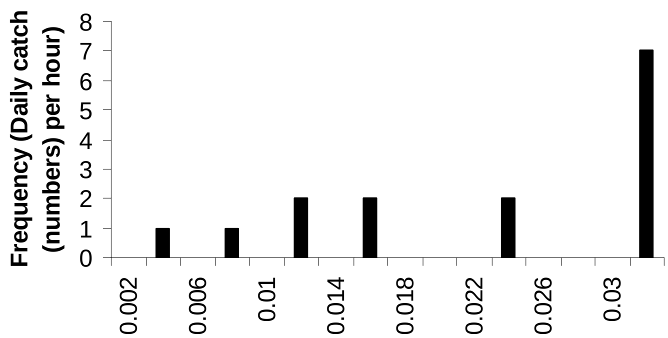


Figure 2l - 1997

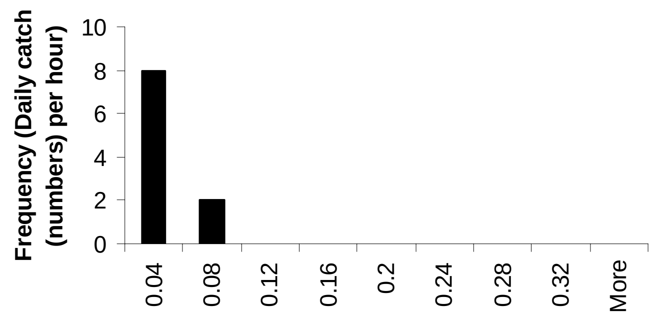


Figure 2m - 1998

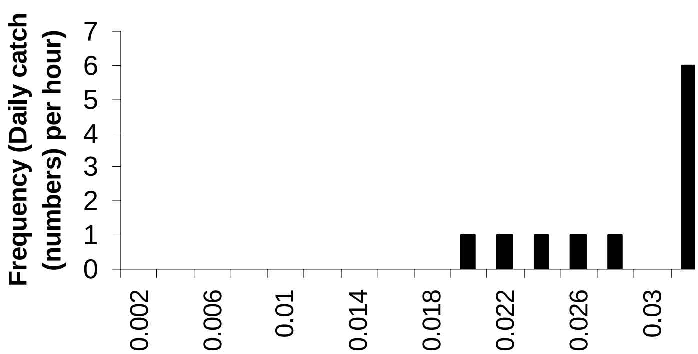


Figure 2n - 1999

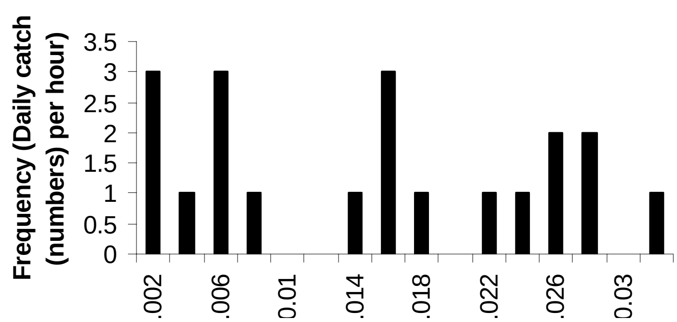


Figure 2o - 2000

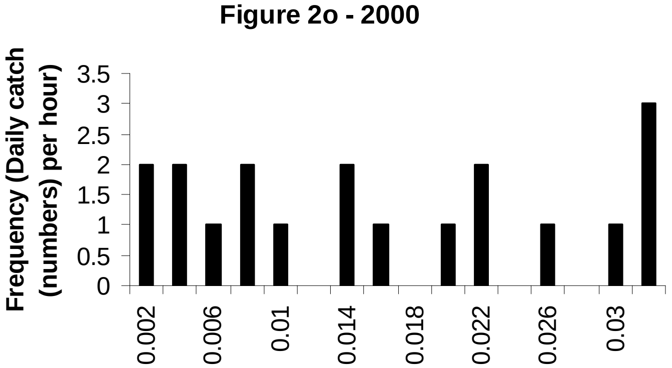
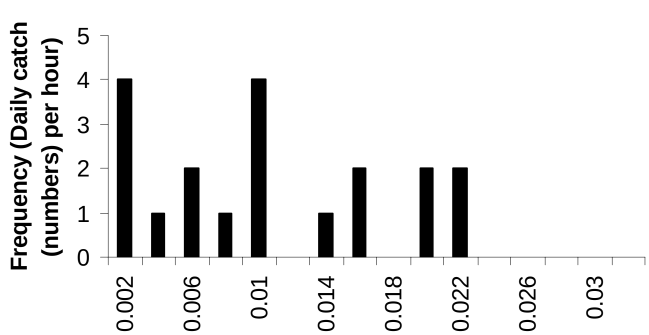
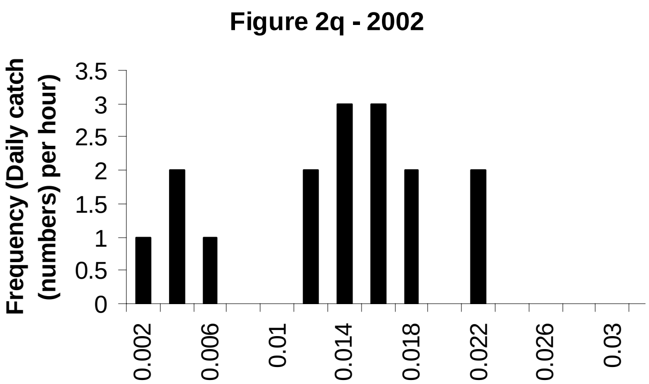
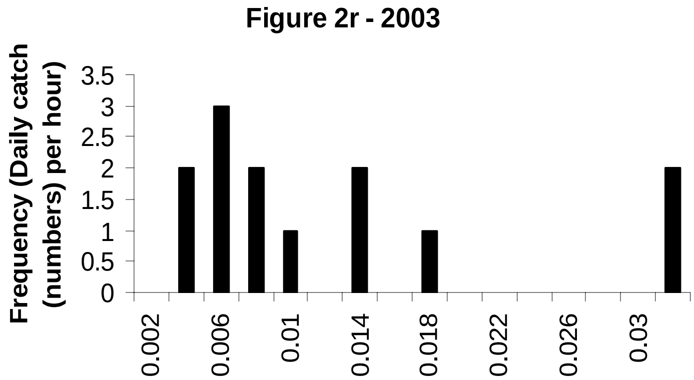


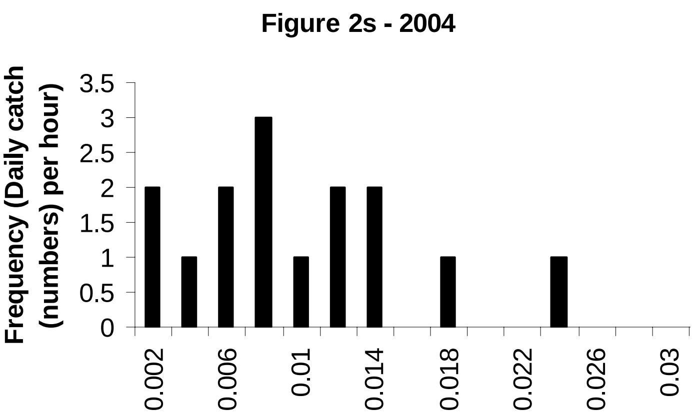
Figure 2p - 2001



Figures AII.2 (cont.) Frequency distributions of CPUE of American shad for 1986 through 2005 from GADNR tag-return collection sampling.







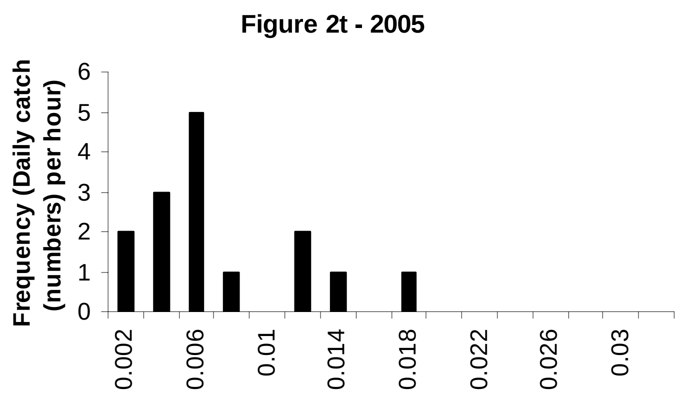
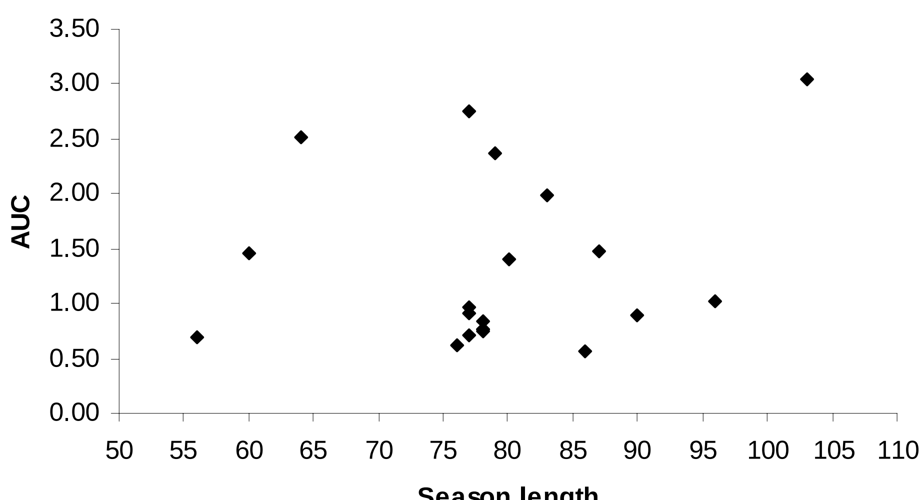


Figure AII.3 Plot of the annual AUC index against sample season length for American shad from 1986 through 2005 from GADNR tag-return collection sampling.



Section 16
Status of the St. Johns River American Shad Stock

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16.1 INTRODUCTION

American shad (*Alosa sapidissima*) occur in rivers of northeast Florida. Adults are present during the winter and spring (November-May) and juveniles occur during the spring and autumn and during the winter in some years. Florida landings of shad expanded rapidly in the late 1800s, peaked early in the 1900s, and declined markedly during the twentieth century (McBride 2000). Landings of shad declined throughout much of their range, Canada to Florida, which led to the passage of the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fishery Management Plan (FMP) for Shad and River Herring in 1985. Continuing declines led to the development of Amendment 1 to this FMP, completed in 1999.

The literature review sections herein are based on an earlier review paper by McBride (2000), updated as appropriate. New data are presented from a Florida Fish and Wildlife Commission (FWC) study of anadromous shad populations in the St. Johns River, largely funded by a Sport Fish Restoration grant (F-106) to the State of Florida. Finally, this report includes a stock assessment based on the best available data for Florida's population of American shad.

16.2 MANAGEMENT UNIT DEFINITION

American shad are anadromous, so each river from Florida to Canada presumably hosts a reproductively isolated population of American shad. Recaptures of fish after an over-wintering period occurred on the same spawning grounds (Hollis 1948; Talbot and Sykes 1958; Nichols 1960; Judy 1961; Leggett and Whitney 1972). Early efforts to separate populations by phenotypic characters were promising (Hill 1959; Nichols 1966b) but no diagnostic tools (either phenotypic or genetic) are available to conclusively define river-specific stocks across this species' latitudinal range (Melvin *et al*. 1992; Epifanio *et al*. 1995; Thorrold *et al*. 1998; Nolan *et al*. 2003). Thus, this assessment simply assumes the three major rivers in Florida supporting American shad (St. Johns River, Nassau River, St. Marys River) each are comprised of separate stocks. While straying may occur between these and other nearby rivers, straying is assumed to be of a very low frequency and not to effect this definition of stock structure in terms of current management practices.

While American shad occur in several northeast Florida rivers, the St. Johns River is the only river in Florida with sufficient data regarding an American shad spawning population. For the purposes of this report, Florida's St. Johns River is defined as a separate management unit of American shad. Hamlen (1884) reported observing anadromous shads in St. Marys River, along the Georgia-Florida border, and Walburg and Nichols (1967) discuss the historical shad fishery there. Rulifson (1994) summarizes what is known about anadromous shad (i.e., *Alosa* species) in Florida's Atlantic rivers, and confirms that there is little data for assessing the populations in any Florida river. A recent (August 2005) query of statewide monitoring databases of the FWC found no American shad in any river or estuary systems other than Florida's St. Johns River, St. Marys River, and the Nassau River.

The St. Johns is the longest river contained entirely within Florida, occupying a watershed area of approximately 8,350 square miles (Figure 16.1). From its mouth to the headwaters, the St. Johns River is about 499 km (310 miles) long but the difference in elevation is only 9.1 m (30 feet), or less than 2 cm per km (~ one inch/mile). The current is usually sluggish so the river is known as a "river of lakes," with a slow-moving flow extending to several appendant lakes or swelling out at various points to create several other shallow-water lakes (Table 16.1; Figure 16.1). Another distinguishing feature is that the St. Johns River typically flows south to north, with its eastern border paralleling (within 5-18 miles) Florida's Atlantic coast. The flow direction can, however, reverse under some conditions (i.e., drought or northern winds). More information about the St. Johns River and its ichthyofauna can be found in McLane (1955), Tagatz (1968), Burgess and Franz (1978), and Bass and Cox (1985).

16.3 REGULATORY HISTORY

Commercial fishing regulations for Florida's American shad populations have existed since at least 1896, when (1) fishing was allowed only from sunrise on Monday to sundown on Saturday and from December 1 to March 31, (2) mesh sizes were restricted to greater than 5 inches for gill nets and to greater than 3 inches for seines, and (3) using seines in the lake portions of the rivers was prohibited (Stevenson 1899; Walburg and Nichols 1967). Moreover, an Act approved in 1893 prohibited net-fishers (except those using cast nets) from taking commercial food-fish within one mile of any pass, inlet, or river mouth connecting with the Atlantic Ocean (Brice 1898).

Regulations for the St. Johns River in 1960 included (1) a restricted commercial season from November 15 to March 15 and (2) an area closed to commercial nets south of Lake George. The legal fishing season for the St. Marys River in 1960 was from December 15 to April 15, but there were no other restrictions for Florida's part of this river (Walburg 1960a; Walburg and Nichols 1967).

A series of regulations in the 1990s caused sharp reductions in Florida's commercial shad landings and effort. Landings for upstream gill-net fishing were severely reduced after January 1, 1992, by a regulation to increase mesh size (>6 inches stretched mesh) to assist in the management of striped bass (*Morone saxatilis*) populations (Williams 1996). The ocean-intercept shad fishery was restricted by net-tending and net soak-time regulations that gradually took effect from March 1992 to May 1994 (Williams 1996). Furthermore, fishing with nets in coastal waters is now severely restricted by a net limitation amendment to Florida's Constitution [§ 16, Art. X] that took effect in July 1995. This amendment prohibits the use of entangling nets, which were commonly used for shad fishing, within 3 miles of the Atlantic coast. Consequently, although sale of American shad is not prohibited, the commercial net fishery for shad has been effectively eliminated within state waters.

Sport fishing for American shad has been regulated by bag limits since 1955, and the initial bag limit of 15 fish per day was lowered to 10 fish in 1973 (Williams 1996). Since January 1, 1990, a saltwater fishing license has been required of most anglers who fish for marine species, and this also applies to anglers who fish for anadromous species such as shad and river herring. Since January 1, 1997 [Chapter 46-52.001 of the Florida Administrative Code] hook and line has been the only allowable fishing gear for American shad, Alabama shad, and hickory shad, and it has been unlawful to possess more than 10 fish of any combination of these species.

The ASMFC oversees management of all U.S. East Coast shad and river herring populations through an FMP subscribed to by the individual Atlantic-coast states. A maximum exploitation rate for Florida's Atlantic populations of American shad was set at 25 percent in 1985 by the ASMFC (ASMFC 1985). Amendment 1 to the ASMFC's FMP for Shad and River Herring calls for: (1) a 5-year phase out of the ocean-intercept fishery by 2005, (2) regulation of the in-river fishery at target exploitation rates (e.g., F_{30}), and (3) implementation of bag limits of 10 fish per day in the recreational fishery (ASMFC 1999).

Amendment 1 also establishes monitoring programs for all states; it requires Florida to monitor commercial and recreational shad fisheries and to complete fishery-independent surveys of American shad (ASMFC 1999).

16.4 ASSESSMENT HISTORY

Commercial shad fishing began in Florida's St. Johns River as early as the 1860s according to reports in the "Bulletin of the United States Fish Commission" (Osborn 1882; Demsey 1887). Within only a few decades, concerns were expressed about downstream netting that "completely block[ed] the river, and prevent[ed] any shad from coming up" (Osborn 1882). There were also calls for a hatchery on the St. Johns River so that "the yield [would] be increased by artificial means" (Henshall 1898). Assessments of the early fishery were limited to catch and effort data, which did demonstrate a sharp peak in landings before the turn of the last century (Stevenson 1899).

The first scientific assessments of American shad in Florida's St. Johns River began in the early 1950s. Talbot and Sykes (1958) tagged 882 fish during the 1952-1953 spawning run and had a 21.3 percent effective recapture rate. Walburg (1960a) tagged another 950 fish during the 1957-58 spawning run and reported an effective recapture rate of 12.7 percent and an estimate of 2.2 to 3.3 million (95% confidence limits) fish available to this fishery. These data were used to estimate a catchability coefficient that was used to estimate population size for a number of years. In this manner, population size was estimated to range from 0.91 to 3.7 million pounds from 1953 to 1965 (Walburg 1960a, b; Nichols 1964, 1965, 1966a).

These population size estimates are roughly equal to the peak yields of Florida's American shad at the turn of the nineteenth century. Thus, either the virgin (or predevelopment) stocks were much larger than those during the 1950s, the mortality rates were astonishingly high at the turn of the nineteenth century, or both of these conditions existed.

During the 1950s, these assessments were focused on allowing sufficient escapement to maintain viable fisheries, and fishing mortality was reasonably low. During the 1950s total fishing mortality ranged between 15 and 37 percent—about 2 to 8% by commercial gill nets, another 7 to 20% by commercial haul seines, and 3 to 8% taken with hook and line by sport anglers (Walburg 1960a, b; Walburg and Nichols 1967; ASMFC 1985).

Biological studies and descriptions of Florida's *Alosa* fisheries are also reported in Williams and Bruger (1972) and Williams *et al*. (1975). These studies provide habitat-based management recommendations, particularly with regard to proposed alterations of river flow and channelization in *Alosa* spawning areas. A review of habitat requirements, specifically in relation to river water levels and flows, was recently completed by Harris and McBride (2004).

When ocean-intercept landings doubled in the 1980s and 1990s (ASMFC 1999), there was an attempt to delineate the stock composition in these mixed-stock ocean fisheries. In particular, there was concern that this ocean fishery could affect smaller stocks—particularly those that were not being monitored closely—negatively. Unfortunately, efforts to identify diagnostic characteristics for river-specific or state-specific stocks failed (Epifanio *et al*. 1995; ASMFC 1998; ASMFC 1999). A recent stock assessment of shad populations (ASMFC 1998) included assessments for 12 selected populations from Maine to Georgia, but no Florida rivers were included in this assessment because of insufficient data. The status and trends of Florida's American shad populations have been tracked since 1999 in annual reports to the ASMFC (e.g., McBride 1999a; McBride and Richardson 2005).

16.5 STOCK-SPECIFIC LIFE HISTORY

American shad are anadromous, spawning in rivers and spending most of their adult lives at sea. The native distribution of American shad ranges from Canada to the southeast U.S. (Limburg *et al*. 2003). Tagging evidence indicates that all American shad migrate to Canada before returning to their natal river to spawn again (Dadswell and Rulifson 1994). American shad tagged within the St. Johns River were not recaptured outside the river, supporting a semelparous life history (Talbot and Sykes 1958; Walburg 1960a).

16.5.1 Growth

Female American shad are larger than males in the St. Johns River (LaPointe 1957; Moody 1961; Davis 1980), even at a common age. LaPointe (1957) reported the mean size of age-4 females as 409 mm (16.1 inches) fork length (FL) and age-four males as 394 mm (15.5- inches) FL. Walburg (1960a) reported the mean size of age-four females as 411 mm FL and age-four males as 389 mm FL. Leggett (1969) reported the mean size of age-four females as 415 mm FL and age-four males as 386 mm FL. Walburg also observed that individuals caught at the beginning of the spawning run (December) are larger than those caught later in the run (January-March). All these size-age relationships are based on Cating's (1953) scale ageing method (see Section 16.8). Walburg (1956), Williams and Bruger (1972), and Williams *et al*. (1975) report on juvenile growth data.

16.5.2 Reproduction

American shad return to Florida rivers to spawn during winter. American shad spawn at similar temperatures across latitudes, so that northern populations spawn later (i.e., into the spring; Leggett and Whitney 1972; Quinn and Adams 1996; Limburg *et al*. 2003). In Florida's St. Johns River, few shad enter the river until temperatures fall below 20^{o}C, generally in November, and peak shad numbers occur when water temperatures are their lowest (15.0^{o}C; Leggett and Whitney 1972). McLane (1955), Walburg (1960a), Leggett and Whitney (1972), Williams *et al*. (1975), and Davis (1980) report spawning adult American shad in the river from November to May. Gonadosomatic indices for American shad in the St. Johns River peak in February: somatic weight steadily decreases while gonad weight initially increases but eventually decreases during the spawning run (Davis 1980; Glebe and Leggett 1981). Williams and Bruger (1972) collected American shad eggs from December to May and reported peak catch rates of eggs in February.

American shad scales have also been examined for spawning marks, but LaPointe (1957), Walburg (1960a) and Leggett (1969) specifically state that no spawning marks were observed on the American shad scales they examined. Additionally, no mature fish tagged within the St. Johns River has been recaptured outside the river (see Section 16.10). Finally, spent fish are not harvested on any downstream migration in the St. Johns River (Stevenson 1899). Collectively, these results support the postulation that fish from Florida's populations do not spawn in more than one year. While American shad returning to spawn will die during that spawning season, there is also new evidence that Florida's American shad spawn multiple times (i.e., multiple batches; Olney and McBride 2003; Appendix II). Ongoing studies are investigating the spawning frequency and duration of American shad in Florida in different winters (Hyle, McBride and Holder, unpubl. data).

Several estimates of the number of yolked oocytes (potential fecundity) are available (Davis 1957; Walburg 1960a; Leggett 1969; Leggett and Carscadden 1978). Olney *et al.* (2001) conclude, however, that American shad have indeterminate fecundity and asynchronous oocyte development; therefore, these estimates of yolked oocyte numbers are difficult to evaluate in terms of realized fecundity. Olney and McBride (2003) estimated batch fecundity for Florida American shad to range from 6,000 to 98,000 eggs (n=11). Future assessments may be able to use egg production as a management benchmark once more reproductive information becomes available.

16.6 HABITAT DESCRIPTION

Florida is the southern distributional limit for American shad. Some individuals may range south to the Tomoka River (just north of Cape Canaveral), but the St. Johns River is typically regarded as containing the southernmost population of this species. There are no reports of American shad south of St. Lucie Inlet (Rulifson 1994; FWC unpubl. data). The southern distributional limit for *Alosa* species is limited by temperature (Hildebrand 1963; Leggett 1969; Leggett and Whitney 1972).

The spawning grounds have been characterized by several egg sampling programs. While it had long been suspected that shad spawn in the upper St. Johns River (Cary 1885; Stevenson 1899), Walburg (1960a) was the first to identify the spawning area as between Crows Bluff (~ rkm 230) and a point south of Lake Harney (~ rkm 320), based on qualitative egg collections made during the year 1953. American shad eggs were also collected between rkm 270 and 370 in 1965 (Nichols 1966a), between rkm 230 and 415 in 1970 (Williams and Bruger 1972), and between rkm 250 and 420 during 1972 and 1973 (Williams *et al*. 1975). Collectively that puts the spawning range of American shad between rkm 230 and 415 of the St. Johns River main stem. Discounting the smaller ranges reported in the earlier studies, which were based on less sampling effort, it would appear that the spawning grounds of American shad are quite stable in location during the last 50 years.

A dam at the downstream end of Lake Washington, rkm 415, has in some years set the upper limit of spawning. This dam was installed sometime early in the last century (Stevenson 1899; Walburg and Nichols 1967). It has a “low flow discharge” design and fish are not impeded in high water level years. Also, at this time, a channel exists around the dam, but it is expected that this channel will be blocked to re-establish the effectiveness of this water control device (B. Eisenhauer, FWC, pers. comm.).

Williams and Bruger (1972) identified spawning substrates as sandy or a mix of sand and mud. Moreover, they concluded that within the river, “[c]urrent, depth, and bottom contour and type apparently determined spawning locations, with most spawning occurring in currents of 1-1.5 ft/sec where there is a clean sand bottom less than 4 m in depth” (Williams and Bruger 1972). Harris and McBride (2004) have reviewed the literature for habitat requirements of American shad in relation to the low flow conditions that are typical of the St. Johns River; this report can be accessed at: research.myfwc.com.

American shad also appear to use at least some the major tributaries of the St. Johns River. McLane (1955) reports a record of American shad from the Oklawaha River (a tributary that joins the St. Johns River at approximately rkm 101). Williams *et al*. (1975) also report finding American shad eggs in Black Creek (connecting at rkm 72) and in the Econlochatchee River (connecting at rkm 311).

American shad are anadromous so their life history depends on sufficient habitat quality in both freshwater and marine systems. McBride (2000) provides a general review of habitat alterations by anthropogenic sources that may effect shad populations; these include dams, river flow alterations, and declining water quality. In brief, only one dam exists on the main stem of the St. Johns River, at Lake Washington, and the Oklawaha River is dammed. No major plans exist for altering the river itself, but there is increasing discussion on what water flow rates and levels should be with regarding to competing demands for water resources between human development and wildlife and fisheries needs. Preservation of sufficient water flows will be important for maintaining anadromous shad stocks in the St. Johns River in the future.

16.7 RESTORATION PROGRAMS

Currently, there are no restoration programs for American shad on the St. Johns River in Florida.

16.8 AGE

Female American shad live longer than males, and the modal age of adult American shad collected on the St. Johns River spawning grounds is four years old, with one exception. LaPointe (1957) reported ages ranging from two to five (n=680). Walburg (1960a) reported ages ranging from two to seven (n=3,129). Leggett (1969) reported ages ranging from three to six (n=449). Finally, Williams *et al*. (1975) reported scale ages ranging from two to seven (n=782) and the modal age was five for fish collected in 1972 and four in 1973. They report that the 1967 and 1969 year classes produced very strong age classes and 1968 was a year-class failure.

These studies provide a benchmark of American shad age structure in Florida, using Cating's (1953) method for scale ageing. A recent study (McBride *et al*. 2005a; Appendix I) challenged the use of Cating's method, which has never been successfully validated across all age classes for any American shad population. At this time, there is no validated method for ageing American shad in Florida so age-based methods of stock assessment are not explored further.

16.9 FISHERY DESCRIPTIONS

16.9.1 Commercial Fisheries

Native Americans fished for anadromous fishes, but unlike other states, there are no specific records of this for Florida (McBride *et al*. 2003; Appendix III). Records of netting for shad in Florida's St. Johns River begin in the mid-1800s (Osborn 1883; Dempsey 1887; Walburg 1960a). This was the last shad fishery to develop along the U.S. East Coast, and it was relatively small compared to shad fisheries in other states (McBride 2000). The rapid expansion of Florida's railroads provided the infrastructure for transporting American shad to northern markets and made Florida's fishery much more valuable (Brice 1898). In 1889 and 1890, Florida's shad landings (>2 million lbs) and their value ($100,000) were higher than those of any other marine product harvested within the state (Smith 1893). Florida's shad landings peaked at the turn of the century at about 1 to 3 million pounds and fluctuated between 200,000 and 900,000 pounds from the 1920s to the 1960s. Landings have declined further, from less than 200,000 pounds in the early 1970s to zero in recent years (Table 16.2; Walburg, 1960a, b; Walburg and Nichols 1967; ASMFC 1985; McBride 2000; McBride and Richardson 2005).

Commercial shad fishing methods have changed over the last century. At the turn of the nineteenth century, Florida's shad were caught primarily in drifting gill nets, secondarily in haul seines, and thirdly in anchored or staked gill nets (Smith 1898; Stevenson 1899; Walburg and Nichols 1967). In the 1950s, most landings of American shad were made by haul seine and landings by gill net were secondary (Walburg 1960a). Historically, gill nets captured more females than males, while haul seine and hook and line catches collected similar numbers of each sex (Walburg 1960a). Haul seining was discontinued during the early 1970s in Florida's St. Johns River (Williams and Bruger 1972), and gill nets were used into the 1990s (McBride 2000).

Florida's shad fishing grounds have also shifted geographically in the last few decades. In the 1950s, the dominant mode of harvest was by set gill nets in the lower river and by haul seine in the middle river (near Palatka, rkm 127; Walburg and Nichols 1967). By the early 1990s, nearly all the shad harvested came from gill nets fished in coastal waters offshore of Mayport (McBride 2000). Fishing offshore of other Atlantic states in the ocean-intercept fishery probably added to the fishing pressure on Florida's populations. Ocean-intercept landings more than doubled in the 1980s and 1990s (ASMFC 1999). Because of concerns that fishing on mixed stocks of shad in the ocean could be adversely affecting small populations—whereas larger and generally better-monitored populations could appear unaffected (ASMFC 1985, 1998)—ocean-intercept fishing was phased out by 2005 (ASMFC 1999).

Data Collection Methods

Commercial landings data for Florida have been tabulated in Walburg (1960a), Walburg and Nichols (1967), and Williams and Bruger (1972). Landings since 1950 can be downloaded from NOAA Fisheries (www.st.nmfs.gov) with one important caveat: landings of "shad" on Florida's west coast are not *Alosa* but rather *Brevoortia*, therefore, a landings request for Florida should be limited geographically to Florida's east coast. In addition, landings data for American shad most likely include some hickory shad (*Alosa mediocris*), which are not kept separate in most years. While hickory shad landings are present separately in the database for only the 1950s, these aggregate landings are not a major problem since historical recreational catches suggest that hickory shad constitute only a very minor portion of the combined catch of American and hickory shad (e.g., 2.4% as reported Walburg 1960a).

Commercial fishing data have been reported to NOAA Fisheries by the FWC since 1986, when Florida law initiated a requirement for all wholesale transactions of marine organisms landed within the state to be reported to the Florida's Marine Fisheries Information System (MFIS). Thus, these recent commercial data represent a census of all legal landings, but catch rates may be biased because trips that do not catch fish do not need to be reported. The MFIS data have been presented to ASMFC in annual compliance reports (e.g., McBride and Richardson 2005). These landings data were grouped annually for the fishing year July to June because *Alosa* species spawn in Florida between November and May. Landings were also restricted by county to limit mis-reporting other species that are commonly called "shad" (i.e., namely *Brevoortia* on Florida's west coast but also gerreids in south Florida).

Commercial Landings

Florida's landings of shad dropped dramatically in the 1990-1991 fishing year, continued to drop during the 1990s, and no landings have been reported since 2000 (Table 16.2). Although sale of American shad is not specifically prohibited, netting regulations imposed in the 1990s led to a virtual closure of the fishery.

Commercial Catch Rate

Catch, effort, and catch rates all declined to zero in response to netting restrictions in the 1990s (Table 16.2).

Commercial Catch-at-Age

No biological samples have been collected from the commercial fishery since the 1970s. Historically, LaPointe (1957), Talbot and Sykes (1958), Walburg (1960a), Leggett (1969), Leggett and Carscadden (1978), Glebe and Leggett (1981), and Williams et al. (1975) collected biological samples from commercial sources.

16.9.2 Commercial Discards and Bycatch

Commercial discard and bycatch rates are unknown but presumably very low because of the severe netting restrictions (see above 16.3).

16.9.3 Recreational Fisheries

Seining for shad was considered sport at the turn of the nineteenth century and anglers were fishing for shad in the St. Johns River as early as the 1880s (Pfeiffer 1975). Nonetheless, Florida's shad sport fishery is generally recognized as originating in 1942 (Snyder 1949; Nichols 1959; Walburg 1960a, b). The introduction of spinning tackle in the 1940s helped popularize shad sport fishing because it was an effective way to fish with the light lures used to catch shad. During the 1950s and 1960s, the shad sport fishery in the St. Johns River was estimated to be larger than the shad sport fisheries in any of the other Atlantic states (Nichols 1959, 1966a; Walburg and Nichols 1967). Fly-fishing for shad has also become popular in recent years (Lindsay 1999). Anglers fish for shad from public boat ramps and at a small number of fish camps on the St. Johns River between Lake Monroe and Lake Poinsett (Branyon 1999; McPhee 2002). Traditional shad fishing spots in this area are found at Marina Isle, Mullet Lake Park, Lemon Bluff, Puzzle Lake, and Hatbill Park. The certified state record fish (a tie) for American shad (5.19 lbs.) were caught in Seminole and Volusia counties (floridafisheries.com).

Nichols (1964, 1965), Walburg (1960a, b), Williams and Bruger (1972), and Williams (1996) have reported other estimates of recreational landings. Walburg (1960a) reports details of the sport fishery, including weekly catches of American shad and hickory shad, by sex, during 1958 and catch and effort data for the 1953 to 1958 fishing seasons.

Data Collection Methods

Recreational landings are available from NOAA Fisheries; however, there are no recreational landings recorded for American shad in Florida. The Marine Recreational Fisheries Statistics Survey does not appear to intersect with the American shad fishery on Florida's St. Johns River because the fishery is concentrated well upstream.

Walburg (1960a) provided a summary of a creel survey of the 1957-1958 American shad sport fishery on the St. Johns River. This included a river-wide survey of all major fish camps, with seasonality of catch and delineated American shad from hickory shad catch. These data were extended to report on the sport catch from earlier spawning years, 1953 to 1958. Other estimates of recreational landing were reported in Nichols (1964, 1965), Walburg (1960b), Williams and Bruger (1972), and Williams (1996). No fish were sampled during these other surveys, except to identify sex in some instances. In 2000, a pilot access-point creel survey was implemented at boat ramps during the peak fishing period (January-March), but only 3 fish were observed over 6 days.

A roving creel survey was used to monitor catches of American and hickory shad during 11 years of the 13-year period: 1992 to 2005. Angler interviews were completed together with instantaneous counts of the number of anglers along an 11.9 km stretch of the river between the mouth of Lake Jessup and the north end of Lake Harney. This region is historically well-know for shad fishing and includes such fishing locations as Marina Isle (still an active fish camp), "Shad Alley," Mullet Lake Park, Lemon Bluff (a historic fish camp), and "Iron Bend" (Branyon 1999, McPhee 2002).

Sampling during the creel survey was stratified by day (week versus weekend) and diurnal period (morning versus afternoon). Shad fishing is concentrated on weekends and holidays (Walburg 1960a), so three weekdays and two weekend days were sampled every two weeks. Holidays were counted as weekend days. Two diurnal periods (0730-1230 and 1230-1730 hours) were used prior to 1997; three diurnal periods (0700-1030, 1030-1400, and 1400-1730 hours) were used from 1997 to 2005.

A boat was launched from the Cameron Wight Park boat ramp, near the mouth of Lake Jessup, no later than one hour of the beginning of the selected diurnal period. Random, equal probability determined whether the instantaneous count of fishing effort was measured on the upstream or downstream run. Instantaneous counts were made of all anglers in all boats within the main stem of the St. Johns River—from the power lines across from the launching boat ramp (rkm 279.7) to the power lines upstream of Iron Bend (rkm 291.6). Angler interviews were completed on the complementary run (i.e., downstream or upstream); anglers were asked what species they targeted, how many hours they fished, the number of all fish caught, and the number of all fish kept. No fish were sampled (i.e., no data on sex, size, etc.); in fact, *Alosa* were only recorded as "shad" as many anglers cannot distinguish between American and hickory shad; blueback herring, on the other hand, are more readily identified and are not targeted in the sport fishery so they should not be mixed in with these catch data.

Catch and effort data from the roving creel were expanded using a Means of Ratio estimator for incomplete-trip interviews (Hoenig *et al*. 1997):

$$\hat{R}_h = \frac{1}{n}\sum_{j=1}^{n}\frac{c_j}{l_j},$$

where is the means of ratio estimate for the species in stratum h, c_j is the catch in interview j, l_j is the total angler-hours in interview j, and n is the total number of interviews in stratum h. The program calculated these values for anglers that said they were targeting shad. The program discarded interviews where the trip length at the time of interview was less than 0.5 hours, regardless of the number of anglers in the boat (Connor, undated).

Recreational Landings

Anglers within the 11.9 km creel survey area caught from 1,260 (2004-2005) to 12,592 (1998-1999) American and hickory shad each year. These estimates, which averaged 5,879 shad per year (+ 3,676 s.d.; n=11 years), were calculated for a 20-week period beginning in early December and ending in late April (Table 16.3).

Recreational Discards & Bycatch

American shad and hickory shad are caught together in the creel area. Catch and release is commonly practiced; the percentage of shad released in the roving creel survey was 79% in 2001-2002, 77% in 2002-2003, 71% in 2003-2004, and 79% in 2004-2005. While some anglers may release hickory shad preferentially, it is more common for anglers to release males versus females. Anglers fishing for freshwater fish, particularly black crappie (*Pomoxis nigromaculatus*), also catch American shad; at this time, the fishing rates and harvest rate of this bycatch have not been calculated.

Recreational Catch Rates

In average or poor fishing years fishing success was typically below 1.0 fish per angler hour, while in better than average years fishing success was typically above 1.0 fish per angler hour (Table 16.3; Figure 16.2).

Recreational Catch-at-Age

No biological samples were collected during the 1992 to 2005 creel survey. It does not appear that biological samples were collected in any historical survey of the recreational shad survey.

16.9.4 Current Status

Today Florida's shad fishery is composed primarily of recreational anglers fishing on the spawning grounds. Fishing catch and effort has declined in the past decade and most anglers practice catch and release (McBride and Richardson 2005). The condition of the stock appears depressed but stable (see Section 16.9).

16.10 FISHERY-INDEPENDENT SURVEYS

16.10.1 Data Collection Methods

Several published studies have collected adult shad independently of the fishery, including: Moody (1961), Davis (1980), and Glebe and Leggett (1981). A few more have collected early life stages of shad with fishery-independent methods, including Walburg (1960a), Nichols (1966a), Williams and Bruger (1972), and Williams *et al*. (1975). These studies were only one or two years in duration.

An electrofishing survey was completed during a 4-year period, 2001 to 2005, to determine spawning seasonality and distribution, and to generate independent estimates of spawner abundance to compare to the creel survey (above). Adult American shad were collected by electrofishing from an 18-foot aluminum boat. The boat was outfitted with a Smith-Root GPP 9.0 control unit connected to two four-dropper Wisconsin rings that extended forward of the starboard and port bow. Pulsed direct current was used with a fixed voltage (340 or 680 V) and hertz (60 or 120 cycles/s) to standardize power transfer at about 10 to 12 amps; actual power measured for 876 transects as 11.2 + 2.3 (mean + s.d.) amps. During a transect, the boat headed downstream at about two knots and one or two biologists used long-handled dip nets to collect stunned *Alosa* species appearing near the surface.

The electrofishing survey covered a broad range of shad spawning locations and months. Effort was allocated broadly along the St. Johns River and within its major tributaries (Table 16.1; Figure 16.1), covering several key areas of the shad spawning grounds. The sampling schedule was also designed to bracket the full period of shad spawning. In the first sampling year, electrofishing occurred monthly in the roving creel area, from December 2001 to April 2002. In the second sampling year, electrofishing occurred every 2 to 3 weeks in the roving creel area, from November 19, 2002 to April 30, 2003, and supplemental sampling stations were developed throughout the year. In the third sampling year, electrofishing occurred every 2 to 3 weeks in the roving creel area from November 18, 2003 to May 12, 2004, and three other areas were sampled at six week intervals: (1) a downstream section of the St. Johns River near the Wekiva River (rkm 254) and within the Wekiva River itself; (2) the Puzzle Lake region (~ rkm 311) and the adjacent Econlochatchee River, both immediately upstream of the roving creel area; and (3) the upstream region between Lake Cane and Lake Poinsett, focused at two nodes—State Road 50 (rkm 344) and State Road 520 (rkm 378). In the final (fourth) sampling year, electrofishing occurred every 2 to 3 weeks in the roving creel area from November 30, 2004 to April 27, 2005, and the same three auxiliary areas were sampled at six week intervals: (1) near and within the Wekiva River, (2) Puzzle Lake and the adjacent Econlochatchee River, and (3) between Lake Cane and Lake Poinsett. Supplemental sampling occurred during the study period in the Puzzle Lake region and within the Econlochatchee River, as well as other major tributaries (i.e., Black Creek, Dunns Creek [rkm 139], and the Ocklawaha River) or other main stem areas downstream of the mouth of the Wekiva River (i.e., Hontoon Landing [~ rkm 235], upstream of Lake Dexter to the south end of Lake George, and the region between the towns of Welatka and Palatka).

All fish were sampled without replacement, except for males and females caught on January 27, 2004 (n=152) in the Puzzle Lake area and nearly all males caught during the 2004-2005 spawning run (n=92). These fish were marked with a hole punched in a medial fin, measured for fork length (FL) to the nearest mm, and released. Three marked fish were recaptured from the first marking event and none were recaptured from the marked fish released in the 2004-2005 spawning year. Using the Lincoln-Peterson model, the estimated number of American shad in the Puzzle Lake area ranged from 12,300 to 13,800 fish in January through February. No further conclusions were reached regarding these preliminary mark-recapture efforts, except that a more focused effort on mark-recapture could potentially yield estimates of population size, mortality, and movements.

Measures of fish density adhered to specific, standardized procedures. First, the electric charge followed a repeating pattern of 25 seconds on pedal and 5 seconds off pedal for a total pedal time of 600 seconds. Second, the transect followed a “sinusoidal” path; this meandering extended from shore to shore where the width of the river was less than approximately 50 m. Where the river was wider, the meandering of each transect extended between the shoreline and mid-channel; the specific “side” of the river was chosen by a coin toss every 4 to 5 transects per day to randomize the sampling locations. Two biologists, both with a long-handled dip net, collected fish on 93.5 percent of all density transects; when only one biologist was available for netting fish occurred during low fish density situations and was not considered to appreciably affect (i.e., lower) measures of fish abundance for these transects. Finally, all density transects were completed during daylight hours. Measures of American shad abundance include only those transects that followed these procedures.

All fish brought back to the lab were measured to the nearest mm FL and weighed—total body weight and gonad weight—to the nearest tenth of a gram. Standard length and total length were measured for most fish to develop conversion equations. The sex and reproductive state of each fish were determined macroscopically.

Other samples were collected as part of a Sport Fish Restoration grant (F-106), and these are either archived or being analyzed. Scales and otoliths were collected as ageing hardparts; the uncertainty about the use of Cating’s (1953) method for ageing American shad has delayed pursuit of ageing these samples (Appendix I). A section of gonad tissue was fixed in 10 percent formalin for all fish collected in 2001 through 2004 and all females during the 2004-2005 spawning year; these samples have been examined to verify assignment of sex and spawning stage, and more research is planned (Appendix IV). If a female was gravid, the rest of the gonad was processed for measuring fecundity and egg diameters; this material is also being analyzed (Appendix IV). American shad were evaluated in relation to external appearance of fish health codes and this information is being reviewed as well (Appendix V).

16.10.2 Fishery-Independent Catch

American shad and hickory shad were collected at various points along the St. Johns River during 2001 through 2005 (Table 16.4). Sampling effort was concentrated on the spawning grounds, from approximately Lake Monroe to Lake Poinsett, and catch was correspondingly higher there than areas farther downstream. These downstream areas of the main stem of the river were also deeper and more channelized, and effort was only focused there during an initial year of sampling effort expansion, 2002-2003. Both American shad and hickory shad were also collected in notable densities in the Wekiva River and the Econlochatchee River.

16.10.3 Fishery-Independent Length, Weight, Catch-at-Age

The body weight (BW, g) of 1,314 American shad collected in the St. Johns River during 2001 to 2005 was significantly and linearly related to fork length (FL, mm) when the data were log transformed. The resulting relationship was $\ln(BW) = -13.75 + 3.425*\ln(FL)$. The slope was significantly different than zero ($P<0.001$). The coefficient of determination was modestly predictive ($r^2=0.64$) and can be improved by selecting sex or spawning condition. The largest individuals were female and the smallest individuals were male. No catch-at-age analysis was preformed.

16.10.4 Fishery-Independent Abundance Indices

Both American shad and hickory shad were found well upstream in Florida's St. Johns River by December of each of the four sampling years, 2001 to 2005 (Figure 16.3). American shad varied dramatically in abundance by location and remained in the river at least until May.

16.11 ASSESSMENT APPROACHES AND RESULTS

16.11.1 Models

This assessment examines catch and effort data, using a falsification approach to test the following hypotheses:

1) H_o: Fishing success (i.e., angler catch rates) is not related to fisheries-independent estimates of abundance. This hypothesis will be tested by correlating fishing success (ratio-of-mean estimates from the creel survey) and geometric mean abundance (shad collected by fisheries-independent electrofishing). If this null hypothesis is rejected—and fishing success is positively correlated with electrofishing abundances—then fishing success should be a useful proxy of annual spawning stock abundance, even though these data cover only a portion of the St. Johns River sport fishery. This is important because the longest-running time series of shad abundance is the roving creel survey, but it is first appropriate to validate that these estimates are in some way related to true shad abundance.

2) H_o: The annual time-series trend for shad abundance is not different than zero. This hypothesis will be tested with regression analysis of the creel survey abundance time-series for the period 1992 through 2005.

3) H_o: American shad mean sizes are not different over time. There is a limited amount of data available for this, and although it is not rigorously tested here, we look to see if fork lengths are similar between different decades. American shad females are larger than males. The motivation here is that shad fisheries are often targeted with gill nets, a gear which is very size selective. Williams and Bruger (1972) concluded that 30 years ago "that heavy fishing pressure, especially for female shad, may have contributed to a decrease in population size;" in particular, they noted that landings from gill nets were about 85 percent females.

4) H_o: Sex ratio of American shad is not different over time. There is a limited amount of data available for this, and although it is not rigorously tested here, we look to see if sex ratios are similar to 50:50 between different decades. As stated above (#3), if size-selective fishing gear is impacting the fishery, it is likely preferentially removing the larger fish, which are generally female. Also, females may be harvested at higher rates than males for roe markets.

In summary, these hypotheses follow the predictions of McBride (1999a, b) that because of the virtual elimination of Florida's commercial fishing effort in the 1990s, there will be increases in shad abundance and there may be increases in average fish size and numbers of female shad (up to a 1:1 sex ratio). These predictions are formed with the expectation that these population characters have been negatively impacted over time by fishing pressure, but that because of new fishing regulations—both within Florida's waters and for the ocean-intercept fishery—these population characters have the capacity to and will rebound within a generation or two (about 4-8 years).

16.11.2 Results

There was a statistically significant and positive relationship between shad abundance measured by electrofishing versus that measured by a roving creel survey (Figure 16.4). This was observed when the creel survey estimates were correlated to electrofishing in either the creel areas (i.e., Lake Monroe to Lake Harney; r=0.41; n=39; P ~ 0.01) or an adjacent, upstream section (Lake Harney to Puzzle Lake; r=0.69, n=16; P<0.01). This correlation analysis demonstrates that the time series of annual measures of angler catch rates can be used as a proxy for population size.

The time series of angler catch rates (fishing success) does not show a statistically significant trend over time, 1993 to 2005 (Figures 16.2 and 16.5). Angler success rates have fluctuated without trend around one shad caught per hour of fishing in the creel area. These relatively stable estimates of catch rate have occurred during a period of generally declining effort in the recreational shad fishery (Figure 16.5).

American shad females were larger than males, which was expected based on earlier studies (Section 16.5). Between decades, however, today's (2001-2005) male American shad today were about five percent shorter and the females were about eight percent shorter than 50 years ago (Figure 16.6).

The proportions of females, relative to females and males combined, have changed notably in the last several decades (Figure 16.7). In the 1950s, male American shad were more abundant early in the spawning run and females became more abundant later in the spawning run. During the complete 1957-1958 spawning run, females were only slightly more abundant than males (n=63,692; prop.(females)=0.53; Walburg 1960a). During recent (2001-2005) spawning runs, females were considerably less abundant compared to males throughout the year. American shad females were only more abundant than males early in the season, when catches were very low. Across all years, males dominated the catch (n=1,786; prop.(f)=0.36).

16.12 BENCHMARKS

Many shad stocks are managed based on mortality benchmarks (i.e., F_{30}). Total mortality estimates are typically estimated from age data. A recent validation experiment on ageing American shad using scales casts doubt on using such hardparts for estimating demographic parameters (McBride *et al.* 2005a). Largely because of this—along with other concerns about estimating natural mortality—this stock assessment avoids such demographic reference points.

The biological reference point used in this stock assessment is derived from catch and effort data. Specifically, a sustained catch rate greater than 1.0 fish per angler hour during the years 2001 to 2005 was proposed by McBride (1999a) as the initial restoration goal. Sustained angler catch rates greater than 1.0 fish per hour was considered as a criteria for accepting that population size had increased because of netting regulations.

16.13 CONCULSIONS AND RECOMMENDATIONS

16.13.1 Evaluation of Current Status

This report describes stable catch rates during a period of declining fishing effort for the shad recreational fishery in Florida's St. Johns River. Also, the average size of shad and the proportions of females have declined markedly during the last several decades. In general, these features do not describe a desirable status for the fishery or for its rebuilding. American shad in Florida's St. Johns River are at historically depressed levels, and at best, can be described as at low but currently stable population sizes.

Landings have declined over the last century, most likely for a variety of reasons. While overfishing has been implicated for Florida's shad population decline (Williams and Bruger 1972), commercial landings and effort have also declined because of declining markets for shad and because of netting regulations within the state. Recreational landings and effort have also been declining within Florida, both historically and within the last decade (Figures 16.2 and 16.5). In addition, it is plausible, and increasingly likely, that environmental degradation within the St. Johns River or other natural perturbations have impacted Florida's shad populations.

McBride (1999a, b) proposed that landings would increase in 2001 through 2005 in response to netting regulations in the 1990s, and if not, that further regulatory options should be considered if fishing pressure is implicated. Fishing is certainly implicated in these discouraging patterns of low abundance, small fish, and skewed sex ratios. In particular gill net gear was commonly used until only 1 to 2 generations ago (approximately 6-12 years ago), and the historic effects of gill net selectivity are most likely to have led to these observed patterns. If these effects are "historical" then current fishing regulations for American and hickory shad need more time. It is projected that the turnover of one more generation (~6 years) should be sufficient to document whether these population parameters are improving. Thus, continued monitoring will be necessary to follow this progress.

It is possible that fishing pressure may continue to be a problem for anadromous shad in Florida. Although the ocean-intercept fishery targeting shad has been closed, non-target mortality may still be significant. Documentation of the catch and release by other states with active coastal gill-net fisheries is important in this regard. Meanwhile, release mortality by Florida's in-river fishery has not been studied, and this may be a critical area for more research and education because so many anglers practice catch-and-release fishing.

Further efforts to rebuild these shad stocks in Florida's St. Johns River should proceed within a comprehensive framework to consider both fishing and other factors affecting these population parameters. The following discussion outlines the important components of fishery production that include different ecological effects at various spatial scales (i.e., in-river versus coastal).

Environmental changes are occurring in coastal and river habitats. Inter-annual or intra-annual variations in rainfall and temperature are caused by El Nino-Southern Oscillation events and the Multi-Decadal Oscillation events (www.swfwmd.state.fl.us). Long-term fluctuations in flow rates across decades have been noted for the St. Johns River and river flow rates may be particularly important in this low-flow river that lacks a fall line (McBride *et al*. 2005b). Water flow can affect egg and larval survival of American shad (Williams and Bruger 1972). At present, it can be said that the location of the spawning ground has remained more or less stationary at least over the last 50 years of plankton surveys. Efforts to protect these areas from further degradation are essential for understanding and maintaining appropriate levels of spawner success and fishery production.

Temperature fluctuations may have a more pronounced effect on anadromous shad species in Florida, where they are at their southern distributional limit. At the very least, coastal temperatures need to cool sufficiently to allow American shad to migrate to northeast Florida and enter into the St. Johns River. Preliminary analyses of surface temperatures at Mayport, Florida (i.e., at the mouth of the St. Johns River) do not indicate the presence of a thermal bottleneck during 2001 through 2005. A newly developed GIS product (Ward, in press) will be used to re-examine near shore temperatures to monitor if temperature bottlenecks occur.

16.13.2 Research Recommendations

Intensive sampling during 2001 through 2005 has been useful for describing the status of the American population in Florida's St. Johns River. Future monitoring of this population with electrofishing should continue. Such sampling may be restricted to the core months of the spawning period for both species—January to April—to decrease costs without losing in sampling power. The creel area and the Puzzle Lake area should be the focus of continued monitoring because they both have several years of baseline data. Also, the longest time-series of abundance data is for the roving creel survey, therefore this survey design should be continued. The survey period of the roving creel survey may be truncated to the core spawning period, if total seasonal catch rates or seasonal fluctuations in catch or effort are not an important goal of the survey. Currently, ASMFC monitoring requirements for Florida included that a creel survey be completed once every five years (ASMFC 1999). Running a creel survey more frequently than twice a decade would, however, lead to considerably improved confidence towards monitoring the stocks and understanding the factors that effect trends in abundance.

More modeling of population and environmental factors is warranted. In the short-term, FWC plans to analyze the trend in annual abundance estimates (i.e., Figure 16.4) as a function of environmental variables such as rainfall, temperature, flow rates, time lags, etc. This will be accomplished with a multiple regression approach, using environmental factors as co-variables, to explore which of these variables is important for explaining long-term trends in abundance. It is also planned to examine the effects of fish size and fish health on spawning frequency and fecundity, using egg production models. In the long-term, more sophisticated populations models should be employed as data becomes available. The stock assessment herein is only intended as a preliminary, baseline perspective.

Finally, it is recommended that more process-oriented research be planned and completed in the future. Likely areas for further investigation—without assignment of priority—include:

1. Continue adult monitoring in sensitive habitats such as the Wekiva River and the Econlochatchee River; as human populations increase and land development expands in central Florida, it will be important to have baseline data to document and conserve these valuable natural resources.
2. Continue, and expand where possible, sampling into more upstream areas of the spawning grounds. Use these data to understand spawning site selection and spawning success.
3. Learn more about the juvenile downstream migration. It is unclear how this occurs from year to year and how it may effect spawning stock size.
4. Initiate a Cating-like study of shad scales and otoliths. Southern populations are not believed to live more than 6 years and if the method could be standardized and eventually validated then new monitoring and modeling options would be available.
5. Initiate a study on catch and release mortality. Use such data educate anglers and lower release mortality.
6. Develop a mark-recapture approach to learn more about population size, mortality, habitat selection, and movements.
7. Create more data regarding habitat selection. Apply such data towards management needs, particularly for minimum flow level determinations as mandated by the St. Johns River Water Management District.

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Table 16.1 Statute miles and equivalent kilometers for major points along Florida's St. Johns River. See Figure 16.1 for map of the St. John's River and route used for calculating distance along the river. (a) The distances below are used in the text; (b) an alternative, but similar distance route was presented in Williams and Bruger (1972).

(a)

Location	**Statute Miles**	**Kilometers**
Mayport, FL (Colreg line)	0	0
Black Creek, mouth	44.5	71.6
Palatka (bridge)	79	127.1
Dunn's Creek (mouth)	86.5	139.2
Welatka	101	162.5
Oklawaha River, mouth	101	162.5
Lake George, south end jetties	122	196.3
Lake Dexter, south end	132	212.4
Lake Beresford, south end	148	238.2
Hontoon Landing		
Wekiva River, mouth	157.5	253.5
Creel Area, downstream start/end	173.8	279.7
Mullet Lake	177	284.8
Creel Area, upstream start/end	181.2	291.6
Lake Harney, north end	186.5	300.1
Lake Harney, south end	191	307.4
Econlochatchee River, mouth	193.5	311.4
Puzzle Lake (middle)	196	315.4
Hatbill Park	205	329.9
Lake Cane, north end		
State Road 50	213.5	343.6
State Road 520	234.9	378
Lake Poinsett, north end		
Lake Poinsett, south end	241	387.8
Lake Washington, north end (dam)	258	415.2
Lake Hellen Blazes	270	434.5
Blue Bypress Lake, south end	296	476.3
Approx. beginning of the SJR	310	498.9

Table 16.1 (cont.) Statute miles and equivalent kilometers for major points along Florida's St. Johns River. See Figure 16.1 for map of the St. John's River and route used for calculating distance along the river. (a) The distances below are used in the text; (b) an alternative, but similar distance route was presented in Williams and Bruger (1972).

(b)

Permanent Stations	River Mile (nautical)	Statute Miles	Kilometers	Location
1	**1**	**1.2**	**1.9**	**Mayport jetty**
2	**20**	**23**	**37**	**Jacksonville Harbor-mouth of Arlington River**
3	**40**	**46**	**74.1**	**Black Creek, across from**
4	**60**	**69**	**111.1**	**Nine Mile Point**
5	**80**	**92.1**	**148.2**	**Buffalo Bluff, between Palatka and Welaka**
6	**97**	**111.6**	**179.6**	**Drayton Island, north of Big Lake George**
	110	126.6	203.7	near Astor
	115	132.3	213	next to Lake Dexter
7	**120**	**138.1**	**222.2**	**south of Lake Dexter**
	125	143.8	231.5	Crows Bluff
	130	149.6	240.7	south end of Lake Beresford
	135	155.4	250	north of entrance to Wekiva River
8	**140**	**161.1**	**259.3**	**north of Lake Monroe**
	147	169.2	272.2	"south end of Lake Monroe"
	155	178.4	287	Mullet Lake
9	**160**	**184.1**	**296.3**	**north of Lake Harney**
	167	192.2	309.3	south end of Lake Harney
	172	197.9	318.5	south end of Puzzle Lake
	174.5	200.8	323.2	
	177	203.7	327.8	
10	**180**	**207.1**	**333.3**	**north of Lake Cane**
	182.5	210	338	
	185	212.9	342.6	
	187.5	215.8	347.2	
	190	218.6	351.9	
	192.5	221.5	356.5	
	195	224.4	361.1	
	197.5	227.3	365.8	
11	**200**	**230.2**	**370.4**	**north of State Road 520**
	205	235.9	379.6	south end of Lake Poinsett
	207.5	238.8	384.3	
	212.5	244.5	393.5	south end of Lake Winder
	215	247.4	398.2	
12	**216**	**248.6**	**400**	**north of dam below Lake Washington (RM 217)**
	222.5	256	412.1	south end of Lake Washington
	225	258.9	416.7	north of Hwy. 192
	227.5	261.8	421.3	"near Lake Hellen Blazes"

Table 16.2 Annual commercial landings (pounds) of *Alosa* in Florida. Landings are presumably all American shad, but reporting did not distinguish between American and hickory shad. Data is restricted to reporting from Nassau, Duval, and St. Johns counties (all coastal), and Putnam County (inland). A fishing year (July-June) is used because the spawning run begins as early as November and continues for several months. Data source: Florida Marine Fisheries Information System. Data for 2004-2005 are preliminary and complete only through June 2005.

Fishing Year	Ocean Landings	Total Landings
1986-1987	142,026	155,430
1987-1988	266,251	266,374
1988-1989	164,839	165,112
1989-1990	169,881	289,293
1990-1991	58,810	71,592
1991-1992	49,633	49,798
1992-1993	24,503	24,503
1993-1994	24,930	24,968
1994-1995	26,791	26,886
1995-1996	3,650	3,650
1996-1997	54	54
1997-1998	18	18
1998-1999	480	480
1999-2000	800	800
2000-2001	0	0
2001-2002	0	0
2002-2003	0	0
2003-2004	0	0
2004-2005	0	0

Table 16.3 Estimates of fishing effort (angler hours), catch (numbers of American shad and hickory shad), and success (shad/hour) for a creel survey area on the St. Johns River, Florida during three representative years: 1994-1995 (an average year), 1998-1999 (the highest catch year), and 2004-2005 (the lowest catch year). A means of ratio estimator was used; N = sample size, Estimate = estimated value, S.E. = standard error of the estimate.

1994-1995

Period	Effort			Catch			Success		
	N	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**
11/3/94-11/16/94	5	0		9	0				
11/17/94-11/30/94	1	0		1	0				
12/1/94-12/14/94	No Data (catch estimate interpolated as 19)								
12/15/94-12/28/94	2	109		4	38		1	0.5	
12/29/94-1/11/95	5	213		20	129		8	0.73	
1/12/95-1/25/95	5	821		31	449		23	0.49	
1/26/95-2/8/95	5	1089		41	423		32	0.44	
2/9/95-2/22/95	4	1057		30	733		22	0.80	
2/23/95-3/8/95	5	3105		88	2400		73	0.79	
3/9/95-3/22/95	5	1198		65	919		25	1.01	
3/23/95-4/5/95	4	473		40	275		8	0.53	
4/6/95-4/19/95	4	24		73	0		1	0	
4/20/95-5/3/95	5	0		81	0				
Entire Survey	**50**	**8089**		**483**	**5366**		**193**	**0.71**	

1998-1999

Period	Effort			Catch			Success		
	N	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**
12/4/98-12/17/98	No Data (catch estimate interpolated as 115)								
12/18/98-12/31/98	No Data (catch estimate interpolated as 330)								
1/1/99-1/14/99	4	338	150	22	660	340	6	1.34	0.61
1/15/99-1/28/99	5	2692	523	92	3379	671	42	1.17	0.11
1/29/99-2/11/99	5	2229	519	58	3304	823	24	1.57	0.22
2/12/99-2/25/99	5	2115	634	62	1724	589	31	0.99	0.11
2/26/99-3/11/99	5	1490	318	55	2392	752	25	1.36	0.33
3/12/99-3/25/99	4	522	95	42	540	336	10	0.98	0.18
3/26/99-4/8/99	5	181	99	60	98	66	3	0.47	0.12
4/9/99-4/22/99	4	25	21	36	0	0	1	0	
Entire Survey	**37**	**9591**	**1044**	**427**	**12097**	**1508**	**142**	**1.2**	**0.09**

2004-2005

Period	Effort			Catch			Success		
	N	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**	**N**	**Estimate**	**S.E.**
11/29/04-12/12/04	3	0	0	1	0				
12/13/04-12/26/04	5	0	0	10	0	0			
12/27/04-1/9/05	5	63	47	13	35	35	3	1.49	1.49
1/10/05-1/23/05	3	76	61	14	25	19	1	0.38	
1/24/05-2/6/05	4	865	446	31	466	176	12	0.53	0.11
2/7/05-2/20/05	4	530	355	20	454	190	8	0.76	0.25
2/21/05-3/6/05	4	262	160	21	221	194	5	0.36	0.29
3/7/05-3/20/05	5	14	10	18	68	37	1	0.50	
3/21/05-4/3/05	5	0	0	22	0	0			
4/4/05-4/17/05	5	0	0	13	0	0			
4/18/05-5/1/05	4	50	36	14	0	0	1	0	
Entire Survey	**47**	**1860**	**598**	**177**	**1270**	**328**	**31**	**0.63**	**0.16**

Table 16.4 Total number of American shad collected by fishery-independent methods in the St. Johns River, Florida, during the years 2001-2005. Sampling areas are ordered downstream and north (top) to upstream and south (bottom). The “creel area” includes the area between Lake Monroe and Lake Harney (bold). Most fish were removed fro life history samples. Most sampling was completed as “density” electrofishing transects (see text for explanation); some fish were sampled by non-standardized electrofishing and standardized gill net samples and these are included as well to identify presence and absence of fish at various locations. Empty cells indicate no sampling effort.

River Section	**2001-2002**	**2002-2003**	**2003-2004**	**2004-2005**
Black Creek			0	1
Palatka	2			
Dunns Creek		0		
Welatka	1			
Oklawaha River			0	0
South end of Lake George		0		
Bluffton		0		
Lake Dexter		0		
Hontoon Landing		0		
Outside Wekiva R.		2	6	0
Wekiva River		0	4	2
Lake Monroe-Mullet Lake	**42**	**135**	**25**	**22**
Mullet Lake-Lake Harney	**14**	**92**	**8**	**1**
Lake Harney-Route 46		102	62	25
Puzzle Lake		108	520	161
Econlochatchee River		5	161	26
Hatbill Park		0		
State Road 50		55	50	133
State Road 520		2	3	11
Total	**59**	**501**	**839**	**382**

Figure 16.1 Map of Florida (inset) and Florida's St. Johns River. Major terrestrial and aquatic features are identified along with the locations of electrofishing sites for the sampling years: 2001-2002, 2002-2003, 2003-2004, and 2004-2005. The length of the river is indicated at 50 mile and 100 km intervals.

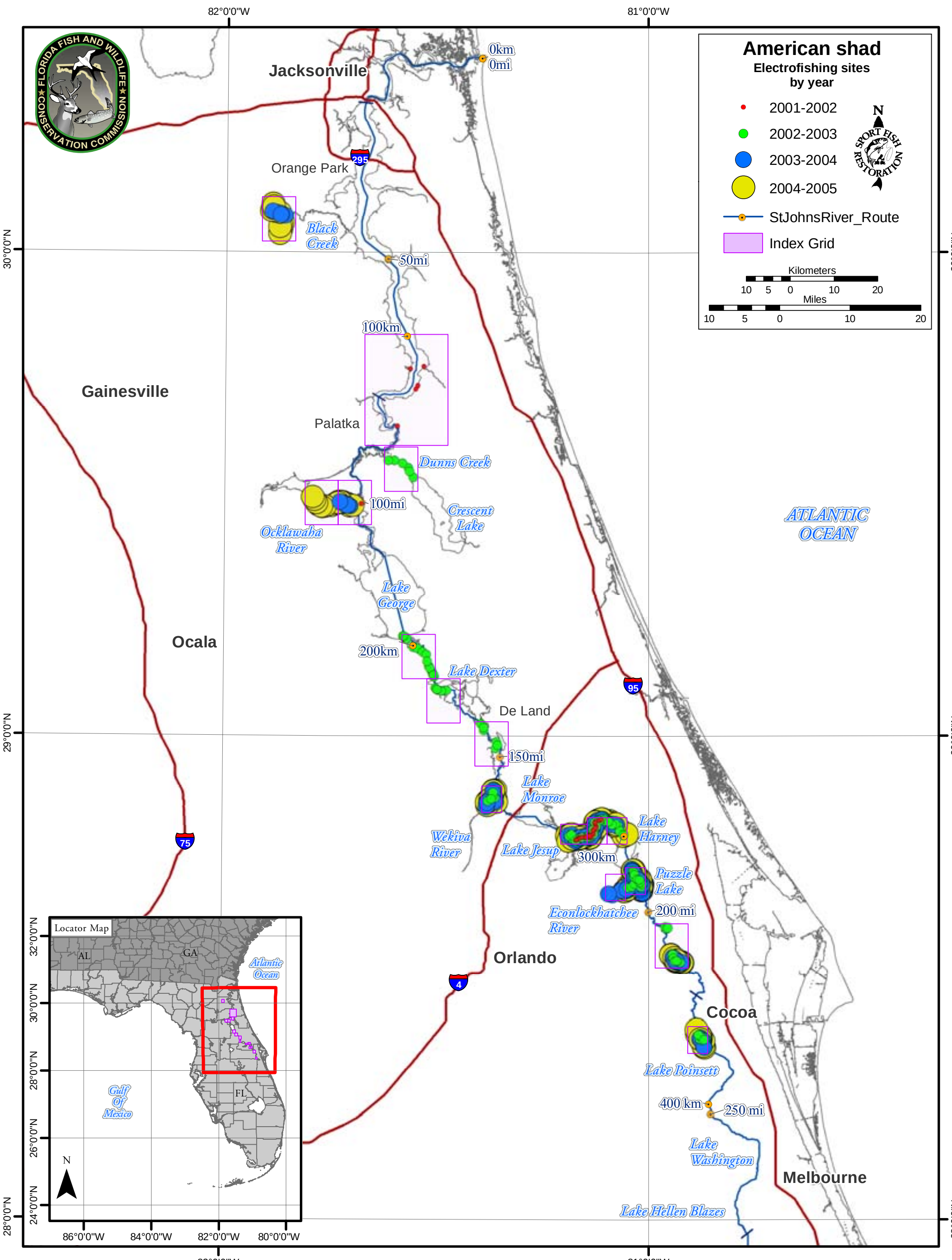


Figure 16.2 The time series of recreational shad catch rates (fishing success) in the creel survey area of Florida's St. Johns River during the period 1992-2005. Fishing success is a ratio of means estimate of the number of fish captured per hour that each species category is harvested. American shad and hickory shad occur together in the creel area and because most anglers do not distinguish between these species, the estimate is a combination of both species. The data presented here are for the periods 3 to 8 (approximately January to March) of each fishing year, when catch rates are highest; the results based on other periods (i.e., 1-10) did not differ. The relationship between fishing success and year was not significant (P>0.05).

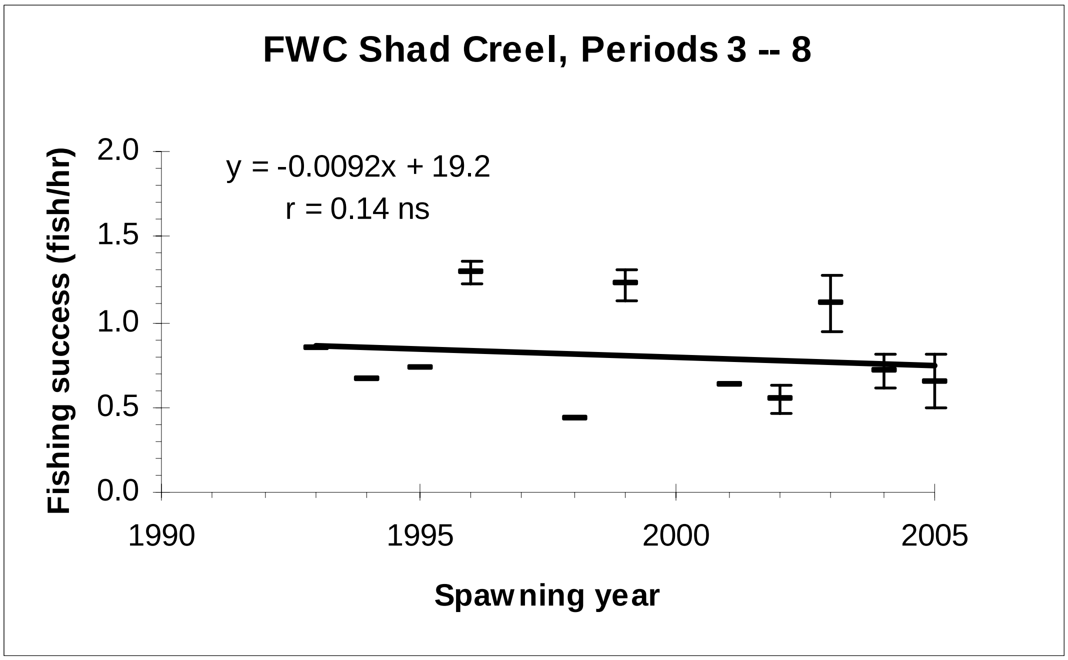


Figure 16.3 Abundance of American shad (top panel) and hickory shad (bottom panel) at various locations along Florida's St. Johns River. Abundance was calculated as the geometric mean number of fish per 10-minute electrofishing transect, ± 95% C.I., per sampling date (with different symbols to identify different years). The selected geographic areas are ordered from downstream to upstream: (a) Wekiva River, (b) the "creel area" (Lake Monroe to Lake Harney), (c) the Puzzle Lake area, (d) the Econolochatchee River, and (e) the southern area that includes State Roads 520 and 50. Date labels indicate the first of each month (i.e., D = December 1).

(a)

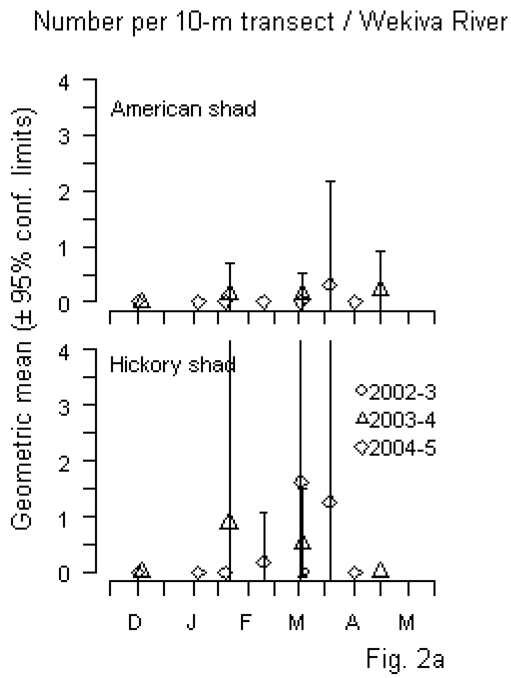


Figure 16.3(cont.) Abundance of American shad (top panel) and hickory shad (bottom panel) at various locations along Florida's St. Johns River. Abundance was calculated as the geometric mean number of fish per 10-minute electrofishing transect, ± 95% C.I., per sampling date (with different symbols to identify different years). The selected geographic areas are ordered from downstream to upstream: (a) Wekiva River, (b) the "creel area" (Lake Monroe to Lake Harney), (c) the Puzzle Lake area, (d) the Econolochatchee River, and (e) the southern area that includes State Roads 520 and 50. Date labels indicate the first of each month (i.e., D = December 1).

(b)

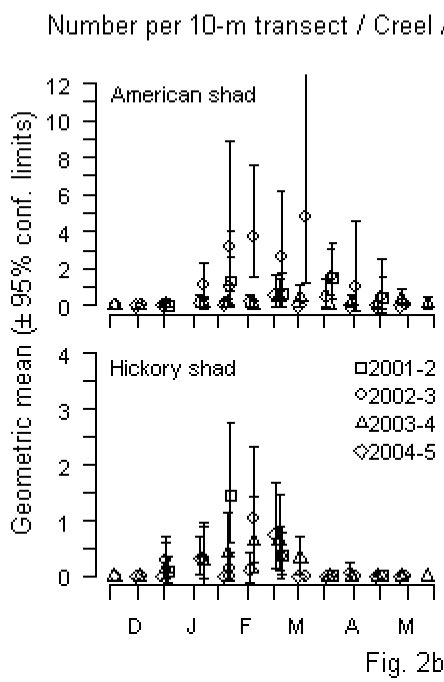


Figure 16.3(cont.) Abundance of American shad (top panel) and hickory shad (bottom panel) at various locations along Florida's St. Johns River. Abundance was calculated as the geometric mean number of fish per 10-minute electrofishing transect, ± 95% C.I., per sampling date (with different symbols to identify different years). The selected geographic areas are ordered from downstream to upstream: (a) Wekiva River, (b) the "creel area" (Lake Monroe to Lake Harney), (c) the Puzzle Lake area, (d) the Econolochatchee River, and (e) the southern area that includes State Roads 520 and 50. Date labels indicate the first of each month (i.e., D = December 1).

(c)

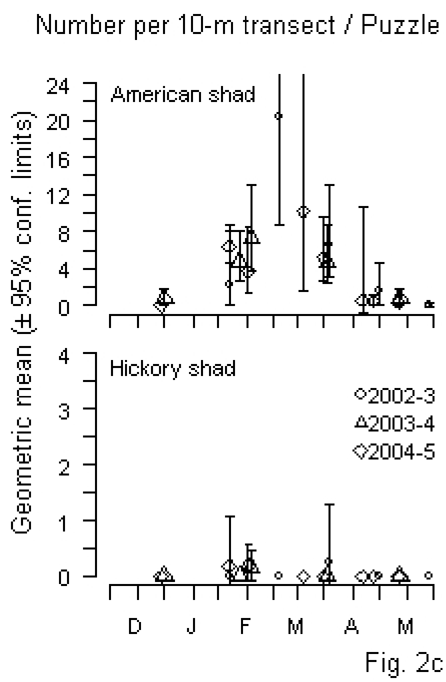


Figure 16.3(cont.) Abundance of American shad (top panel) and hickory shad (bottom panel) at various locations along Florida's St. Johns River. Abundance was calculated as the geometric mean number of fish per 10-minute electrofishing transect, ± 95% C.I., per sampling date (with different symbols to identify different years). The selected geographic areas are ordered from downstream to upstream: (a) Wekiva River, (b) the "creel area" (Lake Monroe to Lake Harney), (c) the Puzzle Lake area, (d) the Econolochatchee River, and (e) the southern area that includes State Roads 520 and 50. Date labels indicate the first of each month (i.e., D = December 1).

(d)

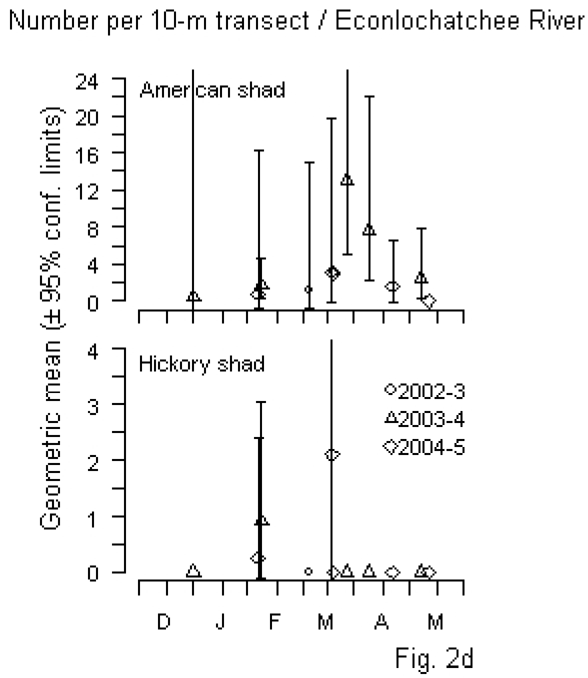


Figure 16.3(cont.) Abundance of American shad (top panel) and hickory shad (bottom panel) at various locations along Florida's St. Johns River. Abundance was calculated as the geometric mean number of fish per 10-minute electrofishing transect, ± 95% C.I., per sampling date (with different symbols to identify different years). The selected geographic areas are ordered from downstream to upstream: (a) Wekiva River, (b) the "creel area" (Lake Monroe to Lake Harney), (c) the Puzzle Lake area, (d) the Econolochatchee River, and (e) the southern area that includes State Roads 520 and 50. Date labels indicate the first of each month (i.e., D = December 1).

(e)

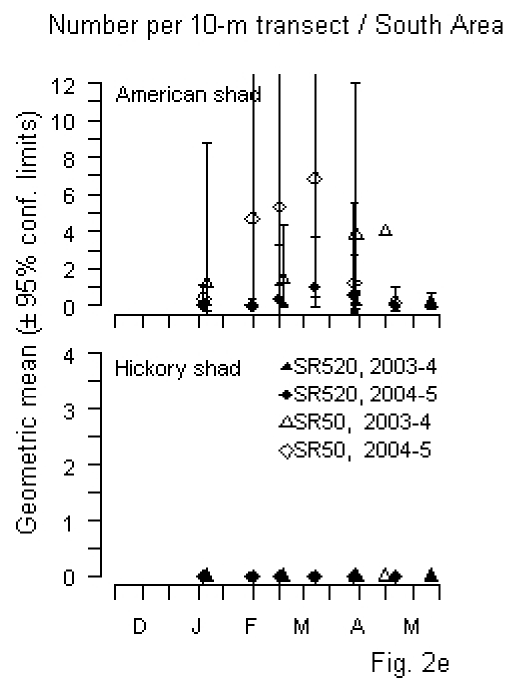
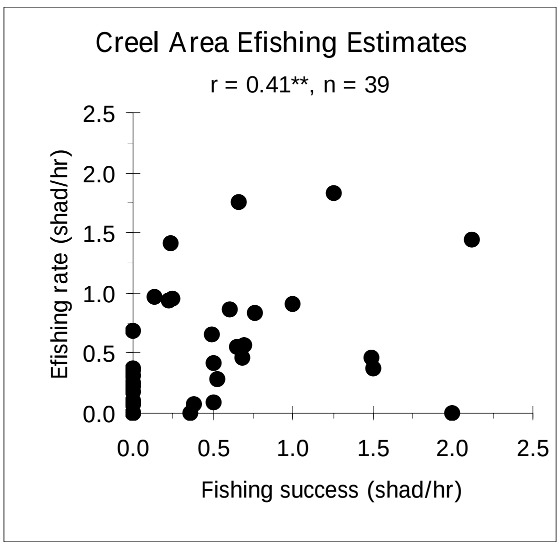


Figure 16.4 The association of shad abundance as measured by electrofishing versus that measured by a roving creel survey in Florida's St. Johns River. Electrofishing abundance is measured as the geometric mean number of American shad and hickory shad combined at two different areas: (a) the creel area between Lake Monroe and Lake Harney and (b) the Puzzle Lake area from Lake Harney to the north end of Puzzle Lake. American shad and hickory shad occur together in the creel area and because most anglers do not distinguish between the species the estimate is a combination of both species. Individual points are measurements for the same two-week periods in four fishing years by each survey. Creel values are ratio of means estimates and electrofishing values are geometric means based on 10-minute transects. The relationship between fishing success and electrofishing rates was significantly and positively correlated (** = $P \leq 0.01$).

(a)



(b)

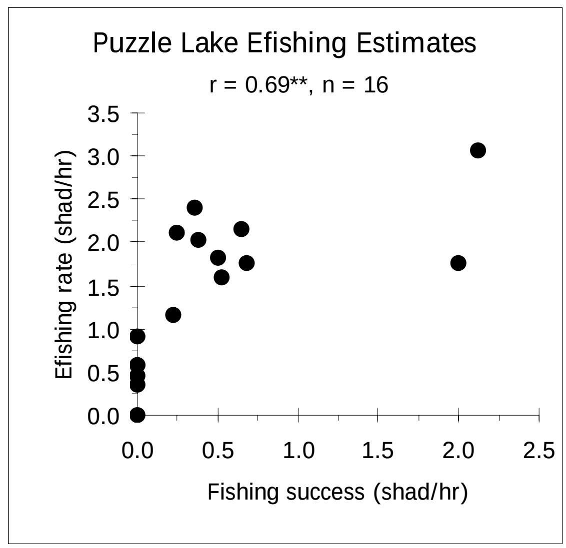


Figure 16.5 The time series of catches (filled boxes) and effort (open boxes) in the recreational creel survey during the period 1992-2005. American shad and hickory shad are targeted together and because most anglers do not distinguish between these species these estimates are a combination of both species. The data presented here are for the periods 3 to 8 (approximately January to March) of each fishing year, when catch and effort are highest; the results based on other periods did not differ.

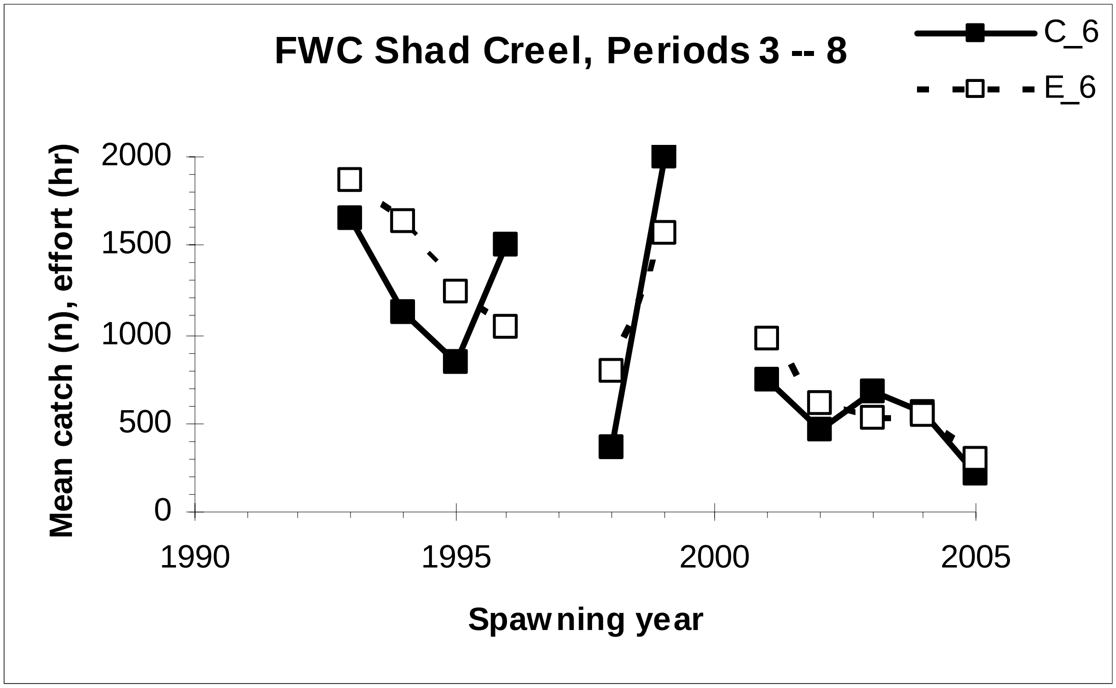


Figure 16.6 Mean fork length of American shad in Florida's St. Johns River during different decades. Males (filled symbols) are plotted separately from females (open symbols). No error bars are available for historic data (triangles)—from commercial haul seines as reported by Walburg (1960a), 1957-1958. Error bars for recent data (diamonds) are 95% confidence limits (from electrofishing collections during 2001-2005 as reported herein).

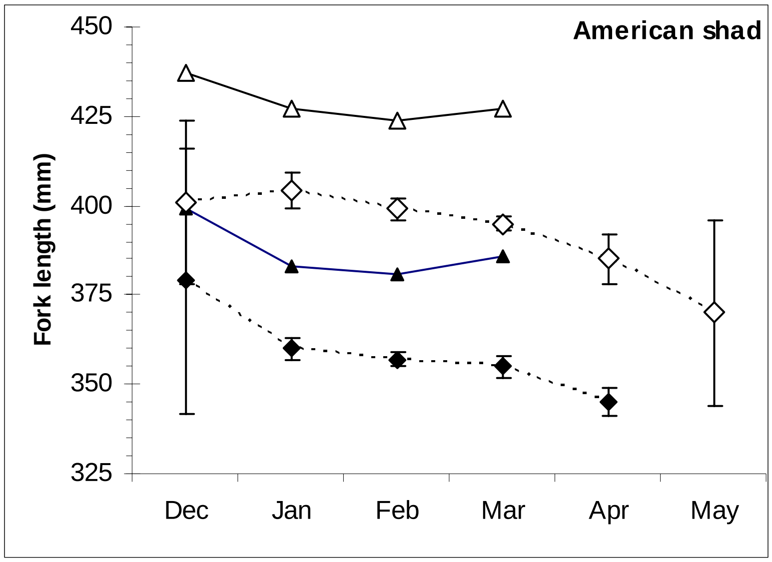
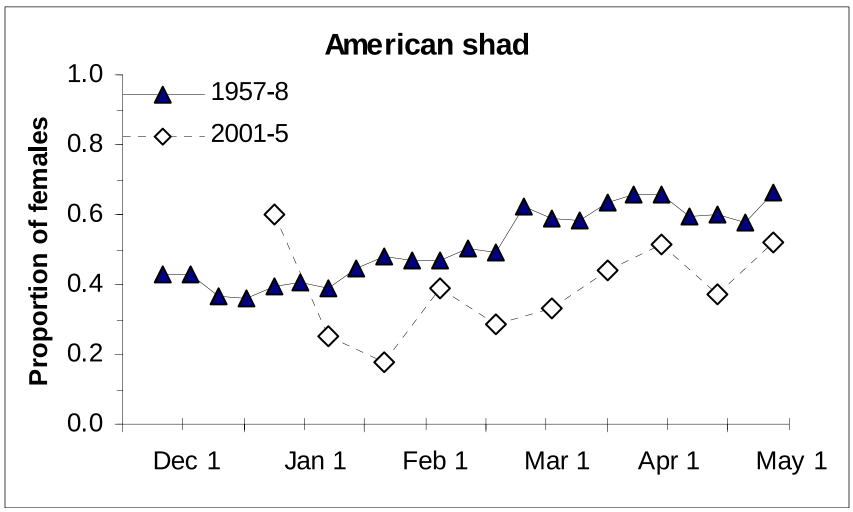


Figure 16.7 Proportion of females in the catch for American shad in Florida's St. Johns River during different decades. Data for 1957-1958 are from a census card survey of anglers (Walburg 1960a). Data for 1971-1972 are from haul seine collections between Palatka and Welatka (Williams *et al*. 197). Recent data (2001-2005) are for electrofishing collections as reported herein.



APPENDIX I

McBride, R.S., M.L. Hendricks and J.E. Olney. 2005. Testing the validity of Cating's (1953) method for age determination of American shad using scales. Fisheries 30(10): 10-18.

Abstract. Cating's method of using scales to age American shad (*Alosa sapidissima*) has been the standard for more than 50 years. However, the only validation of this method is for ages 4-6 in the Connecticut River. To test the method for these—and older—age classes in another river, we obtained scales from 52 known-age fish from two Pennsylvania rivers and had 13 experienced biologists estimate ages using Cating's method. Each biologist read the scale impressions twice, and these readings were then assessed in terms of precision, accuracy, and bias. Percent agreement between estimates for the same scale set (precision) ranged from 50.0 to 76.5 %. Percent agreement between estimated age and known age (accuracy) was highest for ages 3-6 (33.7-48.5%), markedly lower for age-7 (12.1%), and lowest for age-8 fish (3.9%). Ages of the youngest fish were often overestimated, and those of the oldest fish were typically underestimated (bias). Therefore, Cating's method is not applicable to American shad in these Pennsylvania rivers. In fact, this scale-ageing method has never been validated across all ages for any American shad stock. Thus, we recommend against using age-based techniques to assess stocks of American shad until further age-validation studies have been completed.

APPENDIX II

Olney, J.E. and R.S. McBride. 2003. Intraspecific variation in batch fecundity of American shad: revisiting the paradigm of reciprocal latitudinal trends in reproductive traits. Biodiversity, Status, and Conservation of the World's Shads. Am. Fish. Soc. Symp. 35: 185-192.

Abstract. American shad in semelparous and iteroparous populations along its native range are thought to have nearly equivalent lifetime reproductive output due to reciprocal latitudinal trends in fecundity and the degree of repeat spawning. Geographic differences in reproductive patterns are believed to be linked to varying environmental conditions, and this fine tuning is considered strong evidence of intraspecific life history evolution in marine fishes. American shad are also multiple or batch spawners but this reproductive trait has only recently been described. Our objectives were to estimate batch fecundity of American shad in semelparous (St. Johns River, Florida) and iteroparous stocks (York River, Virginia and Connecticut River, Massachusetts), and to re-evaluate annual and lifetime fecundity in these populations. Hydrated females were collected on the spawning grounds of each river. Hydrated oocytes were counted in subsamples from each ovary and batch fecundity was estimated gravimetrically. Estimates of hydrated oocytes/g ovary were found to be independent of subsample location in the gonad. Log-transformed relationships of batch size and total fish weight were highly significant for females in the St. Johns and York rivers, and marginally significant for Connecticut River fish. Adjusting for body size, we found no significant differences in batch size among these stocks. We conclude that batch fecundity of American shad does not vary significantly among semelparous (St. Johns River) and iteroparous populations (York and Connecticut rivers). In all stocks of American shad, spawning frequency and duration are unknown, and seasonal or lifetime egg production cannot be estimated. Thus, hypotheses portraying latitudinal variation in fecundity as an evolutionary response to decreased levels of iteroparity in stocks of American shad are unconfirmed.

APPENDIX III

McBride, R.S., M. Russo and I. Quitmyer. 2003. Morphometrics of herring (Clupeidae) skeletal and otolith remains: implications for zooarchaeology of Florida's St. Johns River. Florida Chapter of the American Fisheries Society. 23th Annual Meeting. Brooksville, FL. February 25-27. (Poster).

Abstract. Herring species, particularly shad (*Alosa*) species, were important to Native Americans and English settlers north of Florida. In this poster we formulate hypotheses for why shad species do not appear to have been important for Florida tribes or Spanish settlers. First, there may be methodological biases in the available data. We find some evidence to support this, because clupeid otoliths are small and likely to fall through ¼" mesh. Also, information is not available for identification of archaeological specimens to the genus or species level within this Family. Taphonomy may also be an issue, because many sites are in proximity to running waters. There are also biological or cultural hypotheses that could explain why these species are rare in midden collections, such as: the fish were not here, the humans were not present during the winter spawning run, the fish were not harvested, or the fish did not end up in middens. These are interesting hypotheses but they suggest that the people of Florida were not taking advantage of a protein source that other cultures used extensively. We discuss our findings from our growing collection of reference material, a search of archival data for midden sites along Florida's St. Johns River, and a review of the literature.

APPENDIX IV

Summary of Reproductive Biology of Florida

Reproductive data was collected for American shad collected during 2001 through 2005 as outlined in the Sport Fish Restoration proposal (F-106). Reproductive measures were made from sex ratios and from gonad weights, as standardized by body weight, as well as from histological preparations of gonad tissue, measurements of whole oocyte diameters, and counts of batch fecundity. These data will be used to document spawning habitats and cycles for American shad. Data have been entered; in many cases data have been proofed or preliminary analyses have been completed. Further analyses and publication is expected.

APPENDIX V

Fish (Shad) Health in Florida

Fish health data was collected for American shad collected during 2001 through 2005 as outlined in the Sport Fish Restoration proposal (F-106). Damage or abnormalities were recorded using codes developed by FWC's Fish Health unit. These codes include external manifestations of damage to the epidermis, skeletal elements, and major organs. These data will be used to document the progression of fish health during the spawning run and for differences between species, areas, year, and sexes. Data have been entered; in many cases data have been proofed or preliminary analyses have been completed. Further analyses and publication is expected.

APPENDIX VI

Draft abstract for Nicholas A. Trippel's Master's thesis (Chair: Dr. M.S. Allen, Dept. Fisheries and Aquatic Sciences, University of Florida). Anticipated defense date: Spring 2006.

Title: Abundance and Potential Effects of Predators on Seaward Migrating Juvenile American Shad in the St. Johns River, Florida

The St. Johns River, Florida was once considered home to the largest recreational American shad, *Alosa sapidissima*, fishery on the Atlantic coast. This fishery has drastically declined due to continuing decreases in American shad abundance in this system. I assessed the temporal trends in juvenile American shad leaving the river, compare catch rates to those of a similar study completed 35 years ago, and evaluated predator diets in the sample area before, during, and after the juvenile American Shad had moved through the area. I also compared predator diets to prey availability over 2004-2005 and estimated caloric values of more common prey to determine the seasonal variation in the relative importance of these species to predator diets within the Palatka area of the St. Johns River. I used a surface trawl to collect prey fish including juvenile American shad, and electrofishing to collect predators for diet analyses. Samples were collected monthly in most months but biweekly during the peak migration period of August-December.

Trawl catch rates of juvenile American shad and other juvenile *Alosa* spp. were extremely low. Only 23 American shad were collected during 12 months of sampling. The highest catch rates occurred in October which was similar to the historical study. Catch rates were similar to those from 35 years ago using similar trawling gear. The surface trawl may not have been an effective sampling method as more juvenile *Alosa* spp. were collected while electrofishing for predators. Electrofishing catch rates peaked in November. Only one American shad and one hickory shad were found in predator diets throughout 12 months of sampling and 1,532 total predator diets measured.

Mixed model analyses determined that prey catches varied throughout the year. Significant differences were detected when comparing catch by month (P<0.0001), catch compared to freshwater or estuarine species (P<0.0001), and the interaction between month and freshwater or estuarine species (P<0.0003). There were freshwater species present year round, while juveniles of several estuarine species were present during different seasons of the year.

Correlation analysis revealed that trawl catches and occurrence of individuals found in diet samples were positively related for several species. These species included Atlantic menhaden, *Brevoortia tyrannus*, (P<0.01), suckermouth catfish, *Hypostomus plecostomus*, (P<0.01), and white catfish, *Ameiurus catus*, (P=0.01), where catch in the trawl was positively related to occurrence in predator diets.

The four most common species collected in trawl and diet samples were threadfin shad, *Dorosoma petenense*, bay anchovy, *Anchoa mitchilli*, Atlantic croaker, *Micropogon undulatus*, and Atlantic menhaden. The number of these species found in largemouth bass, *Micropterus salmoides*, diets varied significantly by month and size class of largemouth bass. Atlantic menhaden were found to be the most energetically beneficial to predators, and I found that during months when they were present all size classes of largemouth bass utilized them as prey.

Management implications of this study include helping to successfully manage the American shad fishery in this river, and to better relate the life history of common prey items in this coastal river system to seasonal and ontogenetic diet shifts for the common predators. I found we need to look more closely into the larval life stages to examine if water quality is having an effect on survivability or to see if there is

lack of critical food (e.g., zooplankton) available to juvenile American shad. Researchers need to look into flow issues related to spawning success of adult fish, water quality, and pollution issues.

See also Trippel (2005) at http://www.sdafs.org/flafs/news/oct05NL.PDF (p. 7 of the newsletter, '*The Shell-cracker*' (Quarterly newsletter for the Florida Chapter of the American Fisheries Society).

APPENDIX VII

Recent (last 5 years) oral or poster presentations related to Florida's American shad and hickory shad.

McBride, R.S. 2005. A brief review and preliminary results of American Shad monitoring and research in Florida. Florida Fish & Wildlife Conservation Commission. St. Petersburg, FL. June 9.

McBride, R.S. 2005. A brief review of American Shad monitoring and research in Florida. Prepared for the Atlantic States Marine Fisheries Commission – Shad/River herring Technical Committee – Stock assessment subcommittee for southern rivers. North Carolina State University, Raleigh, NC. April 5-7.

McBride, R.S. 2005. Welcoming remarks for the symposium: Florida's Diadromous Fishes: their biology, ecology, management, and conservation. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24.

McBride, R.S., J.C. Holder and R.O. Williams. 2005. The biology, ecology, management, and conservation of Florida's *Alosa* species. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24.

Harris J.E., R.S. McBride and R.O. Williams. 2005. Comparison of life history and population dynamics of hickory shad in the St. Johns River, Florida, in the 1970's and 2000's. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24. (Presented by K. Maki).

Trippel, N.A., M.S. Allen and R.S. McBride. 2005. Seasonal changes in prey abundance relative to predator diets in the St. Johns River, Florida. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24.

McBride, R.S., J.E. Harris and J.C. Holder. 2005. Abundance and length of American shad, *Alosa sapidissima*, collected by electrofishing in the St. Johns River, Florida. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24. (Poster).

McBride, R.S. and R.E. Matheson. 2005. Florida's Diadromous Fishes: biology, ecology, management, and conservation. Florida Chapter of the American Fisheries Society. 25th Annual Meeting. Ocala, FL. February 22-24. (Poster, presented by R.E. Matheson).

McBride, R.S., K.L. Maki and J. De Silva. 2004. Lessons learned from measuring ageing precision of simulated fish populations. Proceedings of the 57^{th} Annual Meeting of the Gulf and Caribbean Fisheries Institute. St. Petersburg, FL. November 8-12.

Harris, J.E., R.S. McBride and R.O. Williams. 2004. Life history of hickory shad, *Alosa mediocris,* in the St. Johns River, Florida. Annual meeting of the American Fisheries Society. Madison, WI. August 22-26.

McBride, R.S. 2004. Summary of the Age Validation Workshop for Known-age American Shad Scales. Virginia Institute of Marine Science. College of William and Mary. Gloucester Point, VA. July 28.

Chandler, G.M., J.C. Holder and R.S. McBride. 2004. The progression of spawning seasonality of American shad in the Saint Johns River, Florida. Florida Chapter of the American Fisheries Society. 24th Annual Meeting. Brooksville, FL. February 23-25.

McBride, R. 2003. FWC's Interdivisional Research on American Shad in the St. Johns River, Florida. Florida Marine Research Institute Seminar Series. St. Petersburg, FL. June 18.

McBride, R.S., M. Russo and I. Quitmyer. 2003. Morphometrics of shad (*Alosa* spp.) skeletal and otolith remains: implications for zooarchaeology of Florida's St. Johns River. Florida Chapter of the American Fisheries Society. 23th Annual Meeting. Brooksville, FL. February 25-27. (Poster).

Whitaker, S. M., L.J. Jenkins, J.C. Holder and R.S. McBride. 2003. Monitoring Florida's American shad population in the St. John's River. Florida Chapter of the American Fisheries Society. 23th Annual Meeting. Brooksville, FL. February 25-27.

McBride, R.S., M. Russo and I. Quitmyer. 2002. Morphometrics of shad (*Alosa* spp.) skeletal and otolith remains: implications for zooarchaeology of Florida's St. Johns River. Annual meeting of the Florida Anthropological Society. St. Peterburg, FL. May 3-5. (Poster).

McBride, R.S. 2002. Florida's shad and river herrings (*Alosa* spp.): A review of population and fishery characteristics. Florida Fly Fishing Association. Monthly Meeting, Cocoa, FL. January 22.

McBride, R., S. Rider, G. Nelson, J. Holder and J. Jenkins. 2001. Status of Florida's shad and river herring (*Alosa* species): changing for the better in northeast Florida? Shad2001: A Conference on the Status and Conservation of Shads Worldwide. Baltimore, MD. May 20-23. (Poster).

Olney, J. E. and R.S. McBride. 2001. Batch fecundity of American shad (*Alosa sapidissima*) in the St. Johns River, Florida (USA). Shad2001: A Conference on the Status and Conservation of Shads Worldwide. Baltimore, MD. May 20-23. (Poster).

McBride, R., R., McMichael, S. Rider and G. Nelson. 2001. Status of Florida's shad and river herring (*Alosa)* species. Southern Division American Fisheries Society 9th Midyear Meeting. Jacksonville, FL. February 22-25. (Poster).