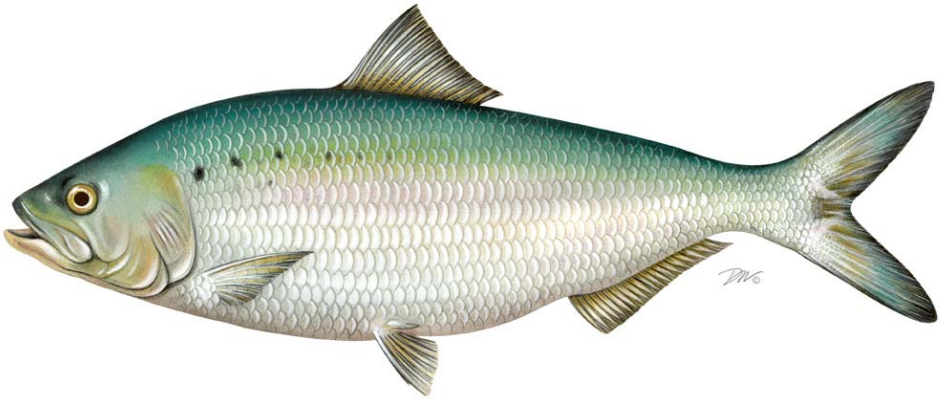
Stock Assessment Report No. 07-01 (Supplement)
of the

Atlantic States Marine Fisheries Commission

American Shad Stock Assessment Report for Peer Review

Volume I



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 I

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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
  Susquehanna River
  Potomac River
  Virginia
  North Carolina
  South Carolina
  Georgia
  Florida

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The Commission appreciates the efforts of the Commission staff who 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 1
Introduction to American Shad Stock Assessment for Peer Review

1.1 INTRODUCTION

This document provides a benchmark assessment of American shad stocks of the U.S. Atlantic Coast from Maine through Florida. It is organized into three major sections: (1) an assessment overview that provides summaries of the most meaningful data from a coastwide perspective and by state and major river system; (2) a hypothesis section where we explore various analyses suggesting reasons for observed change; and (3) state and river-specific source documents that provide background materials and summaries of all available data.

This document was prepared by the Stock Assessment Subcommittee of the Atlantic States Marine Fisheries Commission (ASMFC) Shad and River Herring Technical Committee. Data were obtained from U.S. Federal and State freshwater and marine resource management agencies, power generating companies, and universities. We routinely interacted with data collectors and managers to insure that application and interpretation of data were appropriate. Data summaries were developed during several regional data workshops whose participants included data generators, resource managers, and assessment scientists. Selection of the most useful data series occurred during a series of assessment workshops that also included data generators as participants.

1.1.1 Assessment Approach

We opted to assess Atlantic coastal shad stocks on an individual basis. As an anadromous species, American shad should be assessed and managed by river system. American shad spawn in rivers along the entire U.S. Atlantic coast and there are gradual (latitudinal) differences among river systems in life history attributes. Of greater consequence are river-specific factors such as the presence of dams (with and without fish passage), water quality problems, and estuarine and in-river fisheries. All of these factors lead to river-specific variation in patterns of abundance and in restoration potential.

We used a simple index based approach in this assessment for several reasons. First is that American shad stocks have been exploited in oceanic and estuarine mixed-stock fisheries as well as river-specific fisheries. A few of the mixed-stock fisheries are adequately monitored but there is almost no information about how to allocate the mixed-stock harvest among stocks. Harvest is monitored for most in-river commercial fisheries but recreational harvest is less often monitored. Almost no information is available on discard or bycatch. The data gaps for American shad can be attributed partly to the many fisheries that harvest American shad (both within and between states) but also to the low priority the species receives in agency monitoring efforts. Declines in American shad abundance and in the importance of its commercial fisheries make the species a low priority for most marine fisheries agencies. This understandable prioritization results in there being few long-term fishery-independent indices, except on rivers with fish passage. Fishery-dependent indices provide some of the longest time series on American shad and may extend back to periods of higher abundance, but are often limited by concerns about changes in effectiveness (catchability) of gear over time. Some of the current fishery-independent surveys should be of sufficient length to be useful in assessments 5 to 10 years from now.

Other factors arguing for a simple index-based approach are uncertainties about the age data and the magnitude of various sources of mortality. The one recent age validation workshop (McBride *et al*. 2005) showed that errors in ageing from scales may result in both imprecision and bias. A detailed analysis of age data may be unproductive until further age validation studies are completed. Total mortality rates reflect the combined impact of intensive fisheries, spawning mortality, predation, and mortality associated with downstream passage at hydroelectric dams in some systems. Almost no stocks have sufficient information to separate mortality into these sources. Uncertainty about natural mortality is perhaps the

biggest limiting factor in drawing strong conclusions about the status of American shad. There are no empirical estimates of natural mortality associated with spawning. Inferences about its magnitude are based almost entirely on total mortality rates and spawning marks on scales. Although interpretation of spawning marks on scales needs an updated validation study, they may help in establishing the magnitude of spawning mortality. Unfortunately, a lack of spawning marks may simply be a reflection of intensive fishing; for example, if a high percentage of migrants are harvested fewer will return to spawn. Considerable uncertainty also exists about the magnitude of predation on American shad. This predation could occur in rivers, estuaries, and in the ocean, and may be an important source of mortality for juvenile or adult American shad. Recent concern has focused on predation by striped bass, whose population has increased coastwide. There is a lot of diet information for striped bass, but the magnitude of predation mortality is difficult to assess because of uncertainty about the proportion of the striped bass population within different bodies of water. The final uncertainty about American shad mortality is the magnitude of ocean harvest. Directed ocean-intercept fisheries were closed in 2005, too recently for the impact of that closure to be evident in this assessment. Mortality due to bycatch in other ocean fisheries is basically unknown.

In this assessment, we focused on evaluations of selected indices of abundance for age-0 and mature shad from various fishery-dependent and independent sample programs, passage numbers at major dams, age and size data, and calculations of total mortality rates. We developed benchmark estimates of total mortality from simple regional biomass-per-recruit models. Data summaries were at the stock level where possible, although ancillary data from mixed stock sources were occasionally used as supporting information. We generally avoided use of tag-recapture population estimates of spawning stock abundance because their use requires many unverified assumptions and we avoided analyses requiring harvest-at-age by stock. We also avoided making sweeping adjustments of entire data time series based on one or two point estimates of adjustment factors. Complex model building and creative data analyses were confined to the hypotheses section.

There were several categories of data that we did not use in this assessment. We explored, but did not use data from the Marine Recreational Fisheries Statistics Survey (MRFSS) for several reasons. Recreational fishermen rarely catch American shad in marine waters. This leads to bias in catch estimates by the MRFSS because data on American shad are often missing from sampling units and must be substituted from larger units. There is also considerable concern about potential species misidentification. Anecdotal evidence from state biologists indicates that hickory shad, which is growing in abundance, have been misidentified as American shad, especially by anglers. Since we had no way to evaluate the potential for these biases, we did not pursue estimates of recreational harvest. We also evaluated, but did not use catches of American shad in the Northeast Fisheries Science Center bottom trawl survey as an abundance index. Again, incidence of shad in the data was low and resulting estimates of CPUE were highly variable and imprecise. Finally, we did not have time to provide an adequate analysis of shad bycatch in commercial fisheries in ocean waters. Data on incidence of American shad in commercial catches were available from National Marine Fisheries Service (NMFS) observer programs and commercial fishing trip reports. However, observations of American shad were a rare event and reasonable extrapolations of total bycatch require a thorough knowledge of NMFS databases and complex analyses to fill in the many missing values in sample units.

This assessment may not provide definitive answers to all the questions plaguing management of Atlantic coastal American shad (fishing, predation, other sources of natural mortality, fish passage), but it gives insight to managers on the complexity of the issues to assist them in their decision-making. It also lays the foundation for future assessments in terms of data sources and methods. Updating these datasets in future years should be straightforward and as datasets get longer, concerns about ageing methods are addressed, and the influence of ocean harvest diminishes these questions may be able to be answered. If the datasets are stronger in future assessments, they may support the use of more complex assessment models.

1.1.2 General Biology

A broad overview of American shad and *Alosa spp.* status, biology, ecology, and population dynamics is available in Limburg and Waldman (2003). Additional information on life history can be found within the individual source documents for each assessment.

Migration and Genetic Information

Migration

Shad spend most of their life at sea, returning to their natal river system only when sexually mature. Prior to the 1950s, very little was known or understood about the ocean migratory routes of immature and adult fish. In one of the first attempts to study shad migration, Vladykov (1950) tagged shad on their spawning run in the St. Lawrence River. Out of system returns ranged from Cape Cod, Massachusetts to ocean waters off Nova Scotia. Talbot and Sykes (1958) conducted their own tagging studies and analyzed data from several tagging experiments of the U.S. Bureau of Commercial Fisheries. They found that both immature and mature shad from the Chesapeake and north summered in the Gulf of Maine, moved south along the coast in the fall, and over-wintered in large groups between North Carolina to Long Island, New York (Talbot and Sykes 1958). Juvenile shad that left their natal system in fall were assumed to have spent the winter in the mid-Atlantic area before joining the coastal migration to the Gulf of Maine. Milstein (1981) reported that young (age-0 and age-1) American shad spend their time in near-shore estuaries supporting Talbot and Sykes (1958) model of juvenile American shad distribution. Talbot and Sykes (1958) also indicated some tag returns from fish tagged in the Gulf of Maine came from southern semelparous stocks. They surmised that these fish were immature when tagged while summering there in previous years.

More recent studies (Dadswell *et al*. 1987; Hattala *et al*. 1998) support these generalized migration patterns. Adult American shad spend summers in northwestern Atlantic waters as far north as the Gulf of Maine, the Bay of Fundy and off the coast of Nova Scotia. In the fall, they begin a southward migration to over-wintering areas off of Maryland, Virginia, and North Carolina.

Several researchers have found that shad prefer fairly narrow ranges of water temperatures, which appear to regulate migratory behavior (Leggett and Whitney 1972; Leggett 1977). These studies concluded that adult American shad migration generally followed a northerly route to the Gulf of Maine and Bay of Fundy in summer, before returning south in the fall following the coast to over-wintering areas near the mid-Atlantic region of the U.S. Neves and Depres (1978) refined this pattern by examining shad presence in NMFS trawl data versus water temperature. They concluded that American shad followed fairly specific temperature windows of 3 to 15ºC during their migration at sea. American shad over-winter from North Carolina to New Jersey; however, Cape Hatteras, North Carolina appears to serve as a dividing point for pre-spawning fish of southern and northern rivers. Water temperatures south of Cape Hatteras generally average about 15ºC. Southern stocks move inshore at or near Cape Hatteras to be inside the Gulf Stream. They follow near-shore southerly currents averaging 15ºC to reach their natal river. Parker's (1992) study tagging shad in southeastern North Carolina confirmed this southerly migration pattern. Pre-spawning fish of northern stocks also move inshore in areas, but north of Cape Hatteras, and move north as northern edge of water temperatures warm to about 4ºC to enter their spawning rivers (Neves and Depres 1978). Peak runs into rivers north of Cape Hatteras occur when water temperatures range from 10 to 15ºC.

Genetic Information

The timing of the pre-spawning shad migration along the coast is important to understand as commercial fisheries from South Carolina to New Jersey and in Rhode Island have exploited this mixed stock

assemblage. The ocean-intercept fishery was closed in 2005, as states instituted regulations that followed ASMFC Amendment 1 to the Shad and River Herring Interstate Fishery Management Plan on January 1, 2005 (see Section 1.1.4).

Investigations were conducted to determine composition of shad captured in the mixed stock directed ocean intercept fisheries in Virginia through New Jersey from the late 1980s to the mid-1990s (Brown and Epifano 1994, Brown 1996). Chapman (1993) investigated the genetic composition of the Susquehanna River stock. Bentzen *et al*. (1989) studied the genetic differences in relation to life history strategies (semelparity versus iteroparity) of east coast American shad stocks.

All studies used restriction enzyme analysis on mitochondrial DNA to determine the genotype frequencies for each stock. Many of the genotypes were common to most stocks, with some geographic clumping. Results (uniqueness of stock) were based on maximum likelihood analysis of genotype frequency distributions. The conclusions of Brown (1996) came under scrutiny when genetic identity was questioned based on comparisons of the otolith marks for each fish sample, which indicated a different stock origin of the same sample.

Age

Please refer to Section on Age Determination (1.1.6).

We do not know the maximum age American shad can attain in the absence of fishing, since all East Coast American shad stocks have been exploited. Most East Coast shad stocks have been exploited prior to the written record in the mid-1800s through the present. Maximum age of southern semelparous (Florida to South Carolina) stocks follows maximum age of maturity. Most fish are mature by age-7. However, the maximum observed age for the Altamaha River, Georgia was age-8 (Godwin and McBay 1967). In the Hudson, shad grew to age-10 in the years following World War II after the stock had experienced a major collapse (Talbot 1954). Recent data from the Hudson River stock indicate that female American shad can reach age-13. Males reach about age-10. Reported maximum age in other east coast iteroparous stocks range from ages 9 to 11 (Connecticut, Leggett 1976; Virginia, Olney and O'Reilly 2002; and North Carolina, S. Winslow, pers. comm.). Maximum age reported for Maine rivers was age-12 (see Section 9.2).

Growth

Growth data are presented in individual chapters.

Reproduction

Spawning runs of American shad begin in Florida in mid-November or early December and sequentially move north with latitude (Mansueti and Kolb 1953). Runs in Georgia and South Carolina generally begin in January and peak in March. By April, American shad runs begin to peak in North Carolina, followed by the runs in Virginia and Maryland. In Delaware, Pennsylvania, and New York, spawning typically peaks in late spring (May) and may extend into early June. New England and Canadian shad spawning runs range from mid-May to late July.

Most American shad native to the rivers of the southeastern U.S. are semelparous, however, in rivers to the north, stocks are iteropaous (Carscadden and Leggett 1975). There is no distinct geographic dividing point between iteroparous and semelparous life-history strategies. Although available data suggest that the transition occurs in southern North Carolina, validation studies of repeat spawning mark determination on scales in this region have not been conducted.

American shad are broadcast spawners—their fertilized eggs are carried by river currents and hatch within 2 to 17 days depending on water temperatures (Jones *et al*. 1978). Larvae drift with the current until they mature into juveniles. The clinal variation in repeat spawning is considered an energy trade off in terms of fecundity to migration and perhaps growth. Since reproductive characteristics vary with latitude, discussion of percent of repeat spawning, maturity, and fecundity are presented separately in the individual chapters.

Leggett and Carscadden (1978) described reciprocal trends between the degree of repeat spawning in American shad and relative fecundity with increasing latitude. A recent investigation of batch fecundity of American shad from the Connecticut River (Connecticut), York River (Virginia), and St. Johns River (Florida) showed that batch fecundity does not vary significantly across latitudes (Olney and McBride 2003).

Natural Mortality

American shad have a complex life history strategy and natural mortality likely varies by life stage. Mortality while at sea is unknown but would represent a combination of natural death, bycatch, and directed ocean harvest. There is no information about at-sea survival except for analyses done on cohorts of stocked fish (Section 10). Natural mortality at sea should be similar to other clupeids.

Post-spawning mortality of adults has been observed in the Delaware River (Chittenden 1976). Weight loss during their freshwater stay varied by size and sex, with an average somatic weight loss of 42% for males and 50% for females (Chittenden 1976). The weight loss is attributed to the lack of suitable prey resources and energetic costs of migration, final gonadal development, and spawning (Chittenden 1976). In other systems, post-spawning mortality is primarily inferred by the presence or absence of spawning marks on scales. Ages based on scales suggest that instantaneous total mortality rates (Z) are high for some populations, but the contribution of fishing (F) and natural (M) mortality to Z is poorly understood because of limitations in tagging programs and fishery records.

Please refer to Benchmark Mortality Calculations section (1.1.5).

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1.1.3 General Regulatory History[1]

American shad have waned in their importance as a food fish since the turn of the 19th century, when they were among the top three species harvested on the Atlantic coast (U.S. Fish Commission 1872-1881). In the late 1880s through the early 1900s shad harvest was massive, nearly 50 million pounds coastwide per year. But in the years shortly following, most East Coast shad stocks experienced serious declines. Stock collapses were a coastwide event (see Section 1.1.7). Overfishing, habitat loss from dam construction, dredge and fill operations, as well as habitat degradation (pollution) are among the primary cause.

Change in human practices was slow to come and the same pattern of events occurred in most all states within another 50 years. Following WWII, some East Coast stocks experienced a second collapse, faulted primarily to overfishing during the war and the seven to ten year period that followed (Talbot 1954; Fredin 1954). Degenerative environmental conditions further contributed to the declines. Degradation that began in the 1800s grew worse: constructing major dams and destroying, providing little or no passage, filling shallow water spawning habitat, and worsening water quality problems associated with pollution created low and no-oxygen blocks in major portions of large rivers (two of the most infamous occurring in the Delaware and the Hudson).

By the early 1980s, stock sizes for most Atlantic coast shad stocks were, in reality, just remnant populations. While moratoriums were in place in several states (Maryland and New England), commercial harvest of American shad continued in others. Despite stock declines and moratoria, the once traditional in-river spring fisheries for roe—the eggs are considered a delicacy—expanded in recent years to include late winter and early spring fisheries in ocean waters and large coastal bay waters. These ocean and bay fisheries exploited the pre-spawning migration of American shad. Current fisheries are relatively small, compared to the magnitude of past fisheries, but it should be noted that current fisheries continue to operate on much smaller stocks than those present 40 or even 20 years ago.

The earliest records of regulations pertaining to management of American shad fisheries date back to the 1700s when Massachusetts, Maryland, and Virginia took legislative action toward managing their fisheries (ASHP 2006; A.C. Carpenter, pers. comm.). Since this time, individual state regulations have managed American shad stocks using gear and effort restrictions, and closed areas and seasons for recreational and commercial fisheries, and catch and effort data reporting for commercial fisheries. State and river-specific regulatory histories and current regulations are contained in the individual reports.

The written historical record varies and is often vague on the driving forces behind the development of fishery management strategies for East Coast states. Beginning about 1868, mid-Atlantic and New England states legislated the creation of fish commissions recognizing the tremendous importance of fish, particularly shad, as a food source. Accounts from the New York Forest, Fish and Game Commission (1908) reported that state commissioners from Maine to Pennsylvania met at a convention in New York City in 1868 to "promote uniformity of law and action among the States" and to discuss "the regulation of nets and netting, the limitation of fishing seasons, and the selection of suitable fishways" with most all of these rules pertaining to take of shad. This is one of the first references on actions taken to regulate fisheries. However, subsequent reference to management actions quickly disappeared, with the primary focus centered on development of hatchery culture.

The results of the 1868 convention are thought to have directly "influenced the foundation" of the US Commission of Fish and Fisheries (New York Forest, Fish and Game Commission 1908). This federal commission came into existence in 1871 and took on the task of increasing the supply of "readily available fish," with American shad as the most prominent species, to meet the increasing demands of a

[1] Portions of this section have been taken from the Atlantic States Marine Fisheries Commission's *Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring* (1999).

growing population in an expanding country. The Commission's tenet of investment of time and money in hatchery programs was deemed necessary on the federal level so that "no one state would be burdened with such an enormous task" (U.S. Fish Commission 1875), even though many states had already made the commitment on their own.

Shad stocks were still quite large during this time period (1870-1890), although it appears from the writings of the U.S. Fish Commission (USFC) and New York Forest, Fish and Game Commission that runs were in the first serious decline (recorded in the written record). One reference from a New York report mentions there were "few fish to speak of from southern rivers," referring specifically to the Potomac River. New York was in search of brood stock to assist in replenishing the Hudson stock, perceived to be in major decline. At the same time, the USFC reported landings from the Potomac at about 6 million fish per year. This number is relatively small, and hence the New York assertion that few fish were in mid-Atlantic rivers, given that another USFC report indicated that about 10 to 20 years earlier Potomac River landings were five times higher at about 33 million.

On the federal level, USFC reports rarely refer to any problems with overfishing, but state that hatchery production would solve the "problems related to fishing practices" and the "other drawback of pollution" in spawning areas. Some states, however, did try to address the changes in fishing practices legislating licensing of fishers, escapement periods and some gear restrictions (Legislature of the State of New York, 1868, cited by Harper's Weekly 1872). But in spite of these attempts at management, most states focused on hatchery production as the best solution to fix the problem of declining runs.

As J.L. McHugh (1970) stated, "[i]t is easy, armed with hindsight, to be critical of the past," concerning fisheries management practices. He also indicated that the philosophy of leaders at the time, Spencer Baird of the USFC along with others in many East Coast states, placed great importance on hatchery culture as a solution to the problems of marine and freshwater fisheries. Under these leaders, the federal and state governments "embarked on a vigorous and apparently completely futile program of fish culture for more than 60 years."

The lack of success of these culture programs can be attributed to the prevalent attitudes of the time. Although some individuals recognized the need to regulate fishermen, the prevalent attitude was that fish commissions could not regulate business nor take away a person's livelihood. In addition, the growing human population created a different set of problems, none of which could be controlled by fish commissions. The environmental degradation from pollution (i.e., sewage wastes, mill effluents, ash and cinder dumped on spawning areas) was tolerated and accepted as "difficulties to be endured." So in the face of these obstacles, fisheries policy was developed for what could be done—hatchery stocking—and not what should be addressed—pollution and fisheries (New York Forest, Fish and Game Commission 1908). Unfortunately this policy continued for the next 100 years.

It is not very clear when the emphasis on hatchery culture began to wane. Most references on hatchery culture practices began to disappear after World War II, a period when a slow but evident awakening in fisheries management was about to begin.

At the beginning of WWII, the "pioneer experiment" began with a consortium of seven states recognizing the need for cooperation to address the condition of coastal fish stocks. The creation of the Atlantic States Marine Fisheries Commission in 1941 initially focused on increasing the food fish supply as it was commonly thought that "food will win the war" (ASMFC 1942). Increasing and maintaining fisheries production was of utmost importance to the war effort. The ASMFC used U.S. Fish and Wildlife Service staff to serve as the primary research arm of the newly formed commission. Early work focused on the need to create a statistical catch reporting system so that consequences of states' actions could be tracked to avoid harm to production levels. Also recognized was the need for a [single] management plan to be implemented as "soon as the war was over."

Some species were recognized as needing special attention: striped bass, flounder, and red drum. Other concerns focused on methods to increase fishing efficiency following the loss of vessels and crew to the war effort and allowing of expansion of fishing areas to inshore areas for trawling. During this period of cooperation, states were still responsible for regulating their own fisheries. Many states relaxed or suspended fishing rules during the war years from 1942 through then end of WWII. Although this temporarily increased production, fishing under relaxed regulations took its toll on shad stocks. The condition of American shad stocks, particularly those of the mid-Atlantic, began to decline throughout the war years, leading up to a second major collapse within a century.

In 1949, the Beaufort, North Carolina Laboratory, under the U.S. Bureau of Commercial Fisheries reactivated, following its closure during WWII, to investigate the declines in East Coast American shad stocks. Overfishing was still not thought of as an important factor on stock size. Mansueti and Kolb (1953) listed overfishing as a possible effect after pollution, siltation of spawning areas, and dam construction. The Lab's "Shad Project" (Talbot, Sykes, Fredin, Walburg, and Nichols, among others) received their initial instruction by Dr. R.J.H. Beverton, the "father" of fish population dynamics analyses. After which they began a series of in-depth investigations in shad populations and factors influencing their abundance in several East Coast systems. The investigators produced what are now considered the "classics" in shad research: studies from the Hudson River (Talbot 1954), Connecticut River (Fredin 1954), Maryland rivers (Walburg 1955), York River (Nichols and Massman 1963), Neuse River (Walburg 1957), Edisto River (Walburg 1956), and St. Johns River, Florida (Walburg 1960). These studies were among the first steps toward understanding population dynamics through analyzing statistical data. Although many factors were identified as influencing shad abundance the recurrent cause of stock decline in most systems during the WWII period was overfishing.

When the anadromous fish program ended in 1967, major shad research projects were completed in systems from the Connecticut River south to the St. Johns River, Florida. A James Sykes, a leader of some of the anadromous fish projects, retrospective (Wolfe 2000) stated that "the greater accomplishment came by way of laying the ground work for future state management of fisheries through provision of baseline population data and methods of stock assessment" that were made available to state marine research agencies, many of which were non-existent at the time.

By 1980, coastwide landings of American shad had fallen from approximately 50 million pounds at the beginning of the twentieth century to 3.8 million pounds. Large declines in commercial landings were perceived as an indication that management action would be required to restore American shad to their former levels of abundance. Therefore, the members of the Atlantic States Fishery Commission (ASMFC) recommended the preparation of a cooperative Interstate Fishery Management Plan (FMP) for American Shad and River Herring. The ASMFC adopted this recommendation in 1981 and the FMP was completed in 1985. The FMP specified recommended management measures, focused primarily on regulating exploitation and enhancing stock restoration efforts. At the time of the 1985 FMP, the ASMFC did not have authority over individual state fisheries and implementation of the Plan was at the discretion of the states. The ASMFC approved a supplement to the FMP in 1988, which included reports prepared by the Shad and River Herring Stock Assessment Subcommittee, summaries of material presented at the 1987 Anadromous Alosine Research Workshop, and changes to management recommendations and research priorities based on new research findings.

In 1994, American shad stocks were continuing to decline, which led the Shad and River Herring Plan Review Team and Management Board to determine that the 1985 FMP was not adequate for protecting or restoring the remaining shad and river herring stocks. The 1985 FMP did not require any specific management approach or monitoring requirements within the management unit—it only asked that states provide annual summaries of restoration efforts and ocean fishery activity. To address the shortcomings of the 1985 FMP, the ASMFC implemented Amendment 1 to the Interstate Fishery Management Plan for

Shad and River Herring. The 1993 Atlantic Coastal Fisheries Cooperative Management Act helped in this effort by requiring states to adopt management guidelines in this and other approved Commission Plans. Amendment 1 was approved in 1999 (ASMFC 1999).

The goal of Amendment 1 is to protect, enhance, and restore East Coast migratory spawning stock of American shad, hickory, shad, and river herring (alewife and blueback herring collectively) in order to achieve stock restoration and maintain sustainable levels of spawning stock biomass. To meet this goal, the Amendment identifies several objectives. The objectives listed below are pertinent to American shad:

1. Prevent overfishing of American shad stocks by constraining fishing mortality below F_{30}.
2. Develop definitions of stock restoration, determine appropriate mortality rates, and specify rebuilding schedules for American shad populations within the management unit.
3. Promote improvements in degraded or historic alsoine habitat throughout the species' range.
4. Establish criteria, standards, and procedures for plan implementation as well as determination of states' compliance with management plan provisions.

Amendment 1 established a five-year phase out of the ocean-intercept fishery for American shad by January 1, 2005 and required fishing mortality targets for specific in-river fisheries (Connecticut River, Hudson River, Delaware River, Upper Chesapeake Bay, Edisto River, Santee River, and Altamaha River). It also required states to implement an aggregate 10-fish daily creel limit in recreational fisheries for American shad and hickory shad in all rivers except the Santee River, where an aggregate limit 20-fish (American and hickory shad) per day creel limit was enacted.

In addition to establishing fishing regulations, Amendment 1 established monitoring requirements for American shad, including juvenile abundance and adult spawning stock surveys and in-river creel surveys. The specific monitoring requirements, both fishery-dependent and independent, have been modified through a Technical Addendum in 2000 and an Addendum in 2002. The current monitoring requirements are contained in Tables 1.1.3-1 and 1.1.3-2. All states have implemented regulations that are compliant with Amendment 1.

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Table 1.1.3-1 Summary of mandatory fishery-independent monitoring programs for American shad as required by Addendum I to Amendment 1 of the Shad and River Herring FMP.

State	System	Sampling Program (annual unless otherwise noted)
ME	Androscoggin & Saco Rivers	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • Hatchery Evaluation
NH	Exeter River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
MA	Merrimack River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
RI	Pawcatuck River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
CT	Connecticut River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM)
NY	Hudson River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM)
	Delaware River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM)
NJ	Delaware River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM)
PA	Susquehanna River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM) • Hatchery Evaluation
	Lehigh River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • Hatchery Evaluation
	Delaware River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM)

Table 1.1.3-1 (cont.) Summary of mandatory fishery-independent monitoring programs for American shad as required by Addendum I to Amendment 1 of the Shad and River Herring FMP (continued).

State	System	Sampling Program (annual unless otherwise noted)
DE	Delaware River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
MD	Upper Chesapeake Bay	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM) • Hatchery Evaluation
DC	Potomac River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
VA	James, York, and Rappahannock Rivers	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • JAI: Juvenile abundance survey (GM) • Hatchery Evaluation
NC	Albemarle Sound and its tributaries, Tar-Pamlico, Neuse, and Cape Fear Rivers	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates • Hatchery Evaluation
SC	Santee-Cooper system, Eidsto River, Winyah Bay and tributaries (Waccamaw and Pee Dee Rivers)*	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates * State may elect to sample these systems on a rotational basis (i.e., one system evaluated per year)
GA	Altamaha River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates
FL	St. Johns River	• Annual spawning stock survey and representative sampling for biological data • Calculation of mortality and/or survival estimates

Table 1.1.3-2 Summary of mandatory fishery-dependent monitoring programs for American shad as required by Addendum I to Amendment 1 of the Shad and River Herring FMP.

State	System	Sampling Program
ME	In-river	• Monitor recreational landings, catch and effort every 5 years.
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch.
NH	In-river/coastal	• Monitor recreational landings, catch and effort every 5 years.
MA	Merrimack River and Connecticut River	• Monitor recreational landings, catch, and effort every 5 years.
CT	Connecticut River	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years.
RI	Pawcatuck River	• Monitor recreational catch and effort every 5 years.
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
NY	Hudson River	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years.
	Delaware River*	• Monitor recreational landings, catch, and effort every 5 years.
NJ	Delaware River and Bay*	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years.
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
DE	Delaware River and Bay	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years.
	Nanticoke River Chesapeake Bay tributary (upstream portion)	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years.
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.

* Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware.

Table 1.1.3-2 (cont.) Summary of mandatory fishery-dependent monitoring programs for American shad as required by Addendum I to Amendment 1 of the Shad and River Herring FMP (continued).

State	System	Sampling Program
PA	Delaware River*	• Monitor recreational landings, catch, and effort every 5 years. (Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware)
MD	In-river	• Monitor recreational landing, catch, and effort every 5 years.
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
DC	Potomac River	• Monitor recreational landings, catch, and effort every 5 years.
VA	In-river	• Monitor recreational landings, catch, and effort every 5 years
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
NC	Albemarle Sound and its tributaries, Tar-Pamlico, Neuse, and Cape Fear Rivers	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
SC	Edisto River, Santee River, Winyah Bay and its tributaries (Waccamaw and Pee Dee Rivers)	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch, and effort every 5 years. * State may elect to sample these systems on a rotational basis (i.e., one system evaluated per year)
	Atlantic Ocean	• Mandatory reporting of catch (numbers and weight and effort form commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Participate in Ocean landings stock composition study.
GA	Ogeechee	• Mandatory reporting of catch (numbers and weight and effort form commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landing, catch, and effort every 5 years.
FL	St. Johns River	• Mandatory reporting of catch (numbers and weight) and effort from commercial fisheries; sub-samples shall indicate size, age, and sex composition of catch. • Monitor recreational landings, catch and effort every 5 years.

* Cooperative effort between New Jersey, New York, Pennsylvania, and Delaware.

1.1.4 Assessment History

Historical Reviews of the American Shad Fishery and Stock

The first extensive report of the U.S. American shad fisheries was done in 1896 by Stevenson (1899). Beginning in 1950, the U.S. Fish and Wildlife service conducted a series of investigations to examine causes of decline, determine factors favoring recovery, and provide management information, all of which was reported in Walburg and Nichols (1967). Major shad rivers in each Atlantic coast state were investigated to collect comprehensive catch and effort data by gear type. For historical perspective, these data were compared to that reported by Stevenson (1899).

ASMFC Atlantic Coast Stock Assessments

Gibson et al. 1988

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 Shepherd stock-recruitment model was used to estimate maximum sustainable yield (MSY) and maximum sustainable fishing rate (F_{msy}). The status of American shad stocks was evaluated by comparing fishing mortality rates (F) in assessed rivers to F_{msy}.

ASMFC 1998

The second coast-wide stock assessment conducted by the ASMFC was completed and reviewed in 1998 by the American Shad and River Herring Technical Committee (ASMFC 1998). Generally, assessments were conducted on a river-specific basis, but some grouping of river systems occurred (e.g., Maine rivers were examined collectively, Upper Bay Maryland, Albemarle Sound, and Waccamaw and Pee Dee rivers). The Thompson-Bell yield-per-recruit (YPR) model was used to derive the overfishing definition (F_{30}) for some shad stocks where possible. The assessment examined catch and harvest data, exploitation rates, fish-lift counts, current and historic coastal (F_c) and in-river (F_r) fishing mortality rates, and other indicators of stock status for American shad from selected stocks or river systems located from Maine to the Altamaha River, Georgia, with special attention on recent (1992 to 1996) stock dynamics. The basis for choosing F_{30} as an overfishing definition was not provided.

Trends in total mortality (Z) were examined for the Pawcatuck River, Rhode Island, upper Chesapeake Bay, Maryland, and tributaries of Albemarle Sound, North Carolina, as well as trends in commercial landings for Maine rivers, North Carolina rivers (Albemarle Sound, Neuse, Pamlico, and Cape Fear rivers), and South Carolina rivers (Waccamaw-Pee Dee, Savannah, Edisto, and Santee rivers). Trends in relative adult stock abundance were examined in the Merrimack River (Massachusetts and New Hampshire) based on fishway counts and in Virginia rivers (James, York, and Rappahannock rivers) based on commercial catch-per-unit-effort.

The 1998 assessment concluded that there was evidence of recent (1992-1996) and persistent stock declines in the Hudson River, New York and York River, Virginia and that stock abundance increased in the Pawcatuck River and Connecticut River in the most recent years examined. The assessment concluded that the drop in commercial landings in the Edisto River was largely due to a reduction in fishing effort and did not reflect stock abundance. In addition, the assessment reported that there was no evidence of recent stock declines for the Merrimack River, Delaware River, upper Chesapeake Bay tributaries, Rappahannock River, James River, Santee River and the Altamaha River. Stock declines inferred from declining trends from river-specific commercial landings were evident for the Neuse River, Pamlico River, Cape Fear River, Waccamaw-Pee Dee River, Savannah River, Albemarle Sound tributaries, and rivers in the state of Maine.

Where estimation of recent F rates (1992-1996) was possible, all were below F_{30}. The assessment also concluded that there was no evidence that the ocean-intercept fishery had an adverse impact on American shad abundance along the Atlantic coast and that there was no evidence of recent (1990-1996) recruitment failure for Maine rivers, Pawcatuck River, Connecticut River, Hudson River, Delaware River, Upper Chesapeake Bay tributaries, Altamaha River and Virginia rivers.

More detailed accounts of previous assessments are provided within each full assessment section. For discussion on how the current approach compares to the previous assessments, please see Section 1.1.1. A broad overview of American shad and other *Alosa spp.* status, biology, ecology, and population dynamics is available in Limburg and Waldman (2003). In that volume, Boreman and Friedland (2003) investigated reproductive potential of American shad in terms of eggs per recruit under different rates of fishing mortality for southern, northern, and Hudson River stocks and concluded that habitat restoration and stocking efforts would augment the rebuilding of stocks where fishing mortality had been reduced. Limburg *et al*. (2003; also in Limburg and Walden (2003)) reviewed life history, habitat issues, exploitation history, and identifies information that would benefit successful management of American shad.

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1.1.5 Benchmark Mortality Estimation Using Biomass-per-Recruit Modeling

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Introduction

In this section, we describe modeling used to develop a benchmark total mortality. We also discuss sensitivity analyses on various model inputs. Since there are many competing theories on relative causes of mortality in Atlantic coastal American shad stocks (see Section 1.5), we decided to develop a benchmark rate for total instantaneous mortality (Z) rather than for an instantaneous rate of fishing (F). This does not eliminate the issue of partitioning mortality into F and the instantaneous rate of natural mortality (M) in modeling, but it does avoid an emphasis on F when comparing the results to observed estimates of Z. The debate remains over causes of decline that is occurring in the majority of East Coast stocks. Limited evaluations of some hypotheses are given in Section 1.5.

We decided to use a Z_{30} as a biological reference point for the American shad. Z_{30} is defined as the total mortality rate that will preserve 30 percent of the unexploited spawning stock biomass per recruit. This is similar to the benchmark used by ASMFC (1998) in the last coast-wide assessment. We used a regional approach to estimate reference points because most individual stocks did not have all of the needed stock specific data. As a comparison we also calculated Z_{30} based on egg-per-recruit (EPR) using fecundity data from the Hudson and York rivers.

Methods

Our analyses augment a basic biomass-per-recruit (BPR) model for females with estimates of egg production for information on EPR. Our model starts with recruits at age one. These recruits are decremented annually by natural mortality until they reach harvestable ages. They are then decremented by natural and fishing mortality through the maximum age observed in the stock or region (Table 1.1.5-1). The numbers of survivors-at-age are multiplied by weight-at-age for estimates of biomass-at-age. As survivors mature, the fraction of females of each age that is mature is multiplied by fecundity at that age. Biomass and egg production by age are summed for all ages. In the final step, total biomass and total egg production are each divided by the number of initial recruits for an estimate of BPR and EPR. The model was run for a range of fishing rates (F) from zero to 0.7. Formulae used in model calculations are summarized in Appendix I of Section 1. River specific model inputs by age are listed in Table 1.1.5-2. We used the assumption of a Type 1 fishery in our analyses. Estimates of Z_{30} were made for New England Rivers in aggregate, the Hudson River, the York River for the Chesapeake Bay region, and North Carolina rivers in aggregate.

We used results from the BPR modeling for our benchmark mortality rates because BPR modeling was possible for all regions. We added EPR analyses to provide perspective and confidence in results.

We included sensitivity analyses for runs of the biomass and egg-per-recruit model to illustrate effects of varying M, of a Type I versus a Type II fishery, and river-specific data inputs on model outputs.

Calculation of F_{30} for the York River

Harvest of American shad in the York River, Virginia, is currently banned except for subsistence fishing by native Americans (the Mattaponi and Pamunkey tribal governments) allowed under a 17th century treaty agreement—the 1677 Treaty at Middle Plantation (www.baylink.org). Fishing is known to occur annually but effort and landings are not reported to the Virginia Marine Resources Commission. As a result, the impact of these removals on the York River stock cannot be assessed easily.

The biomass model run for the York River was configured for the Native American drift gill-net fishery to provide a baseline overfishing definition (F_{30}) that might help evaluate the impact of such fisheries if an estimate of fishing rate were known.

Selection of Model Inputs

One important point for the reader to note is that the stock-specific data inputs used in all the modeling have been obtained from fished stocks. These data may not reflect those characteristics from an unfished stock.

Natural Mortality

The debate on the appropriate level of natural mortality (M) for American shad remains unresolved. Previous assessments have used a variety of values for M. ASFMC (1998) used different values for M, for different age groups and stocks. These values were M=0.3 for ages one through three (all stocks), M=2.5 for ages four through eight for southern semelparous stocks; and M=1.5 for ages four through 10 for northern iteroparous stocks, except the Hudson (Table 1.1.5-1). The high values of M for the older ages were calculated from age structure data of the Connecticut River shad stock and the mortality that stock was experiencing. For the Hudson, values used were M= 0.30 for ages one through three and 0.60 for ages six through 10 (ASMFC 1998).

Gibson *et al*. (1988) used age invariant (constant), river-specific natural mortality, calculated using a variety of age-based methods (Hoenig 1983; Pauly 1980; Leggett 1976). No specific values were provided in the report. Deriso *et al*. (2000) used an age invariant rate of 0.3 for Hudson River American shad. Carmichael (1999) used an M=0.5 for the assessment of Chowan River, North Carolina blueback herring. A constant M of 0.2 was used for Atlantic herring, with an age 10+ group (ASMFC 1999). Given that shad live longer than blueback herring, and as long, if not longer, than Atlantic herring, the value of M=0.3 appears reasonable.

In this assessment, we used age invariant values obtained by Hoenig's method (1983) based on the maximum observed age within region.

River-Specific Inputs: Maturity, Fecundity, and Partial Recruitment Vector

The remaining inputs of maturity (percent mature-at-age)—fecundity and partial recruitment (PR) vector—were based on available data obtained from each river system or region (Table 1.1.5-2; Figure 1.1.5-1). We attempted to use river-specific data wherever possible. Data from a neighboring system were used if a specific input was not available (e.g., we used the Hudson PR vector was used for the New England region).

Comparison of inputs indicated several differences among systems. American shad of the Connecticut River (ASMFC 1998) matured at a faster rate than shad in the other regions or rivers (Table 1.1.5-2; Figure 1.1.5-1). Fecundity data were available for the Hudson and the York rivers. Full recruitment to fishing occurred at a younger age in shad of the Connecticut (ASMFC 1998) and York rivers than in shad of the Hudson River and Albemarle Sound (Figure 1.1.5-1). It is possible that fisheries in the Connecticut and the York rivers used smaller mesh gill nets than in the other rivers. PR vector data were based on in-river fisheries only as no data were collected on any of the directed mixed stock ocean or estuary fisheries before the closure.

The previous assessment (ASFMC 1998) used a von Bertalanffy growth curve based on data from the Connecticut River to estimate weight-at-age for the different stocks (northern, southern, and Hudson) by varying W_∞. The other parameters (K and t_0) remained constant. In each case, weight-at-age was over-estimated as compared to observed river-specific data (Table 1.1.5-2; Figure 1.1.5-1).

York River Inputs

The model required an age-based partial recruitment vector for the drift gill nets used in the Native American fishery. Concurrent (1998-2000) drift gill net (DGN) data from the Native American fishery and pound net data from commercial nets (considered non-selective gears) were available and selectivity was estimated using an age-length key as reported in Appendix II.

If the drift gill-net fishery is the sole source of removals from the York River stock, then the dome-shaped recruitment vector developed solely from the fishery (Appendix II) might be considered appropriate as model input; however, known directed (ocean fishery) and bycatch removals (see Sections 1.1.7 and 12), along with other unknown sources of fishing mortality make this scenario improbable. Therefore, the partial recruitment vector used in our modeling assumed full recruitment to the gear after age-5.

Other parameter inputs (maturity-at-age, fecundity-at-age) for the York River yield model were obtained from Maki *et al*. (2001) and Hyle (2005), respectively. Weight-at-age for York River fish was estimated from the best fit Linear von Bertalanffy model (see Section 12, Table 12-14) using the following relationship:

$$Weight = a[(498.2 + 6.2(Age))(1 - e^{-0.46(Age-0.07)})]^b$$

In the nonlinear regression solution, model parameter estimates were: a = 0.000056, b = 2.752. Model inputs are listed on Tables 1.1.5-1 and -2.

Sensitivity Analyses of Model Inputs

We conducted various sensitivity analyses of model inputs using the Hudson and York River's BPR model to calculate an F_{30} using a variety of data inputs. Here we focused on an F_{30} rather than a Z_{30} to keep output curves on the same x-axis while varying M and other factors.

Natural Mortality

A major issue during the last assessment was sensitivity of the BPR model to changes in various inputs.

The most contested debate centered on the selection of M. Since M remained in debate, Hattala and Kahnle (1998) presented an analysis of the sensitivity of F_{30} from BPR modeling to M inputs ranging from 0.2 to 1.4. Rather than repeat that analysis in this paper, we selected a subset of values to illustrate

effects. For this exercise, we ran the Hudson River BPR and EPR models using constant, age-invariant values of M= 0.3, 0.5, and 0.7 (Table 1.1.5-1). All other inputs (weight, maturity, and fecundity-at age, and partial recruitment vector) remained constant. To provide further contrast to the age invariant values, we also used age dependent values, which decreased with age, based on a method by Boudreau and Dickie (1989) and Dickie *et al*. (1987; Table 1.1.5-1). These authors related M to a specific rate of production (biomass) for each size group (age) in a population. The curve of M on age is an indication of the natural mortality pattern of a stock. Given that immature American shad and other herring are forage for many fish predators, it is likely that M is not age invariant and that it is higher at young ages. Since M remains uncertain, we conducted this sensitivity analysis to determine effects of various values of M on estimates of an overfishing definition.

Maturity, Fecundity, and Recruitment Vectors

We included additional runs of the BPR and EPR model, using data inputs for two rivers to illustrate effects of using river-specific data inputs on model outputs. The data of concern were age-specific fecundity and weight, a maturity schedule, and a partial recruitment vector (vulnerability to a fishery). We did this to illustrate the inherent uncertainty associated with altering one system's data to mimic other stocks (ASMFC 1998) rather than using available, or adjacent river systems, stock-specific data. Maturity schedules were similar for each of the stocks; however, there were differences in input data for fecundity, partial recruitment vectors, and weight-at-age (Figure 1.1.5-2). Leggett and Carscadden (1978) suggested that fecundity-at-age varied with latitude along the East Coast. Values for the Hudson are less than for the York, a system to the south, following the pattern suggested.

Partial recruitment vectors are a function of the how each fishery operates and gear used to capture each size and age class of fish. Partial recruitment vectors, calculated from age structure data were obtained from in-river fisheries in each system. Even though mesh size used in the two river fisheries was similar (5.25 in versus 5.5 in), data from the York indicated a higher vulnerability (to the fishery) of age-4 through 7 fish (Figure 1.1.5-2). Shad caught in the Hudson River fishery were on average 45-48 mm larger than those caught in the York (see Sections 7 and 12). Weight-at-age was also smaller for the York than for the Hudson stock (Figure 1.1.5-2).

In the initial benchmark model runs, M varied for the two stocks as observed maximum age observed in the stock were different. For the sensitivity analyses model runs, M was held constant at 0.5 to examine differences the stock specific inputs (Table 1.1.5-2) would generate.

Fisheries Type

Biomass-per-recruit modeling requires an assumption of how natural and fishing mortality overlap during the biological year. A Type 1 fishery assumes that natural morality occurs after fishing ends. A Type 2 fishery assumes that fishing and natural mortality operate concurrently (Ricker 1975). We calculated a Z_{30} for the Hudson using both Type 1 and Type 2 fisheries to examine if differences occur.

Results

Benchmark Definitions

Z_{30} – All Regions

We selected our regional benchmark mortality values from the BPR analyses using age invariant M. From these analyses, Z_{30} ranged from 0.54 to 0.76 depending on region. The Z_{30} EPR calculated for comparison

of the Hudson and York rivers were almost identical to those obtained from BPR analyses (Table 1.1.5-4). Curves of BPR at increasing levels of Z showed highest values of BPR at each Z for the Hudson River, followed by the Albemarle, York River, and New England (Figure 1.1.5-2). Curves of EPR values at increasing levels of Z showed higher values for the York River, than for the Hudson River (Figure 1.1.5-2). Note that the curves start at different values of Z because natural mortality varied among systems.

Benchmark estimates from ASMFC (1998) were much higher; than our results if our Z_{30} was translated to F30 by subtracting M (Table 1.1.5-4).

York River F_{30}

The benchmark fishing rate (F_{30}) for the drift gill-net fishery in the York River is estimated to be 0.27 (Table 1.1.5-3).

A benchmark developed for the York River (17.44, the geometric mean of the catch index values observed in 1953-1957) is based on shad abundance in the 1950s and is higher than the geometric mean catch index of current monitoring data (see Section 12). Additional control rules should be the target fishing rate (F_{30} = 0.27) for the Native American fishery and target total mortality rate (Z_{30} = 0.62). To apply these rules, an estimate of F by the Native American fishery and a better understanding of natural mortality are required.

Sensitivity Results

Natural Mortality

The response of EPR, BPR, and F_{30} varied with the value of M used in the analyses. Curves of EPR and BPR at increasing levels of Z showed that highest values EPR and BPR were produced by lowest values of age invariant M (Figure 1.1.5-3).

For a constant, age-invariant M, the F_{30} increased with increasing M. The F_{30} values ranged from F_{30} = 0.22 (EPR) when M=0.3 to F_{30} = 0.36 for M=0.7 (Table 1.1.5-4). Estimates of F_{30}, based on BPR, were similar and ranged from 0.24 to 0.38. For age-specific values of M, the resulting values of F_{30} were lower than age invariant M for either EPR or BPR. For age-specific M, F_{30} was equal to 0.19 for EPR, and 0.21 for BPR (Table 1.1.5-4).

River-Specific Inputs

M was held constant at M=0.5 for the Hudson and the York River stocks. As expected, estimates for EPR were highest for the more southern York River stock, dropping slightly for the Hudson to the north (Table 1.1.5-4, Figure 1.1.5-4). The same pattern of south to north did not occur for the BPR curves (Figure 1.1.5-4). The Hudson River BPR estimates were higher at F estimates near 0; however, the York River's curve was similar to the Hudson River's F values greater than of 0.4.
It should be noted that fecundity-at-age and biomass-at-age are both affected by fishing because fishing tends to remove the largest fish. These effects should be kept in mind when considering results of any EPR or BPR analyses. Fecundity-at-age data for the Hudson River stock were produced when stocks were recovering from the overfishing events following WWII. The weight-at-age data used for the Hudson River and perhaps the York River stocks showed recent declines. Ideal data inputs would be observations taken during a time period when fishing impacts were fairly low. Unfortunately, no data exists for any east coast shad stock under these conditions.

Type 1 and Type 2 Fisheries

We used the assumption of a Type 1 fishery in our analyses, but added a Type 2 case to identify effects of these fishery assumptions on our analyses output. Given the stress of spawning experienced by American shad (movement from fresh to saltwater, little or no food consumption while spawning) and the lengthy exposure to fisheries (late February - ocean fisheries, to May - terminal in-river fishery), we feel a Type 2 fishery where both natural and fishing mortality are occurring simultaneously can be more realistic. However, analyses results using Type I and Type II mortality assumptions were essentially the same (Table 1.1.5-4).

Discussion

Models and analyses presented in this section were developed to provide Atlantic coastal states with an approach to assessing the status of American shad stocks. We used the EPR and BPR modeling to identify a benchmark definition of Z because we felt that the use of a simple approach would set a reasonable standard for evaluating current estimates of Z available for Atlantic coastal shad stocks comparable to reference points arrived at by other methods. However, even this simplified approach was limited by its reliance on data inputs that were obtained from fished stocks.

Another aspect of this section was to compare this assessment to the 1998 ASMFC American shad assessment since some issues remain unresolved. These assessment models are not overly complicated, but they do require attention to data inputs. In this document we attempt to clarify the data choices made and outline the supporting reasoning. We also hope that this paper will assist others in better understanding methodology and implications for other East Coast systems.

Natural Mortality

The choice of a value for M is very important to all modeling work on American shad. Natural mortality rates of fishes are inversely related to longevity. American shad populations with no repeat spawning, such as in southern stocks, clearly have a higher natural mortality rate than those that exhibit iteroparity. Fish in most southern stocks rarely reach a maximum age of eight, few fish reach age seven. Most northern stocks, north of North Carolina, have some degree of repeat spawning; maximum age falls within the range of eight to 11 or 12, with the exception of the Hudson River. Model runs, with a selected M, that generate the virgin stock size benchmark, should, at minimum, use maximum ages observed in the wild populations. If they do not, then virgin stock size can be underestimated.

Maximum age of Hudson shad most often equals 12, a few fish have been observed at age 13. These older ages in the Hudson stock suggest M should be fairly low to reflect the stock's longevity. It is not clear how old shad can get since current data (collected within the last 27 years) reflect conditions present in shad populations at low stock size and the effects of fishing.
For comparative value, many other fish stocks have similar natural mortality rates. Age invariant M has been the choice of most assessments. For top end predators, natural mortality is fairly low (striped bass, M=0.15; ASMFC 2005). Shad, however, fall into the prey species category at younger ages, until they grow large enough to avoid predation. For a similar prey-type, though non-anadromous, clupeid species, Atlantic herring, the value selected for M is 0.2 (SAW 1996). For another anadromous species, Atlantic salmon, the value of M=0.12 is used (Freidland *et al*. 1994).

River-Specific Input Data

Effects of using different river-specific biological input data were confounded in our analysis because we did not hold any one input constant while varying others. It appears that the modeling was more sensitive to changes in M than other biological inputs.

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Table 1.1.5-1b American shad natural mortality rates used in Thompson Bell Biomass-per-recruit model.

Region	Maximum Observed Age, Age, or Age Group	Age Invariant Natural Mortality*
Current Assessment		
New England	11	0.38
Hudson River, NY	14	0.30
York River, VA	12	0.35
Albemarle Sound, NC	10	0.42
Sensitivity Analysis	14	0.30
	8	0.50
	6	0.70
		Age Variant M**
	1	0.51
	2	0.37
	3	0.29
	4	0.25
	5	0.23
	6	0.21
	7	0.20
	8	0.20
	9	0.19
	10	0.19
	11	0.19
	12	0.19
	13	0.19
	14	0.19
ASMFC 1998 (Previous Assessment)		
All rivers	1-3	0.3
Hudson	4-10	0.6
Northern rivers (NC-ME)	4-10	1.5
Southern rivers (SC-FL)	4-8	2.5

* Hoenig 1983
**Boudreau and Dickie (1989) and Dickie *et al*. (1987)

Table 1.1.5-2b River-specific life history and fishery data used as inputs to the Thompson Bell biomass-per-recruit model.

Age	Maturity					Weight-at-age						
	New England	Hudson R. NY	York R. VA	Albemarle S. NC	ASMFC 1998	New England	Hudson R. NY	York R. VA	Albemarle S. NC	ASMFC 1998 Von B		
						Gompertz	Gompertz	Linear von Bertalanffy	Gompertz	North	South	Hudson
1	0%	0%	0%	0%	0%	22	142	82	65	43	30	55
2	0%	0%	0%	0%	0%	164	391	363	299	353	247	459
3	0%	0%	2%	1%	20%	492	774	709	722	903	632	1174
4	2%	15%	33%	18%	60%	901	1228	1026	1203	1541	1079	2004
5	25%	63%	68%	70%	100%	1258	1676	1287	1614	2157	1510	2805
6	61%	91%	80%	98%	100%	1510	2068	1492	1912	2695	1886	3503
7	86%	98%	100%	100%	100%	1670	2383	1653	2109	3137	2196	4078
8	96%	100%	100%	100%	100%	1766	2623	1782	2231	3486	2440	4532
9	100%	100%	100%	100%	100%	1820	2798	1889	2305	3755		4882
10	100%	100%	100%	100%	100%	1851	2923	1981	2349	3959		5147
11	100%	100%	100%			1868	3010	2064				
12		100%	100%				3071	2141				
13		100%					3112					
14		100%					3140					
Age	**Partial Recruitment Vector**					**Fecundity**						
1		0.00	0.00	0.00	0.00		-	-				
2		0.00	0.00	0.00	0.00		-	-				
3		0.14	0.03	0.00	0.00		95491	249268				
4		0.17	0.64	0.04	0.45		157637	360980				
5		0.40	1.00	0.32	0.90		219783	452682				
6		0.70	1.00	0.65	1.00		281929	524888				
7		0.87	1.00	0.88	1.00		344075	581546				
8		0.95	1.00	0.98	1.00		406221	626905				
9		1.00	1.00	1.00	1.00		468367	664476				
10		1.00	1.00	1.00	1.00		530513	696871				
11		1.00	1.00				592659	725932				
12		1.00	1.00				654805	752922				
13		1.00					716951	-				
14		1.00					779097	-				

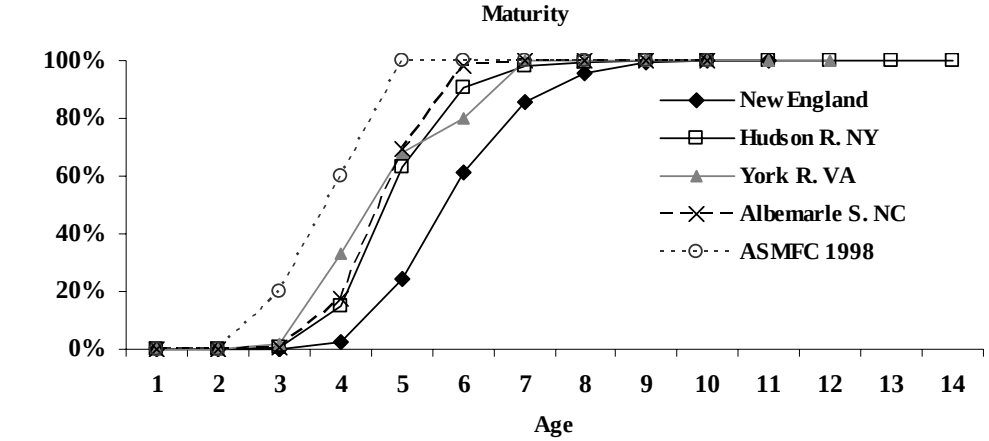
Table 1.1.5-3b Results of benchmark determination (Z_{30}) from the Thompson-Bell biomass per recruit model, modified for egg-per-recruit, for regional American shad stocks.

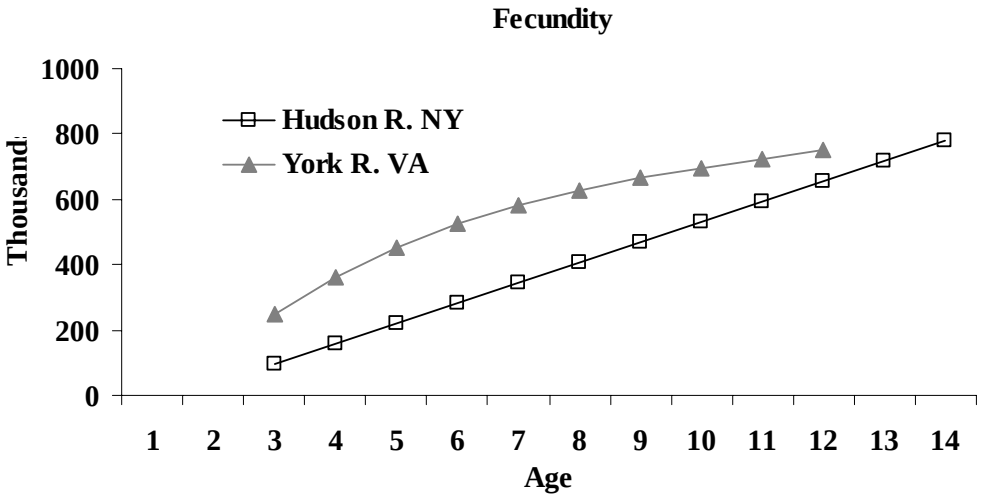
Region	Max Age or Age Group	M	Z_{30}		F_{30}
			EPR	BPR	
New England	11	0.38	-	0.64	
Hudson River, NY	14	0.30	0.52	0.54	
York River, VA	12	0.35	0.62	0.62	0.27
Albemarle Sound, NC	10	0.42	-	0.76	
ASMFC 1998					
All rivers	1-3	0.3			
Hudson	4-10	0.6		0.99	0.39
Northern rivers (NC-ME)	4-10	1.5		1.93	0.43
Southern rivers (SC-FL)	4-8	2.5		2.98	0.48

Table 1.1.5-4b Results of sensitivity of the Thompson-Bell biomass-per-recruit model to variation in M and river-specific inputs (maturity, fecundity and partial recruitment vector).

			F_{30}				Z_{30}			
			Type 1		**Type 2**		**Type 1**		**Type 2**	
Type of Analyses	**Max Age or River System**	**M**	**EPR**	**BPR**	**EPR**	**BPR**	**EPR**	**BPR**	**EPR**	**BPR**
Natural mortality	14	0.30	0.22	0.24	0.23	0.25	0.52	0.54	0.53	0.55
river input = constant	8	0.50	0.29	0.31	0.30	0.32	0.79	0.81	0.80	0.82
	6	0.70	0.36	0.38	0.37	0.39	1.06	1.08	1.07	1.09
Natural mortality age variant		see Table 1.1.5-3	0.19	0.21						
River specific inputs	Hudson	0.50	0.29	0.31			0.79	0.81		
M = constant	York	0.50	0.32	0.32			0.82	0.82		

Figure 1.1.5-1b River-specific life history and fishery data, along with data from ASMFC1998, used as inputs to the Thompson Bell Biomass -per-recruit model.





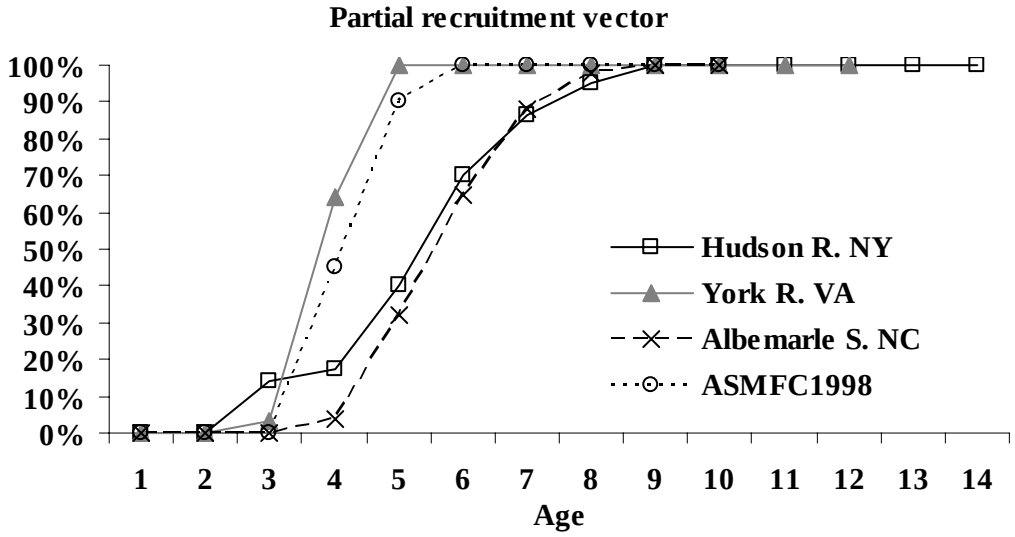


Figure 1.1.5-1b (cont.) River-specific life history and fishery data, along with data from ASMFC1998, used as inputs to the Thompson Bell Biomass -per-recruit model.

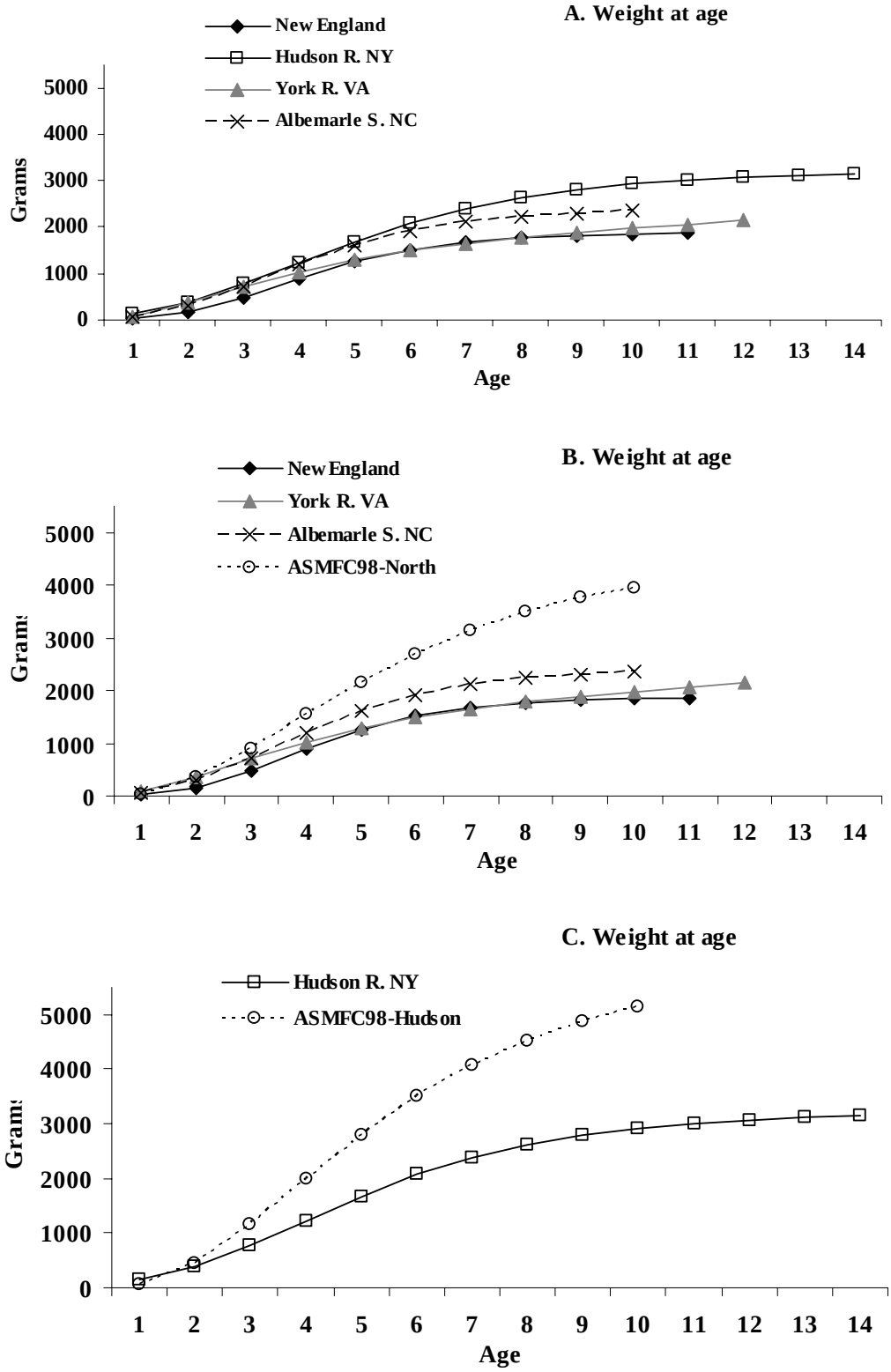


Figure1.1.5-2b Biomass-per-recruit and egg-per-recruit for regional American shad stocks.

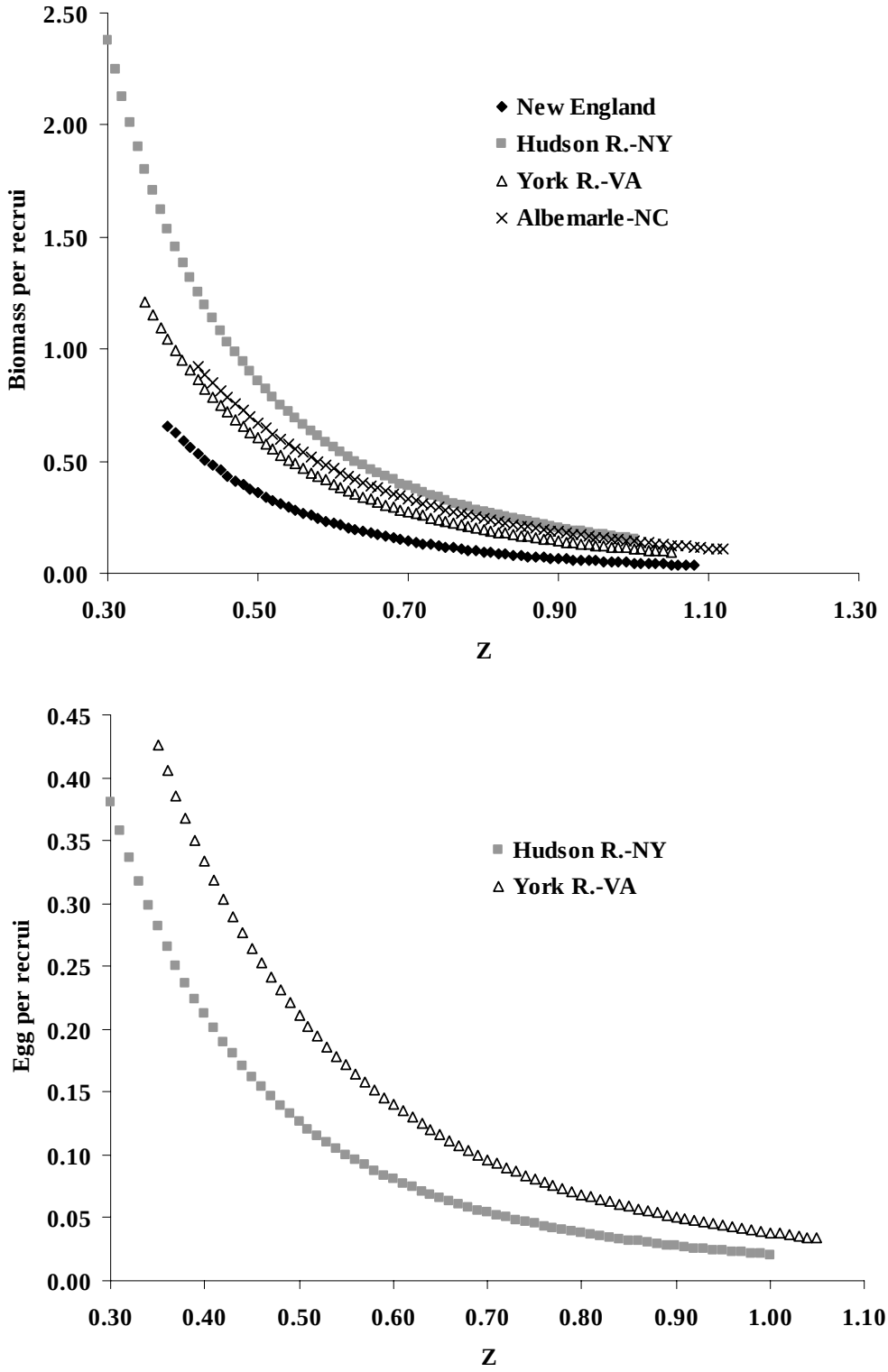
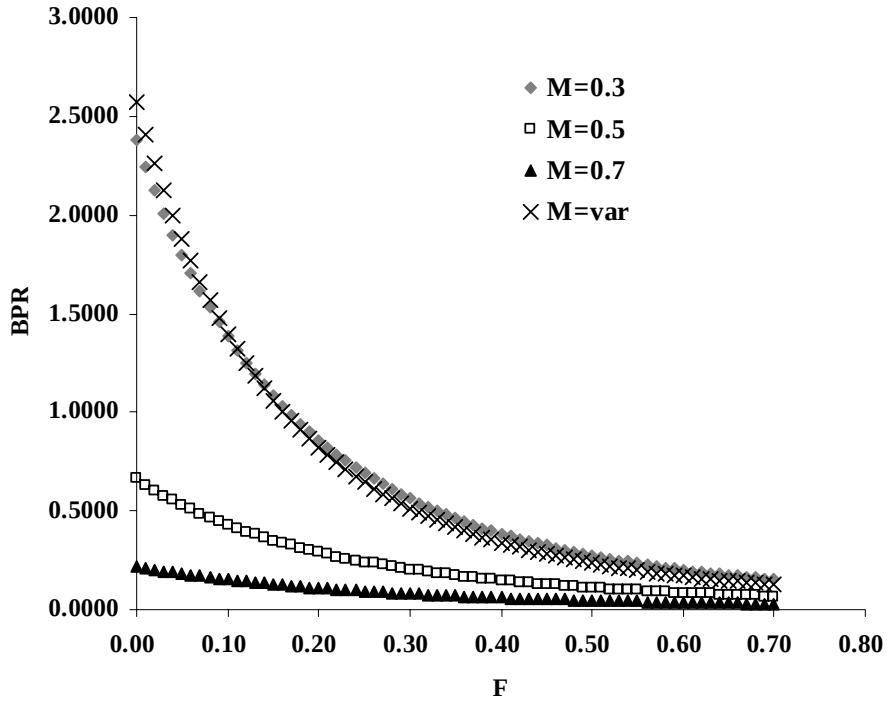


Figure 1.1.5-3b Sensitivity of changes in BPR model to variation in M, with river–specific input held constant.



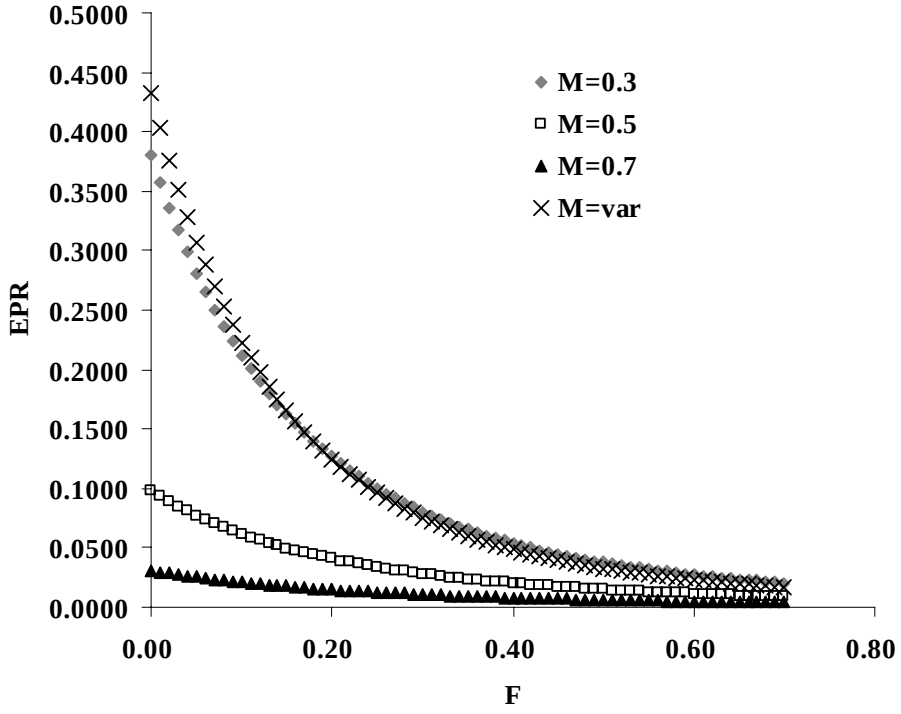
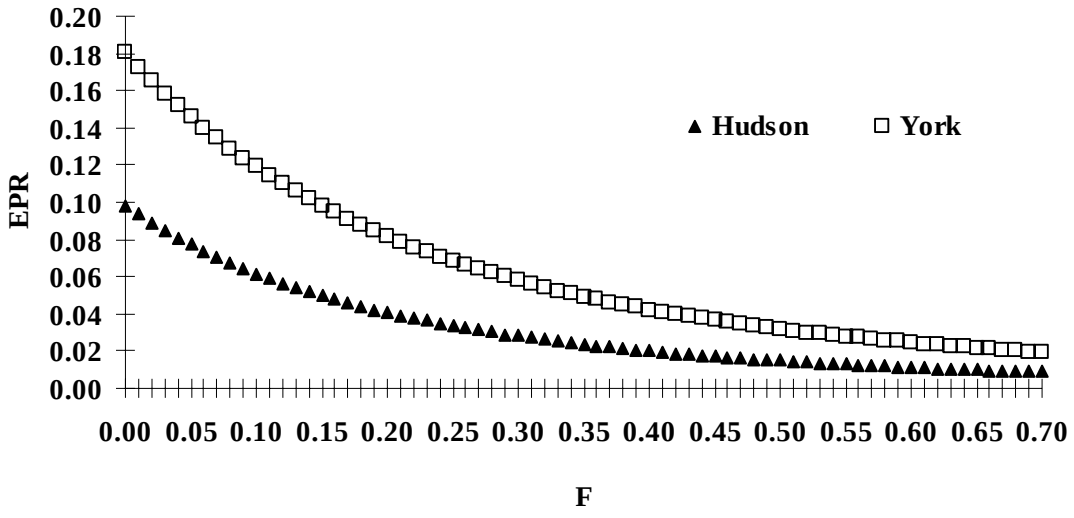
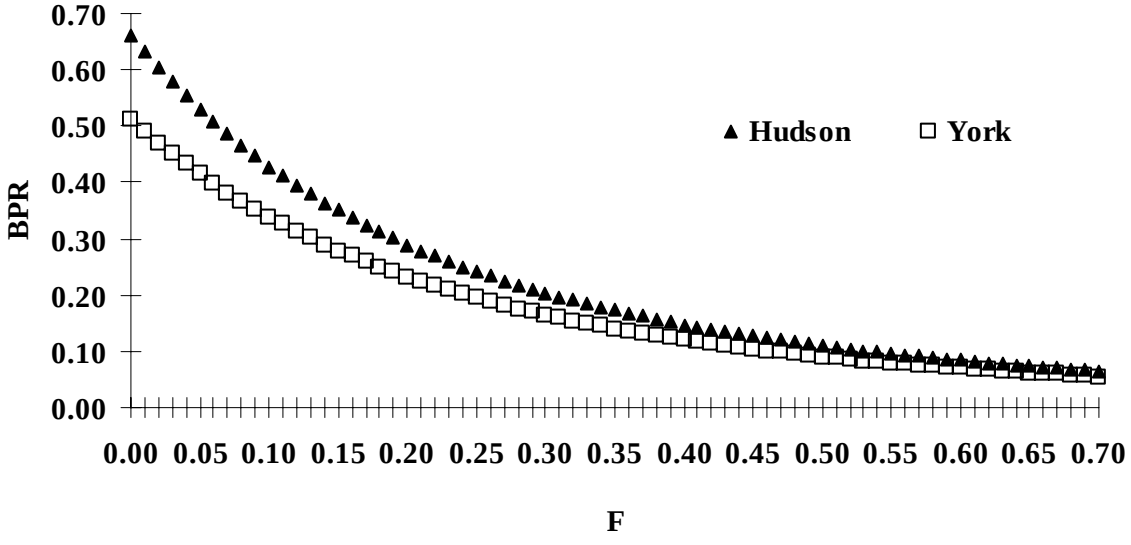


Figure 1.1.5-4b Sensitivity of changes in BPR model to changes in river-specific inputs with M held constant at 0.5





Revisions to Benchmark Mortality Estimation Using Biomass-per-Recruit Modeling Based on Recommendations from the Peer Review Panel

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The following section addresses only a portion of the suggestions made by the American Shad Peer Review Panel. The Stock Assessment Subcommittee (SASC) Chair was asked to provide these revised estimates during the Panel's meeting. These changes were made during the meeting because they could be accomplished in a short period of time and would have an implication on the benchmarks used to determine the status of the American shad stocks. The Panel refers to these revised estimates in the American Shad Advisory Report, therefore the results are provided in this addendum. The Peer Review Panel made additional suggestions, but the SASC and Technical Committee will work cooperatively to explore those recommendations if directed by the Shad and River Herring Management Board.

The following materials respond to critiques by the Peer Review Panel on the formulation in our biomass per recruit modeling. The panel made suggestions regarding the application of mortality rates to immature and mature fish, the form of the recruitment or vulnerability vector, and the application of vulnerability to exploitation rate (μ) rather than fishing mortality (F).

Benchmark Model

- We applied a survival value (S) at age, which included F and natural mortality (M), to the Number at age of immature fish.
- We developed recruitment vectors from empirical age data from various gears and maturity schedules from repeat spawn data.
- We applied the recruitment vector and maturity schedule at age to μ at age.
- We used a Type I fishery.

Review Panel Suggestions

- Apply only M to number at age of immature fish.
- The maturity schedule may have confounded the recruitment vectors. To reduce these confounding effects, assume a recruitment of 1 for all ages.
- Apply the recruitment vector at age to F before converting to μ, and then apply the maturity schedule at age to μ.
- The fishing season fits between a Type I and a Type II fishery. Try both types to provide bounds on the resulting Z_{30}[^] estimates.

Results (Table 1.1.5-3rev)

- In all cases, the revised Z_{30} values were higher than the Z_{30} values calculated in our original assessment formulation. Relative change was greatest for New England and Albemarle Sound in North Carolina. All revised Z_{30} estimates were lower than the Z_{30} values (calculated from F_{30}[†]+M) calculated in the 1998 ASMFC assessment.
- In all cases the Type I fishery calculations produced a higher benchmark Z than the Type II fishery calculations; however, differences were small.

[^] Z_{30} is the total mortality rate that will preserve 30% of the unexploited spawning biomass per recruit.
[†] F_{30} is the fishing mortality rate that will preserve 30% of the unexploited spawning biomass per recruit.

Table 1.1.5-3rev Results of benchmark determination (Z_{30}) from the Thompson-Bell biomass-per-recruit model, modified for egg-per-recruit, for regional American shad stocks. Non-bold values are from original assessment and based on a Type I fishery. Bold values were results of revised calculations for Type I (T1) and Type II (T2) fisheries.

Region	**Max Age or Age Group**	**M**	**Z_{30}**		**F_{30}**
			EPR	**BPR**	
New England	11	0.38	-	0.64	-
	revised T1		**-**	**0.98**	**-**
	revised T2		**-**	**0.91**	**-**
Hudson River, NY	14	0.30	0.52	0.54	-
	revised T1		**0.68**	**0.73**	**-**
	revised T2		**0.57**	**0.62**	**-**
York River, VA	12	0.35	0.64	0.63	0.28
	revised T1		**0.85**	**0.85**	**0.50**
	revised T2		**0.76**	**0.76**	**0.41**
Albemarle Sound, NC	10	0.42	-	0.76	-
	revised T1		**-**	**1.01**	**-**
	revised T2		**-**	**0.94**	**-**
ASMFC 1998					
All rivers	1-3	0.3			
Hudson	4-10	0.6		0.99	0.39
Northern rivers (NC-ME)	4-10	1.5		1.93	0.43
Southern rivers (SC-FL)	4-8	2.5		2.98	0.48

1.1.6 Age Determination in American Shad

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Age is estimated using scales and otoliths in American shad and other alosine fishes, including the river herrings (Cating 1953; Libby 1985; Marcy 1969; Rothschild 1963). Scale-based ageing of American shad is the predominant method in current coastwide monitoring programs from Maine to Florida. Otolith-based ageing is the method of choice of certain management agencies, especially those that are engaged in hatchery-based restoration activities (e.g., Pennsylvania Fish and Boat Commission, Virginia Department of Game and Inland Fisheries). Both scale- and otolith-based approaches have been used since the early 1900s (Leim 1924; Barney 1924). Scale-based methods have been validated for the Connecticut River (Judy 1961, but see McBride *et al*. 2005). Although otoliths now form the basis for most age and growth studies of fishes (Campana 1999), the validity of utilizing otoliths to age American shad, with the exception of larval shad (Savoy and Crecco 1987), has not been established.

Generally, scales are removed from the upper left lateral region just below the dorsal fin. Scales are cleaned and either pressed on acetate sheets or mounted on glass slides for viewing (see individual stock assessments for details of these methods). Cating (1953) provided criteria to enumerate presumptive annulus in American shad scales. The criteria are based on the assumption that annuli are consistently located in relation to the position of transverse grooves on the scale surface. Specifically, the first annulus is located within the first 4-7 transverse grooves; the second annuli is located between the 8th and 11th; and the third annulus is located between the 12th and 16th transverse grooves. Fish older than three years are aged using a combination of these criteria and the enumeration of spawning marks (persistent scars caused by erosion of the scale margin during spawning).

Both sagittal otoliths are removed from the auditory capsules and cleaned. In most monitoring programs that use otolith-based methods, one otolith is mounted, ground or sectioned and examined for tetracycline marks applied to larvae in the hatchery. Biologists identify the presence and pattern of the tetracycline tag using an epifluorescent microscope and can determine age in some cases using cohort-specific hatchery marks. The second otolith of the pair is examined as a whole structure (that is, not sectioned or ground) under a dissecting microscope (see individual stock assessments for details). Presumptive annuli are enumerated as one opaque zone and its successive hyaline zone.

Scale-based and otolith-based approaches to age American shad may not be interchangeable methods and there are few published studies that address this question. Olney and Hoenig (2000) compared ages determined by scales and otoliths in samples collected in 1998 and 1999 in Virginia samples. Scale and otolith methods 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. Differences between methods were significant in each year. Aschenbach *et al*. (1996) reported low agreement between paired comparisons of ages determined by scales and sectioned otoliths. In 57 percent of their comparisons, scales yielded older ages than otoliths. In these studies, otolith and scale ages differed predominantly by one year.

The apparent capability to infer spawning history of an individual fish by enumerating spawning marks is considered a unique advantage of the scale-based method in comparison to otolith-based approaches. In their classic study of population-level variation in reproductive characteristics, Leggett and Carscadden (1978) used spawning marks on scales to describe variation in the degree of iteroparity in American shad across its native range. Spawning marks also have enabled the estimation of maturity schedules for American shad (Maki *et al*. 2001, 2002) and are used in current coastwide monitoring programs to estimate frequency of repeat spawning and total mortality.

Largely as a result of an early demonstration of the validity of Cating's (1953) techniques, scale ageing has become the standard for shad assessments. Judy (1961) validated scale-based ageing methods for ages 3-5 in the Connecticut River. In the study, Judy marked 100,000 juvenile fish in 1952 by clipping pelvic fins and then recaptured survivors when they matured between 1956 and 1958. Ages were 98 percent accurate among the 129 recaptured fish and the sample included both virgin and previously spawned individuals. Thus, both annuli and spawning marks on scales were considered valid indicators of age.

In August 2004, an ASMFC age-determination workshop using 52 known-age fish from the Delaware River system was held to provide another test of the validity of scale-based ageing techniques. McBride *et al*. (2005) reported the results of these trials. Thirteen biologists from the ASMFC Shad and River Herring Technical Committee participated in the trials. All individuals were actively engaged in age determination of American shad in their respective states but some were more experienced in scale-ageing techniques than others. Each biologist read the scale sample twice. Precision (agreement between age estimates from the same scales) ranged from 50-76.5 percent. Accuracy (agreement between scale age and known age) was highest for ages 3-6 (33.7-48.5%) and lowest for older fish (3.9-12.1%, ages 7 and 8). Bias was detected in the trials. Ages of younger fish were sometimes overestimated and ages of older fish were typically underestimated. McBride *et al*. (2005) concluded that the scale-based method was not applicable to stocks in certain rivers and recommended against using age-based techniques to assess stocks of American shad until further age-validation studies were completed.

Both of these age validation studies (Judy 1961; McBride *et al*. 2005) are subject to criticisms and constraints. Judy (1961) did not describe a protocol that McBride *et al*. (2005) considered a blind trial. That is, it is unknown if ages were determined by scale readers who were unaware of the ages of the sample. This could have occurred since the readers in Judy's trials might have known which year marked juveniles were captured as virgin adults. Since known-age American shad are difficult to obtain, McBride *et al*. (2005) used cultured fish that had been recaptured in the Delaware River. In some cases, scale samples came from fish that were recaptured after long migrations (~ 300 km upriver). Several biologists in the McBride *et al*. (2005) trials noted that some scales were highly eroded and difficult to read. A serious problem could have resulted if the erosion on these scales obscured annuli, especially along the scale margin. McBride *et al*. (2005) acknowledged that other monitoring programs sample migrating shad in shorter rivers or at locations near the river mouth, thereby potentially avoiding the erosion effects observed in their trials.

Given the foregoing considerations, the American shad stock assessment subcommittee chose to moderate its use of age data in the following coastwide assessment but not abandon these data entirely. We evaluated age determination methods and results on a case-by-case basis in each jurisdiction by closely examining ageing methods, age structure, and spawning history data for signs of bias or inaccuracy. These signs included extreme truncation of ages when size data suggested older fish in samples, absence of repeat spawners when iteroparity was expected, and cases in which state biologists acknowledged that they were inexperienced and lacked confidence in their scale reading techniques. We examined mean age and mean size data from individual states for consistency (Appendix B). In these plots, we looked for evidence that the ratio of mean age to mean size did not vary appreciably over the available time series. We chose not to use age data from the Delaware system in light of the McBride *et al*. (2005) results. We had greater confidence in age data in the Connecticut River, the site of Judy's (1961) validation, and in systems where fish were collected prior to long migrations. We also had greater confidence in ages that were determined by more experienced biologists, a consideration supported by the results of McBride *et al*. (2005).

Fifty years ago, Mansuetti and Kolb (1953) noted that "great difficulty has been experienced by biologists in ageing shad." Since that time, shad biologists have not made significant advances in this field. However, new tools are now available in the form of natural tags to test our methods and develop new

approaches. For example, in an ongoing study, biologists are using oxygen isotopes in otoliths as a natural tag to track recruitment of specific cohorts of American shad. The returning adults are available for study as known-age fish beginning in 2006 and will be used to evaluate multiple ageing techniques.

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1.1.7 Coastwide Commercial Landings of American Shad

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Introduction

Ocean and mixed stock (OMS) fisheries have probably caught American shad for as long as the species has been fished. Beginning in the early 1980s, changes in interstate management focused on increasing restrictions to aid in the recovery of the striped bass stock. We suspect these restrictions forced fishers to look to other species to fill the gaps. American shad became a small, but important component of the ocean fishery during the late winter and early spring during the 1980s through 2005. During this 25 year period, changes in some American shad stocks began to occur which could not be explained by in-river harvest. Attention focused on the increased losses from the OMS fishery.

The OMS fisheries for American shad can be characterized as either a directed (targeted) fishery or a "known" bycatch fishery (documented by NMFS landings). Directed fisheries occurred in Rhode Island and states from New Jersey to South Carolina. These directed fisheries were closed in 2005. Known bycatch fisheries occur in New York and to a lesser degree, in the New England states (Maine to Massachusetts, Table 1.1.7-1). The few exceptions that have neither type of OMS fishery are the states of Georgia, Florida, Pennsylvania and, very minimally, Connecticut.

An additional mixed stock fishery continues to occur within the non-ocean waters of Delaware and New Jersey in lower Delaware Bay. This fishery has the potential to harvest fish from a wide range of shad stocks from South Carolina to Quebec.

A mixed stock bycatch fishery occurs in Chesapeake Bay. This bycatch is probably discarded and is not quantified. Harvest of American shad in the Chesapeake Bay is banned and there are no reporting requirements for discards by pound nets and other gears.

Lastly, one component of bycatch is more nebulous – and that is the fisheries where young shad are landed as unidentified bait. One fishery was observed on many occasions by individual states' biologists, but could not be tracked well by any data reporting system since young fish were often difficult to identify and were lumped into the ubiquitous baitfish category in the NMFS reporting system.

Stock composition of OMS landings of American shad is important to assessing impacts of the losses to individual stocks. Good data on stock composition of shad OMS harvest are not available. However, published and unpublished tag release recapture studies of American shad have been conducted at several locations along the U.S. Atlantic coast. Studies include tag release locations in spawning estuaries and in mixed stock locations along the coast. There have also been a few DNA studies of stock composition of the OMS harvest. Both tag release recapture and DNA studies provide some insight on stocks that might have contributed to the mixed stock harvest.

In this section, we summarize available data on commercial in-river and OMS landings of American shad along the U.S. Atlantic coast. We also summarized available tag release recapture and DNA data on American shad.

Methods

Landings data were obtained from the National Marine Fisheries Service (NMFS) and from individual states. In some cases, landings were provided by both sources. Since 1998, landings were reported in annual ASMFC state compliance reports. State biologists were queried about the accuracy of landings data and occasional adjustments were made for obvious errors. For example, Florida landings were occasionally inflated by the inclusion of gizzard shad from locations such as the west coast where American shad are not present. Whenever state and NMFS landings differed for a given state and the discrepancy could not be resolved, we selected the higher value. This was an infrequent occurrence.

We segregated landings data summaries into in-river losses and ocean/mixed stock losses. The latter category includes mixed stock losses in lower Delaware Bay but not losses in Chesapeake Bay. We did not include data on potential losses of American shad to the coastal bait fishery.

DNA analyses and tag release-recapture data for American shad along the U.S. Atlantic coast were obtained from available reports and publications.

Restults

Landings

The OMS fisheries occurred primarily on pre-spawn shad beginning in late winter in southern states (North Carolina to South Carolina), late February through April in mid Atlantic states, and from summer through fall in New England waters. OMS fisheries to the south of North Carolina were not very large and most shad landings were from within state natal rivers (Figure 1.1.8-1, Table 1.1.8-2). Total natal river landings from this region (North Carolina to Florida) declined from the late 1970s to the late 1980s and then stabilized at a low level. Total mixed stock landings from this region increased from the late 1970s through the late 1980s and then decreased through 2005. Total mixed stock landings in this region only exceeded total natal river landings in one year (1988). A very different pattern occurred in the mid Atlantic and north (Maine through Virginia). Harvest in the OMS fisheries in this region was equal to or greater than harvest in natal river systems in those states that allowed fisheries (Figure 1.1.8-1, Table 1.1.8-2). Since 1970, total natal river landings generally declined while total mixed stock landings generally increased. Total mixed stock landings in this region exceeded natal river landings in the late 1980s and remained relatively high until about 2003 (Figure 1.1.8-2). It should be noted here that Maine and Massachusetts have not allowed any American shad to be landed since the 1960s.

DNA and Tagging Data

Only two DNA mixed stock analysis studies have been conducted on American shad. Brown and Epifano (1994) obtained genetic samples from fish in the commercial harvest off of the coasts of Maryland and Virginia in 1991-1993. Results indicated high variation in stock composition among locations and among years. Results also differed between the DNA study and a tagging study (Jesien 1992) that released fish at the same locations (Figure 1.1.8-2). The second DNA study was conducted off the NJ coast in 1996 (Brown 1996) and concluded that fish originated from Canadian, Hudson River and Susquehanna River stocks. The results of this study were deemed questionable by the ASMFC Shad and river herring Technical Committee, since the Susquehanna River is primarily comprised of hatchery produced shad of Hudson River or Delaware River origin. The true Susquehanna stock may still exist, but as a tiny remnant given that major component of the returning stock are from hatchery contributions.

The results of several tagging studies (Talbot and Sykes 1958, Miller 1982 and Leggett unpublished) were summarized by Dadswell et al. (1987). The pattern of tag returns described the coastal migration of American shad. Shad from all regions of the coast summered in the Bay of Fundy, off the St. Lawrence,

and off the Canadian Maritimes/Gulf of Maine. Three "partially distinct" wintering areas occurred off Florida, the mid-Atlantic Bight, and the Scotian shelf. Parker (1992) and McCord (1988) tagged fish off of North and South Carolina; most shad were caught in each of the respective state's waters or in systems to the south (Figure 1.1.8-3C and D). Jesien (1992) tagged shad in the ocean fishery off the coasts of Virginia and Maryland. In each of the years, a different mix of returns came from a wide range of the coast (GA to MA). Most of the fish tagged in the Maryland-Virginia region were recaptured in either Virginia rivers or the Delaware River south (Figure 1.1.8-3B).

The most recent tagging data are from an ongoing study initiated in 1995 by New York and New Jersey (Figure 1.1.8-3A). Most (25%) of the released shad tagged in lower Delaware Bay were harvested in the mixed stock fishery within the Bay. An additional 22% were caught in ocean fisheries, the directed portion of which is now closed. Others were recaptured either in the Delaware, Hudson and Connecticut rivers along with an array of returns from the St. Lawrence River and Canadian rivers to the north, to the Santee River in the south.

Discussion

Clearly, the OMS harvest has been a large component of total American shad harvest over the last 25 years and since the late 1980s, it was the dominant component of shad harvest from Virginia north. Although directed harvest of American shad in U.S. Atlantic coastal ocean waters stopped in 2005, it cannot be ignored in any assessment of American shad stock change. This is especially true given the wide range of stocks harvested and potentially affected by the mixed stock fishery.

Landings data were affected by a variety of reporting issues. States collecting and reporting data stated that underreporting was common among commercial fishermen. Moreover, some segments of the fishery in inland waters went unreported because fish were sold in local markets and not captured in the reporting process. Given these problems, it is likely that summarized data were biased low. However, they still provided valuable insight into the general magnitude and trends of harvest along the U.S. Atlantic coast.

Information on stock composition of the mixed stock harvest remains imprecise. DNA stock identification studies on American shad are still in their infancy and need work on verification and refinement. Tag release – recapture methods were affected by poorly known recapture effort, unknown reporting rates, and small recapture sample sizes. However, the approach remains valuable because data from many studies are available and two studies have been ongoing for over ten years. Moreover, tag release and recapture locations and times are generally reliable. Otolith chemical signature analysis is a new and promising technique (Walther *et al.*, in press), but no data on ocean shad stock composition have been produced.

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Table 1.1.7-1 Existing mixed stock fisheries and past directed mixed stock fisheries for American shad along the Atlantic coast.

State	Ocean Waters			Estuarine Stock Fishery	
	Directed Fishery (prior to 2005)	***Bycatch Fishery***	**Undocumented Bycatch**	**Area**	**Potential Stocks Affected**
Maine		No landing allowed	X		
New Hampshire		EEZ landings only, 5% trip limit	X		
Massachusetts		No landing allowed	X		
Rhode Island	X	No landing allowed	X		
Connecticut			X		
New York		5% trip limit	X		
Pennsylvania					
New Jersey	X		X	Lower Delaware Bay	SC to Canada
Delaware	X		X	Lower Delaware Bay	SC to Canada
Maryland	X		X	Chesapeake Bay	VA, MD, PA, DE
Virginia	X		X	Chesapeake Bay	VA, MD, PA, DE
North Carolina	X		X		
South Carolina	X		X		
Georgia			X		
Florida			X		

Table 1.1.7-2 Summary of American shad commercial landings (kg) as reported for inland natal and mixed stock/ocean fisheries by National Marine Fisheries Service and/or respective state agencies.

(a) Inland Natal River Systems

YEAR	ME	NH	MA	RI	CT	NY1	NJ	DE	MD	VA	NC	SC	GA	FL	TOTAL
					CT R.	HR(+NJhr)	DE R.	DE R.	a-1980	a-1994					
1970					78,518	113,763	2,223	-							**194,504**
1971					109,182	84,959	1,179	-							**195,320**
1972					113,037	144,562	953	-							**258,552**
1973					116,847	121,020	726	-							**238,594**
1974					112,130	110,678	544	136							**223,489**
1975					75,071	114,806	-	862							**190,739**
1976					177,811	98,930	-	-	213,777						**490,519**
1977					150,777	94,167	-	1,542	196,083						**442,569**
1978					138,938	206,207	-	-	196,906						**542,050**
1979					93,804	232,833	-	-	122,835			51,512			**500,984**
1980					140,843	595,622	-	2,815	45,266	398,243	88,571	52,382	85,499		**1,409,240**
1981					147,284	281,323	-	5,785	37,859	101,352	110,717	134,656	88,825		**907,800**
1982					128,369	171,869	499	10,262	22,633	139,872	157,795	69,556	97,607		**798,461**
1983					193,234	208,384	1,950	6,826	16,049	211,022	200,532	57,075	133,214		**1,028,285**
1984					180,896	318,155	3,357	6,450	19,135	283,681	259,156	65,053	120,051		**1,255,934**
1985					182,347	342,951	10,478	13,289	3,704	136,455	148,091	105,019	121,395		**1,063,729**
1986					146,059	362,321	8,029	12,983	4,732	98,670	140,937	116,224	78,459	6,203.9	**974,618**
1987					151,457	310,345	9,163	4,736		107,795	129,949	57,557	113,173	6,080.1	**890,255**
1988					85,776	355,138	7,847	11,074		24,683	105,672	50,415	91,981	55.8	**732,642**
1989					82,147	220,314	7,620	5,556		46,886	129,207	53,786	92,173	123.8	**637,813**
1990					117,675	210,257	18,309	7,264		58,509	125,414	28,909	59,058	54,165.3	**679,560**
1991					67,722	149,401	10,475	5,314		23,058	116,707	46,035	51,721	5,797.9	**476,231**
1992					65,454	120,475	18,945	4,194		20,866	97,617	61,662	65,657	74.8	**454,946**
1993					43,845	62,692	8,869	5,900		30,106	68,343	22,537	57,096	-	**299,388**
1994					47,174	90,072	4,112	6,508			34,963	22,793	66,834	17.2	**272,475**
1995					27,931	112,885	5,357	6,483			46,668	69,529	97,918	43.1	**366,815**
1996					30,281	83,690	499	4,579			63,942	145,437	104,136	-	**432,564**
1997					41,279	67,799	4,196	3,843			54,983	104,310	93,748	-	**370,158**
1998					40,526	105,484	34	3,650			95,046	161,589	95,636	-	**501,964**
1999					20,219	66,501	2,572	932			44,748	92,727	45,328	-	**273,027**
2000					48,724	69,555	19,640	3,115			84,850	201,293	60,939	-	**488,117**
2001					26,869	45,997	31,343	1,668			63,157	97,614	54,604	-	**321,252**
2002					49,034	59,242	14,854	1,139			120,784	204,179	28,734	-	**477,964**
2003					50,407	49,998	38,192	2,154			173,609	160,751	37,002	-	**512,112**
2004					30,086	33,040	41,764	1,368			118,997	152,635	17,213	-	**395,103**
2005					32,626	23,807	21,112	307			86,656		18,071	-	**182,579**

Table 1.1.7-2 (cont.) Summary of American shad commercial landings (kg) as reported for inland natal and mixed stock/ocean fisheries by National Marine Fisheries Service and/or respective state agencies.

(b) Mixed Stock/Ocean Fishery

YEAR	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL2	TOTAL
1970						4,445	23,905	6,078							**34,428**
1971						1,361	16,965	3,447							**21,773**
1972						4,082	23,542	4,173							**31,797**
1973						1,497	19,505	3,447							**24,449**
1974						181	23,814	3,629							**27,624**
1975						136	38,556	7,620							**46,313**
1976						1,134	31,933	16,148							**49,216**
1977						544	60,873	32,251							**93,668**
1978	11,118		363			907	59,512	31,707							**103,607**
1979			544			3,674	40,280	43,047				37,879			**125,424**
1980	12,682	3,130	3,810	907		51,484	54,296	40,731		43,507	1,789	70,341			**282,675**
1981	41,096	2,540	7,575	14,243		26,445	59,286	83,711		125,048	48,723	67,837			**476,504**
1982	11,741	1,225	13,336	35,970		33,385	126,917	148,498		125,645	29,021	111,171			**636,909**
1983	17,554	1,542	6,124	10,660		14,969	88,860	98,773	9,092	94,216	1,718	93,225			**436,732**
1984	15,157	2,313	13,472	16,602	70	15,241	94,802	93,342	8,658	292,272	6,129	178,240			**736,298**
1985	7,258	3,311	10,115	41,187	-	42,548	97,615	78,245	68,054	150,666	1,433	62,395			**562,826**
1986	10,438	7,666	27,261	23,769	431	33,067	71,215	96,143	57,255	161,295	28,616	102,255			**619,410**
1987	11,975	18,734	18,507	47,129	-	5,262	83,689	111,614	54,116	179,275	18,671	163,122		64,423	**776,517**
1988	14,461	20,837	22,967	55,339	181	7,031	105,916	132,047	120,042	194,521	22,720	117,209		120,771	**934,042**
1989	21,091	13,882	6,178	19,038	533	10,342	181,077	98,268	221,272	181,332	17,485	103,528		74,771	**948,798**
1990	5,354	17,330	2,540	10,337	1,393	2,444	203,801	215,420	128,663	147,500	16,812	73,199		77,058	**901,851**
1991	903	8,584	289	12,617	445	11,923	174,343	231,542	106,139	181,274	8,717	65,433		26,676	**828,885**
1992	658	4,492	140	6,029	161	9,585	129,552	124,326	90,191	196,043	10,866	49,490		22,514	**644,046**
1993	-	2,971	181	18,394	110	3,510	145,194	134,309	35,329	220,801	12,756	29,455		11,115	**614,124**
1994	477	12,803	130	8,137	848	2,722	98,372	102,474	15,261	171,361	15,375	32,618		11,308	**471,885**
1995	173	13,862	206	12,683	27	6,552	126,971	86,653	27,491	68,453	46,714	60,021		12,152	**461,959**
1996	485	16,118	61	6,452		11,458	95,275	120,241	60,165	108,008	26,385	100,719		1,656	**547,022**
1997	88	11,538	341	16,674		17,100	102,278	74,174	75,357	162,306	44,594	51,400		24	**555,876**
1998	192	6,881	801	15,236		41,424	105,678	94,641	54,085	157,628	53,533	30,612		8	**560,719**
1999	77	1,667	101	20,076		31,130	118,437	102,676	27,703	105,034	14,951	8,768		218	**430,837**
2000	132	2,695	122	7,854		11,603	96,983	75,384	16,350	74,481	50,319	40,342		363	**376,627**
2001	216	368	477	30,777		14,173	91,200	127,882	26,028	114,588	5,370	41,942			**453,021**
2002	8	-	192	39,553		27,634	110,488	55,201	18,741	69,087	3,800	38,293			**362,998**
2003	2	1	503	17,548		11,100	68,843	40,035	4,869	23,369	5,677	16,823			**188,769**
2004	4	49	12	6,652		6,828	56,996	78,933	3,795	25,087	3,050	20,839			**202,245**
2005	88	11	-	-		1,950	20,009	55,762			101				**77,922**

Table 1.1.7-2 (cont.) Summary of American shad commercial landings (kg) as reported for inland natal and mixed stock/ocean fisheries by National Marine Fisheries Service and/or respective state agencies.

(c) Total Landings

YEAR	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	TOTAL
1970					78,518	118,208	26,127	6,078			432,372	67,087	241,088	99,021	**1,068,500**
1971					109,182	86,320	18,144	3,447			308,539	45,042	190,512	114,534	**875,720**
1972					113,037	148,645	24,494	4,173			212,504	72,122	155,993	54,432	**785,401**
1973					116,847	122,517	20,231	3,447			145,606	11,884	108,592	44,906	**574,031**
1974					112,130	110,860	24,358	3,765			167,303	11,022	73,347	45,360	**548,145**
1975					75,071	114,942	38,556	8,482			109,426	28,305	82,555	14,833	**472,170**
1976					177,811	100,064	31,933	16,148	213,777		75,837	14,697	42,049	12,519	**684,836**
1977					150,777	94,712	60,873	33,793	196,083		54,896	-	53,523	43,910	**688,566**
1978	11,118		363		138,938	207,114	59,512	31,707	196,906		182,355	-	107,934	59,441	**995,387**
1979			544		93,804	236,507	40,280	43,047	122,835		126,133	89,391	121,509	52,078	**926,128**
1980	12,682	3,130	3,810	907	140,843	647,106	54,296	43,546	45,266	441,750	90,360	122,723	85,499	-	**1,691,916**
1981	41,096	2,540	7,575	14,243	147,284	307,768	59,286	89,495	37,859	226,400	159,440	202,492	88,825	-	**1,384,304**
1982	11,741	1,225	13,336	35,970	128,369	205,254	127,416	158,760	22,633	265,517	186,816	180,727	97,607	-	**1,435,370**
1983	17,554	1,542	6,124	10,660	193,234	223,353	90,811	105,598	25,140	305,237	202,251	150,299	133,214	-	**1,465,017**
1984	15,157	2,313	13,472	16,602	180,966	333,396	98,159	99,792	27,793	575,952	265,285	243,294	120,051	-	**1,992,232**
1985	7,258	3,311	10,115	41,187	182,347	385,498	108,093	91,534	71,757	287,122	149,524	167,414	121,395	-	**1,626,556**
1986	10,438	7,666	27,261	23,769	146,490	395,389	79,244	109,126	61,987	259,965	169,553	218,479	78,459	6,204	**1,594,029**
1987	11,975	18,734	18,507	47,129	151,457	315,607	92,852	116,349	54,116	287,070	148,620	220,680	113,173	70,503	**1,666,772**
1988	14,461	20,837	22,967	55,339	85,957	362,169	113,763	143,121	120,042	219,204	128,391	167,624	91,981	120,827	**1,666,684**
1989	21,091	13,882	6,178	19,038	82,680	230,656	188,698	103,825	221,272	228,218	146,692	157,314	92,173	74,895	**1,586,611**
1990	5,354	17,330	2,540	10,337	119,068	212,701	222,110	222,684	128,663	206,008	142,226	102,108	59,058	131,223	**1,581,412**
1991	903	8,584	289	12,617	68,167	161,325	184,817	236,856	106,139	204,332	125,424	111,468	51,721	32,474	**1,305,116**
1992	658	4,492	140	6,029	65,616	130,060	148,497	128,520	90,191	216,909	108,484	111,153	65,657	22,588	**1,098,993**
1993	-	2,971	181	18,394	43,955	66,202	154,063	140,210	35,329	250,907	81,099	51,992	57,096	11,115	**913,512**
1994	477	12,803	130	8,137	48,023	92,794	102,484	108,981	15,261	171,361	50,338	55,411	66,834	11,325	**744,360**
1995	173	13,862	206	12,683	27,958	119,437	132,328	93,137	27,491	68,453	93,381	129,550	97,918	12,195	**828,774**
1996	485	16,118	61	6,452	30,281	95,148	95,774	124,820	60,165	108,008	90,327	246,156	104,136	1,656	**979,586**
1997	88	11,538	341	16,674	41,279	84,900	106,474	78,018	75,357	162,306	99,577	155,710	93,748	24	**926,034**
1998	192	6,881	801	15,236	40,526	146,907	105,712	98,291	54,085	157,628	148,579	192,200	95,636	8	**1,062,683**
1999	77	1,667	101	20,076	20,219	97,631	121,009	103,609	27,703	105,034	59,699	101,495	45,328	218	**703,864**
2000	132	2,695	122	7,854	48,724	81,159	116,624	78,499	16,350	74,481	135,168	241,635	60,939	363	**864,744**
2001	216	368	477	30,777	26,869	60,170	122,543	129,550	26,028	114,588	68,528	139,556	54,604	-	**774,273**
2002	8	-	192	39,553	49,034	86,876	125,341	56,340	18,741	69,087	124,584	242,472	28,734	-	**840,962**
2003	2	1	503	17,548	50,407	61,098	107,036	42,188	4,869	23,369	179,286	177,574	37,002	-	**700,882**
2004	4	49	12	6,652	30,086	39,868	98,760	80,301	3,795	25,087	122,047	173,473	17,213	-	**597,348**
2005	88	11	-	-	32,626	25,757	41,121	56,069	-	-	86,757	-	18,071	-	**260,501**

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

Figure 1.1.7-1 American shad landings from natal Atlantic coast rivers and mixed stock fisheries, 1970-2005. "Total" landings not specified to natal or mixed.

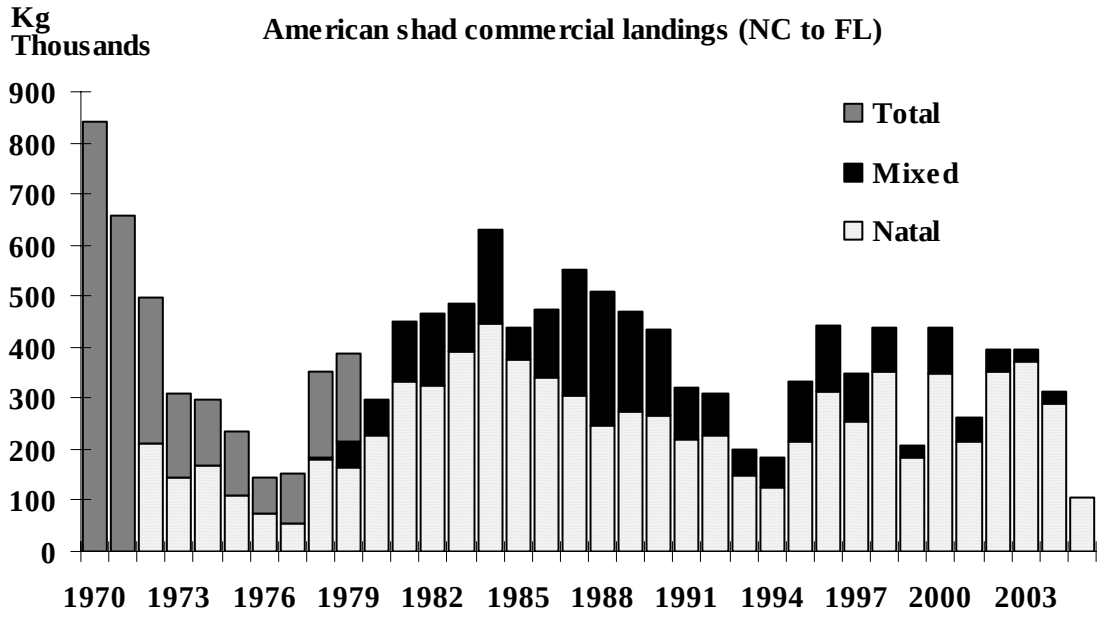
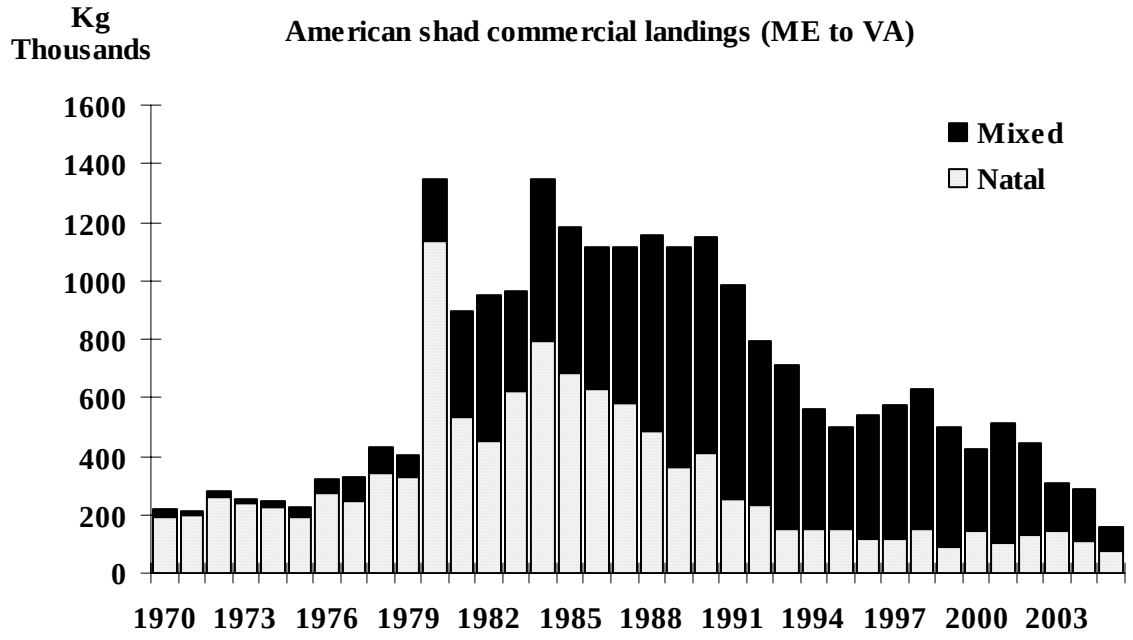


Figure 1.1.7-1 (cont.) American shad landings from natal Atlantic coast rivers and mixed stock fisheries, 1970-2005. "Total" landings not specified to natal or mixed.



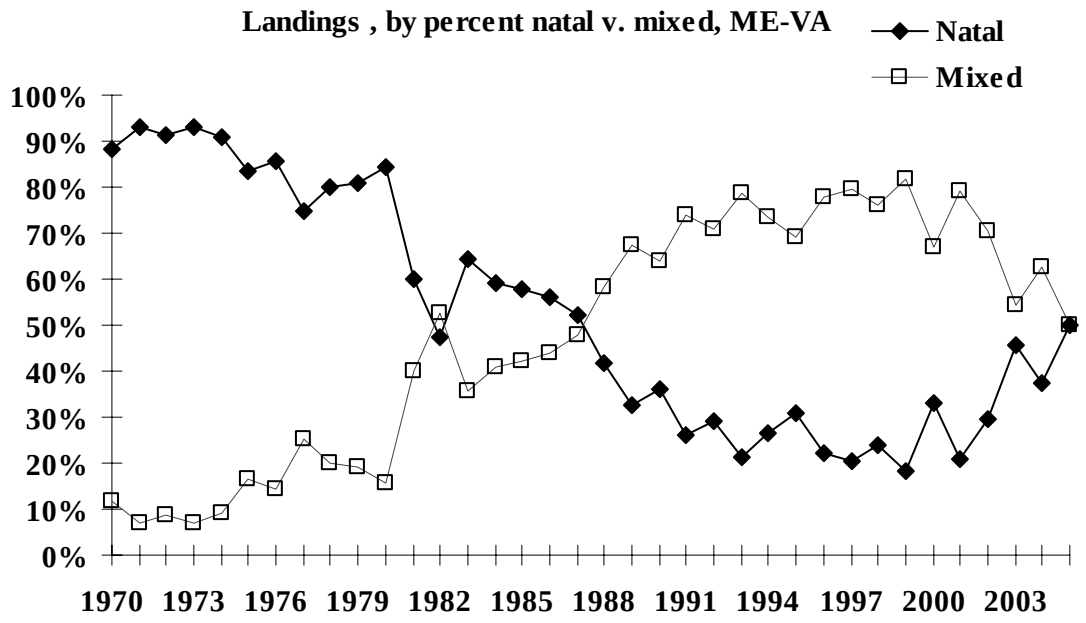
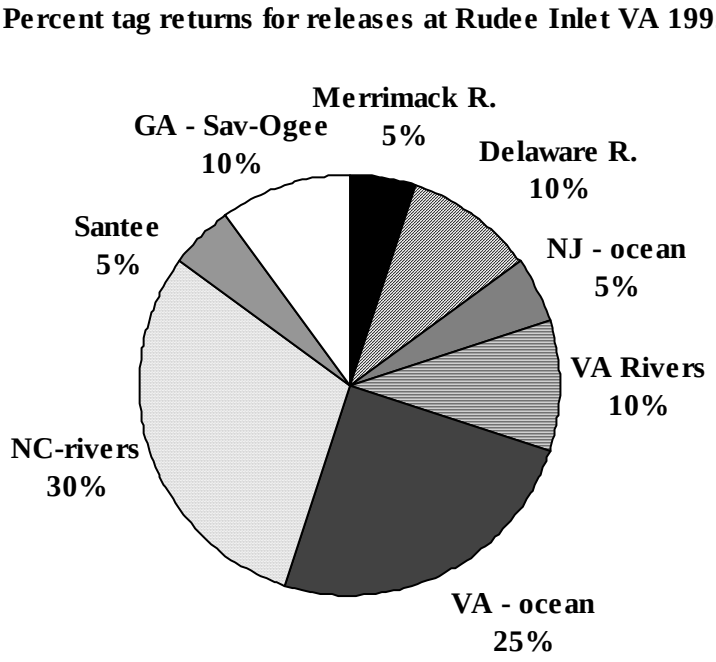


Figure 1.1.7-2 Comparison of tag returns of shad released near Rudee Inlet VA and results of DNA analyses for shad sampled in the same area, 1992.



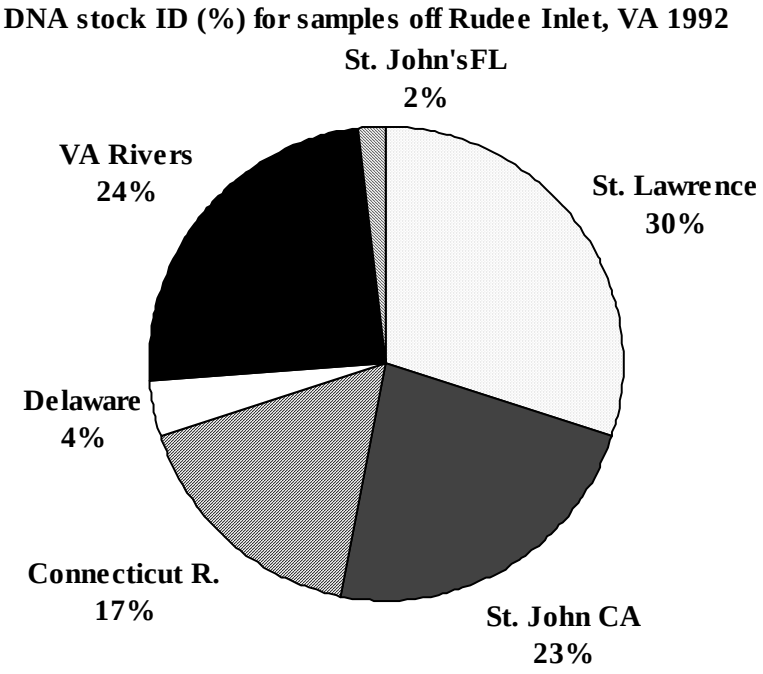
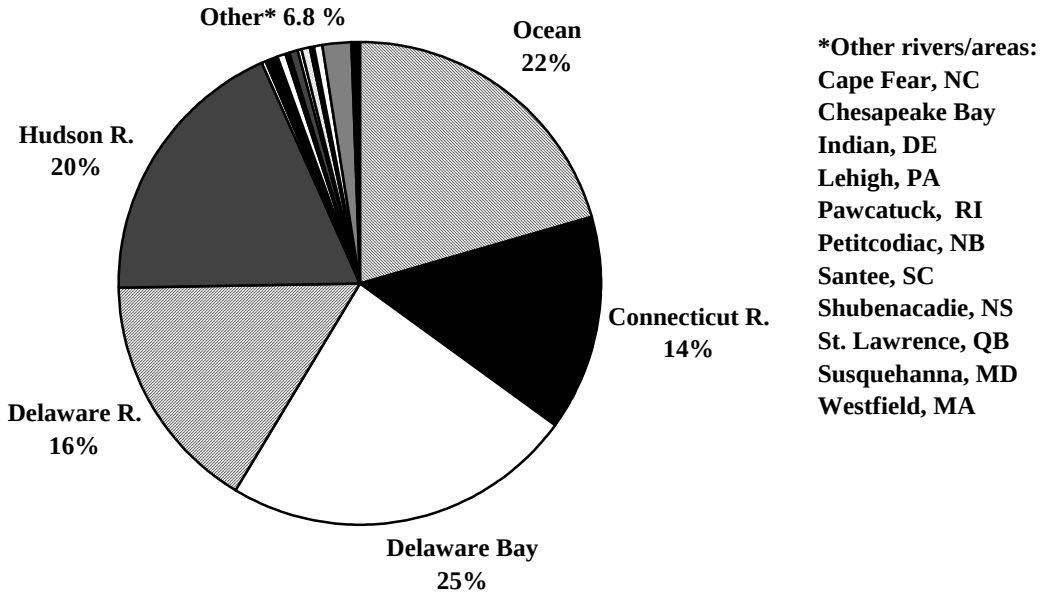


Figure 1.1.7-3 Tag returns from studies conducted along the Atlantic coast in lower Delaware Bay, MD-VA, North Carolina and South Carolina coasts.

A **Tag returns from A. shad tagged in Lower Delaware Bay, 1995-2005**



B **Tag returns from A. shad released off MD-VA coast, 1991-92**

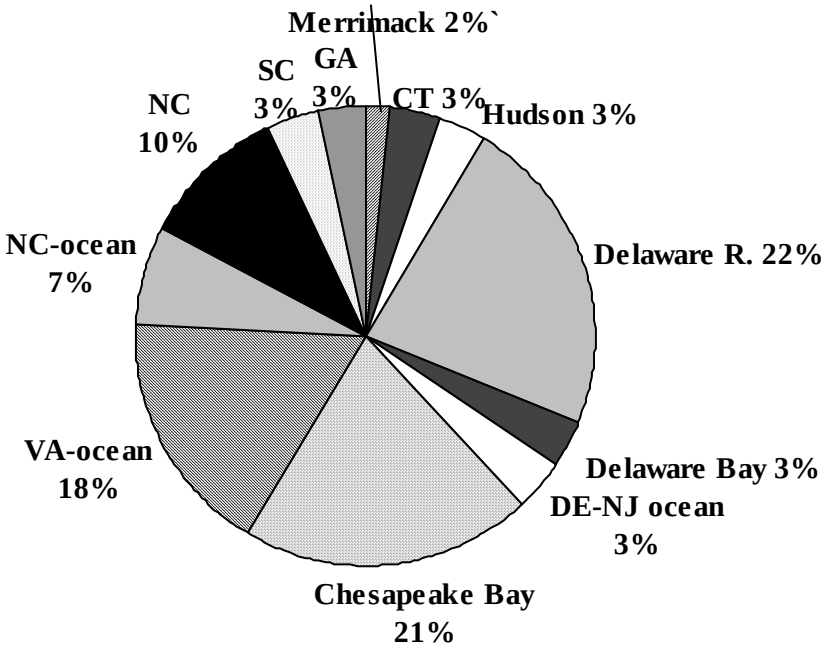
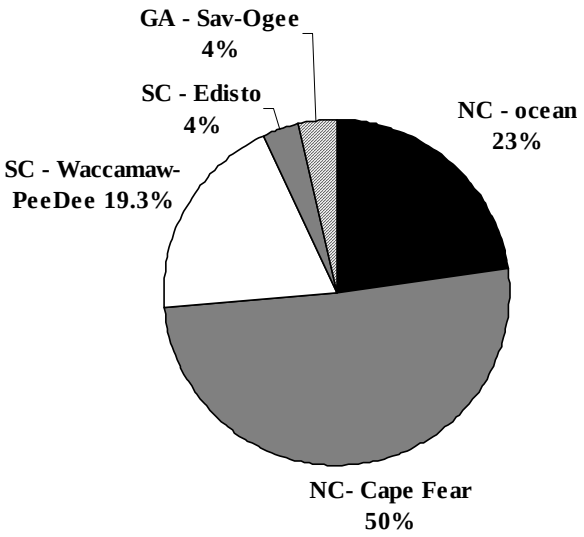


Figure 1.1.7-3 (cont.) Tag returns from studies conducted along the Atlantic coast in lower Delaware Bay, MD-VA, North Carolina and South Carolina coasts.

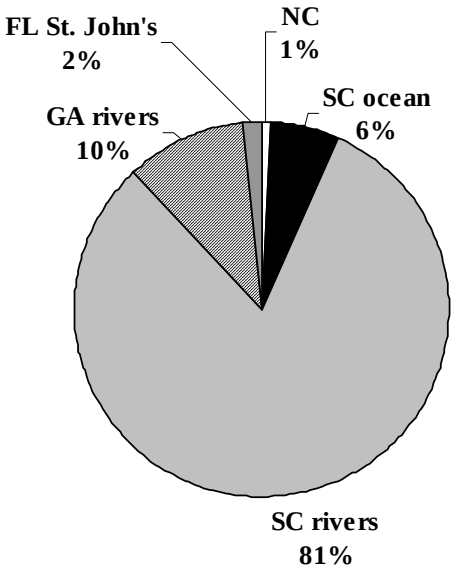
C

Tag returns for A. shad tagged off NC shore, 1989-1990



D

Tag returns from A. shad released off S. Carolina 1986-1988.



1.2 COASTWIDE SUMMARIES

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The following section provides a coastwide overview of juvenile abundance indices, upriver passage numbers at dams, total mortality estimates, mean length and age, and catch-per-unit-effort (CPUE) estimates evaluated in this assessment. An overview of the rivers contained within this stock assessment, information on current American shad fisheries, and data use and availability is provided in Table 1.2.

1.2.1 Juvenile Abundance Indices

Approach

All available juvenile abundance indices (JAI) were examined for temporal and geographic patterns in young-of-year production (Figure 1.2.1). No young-of-year data are available south of Albemarle Sound.

New England

Young-of-year production in New England has varied without trend for the last 20 years with the exception of a dramatic rise for the Merrymeeting Bay and a moderate rise in the Connecticut River data since 2001 (Figure 1.2.1a). All indices (Maine, Connecticut, and Rhode Island) had synchronous declines in 1998 and 2001.

Hudson and Delaware Rivers

Hudson River and non-tidal Delaware River JAIs increased though late 1980s. The Hudson River experienced, before undergoing a general decline with poor recruitment in the Hudson since 2002 (Figure 1.2.1b). The non-tidal Delaware River trend experienced a peak in 1996 followed by an alternating pattern of decrease (1996-2002) and increase (2002-2005). There was an increase in the tidal Delaware River JAI in 1988 followed by fluctuation without trend through the present. All three indices show a decrease in 2002.

Upper Chesapeake Bay (Maryland) and Potomac River

Young-of-year production in the upper Chesapeake Bay has increased since 1995, but the index has shown wide year-to-year fluctuations (Figure 1.2.1c). JAIs for the Nanticoke River and Potomac River have increased steadily since 1995.

Lower Chesapeake Bay Rivers (Virginia) and Albemarle Sound

All JAI indices from the lower Chesapeake Bay (James, York, and Rappahannock rivers) and Albemarle sound show have a period of relatively high values in early 1980s, a low period from the mid-1980s to the

mid-1990s, and then occasional high values until 2005 when all indices declined (Figure 1.2.1d). Virginia rivers show greater interannual fluctuation than the Roanoke River (Albemarle Sound). The James River JAI time series displays no measurable recruitment in most years with only 5 non-zero years since 1980. Strong recruitment occurred in 1996 and 2003 on the York River. The Rappahannock JAI had moderate peaks in 1996, 2003 and 2004. In other years on these systems, recruitment was low to moderate. The York River and Rappahannock River JAIs had peaks in 1996 and 2003 with low values in between. There has been consistent young-of-year production on the Albemarle Sound since the mid-1990s, but poor young-of-year production occurred in 2000, 2004, and 2005.

1.2.2 Upriver Fish Passage

Data on annual numbers of fish passed upriver at dams on several Atlantic coastal rivers exhibited a coastwide pattern of increase followed by a decrease (Figure 1.2.2). Interestingly, the timing of this pattern varied somewhat among rivers. Passage at dams from the Santee River in South Carolina to the Lehigh River (a tributary of the Delaware River in Pennsylvania), the Merrimack River in Massachusetts, and the Saco River in Maine peaked in 1999 through 2002. Passage on the Connecticut River peaked in 1992 and on the Pawcatuck River in 1985; however, even at these facilities there was a moderate increase prior to 1999 or 2002 followed by a decline. Fish passage facilities take some time (years) to optimize passage and it is expected that there would be an increase in passage as operational experience is gained at each facility. Still, it is unexpected that passage on so many rivers would decline at approximately the same time. This observation suggests a coastwide change in environmental conditions or mortality factors that affected stocks from South Carolina to Maine within the last five years.

1.2.3 Total Mortality

This section discusses observed temporal and spatial patterns observed in total mortality rate (Z) estimates for Atlantic coast American shad stocks from Maine to North Carolina (Figure 1.2.3). Data were obtained from fishery-independent and fishery-dependent sources. Please see individual state assessments (Sections 2 to 16) for details of the datasets used. Total mortality estimates were not developed for the Delaware River (ageing issues) or for rivers from South Carolina through Florida (lack of age data and stocks are semelparous). Z_{30} benchmarks were developed for regions from New England through North Carolina (see Section 1.1.5), but not for stocks from South Carolina through Florida.

Contrast among years was observed in Z-values within several systems, especially in systems with long datasets (Figure 1.2.3). Annual Z-estimates for males and females in the Connecticut River fluctuated without trend from 1980 through the mid-1990s. Interannual variation for both sexes then increased, and Z-estimates for females remained at the same level while those for males increased dramatically during the last 10 years. Z-estimates for the Hudson River (both sexes) were slightly above the Z_{30} for that river for the later half of the 1980s. Estimates then climbed dramatically and remained high until the last couple of years when estimates began to decline. Annual Z-estimates for females in Virginia rivers remained above Z_{30}, but have generally declined since the late 1990s when these time series begin. Trends were not obvious for males in Virginia Rivers because of small sample sizes.

The Z-estimates in several systems fluctuated without trend for the duration of the time series (Figure 1.2.3). Estimates for sexes combined in Maryland rivers of the upper Chesapeake Bay fluctuated but were well above Z_{30}. Z-estimates for both sexes fluctuated just above Z_{30} in the Nanticoke River (Chesapeake Bay) and Albemarle Sound in North Carolina; annual fluctuations in Z were larger in the Nanticoke River than Albemarle Sound until recent years. Potomac River Z-estimates for American shad are available for the last four years and they have declined.

Small sample sizes and data gaps among years clouded interannual patterns in North Carolina rivers south of Albemarle Sound and in most New England rivers. Z-estimates for the Exeter River in New Hampshire have fluctuated around Z_{30} for the last 15 years.

Available Z-estimates generally exceeded Z_{30} for most years in rivers where data were suitable for catch curve analysis and where data supported spawning stock biomass-per-recruit (SSBPR) modeling (Figure 1.2.3). There is evidence in these data, in conjunction with other data summarized in this assessment, that Z-values at these levels have affected stock characteristics. In the Hudson River stock, abundance, mean size, and mean age were relatively high in the 1980s when Z-values were relatively low. As Z-values climbed in the 1990s, abundance, mean size, and mean age all have declined. In the Connecticut River, mean age and mean repeat spawn have declined as Z-values increased. The Z-estimates in Albemarle Sound have remained at levels just about Z_{30} and abundance of mature American shad in that system has increased. Finally, although Z-values in the upper Chesapeake Bay have fluctuated without trend, they have been very high and that stock has declined.

1.2.4 Mean Length and Mean Age Summaries

Approach

In this assessment we often used interannual change in mean age to corroborate change in recruitment or mortality. Given the uncertainty about ageing of American shad (see Section 1.1.7) and the possibility that interranual change in mean age could be caused by concomitant change in ageing techniques, we thought it important to evaluate interannual consistency of ageing in the age data developed for this assessment. Since fish generally get older as they grow in length, we expected that changes in annual mean length would be correlated with changes in mean age for the same samples unless ageing technique varied over the time series. Absence of a significant relationship was considered an indication that ageing technique had changed. We assumed that length was measured without error. Since over twenty years of data were available in several systems, many shad populations experienced change in recruitment or mortality that led to change in mean length and mean age. Some age and length datasets varied substantially over the time series and provide good contrast for these analyses. We did not consider this evaluation a test of ageing accuracy.

For this evaluation, we plotted annual mean length and mean age on year by sex where available for each sample program and system. We further analyzed these relationships with regressions of age on length. In most cases, we queried agencies that generated age datasets about experience and consistency in personnel making age determinations.

Results

Results of our analyses were mixed. Plots of mean length and mean age suggested that ageing techniques were consistent for some datasets and not for others (Figure 1.2.4). In six of 23 datasets tested, the slope between age and length was significantly different from zero ($P<0.05$) for both sexes (Table 1.2.4). Significant slopes also occurred in two datasets for males only and in five datasets for females only. Slopes were not significant for either sex in eight datasets. There was no apparent geographic or regional pattern in significant slopes. However, those datasets in which trends were significant for both sexes tended to be from agencies where a single individual with many years of experience aged the scales for the entire time series. In some datasets without significant trends, a change had occurred in personnel during the time series. In others, aberrant ages appeared early in the time series as the person making age determinations was gaining experience. It was interesting that ageing of females was consistent in more

datasets than males. All of the significant female datasets were from regions where shad were iteroparous spawners and spawning marks were expected on scales. Such marks very likely aided in age determinations of scales. It should be noted that small sample sizes might have skewed age results in some datasets. There was no relationship between number of years in the dataset and significance. In this assessment, we generally avoided use of age data to infer change in stock characteristics from time series without significant slopes.

1.2.5 Coastwide CPUE Trends

Approach

We evaluated trends in fishery-dependent and independent CPUE indices of adult American shad along the Atlantic coast with linear regressions, or in the case of the Altamaha River, with a quadratic relationship. In some instances, the available data were sub-set into shorter periods to examine trends in different portions of the time series. These analyses and accompanying statistics facilitated an objective assessment of trends over time. Results were reported for river-specific datasets and for datasets that contained CPUE for mixed stock fisheries (Table 1.2.5). The term “mixed stock” includes those shad partaking in the coastal ocean migration as well as those that are caught in estuarine waters before beginning migrations up natal streams.

New England

There were no in-river adult CPUE indices available for American shad from Maine to Rhode Island. American shad abundance indices developed from surveys conducted by Connecticut Department of Environmental Protection in the Connecticut River and the Long Island Sound did not show a significant trend over the past two decades.

Hudson and Delaware Rivers

There was a significant negative trend in the Hudson River commercial gill net CPUE from 1986 to 1999. Although this time series continued through 2001, sample sizes are too low to provide confidence in later CPUE estimates. The longest time series of CPUE data for the Delaware River came from the Lewis haul fishery, which is a small commercial operation above tidal waters. The CPUE from this fishery increased significantly concurrent with marked water quality improvements associated with implementation of the Clean Water Act. Both the Lewis haul seine index and the Delaware commercial CPUE have declined significantly in the past 17 years.

Chesapeake Bay

Hook and line CPUE of American shad in the Susquehanna River collected by the Maryland Department of Natural Resources increased significantly from 1984 to 2001, but CPUE has decreased in recent years. Commercial pound net CPUE on the Nanticoke River has increased significantly since 1988, while there has been no trend in commercial fyke net CPUE. During the last 10 years, both the fishery-dependent pound net CPUE and fishery-independent gill net CPUE have increased significantly on the Potomac River. There has been no trend in staked gill net CPUE on either the York or the Rappahannock Rivers since 1998, while there has been a significant increase in staked gill net CPUE on the James River over the same time. There has been no trend in fishery-independent electrofishing or gill-net survey indices on the James River.

North Carolina

In Albemarle Sound, there has been a significant increase in fishery-independent gill net CPUE over the past 16 years and in the fishery dependent gill net CPUE over the past 12 years. There are no significant trends in any other North Carolina river systems.

South Carolina, Georgia, and Florida

The commercial drift gill net CPUE for American shad in Winyah Bay, South Carolina did not show a significant trend from 1981 to 1997. Commercial gill net CPUE in the Waccamaw River increased significantly from 1979 to 2005, while there was no trend in CPUE for American shad from the Pee Dee River from 1979 to 1999.

While both the upper set gill-net fishery and lower drift net fishery CPUE indices increased on the Santee River, only the increase in the lower drift net series was significant. In contrast, two of three commercial set gill-net CPUE series sets for the Edisto River showed a significant decline.

No significant trends were detected in the commercial gill-net CPUE indices for American shad in the Combahee River or the Savannah River, nor were any significant trends in CPUE series detected for the Altamaha River, Georgia (area under the curve of catch/net hour from fish tagging collections) or the St. Johns River, Florida (recreational creel survey).

Table 1.2 List of rivers contained within this stock assessment, information on current American shad fisheries, and data use and availability. Please note that while rivers are listed in groups according to their geographic location, they are only assessed in one section (e.g., the Savannah River borders South Carolina and Georgia, it is only assessed in Section 14, which includes all South Carolina rivers and not in Section 15, which includes all Georgia rivers). American shad stocks assessed are bolded. If a recreational fishery is permitted, the creel limit for that fishery is indicated. Rivers with different creel limits in different states have the creels for each state separated by a "/" (e.g., St. Marys River: 8/10—Georgia creel limit/Florida creel limit). **Y** = yes; Moratorium = commercial moratorium; ★ = moratorium exists but bycatch is permitted; CR = catch and release; FD = fishery-dependent; FI = fishery-independent; JAI = juvenile abundance index; ● = data available and used for assessment; ○ = data available but **not used** for assessment. Empty cells indicate a negative response.

State	River*	Assessed	Fishery			Available Data			
			Moratorium	Commercial	Recreational	FD - Comm	FD - Rec	FI - Adult	JAI
ME	Nonesuch		★		2/day				
	Presumpscot		★		2/day				
	Royal		★		2/day				
	Merrymeeting Bay		★		2/day			○	○
	Kennebec	**Y**	★		**2/day**				●
	Cathance		★		2/day			○	○
	Androscoggin	**Y**	★		**2/day**				●
	Abbadagasett		★		2/day				○
	Eastern		★		2/day				○
	Sheepscot		★		2/day				
	Penobscot		★		2/day				
	Narraguangus		★		2/day			○	
	Pleasant		★		2/day				
	Harrington		★		2/day				
	Chandler		★		2/day				
	Machias/East Machias		★		2/day				
	Denny's		★		2/day				
	St. Croix		★		2/day				
	Saco	**Y**	★		**2/day**			●	
	Mousam		★		2/day				
	St. George		★		2/day				
	Medomak		★		2/day				
	Sebasticook		★		2/day				

* River unless otherwise noted.

Table 1.2 (cont.) List of rivers contained within this stock assessment, information on current American shad fisheries, and data use and availability. Please note that while rivers are listed in groups according to their geographic location, they are only assessed in one section (e.g., the Savannah River borders South Carolina and Georgia, it is only assessed in Section 14, which includes all South Carolina rivers and not in Section 15, which includes all Georgia rivers). American shad stocks assessed are bolded. If a recreational fishery is permitted, the creel limit for that fishery is indicated. Rivers with different creel limits in different states have the creels for each state separated by a "/" (e.g., St. Marys River: 8/10—Georgia creel limit/Florida creel limit). **Y** = yes; Moratorium = commercial moratorium; ★ = moratorium exists but bycatch is permitted; CR = catch and release; FD = fishery-dependent; FI = fishery-independent; JAI = juvenile abundance index; ● = data available and used for assessment; ○ = data available but **not used** for assessment. Empty cells indicate a negative response.

State	River*	Assessed	Fishery			Available Data			
			Moratorium	Commercial	Recreational	FD - Comm	FD - Rec	FI - Adult	JAI
NH	Cocheco		Y		2/day			○	
	Exeter	Y	Y		2/day			●	
	Oyster		Y		2/day			○	
	Lamprey		Y		2/day			○	
	Winnicut		Y		2/day			○	
	Great Bay Estuary		Y		2/day				○
	Salmon Falls		Y		2/day				
	Taylor		Y		2/day			○	
MA	**Merrimack**	Y	Y		**6/day**			●	
	Neponset		Y		6/day				
	Charles		Y		6/day				
	Palmer		Y		6/day				
	Indianhead		Y		6/day				
RI	Runnins		Y						
RI/CT	**Pawcatuck**	Y	Y		**CR**			●	●
MA/CT	**Connecticut**	Y		Y	**6/day**	○	○	●	●
CT	Thames								
	Housatonic								
NY	**Hudson**	Y		Y	**6/day**	●	●	●	●
NY/PA/NJ/DE	**Delaware River and Bay**	Y		Y	**6/6/6/10**			●	●
MD	**Nanticoke**	Y	Y					●	●
	Choptank		Y		CR	○		○	○

* River unless otherwise noted.

Table 1.2 (cont.) List of rivers contained within this stock assessment, information on current American shad fisheries, and data use and availability. Please note that while rivers are listed in groups according to their geographic location, they are only assessed in one section (e.g., the Savannah River borders South Carolina and Georgia, it is only assessed in Section 14, which includes all South Carolina rivers and not in Section 15, which includes all Georgia rivers). American shad stocks assessed are bolded. If a recreational fishery is permitted, the creel limit for that fishery is indicated. Rivers with different creel limits in different states have the creels for each state separated by a "/" (e.g., St. Marys River: 8/10—Georgia creel limit/Florida creel limit). **Y** = yes; Moratorium = commercial moratorium; ★ = moratorium exists but bycatch is permitted; CR = catch and release; FD = fishery-dependent; FI = fishery-independent; JAI = juvenile abundance index; ● = data available and used for assessment; ○ = data available but **not used** for assessment. Empty cells indicate a negative response.

State	River*	Assessed	Fishery			Available Data			
			Moratorium	Commercial	Recreational	FD - Comm	FD - Rec	FI - Adult	JAI
MD (cont.)	Patuxent		Y		CR	○		○	○
	Pocomoke		Y			○			
	Chesapeake Bay		Y			○			
PA/MD	**Susquehanna River and Flats**	Y	Y		CR	○	○	●	●
MD/DC/VA	**Potomac**	Y	★		CR	●		●	●
VA	**York**	Y	★		CR	●	○	●	●
	James	Y	★		CR	●	○	●	●
	Rappahannock	Y	★		CR	●	○	●	●
NC	**Albemarle Sound**	Y		Y	10/day	●	○	●	○
	Roanoke	Y		Y	10/day		○	●	
	Chowan			Y	10/day				
	Pamlico Sound			Y	10/day	○			
	Tar-Pamlico	Y		Y	10/day	●	○	●	
	Neuse	Y		Y	10/day	●	○	●	
	Cape Fear	Y		Y	10/day	●	○	●	
SC	**Winyah Bay**	Y		Y	10/day	●			○
	Waccamaw	Y		Y	10/day	●		○	
	Great Pee Dee	Y		Y	10/day	●			
	Little Pee Dee			Y	10/day	○			

* River unless otherwise noted.

Table 1.2 (cont.) List of rivers contained within this stock assessment, information on current American shad fisheries, and data use and availability. Please note that while rivers are listed in groups according to their geographic location, they are only assessed in one section (e.g., the Savannah River borders South Carolina and Georgia, it is only assessed in Section 14, which includes all South Carolina rivers and not in Section 15, which includes all Georgia rivers). American shad stocks assessed are bolded. If a recreational fishery is permitted, the creel limit for that fishery is indicated. Rivers with different creel limits in different states have the creels for each state separated by a "/" (e.g., St. Marys River: 8/10—Georgia creel limit/Florida creel limit). **Y** = yes; Moratorium = commercial moratorium; ★ = moratorium exists but bycatch is permitted; CR = catch and release; FD = fishery-dependent; FI = fishery-independent; JAI = juvenile abundance index; ● = data available and used for assessment; ○ = data available but **not used** for assessment. Empty cells indicate a negative response.

State	River*	Assessed	Fishery			Available Data			
			Moratorium	Commercial	Recreational	FD - Comm	FD - Rec	FI - Adult	JAI
SC (cont.)	Lynches			Y	10/day	○			
	Black			Y	10/day	○			
	Sampit			Y	10/day	○			
	Bull Creek			Y	10/day				
	Santee	Y		Y	**20/day**	●	●	●	○
	Cooper	Y		Y	**10/day**	●	●	○	
	Wateree			Y	10/day			○	
	Congaree			Y	10/day				
	Broad			Y	10/day				
	Wando			Y	10/day				
	Ashely			Y	10/day				
	Ashepoo			Y	10/day	○			
	Combahee	Y		Y	**10/day**	●			
	Edisto	Y		Y	**10/day**	●		○	○
	Coosawatchie			Y	10/day				
SC/GA	**Savannah**	Y		Y	**10/8**	●	○		
GA	**Altamaha**	Y		Y	**8/day**	●		●	○
	Ogeechee	Y		Y	**8/day**	●	●		○
	Satilla			Y	8/day	○			
GA/FL	St. Marys			Y ^	8/10	○			
FL	**St. Johns**	Y		Y ^	**10/day**	○	●	●	
	Nassau				10/day				

* River unless otherwise noted.
^ Commercial fishery is not active due to net bans.

Table 1.2.4 Linear regression statistics for comparison for relationships of mean age and mean total length in several Atlantic coastal rivers. Significant trends (*P*-value < 0.05) are identified by: **Bold** = Positve trend; ***Bold Italics*** = Negative trend.

River	Male			Female		
	R-Square	***P***	**Slope**	**R-Square**	***P***	**Slope**
Saco, ME	0.623	0.061	0.013	**0.693**	**0.039**	**0.007**
Exeter, NH	**0.346**	**0.021**	**0.022**	*0.003*	*0.835*	*0.003*
Pawcatuck, RI	*0.037*	*0.566*	*0.004*	*0.061*	*0.489*	*0.005*
Hudson, NY	**0.753**	**0.000**	**0.021**	**0.720**	**0.000**	**0.021**
Susquehanna, MD	**0.722**	**0.001**	**0.017**	**0.539**	**0.010**	**0.009**
Potomac, MD	*0.357*	*0.287*	*0.004*	**0.851**	**0.025**	**0.010**
York, VA	0.414	0.085	0.039	**0.687**	**0.011**	**0.031**
Rappahannock, VA	*0.255*	*0.247*	*0.066*	0.342	*0.167*	0.029
James, VA	*0.285*	*0.217*	*0.021*	**0.756**	**0.011**	**0.039**
Roanoke, NC (Inland)	*0.217*	*0.351*	*0.031*	*0.331*	*0.232*	*-0.037*
Albemarle, NC	*0.401*	*0.177*	*0.027*	*0.267*	*0.293*	*0.017*
Tar-Pamlico, NC (Inland)	*0.286*	*0.274*	*-0.019*	***0.701***	***0.038***	***-0.042***
Pamlico, NC	*0.769*	*0.123*	*0.038*	*0.007*	*0.913*	*0.003*
Neuse, NC (Inland)	**0.649**	**0.053**	**0.022**	**0.854**	**0.008**	**0.024**
Cape Fear, NC (Inland)	*0.050*	*0.669*	*-0.008*	*0.203*	*0.369*	*0.061*
Cape Fear, NC	**0.814**	**0.014**	**0.016**	**0.702**	**0.037**	**0.015**
Santee, SC	0.613	0.066	0.060	*0.094*	*0.554*	*0.013*
Waccamaw, SC	**0.677**	**0.023**	**0.012**	*0.392*	*0.133*	*0.019*
Edisto, SC	**0.817**	**0.005**	**0.021**	**0.906**	**0.001**	**0.030**
PeeDee, SC	**0.713**	**0.017**	**0.014**	**0.660**	**0.026**	**0.025**
Altamaha, GA	*0.001*	*0.969*	*0.000*	*0.017*	*0.870*	*0.002*

Table 1.2.5 Summary of trends in catch-per-unit-effort (CPUE) from fishery-dependent and independent datasets for adult American shad using linear regressions of CPUE against year by river and by dataset. Datasets that sample mixed stocks of American shad are found at the end of the table. Not all datasets had data for all years. Significant trends (*P*-value < 0.05) are identified by: **Bold** = Positve trend; ***Bold Italics*** = Negative trend. FD = Fishery-dependent, FI = Fishery-independent.

State	River	Adult Index	Trend	Years	N-obs	Slope (CPUE)	R-squared	*P*-value
FL	St. Johns	Roving Creel Survey-CPUE	Non-significant	1992-2005	11	-0.009	0.140	>0.05
GA	Altamaha	FI-Drift Gill Net CPUE	Nonlinear	1986-2005	20	a= -0.014, b= 0.323, c= -0.018	0.3381	a= 0.012, b= 0.009, c= 0.971
		FD-Gill Net CPUE	Non-significant	1982-1991	10	0.080	0.002	0.899
		FD-Drift Gill Net CPUE	Non-significant	2000-2005	6	4.107	0.151	0.446
	Savannah	FD-Drift Gill Net CPUE	Non-significant	2000-2005	6	-6.700	0.460	0.137
SC	Waccamaw	**FD-Drift Gill Net CPUE**	**Positive**	**1979-2005**	**25**	**0.095**	**0.476**	**<0.001**
	Pee Dee	FD-Set Gill Net CPUE	Non-significant	1979-1999	20	-0.006	0.017	0.580
	Santee	FD-Set Gill Net CPUE	Non-significant	1992-2005	14	0.160	0.137	0.051
		FD-Drift Gill Net CPUE	**Positive**	**1980-2003**	**23**	**0.049**	**0.329**	**0.004**
	Edisto	***FD-Set Gill Net CPUE***	***Negative***	***1980-2004***	***23***	***-0.035***	***0.186***	***0.040***
		FD-Set Gill Net CPUE	Non-significant	1979-2004	21	-0.062	0.097	0.169
		FD-Set Gill Net CPUE	***Negative***	***1980-2004***	***23***	***-0.040***	***0.184***	***0.041***
	Combahee	FD-Set Gill Net CPUE	Non-significant	1993-2004	11	0.012	0.019	0.683
	Savannah	FD-Set Gill Net CPUE	Non-significant	1980-2005	24	-0.010	0.011	0.632
NC	Roanoke	FI-Electrofishing CPUE	Non-significant	2000-2005	6	3.569	0.294	0.266
	Pamlico	FD-Gill Net CPUE	Non-significant	1994-2005	12	-1.840	0.040	0.570
	Tar	FI-Electrofishing CPUE	Non-significant	2000-2005	6	-8.617	0.063	0.685
	Neuse	FD-Gill Net CPUE	Non-significant	1994-2005	12	4.450	0.170	0.190
		FI-Electrofishing CPUE	Non-significant	2000-2005	6	1.738	0.503	0.114
	Cape Fear	FD-Gill Net CPUE	Non-significant	1994-2005	12	-2.110	0.100	0.330
		FI-Electrofishing CPUE	Non-significant	2000-2005	6	-21.620	0.218	0.428

Table 1.2.5 (cont.) Summary of trends in catch-per-unit-effort (CPUE) from fishery-dependent and independent datasets for adult American shad using linear regressions of CPUE against year by river and by dataset. Datasets that sample mixed stocks of American shad are found at the end of the table. Not all datasets had data for all years. Significant trends (*P*-value < 0.05) are identified by: **Bold** = Positve trend; ***Bold Italics*** = Negative trend. FD = Fishery-dependent, FI = Fishery-independent.

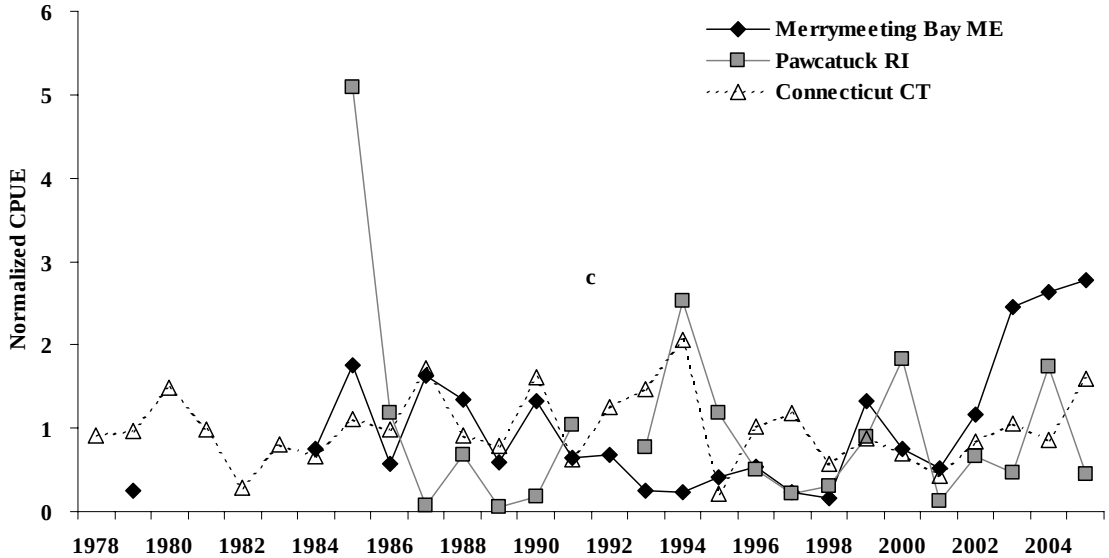
State	River	Adult Index	Trend	Years	N-obs	Slope (CPUE)	R-squared	*P*-value
VA	James	**FD-Staked Gill Net CPUE**	**Positive**	**1998-2005**	**8**	**0.750**	**0.646**	**0.016**
		FI-Electrofishing CPUE	Non-significant	2000-2004	5	0.047	0.044	0.689
		FI-Gill Net CPUE	Non-significant	2000-2005	6	0.900	0.138	0.538
	York	FD-Staked Gill Net CPUE	Non-significant	1998-2005	8	-0.597	0.175	0.302
	Rappahannock	FD-Staked Gill Net CPUE	Non-significant	1998-2005	8	0.688	0.476	0.058
PRFC	Potomac	**FI-Gill Net CPUE**	**Positive**	**1996-2005**	**10**	**0.417**	**0.874**	**<0.001**
		FD-Pound Net CPUE	**Positive**	**1988-2005**	**18**	**0.717**	**0.822**	**<0.001**
MD	Susquehanna	**FD-Hook and Line CPUE**	**Positive**	**1984-2005**	**22**	**0.547**	**0.630**	**<0.001**
			Postive	**1984-2001**	**18**	**0.740**	**0.780**	**<0.001**
			Non-significant	2002-2005	4	-2.014	0.624	0.210
	Nanticoke	**FD-Pound Net CPUE**	**Positive**	**1988-2005**	**17**	**0.034**	**0.247**	**0.042**
		FD-Fyke Net CPUE	Non-significant	1988-2005	18	0.001	0.001	0.917
DE, PA, NJ, NY	Delaware	**FD-Lewis Haul Seine CPUE**	**Positve**	**1925-2005**	**81**	**0.217**	**0.159**	**<0.001**
			Negative	***1989-2005***	***17***	***-2.391***	***0.579***	***<0.001***
		FD-Delaware Gill Net CPUE	***Negative***	***1989-2005***	***17***	***-2.592***	***0.392***	***0.009***
NY	Hudson	***FD-Male Gill Net CPUE***	***Negative***	***1986-1999***	***14***	***-1.430***	***0.590***	***0.001***
		FD-Female Gill Net CPUE	***Negative***	***1986-1999***	***14***	***-2.960***	***0.700***	***0.000***
CT	Connecticut	FD-Gill Net CPUE	Non-significant	1981-2005	25	-0.034	0.019	0.511
RI	Pawcatuck	No CPUE data	na	na	na	na	na	na
MA	Merrimack	No CPUE data	na	na	na	na	na	na
NH	Exeter, Lamprey, Cocheco	No CPUE data	na	na	na	na	na	na
ME	Androscoggin, Kennebec, Cathance, Eastern	No CPUE data	na	na	na	na	na	na

Table 1.2.5 (cont.) Summary of trends in catch-per-unit-effort (CPUE) from fishery-dependent and independent datasets for adult American shad using linear regressions of CPUE against year by river and by dataset. Datasets that sample mixed stocks of American shad are found at the end of the table. Not all datasets had data for all years. Significant trends (*P*-value < 0.05) are identified by: **Bold** = Positve trend; ***Bold Italics*** = Negative trend. FD = Fishery-dependent, FI = Fishery-independent.

State	Mixed Stock	Adult Index	Trend	Years	N-obs	Slope (CPUE)	R-squared	*P*-value
SC	Winyah Bay	FD-Drift Gill Net CPUE	Non-significant	1981-1997	17	0.060	0.050	0.390
NC	Albemarle Sound	**FD-Gill Net CPUE**	**Positive**	**1994-2005**	**12**	**7.487**	**0.443**	**0.018**
		FI-Gill Net CPUE	**Positive**	**1991-2005**	**16**	**0.005**	**0.418**	**0.009**
MD	Upper Chesapeake Bay	FD-Pound Net CPUE	Non-significant	1988-2000	13	1.006	0.220	0.124
CT	Long Island Sound	FI-Trawl Survey (Spring)	Non-significant	1984-2005	22	-0.016	0.103	0.146
		FI-Trawl Survey (Fall)	Non-significant	1984-2004	21	-0.037	0.063	0.274

Figure 1.2.1–1 Normalized juvenile abundance indices by year for Atlantic coast rivers: (a) Merrymeeting Bay, Pawcatuck River, Connecticut River; (b) Hudson River, Delaware River (striped bass recruitment survey—tidal, shad recruitment survey—non-tidal); (c) Upper Chesapeake Bay, Nanticoke River, and Potomac River; and (d) Rappahannock River, York River, James River, and Albemarle Sound.

(a)



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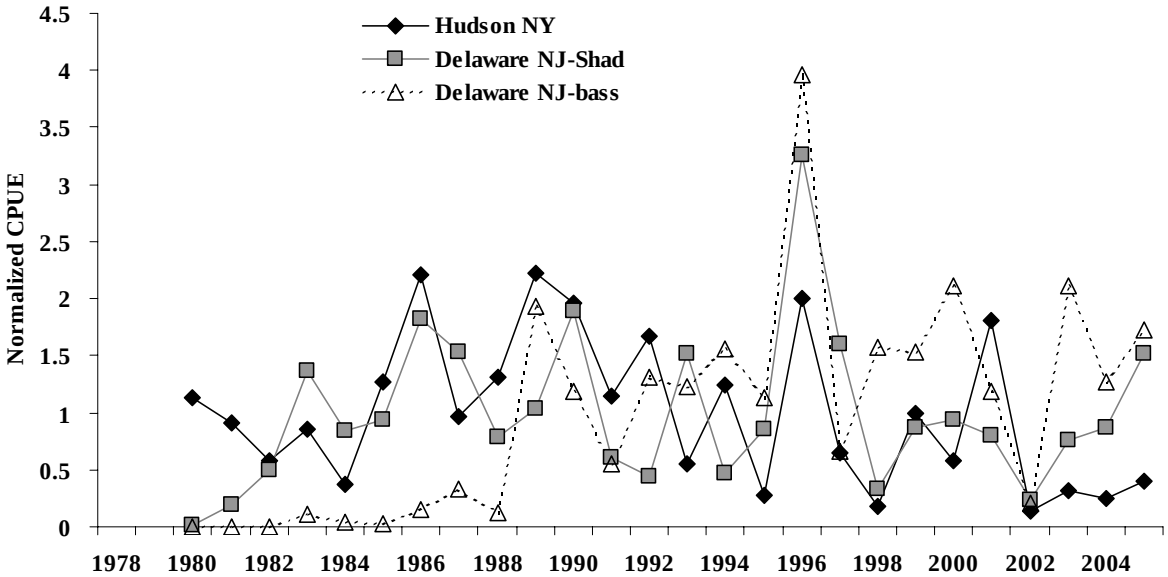
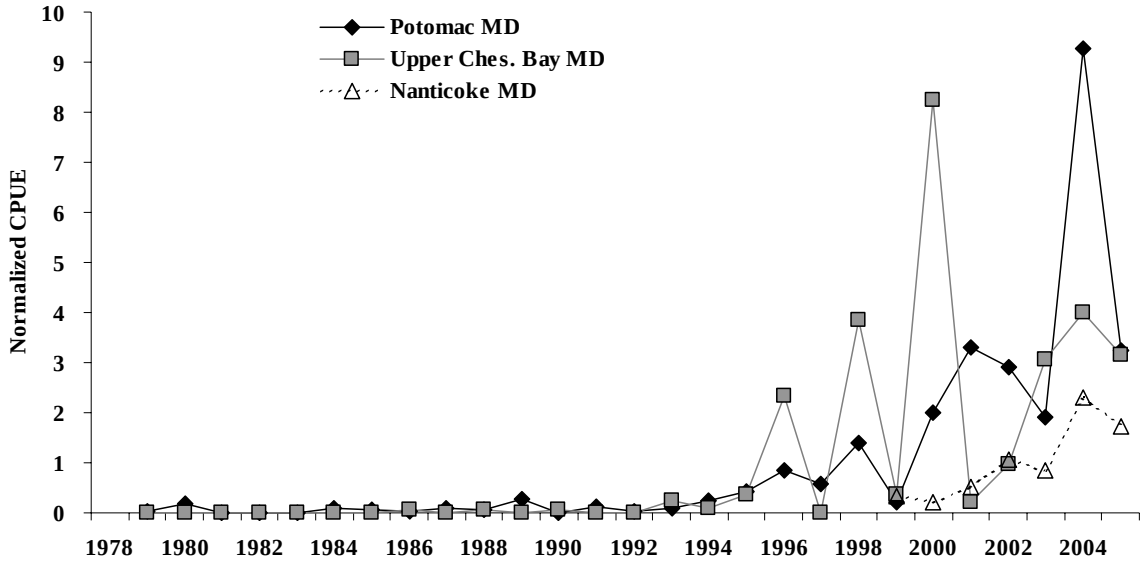


Figure 1.2.1–1 (cont.) Normalized juvenile abundance indices by year for Atlantic coast rivers: (a) Merrymeeting Bay, Pawcatuck River, Connecticut River; (b) Hudson River, Delaware River (striped bass recruitment survey—tidal, shad recruitment survey—non-tidal); (c) Upper Chesapeake Bay, Nanticoke River, and Potomac River; and (d) Rappahannock River, York River, James River, and Albemarle Sound.

(c)



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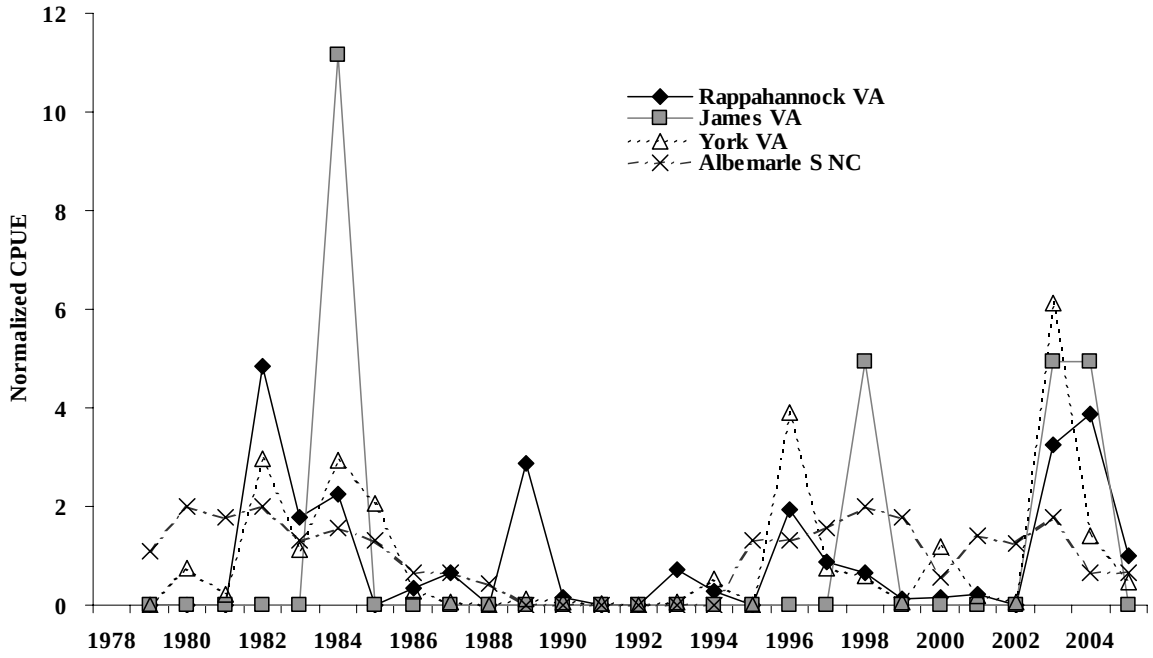


Figure 1.2.2. Coastwide plots of fish-lift and fishway annual counts of American shad on rivers along the U.S. Atlantic coast from the Saco River, Maine to the Santee River, South Carolina. All count data are plotted on the same x-axis to ease temporal comparisons, but note that y-axis scales differ.

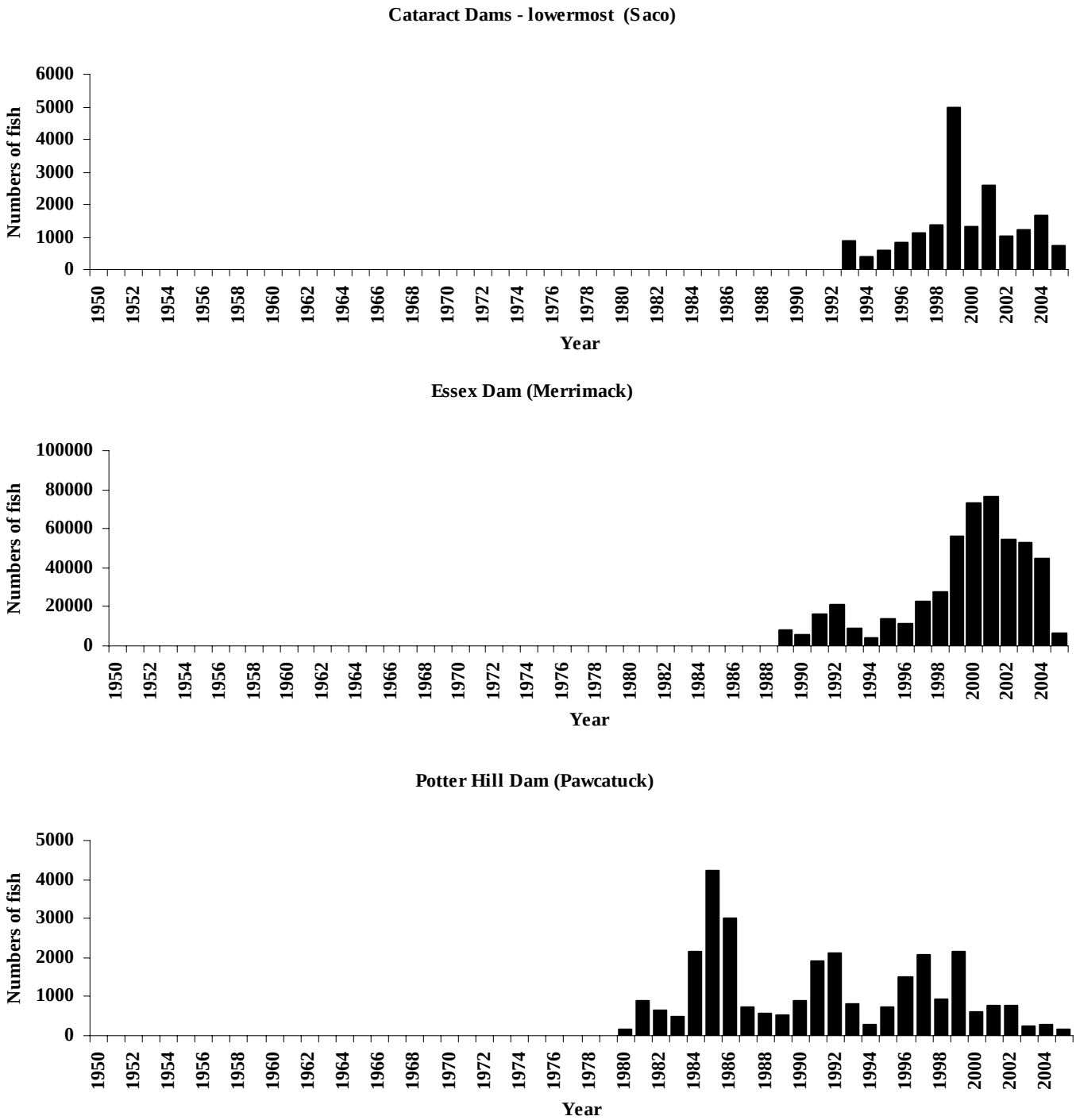
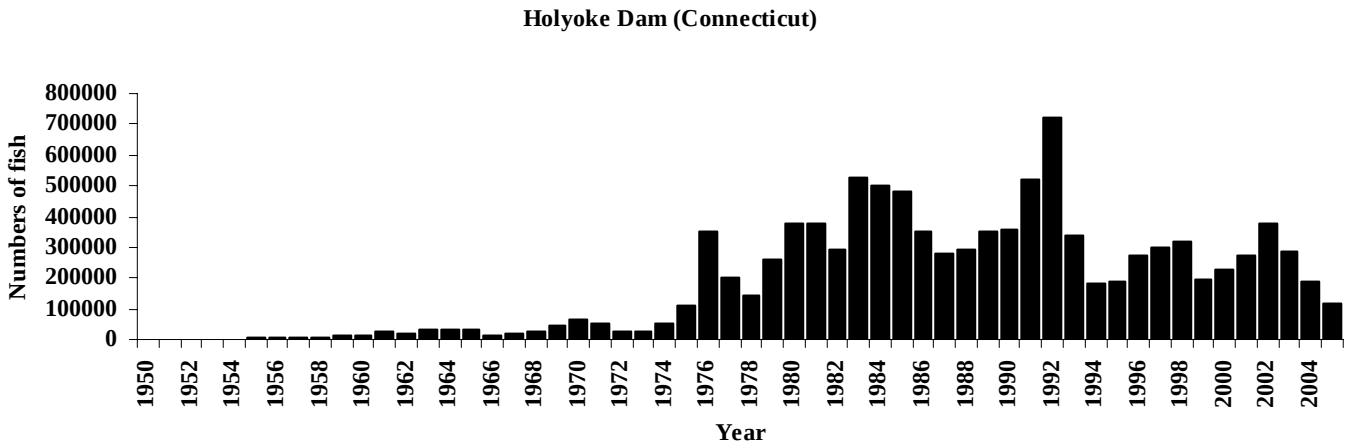
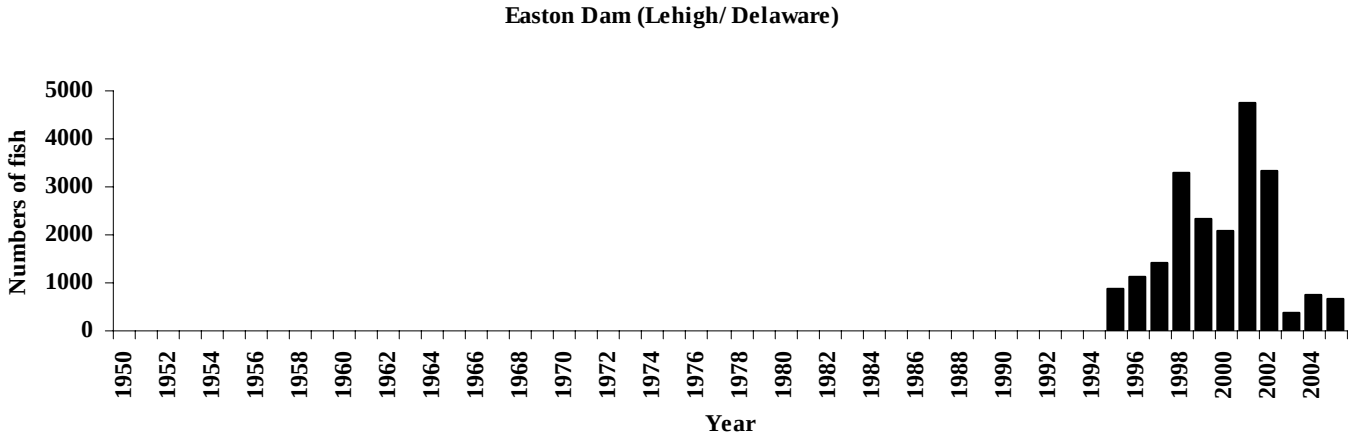


Figure 1.2.2 (cont.) Coastwide plots of fish-lift and fishway annual counts of American shad on rivers along the U.S. Atlantic coast from the Saco River, Maine to the Santee River, South Carolina. All count data are plotted on the same x-axis to ease temporal comparisons, but note that y-axis scales differ.





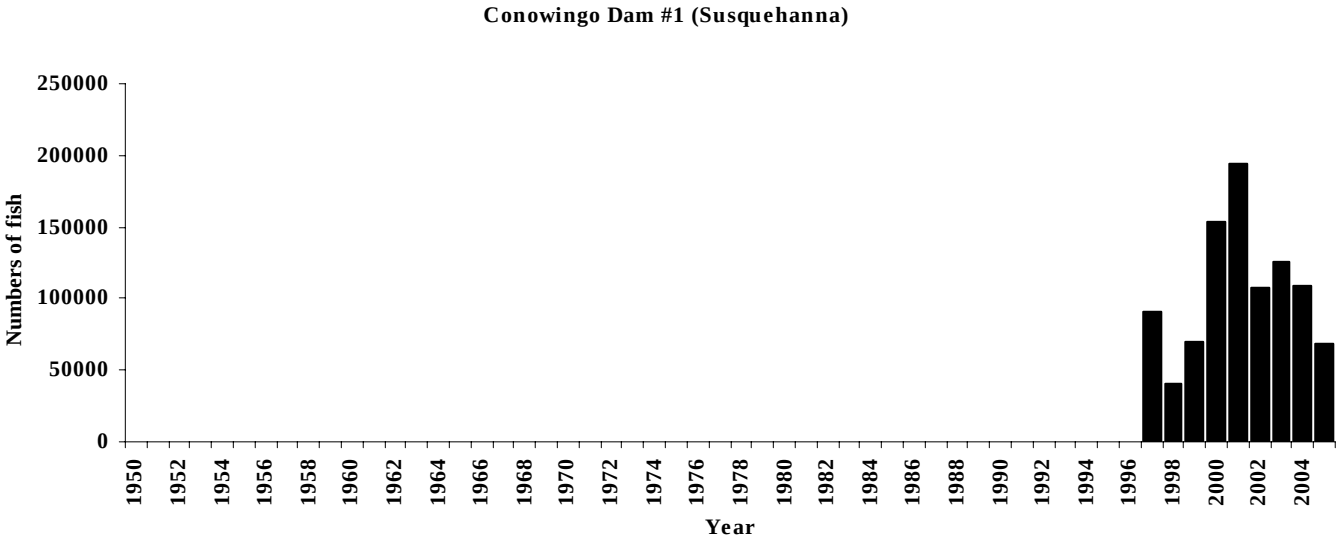
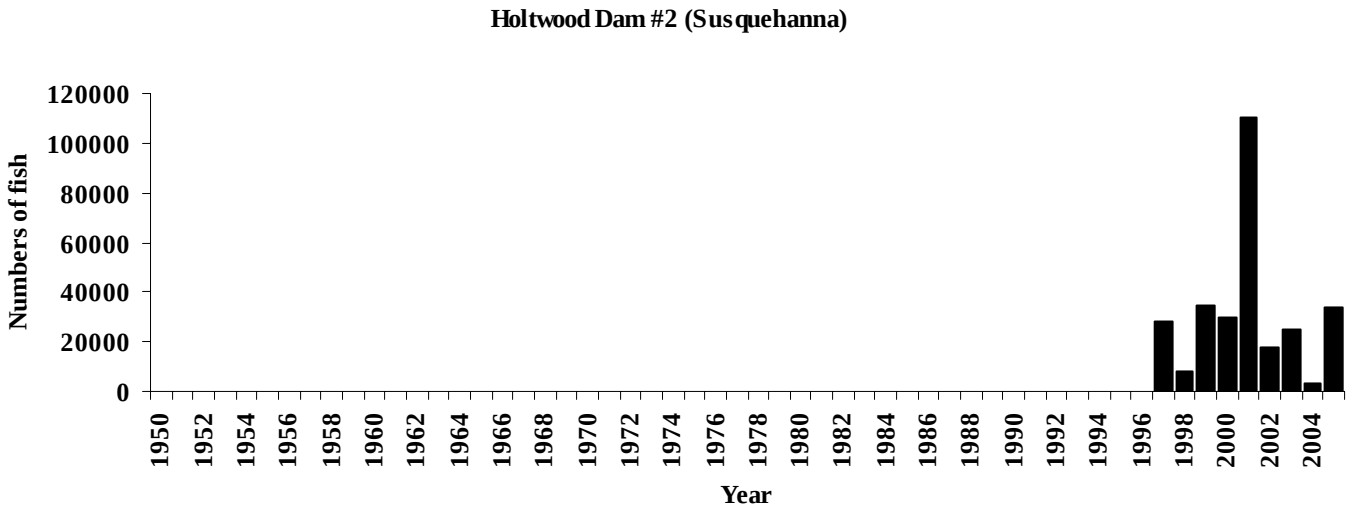
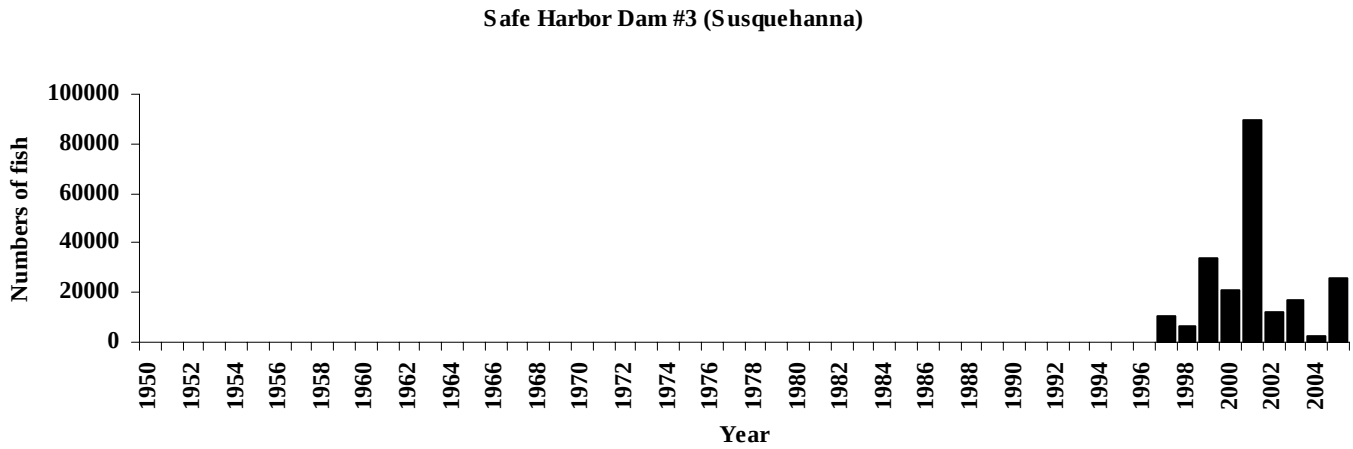


Figure 1.2.2 (cont.) Coastwide plots of fish-lift and fishway annual counts of American shad on rivers along the U.S. Atlantic coast from the Saco River, Maine to the Santee River, South Carolina. All count data are plotted on the same x-axis to ease temporal comparisons, but note that y-axis scales differ.





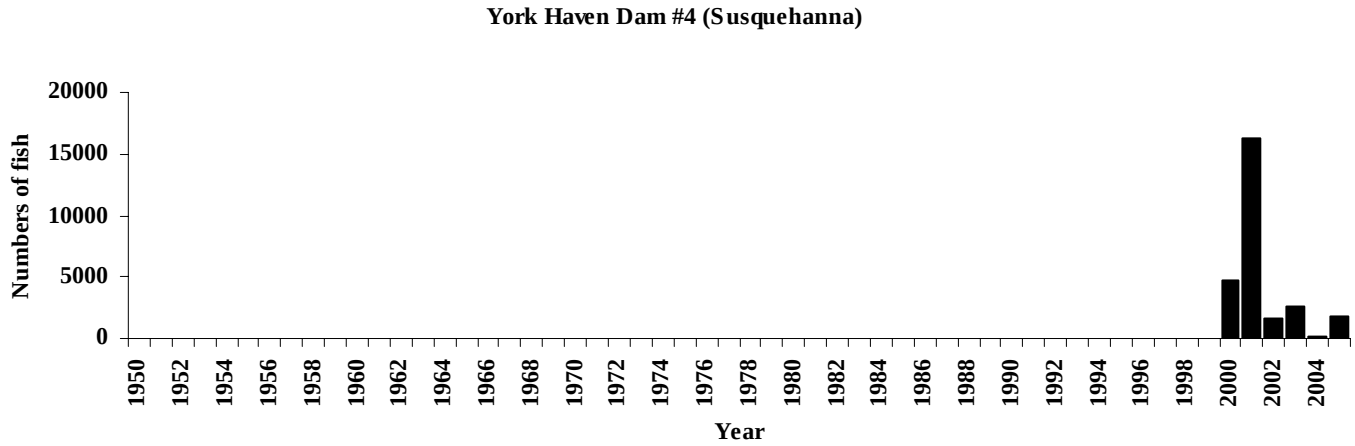
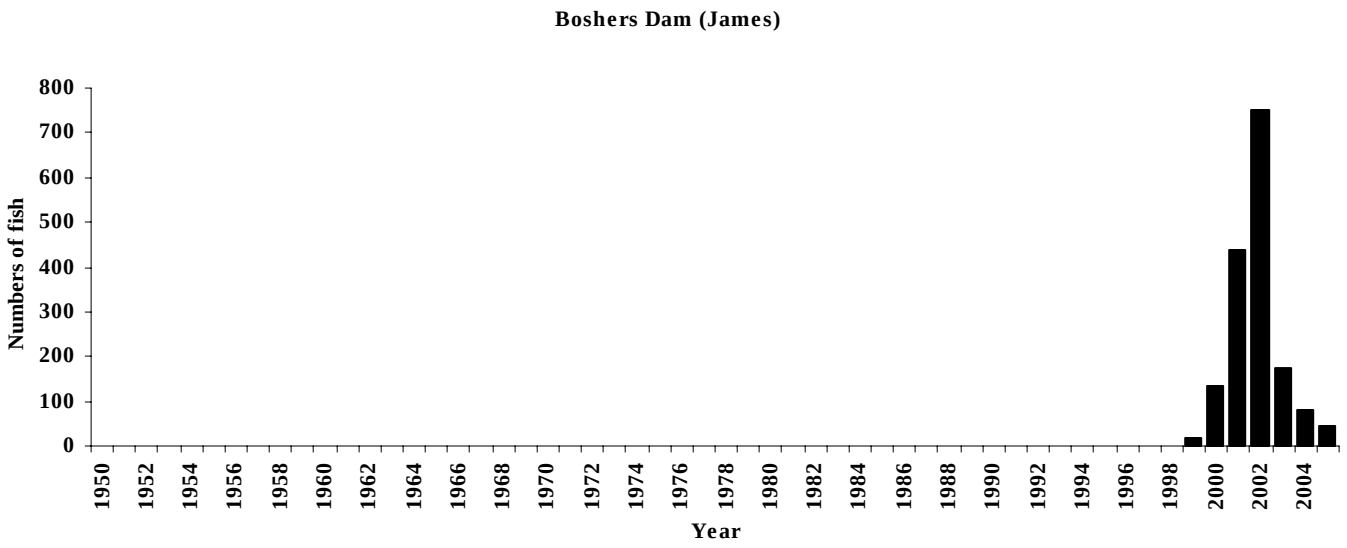


Figure 1.2.2 (cont.) Coastwide plots of fish-lift and fishway annual counts of American shad on rivers along the U.S. Atlantic coast from the Saco River, Maine to the Santee River, South Carolina. All count data are plotted on the same x-axis to ease temporal comparisons, but note that y-axis scales differ.



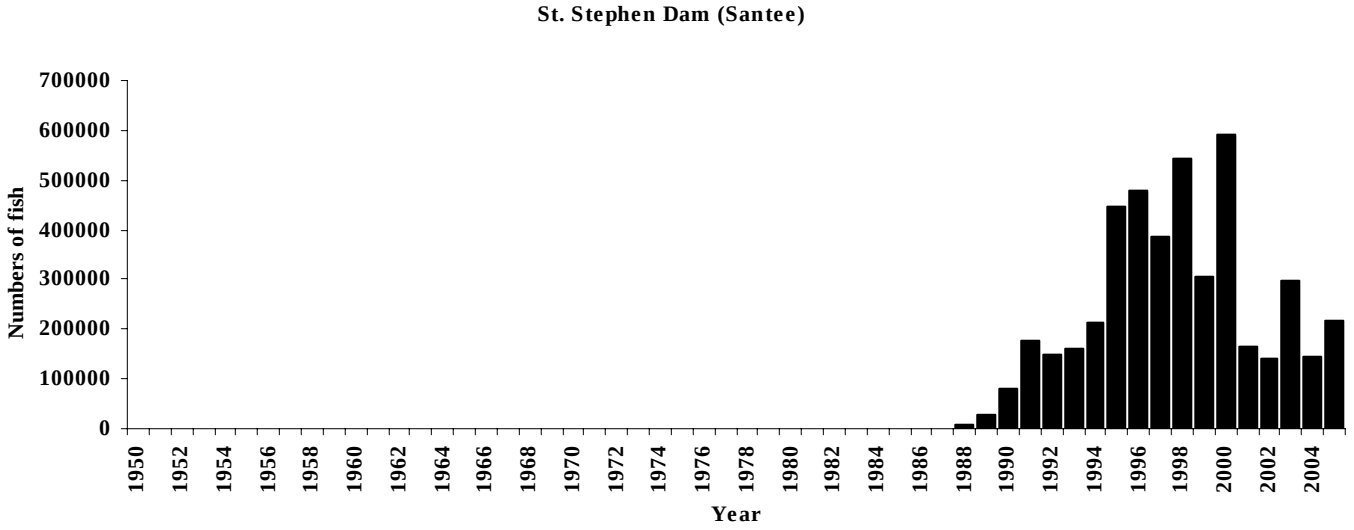


Figure 1.2.3. Plots of scale based estimates of total mortality for American shad stocks by river system on the U.S. Atlantic coast from the Saco River, Maine to the Cape Fear River, North Carolina. Z_{30} estimates are plotted for systems compared to the benchmark. FI = fishery-independent, FD = fishery-dependent.

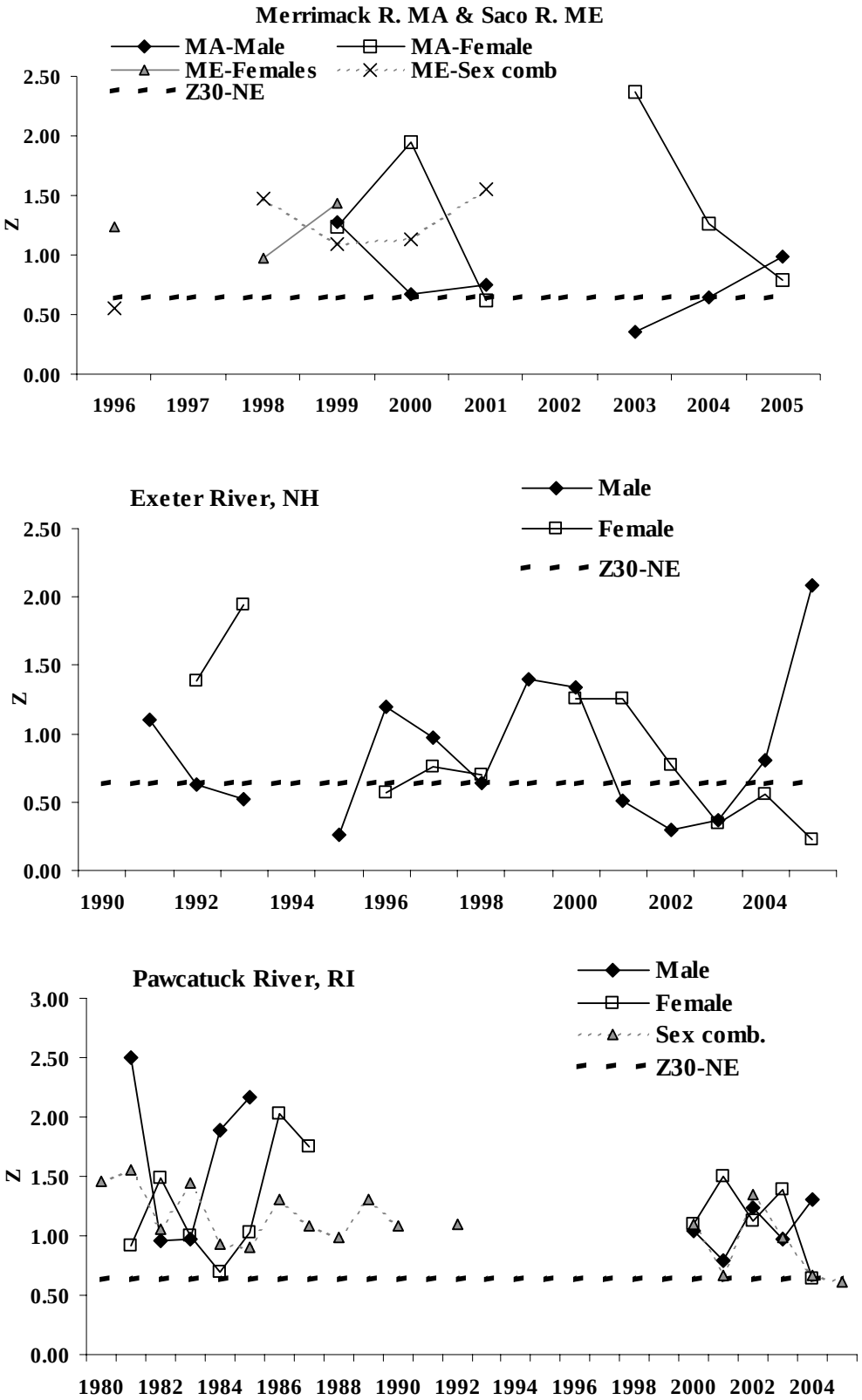
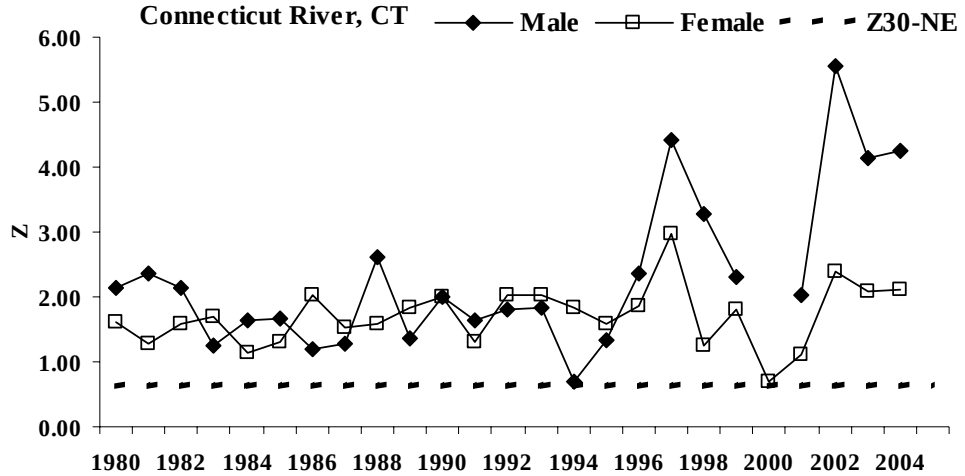
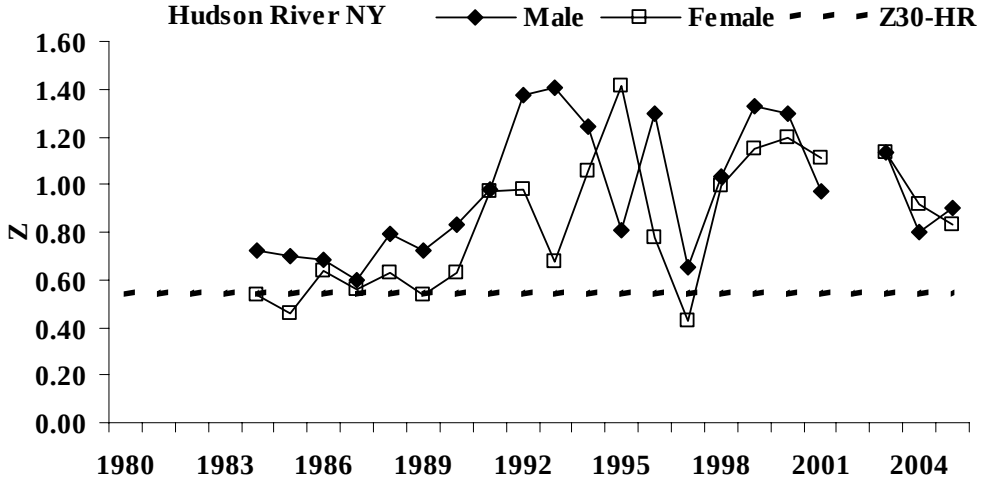


Figure 1.2.3 (cont.) Plots of scale based estimates of total mortality for American shad stocks by river system on the U.S. Atlantic coast from the Saco River, Maine to the Cape Fear River, North Carolina. Z_{30} estimates are plotted for systems compared to the benchmark. FI = fishery-independent, FD = fishery-dependent.





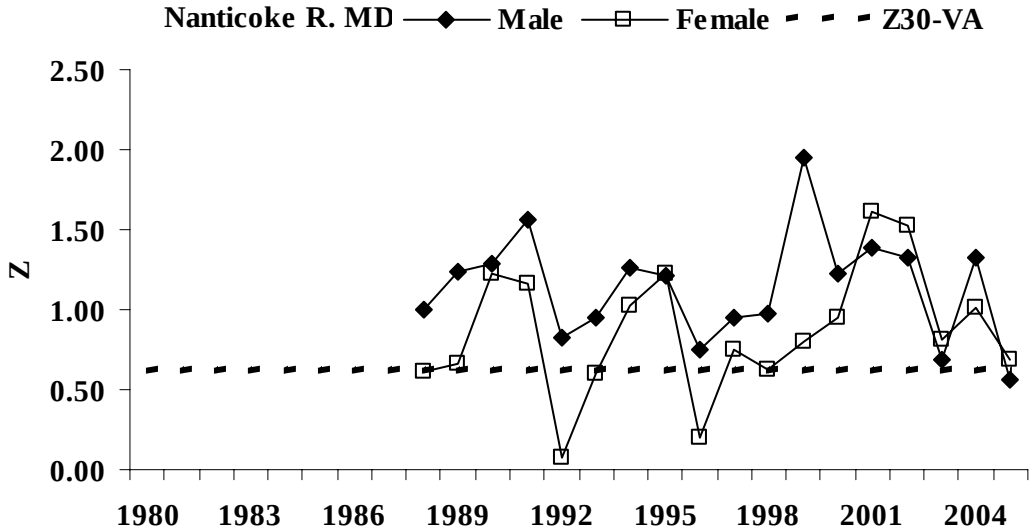
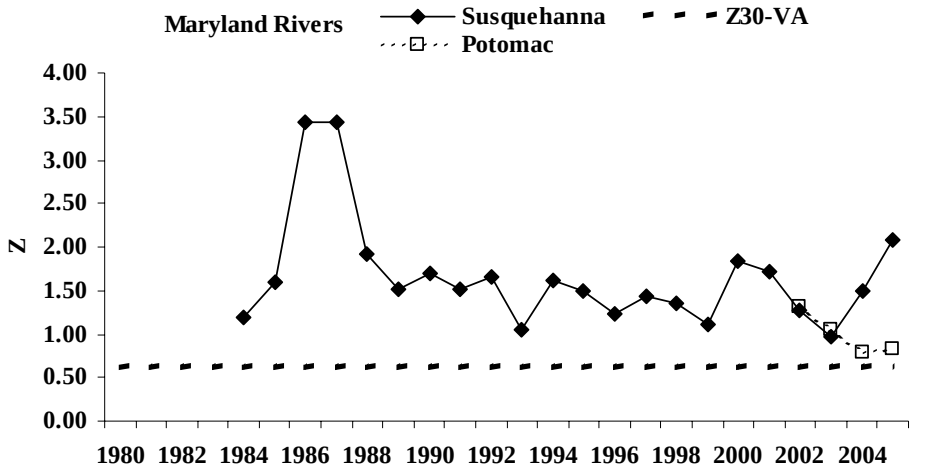
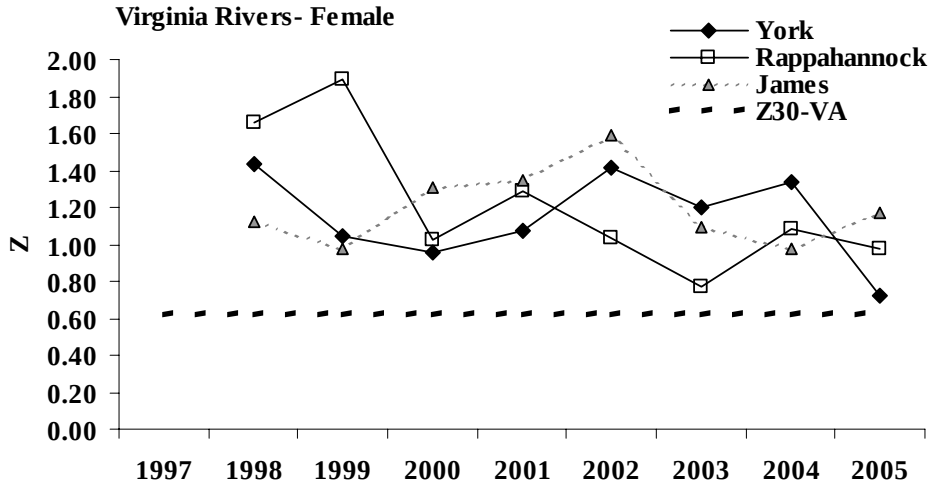


Figure 1.2.3 (cont.) Plots of scale based estimates of total mortality for American shad stocks by river system on the U.S. Atlantic coast from the Saco River, Maine to the Cape Fear River, North Carolina. Z_{30} estimates are plotted for systems compared to the benchmark. FI = fishery-independent, FD = fishery-dependent.





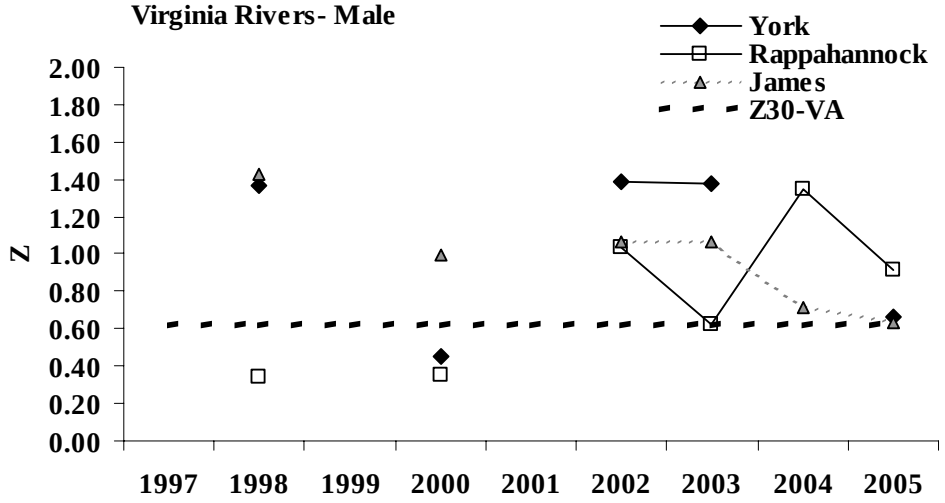


Figure 1.2.3 (cont.) Plots of scale based estimates of total mortality for American shad stocks by river system on the U.S. Atlantic coast from the Saco River, Maine to the Cape Fear River, North Carolina. Z_{30} estimates are plotted for systems compared to the benchmark. FI = fishery-independent, FD = fishery-dependent.

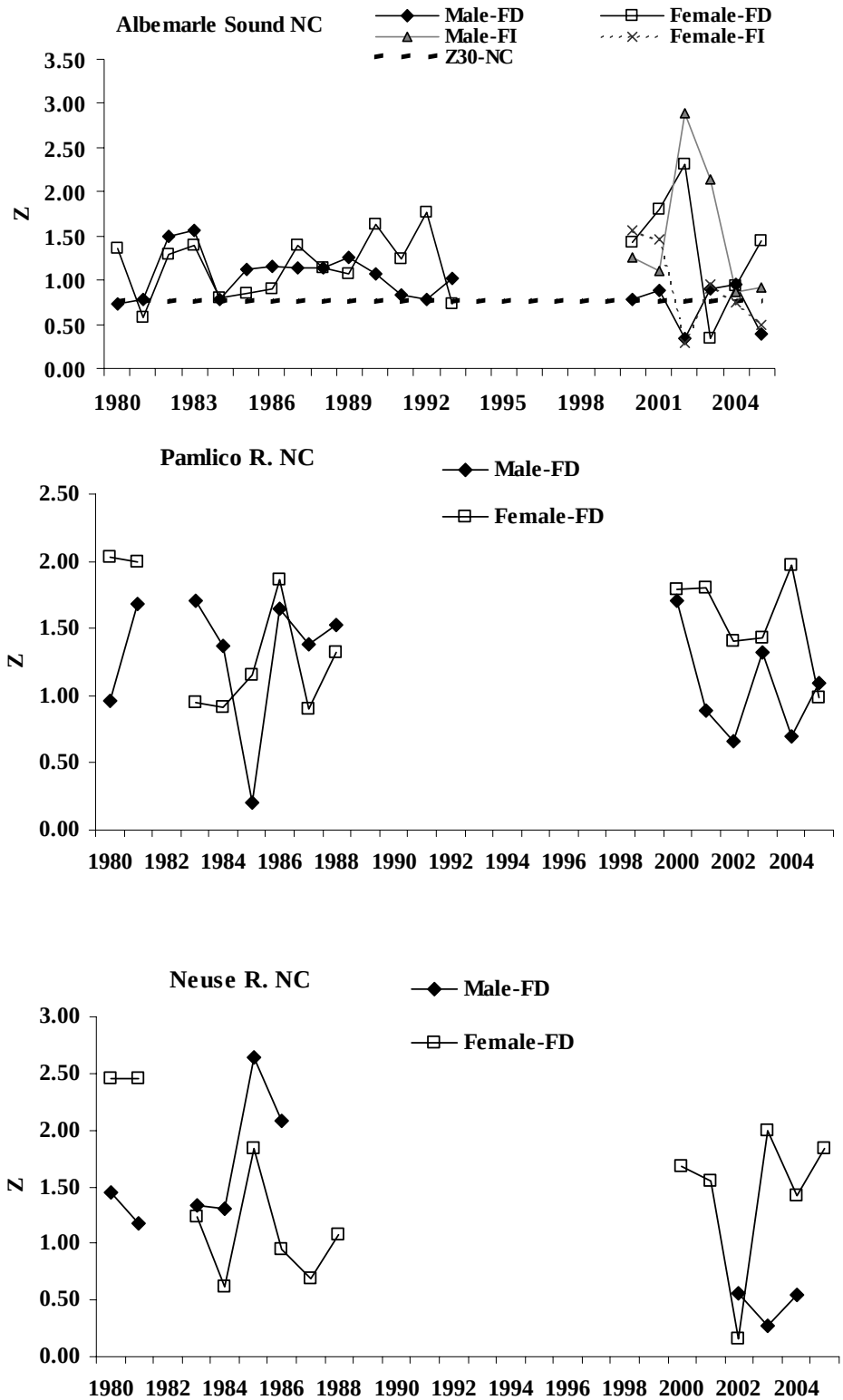


Figure 1.2.3 (cont.) Plots of scale based estimates of total mortality for American shad stocks by river system on the U.S. Atlantic coast from the Saco River, Maine to the Cape Fear River, North Carolina. Z_{30} estimates are plotted for systems compared to the benchmark. FI = fishery-independent, FD = fishery-dependent.

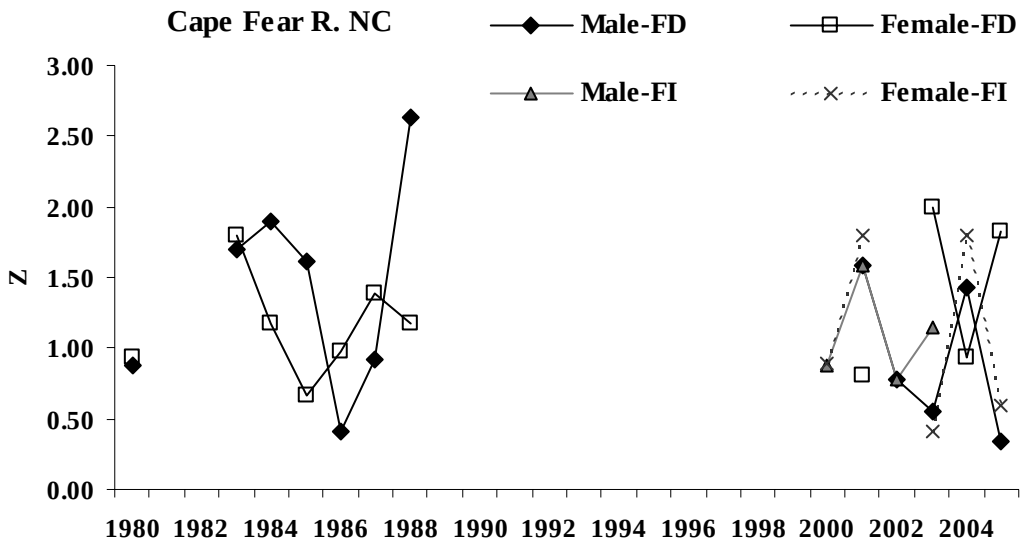


Figure 1.2.4. Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.

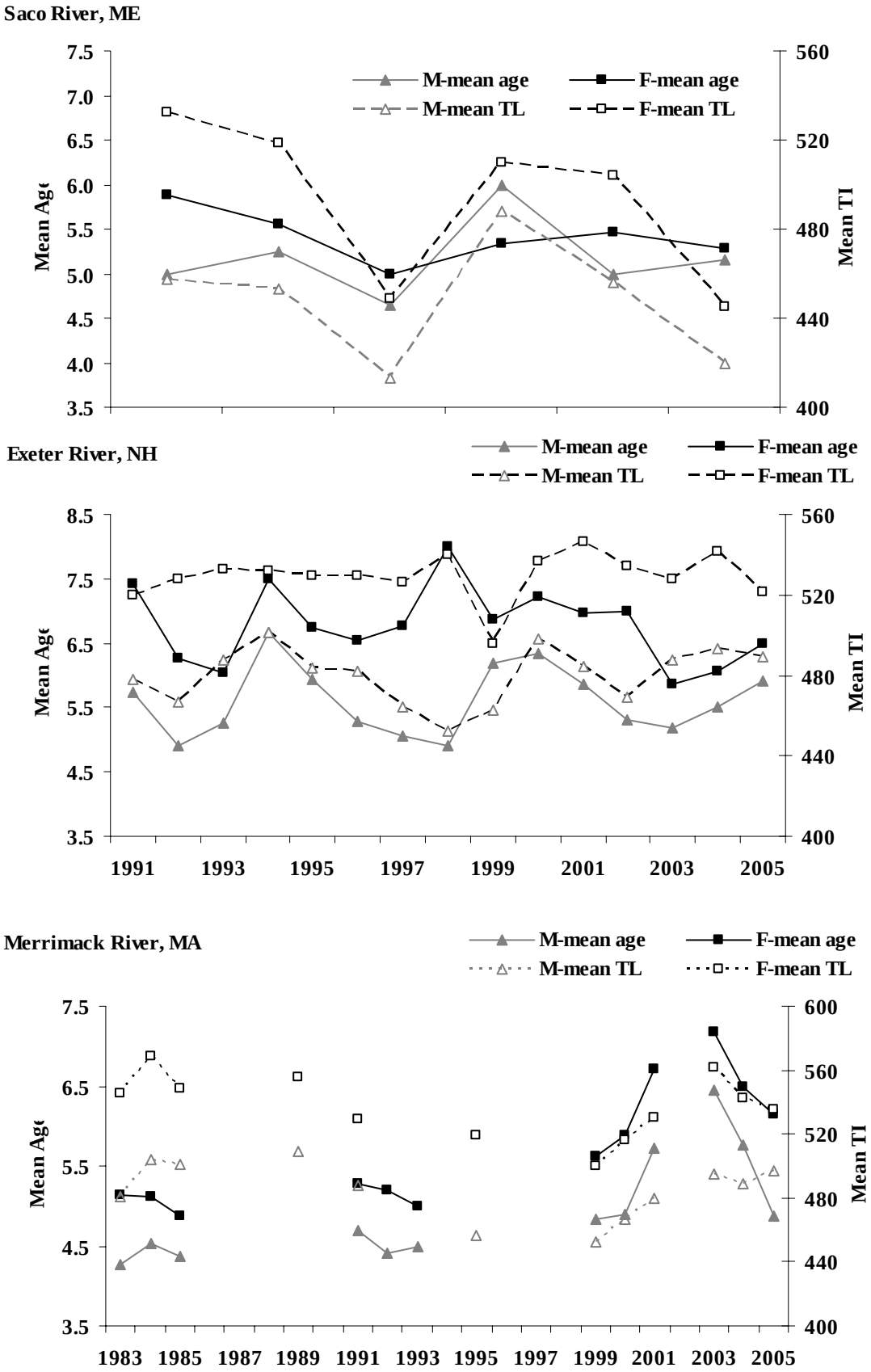
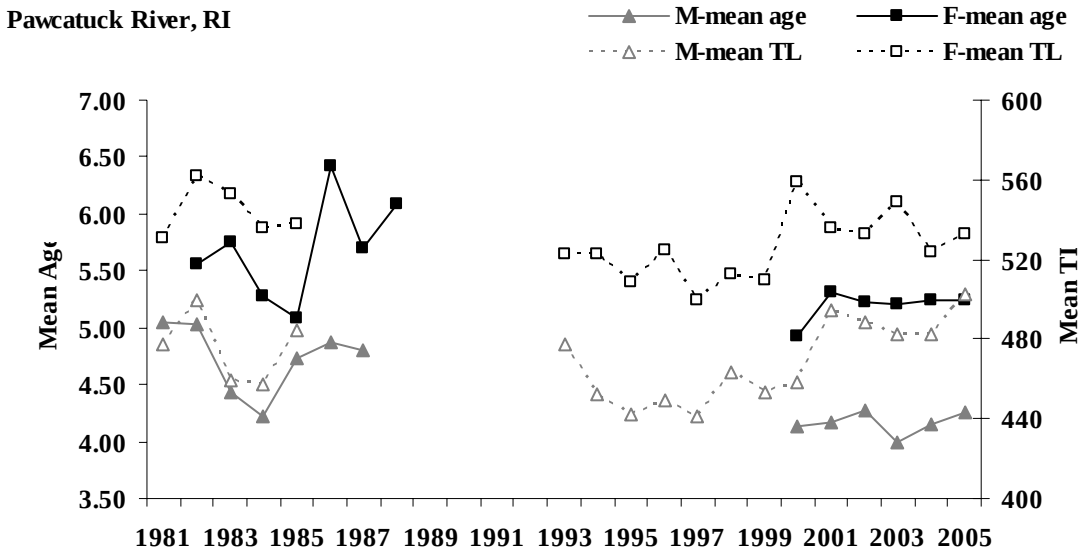


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.



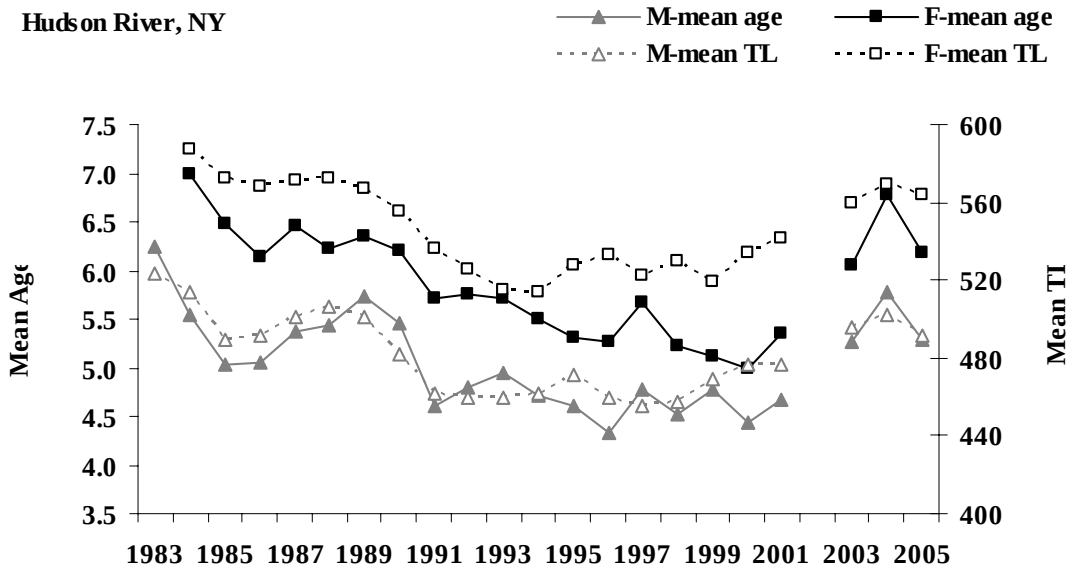
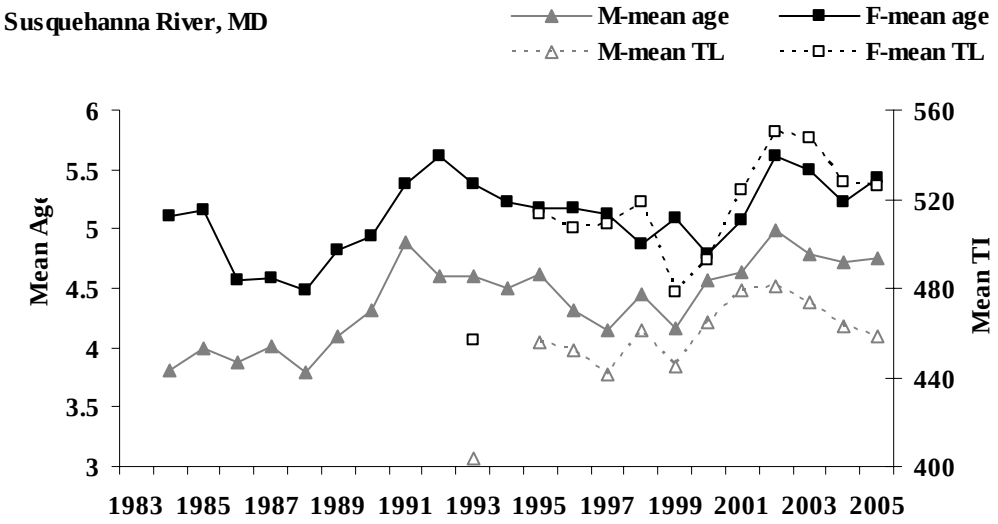


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.



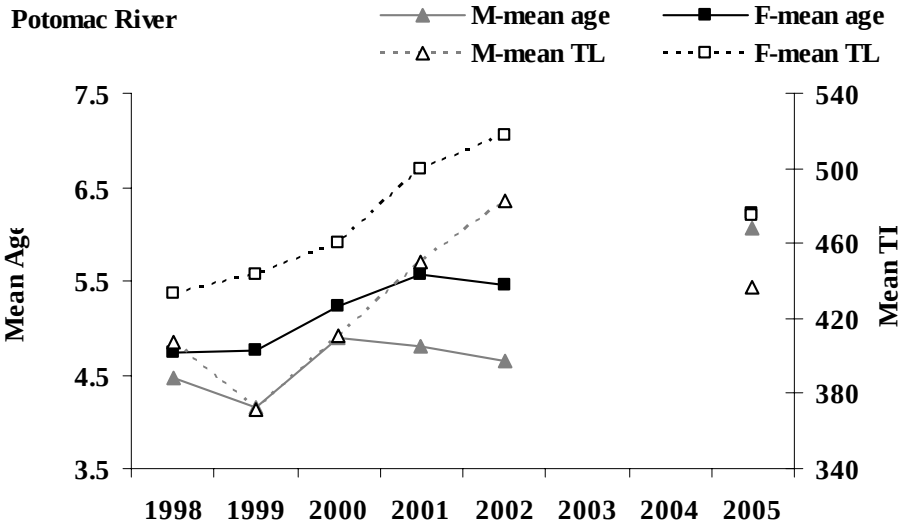
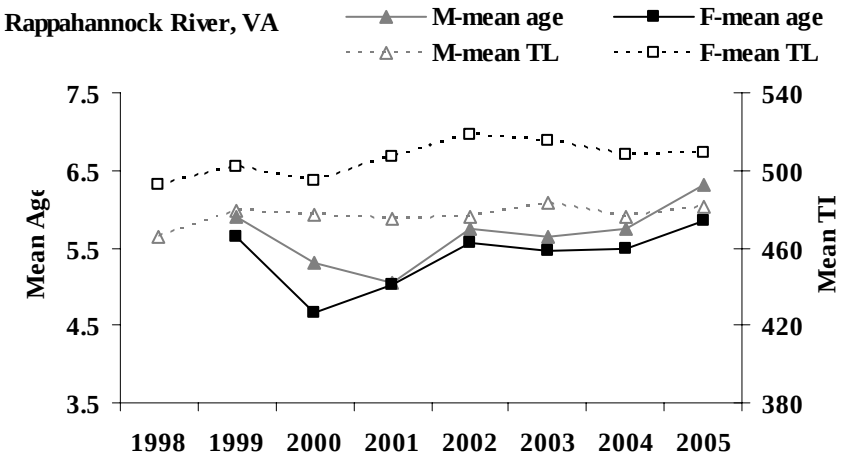
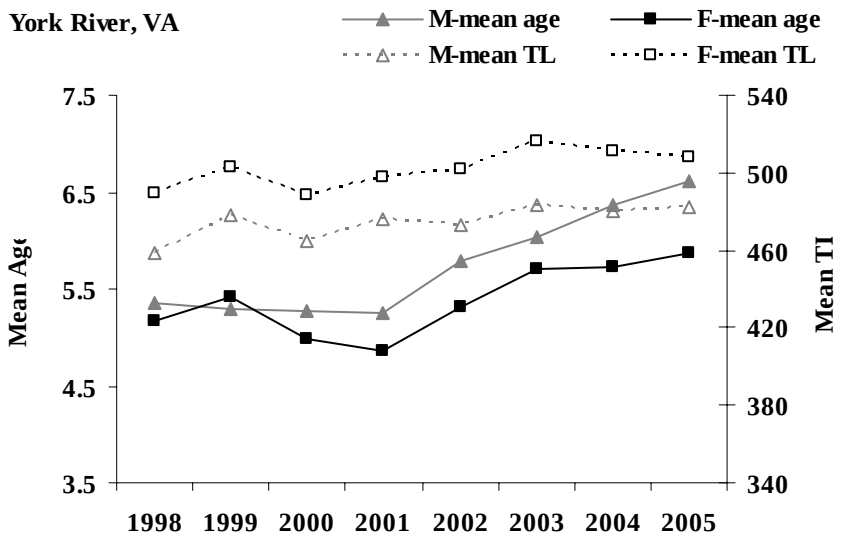


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.





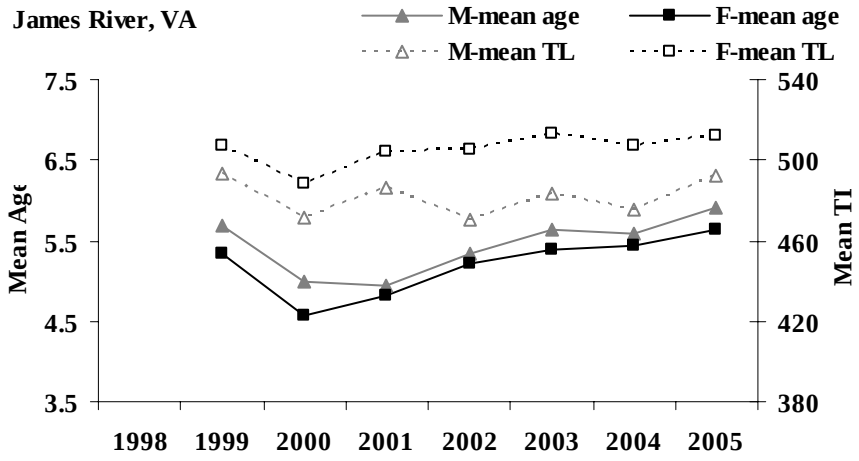
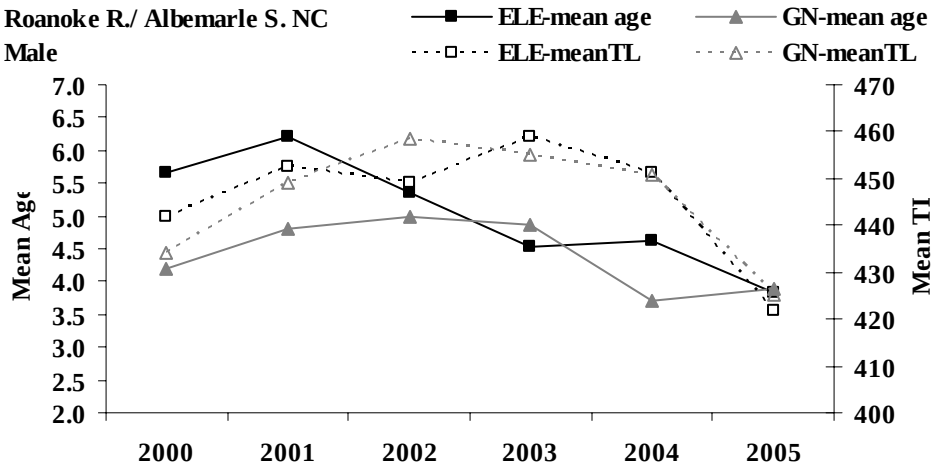
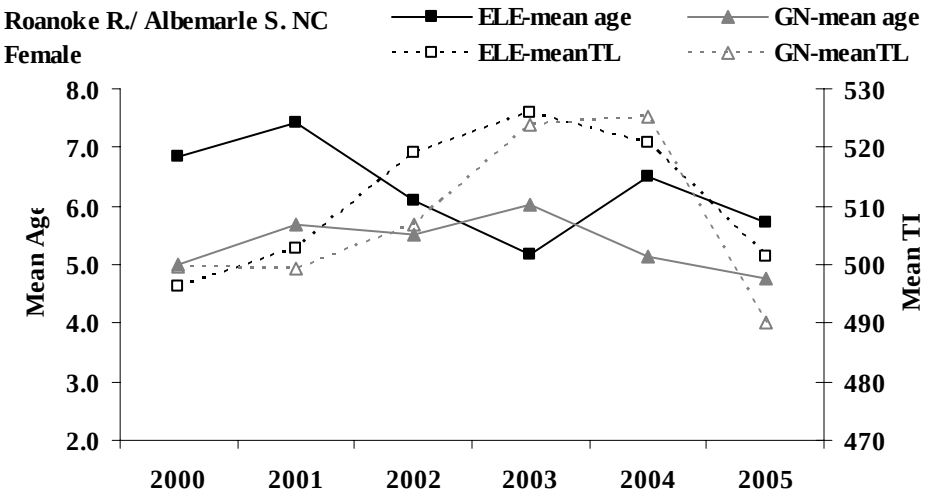


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.





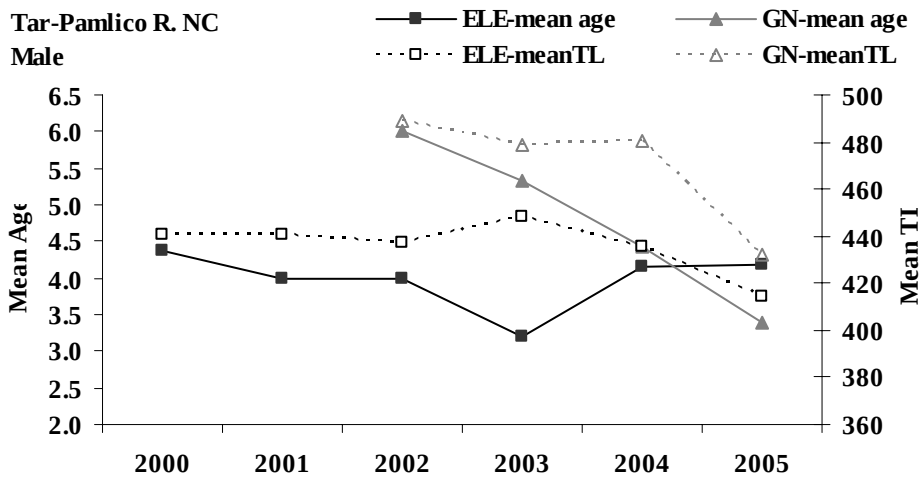


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.

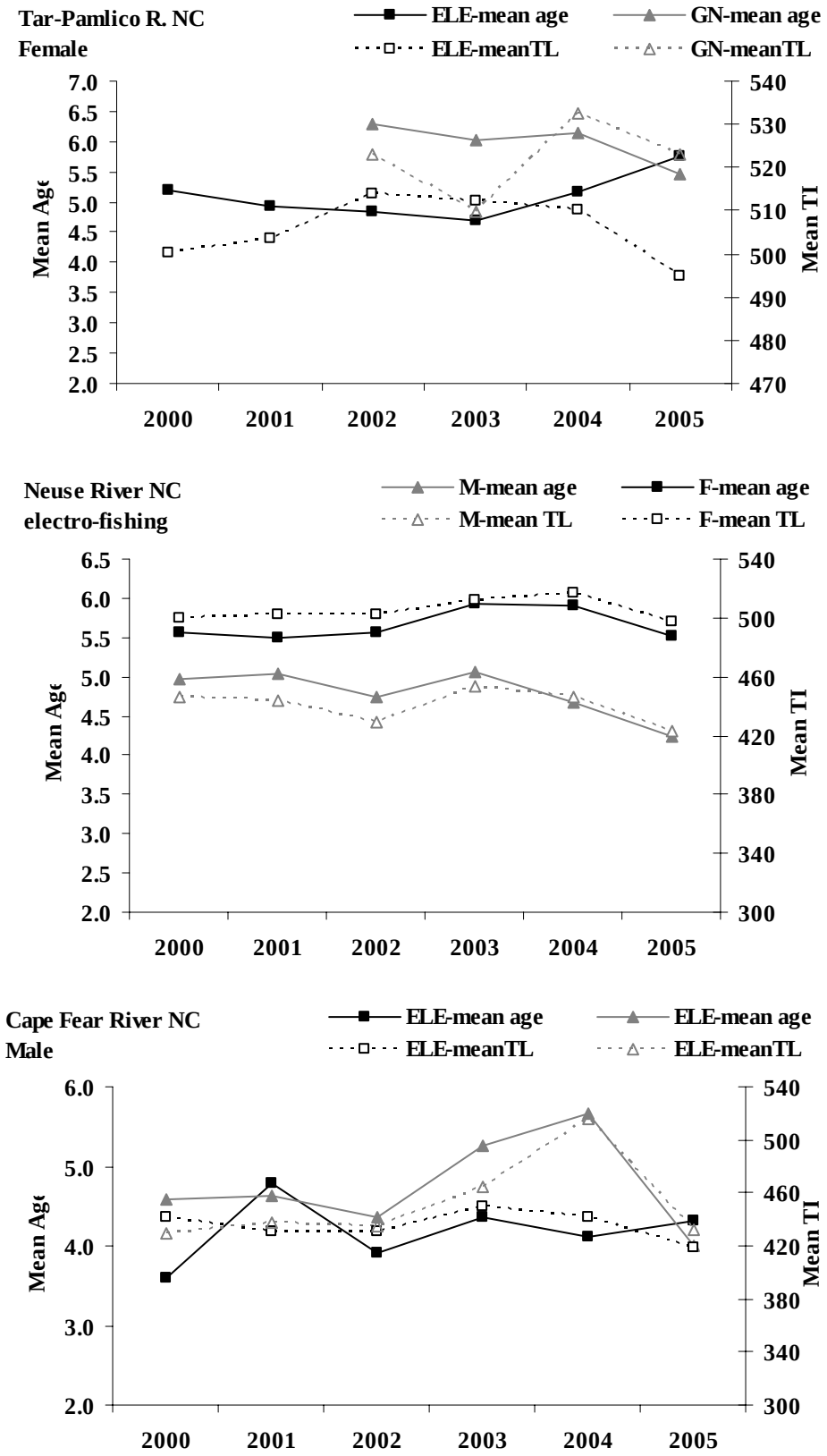
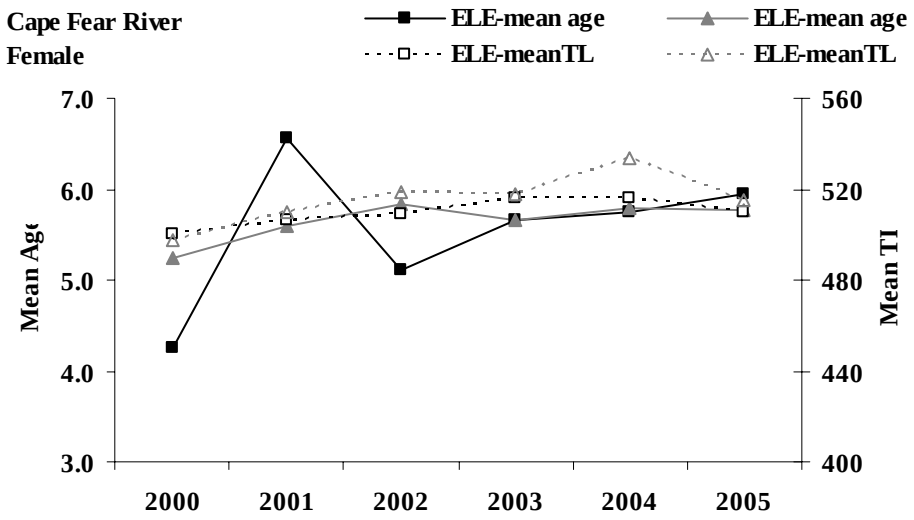
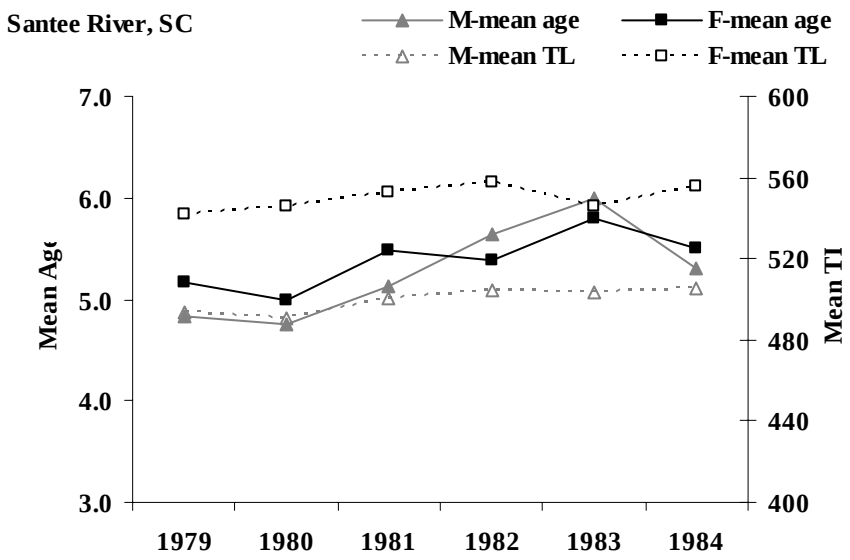


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.





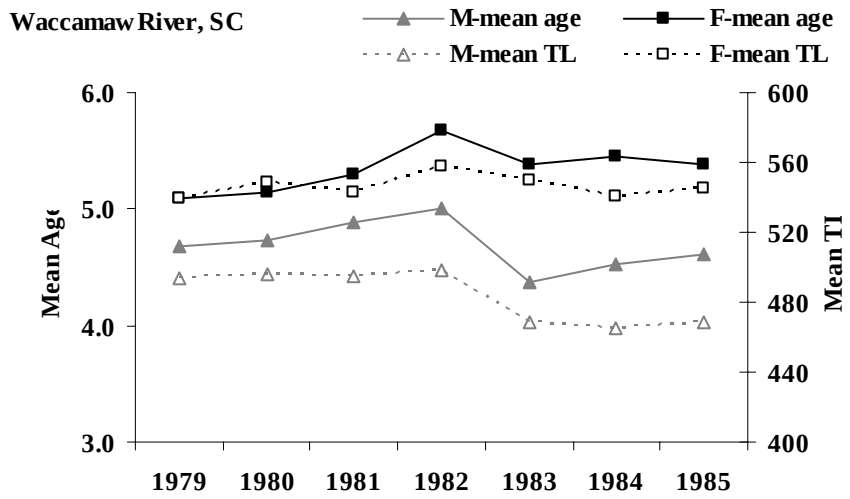
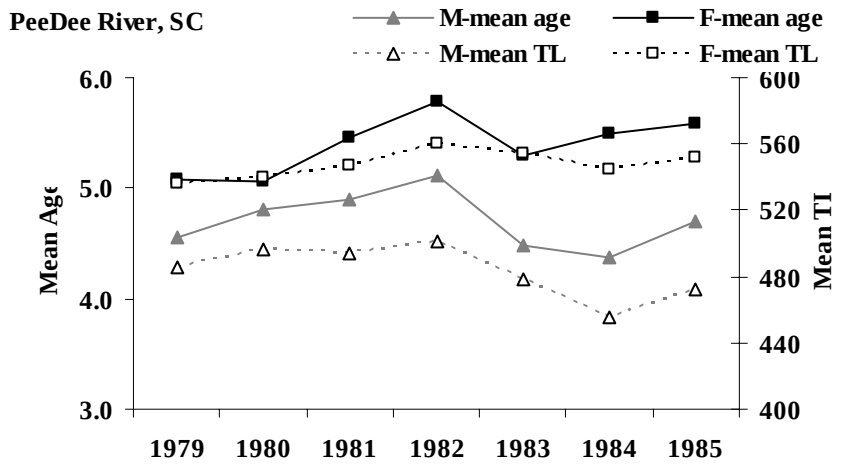
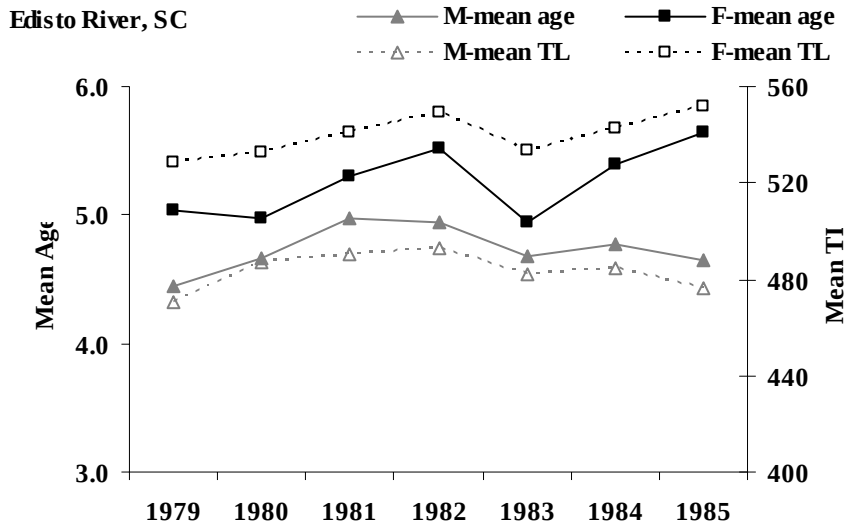


Figure 1.2.4 (cont.) Plots of mean length versus mean age by river system from the Saco River, Maine to the Altamaha River, Georgia.





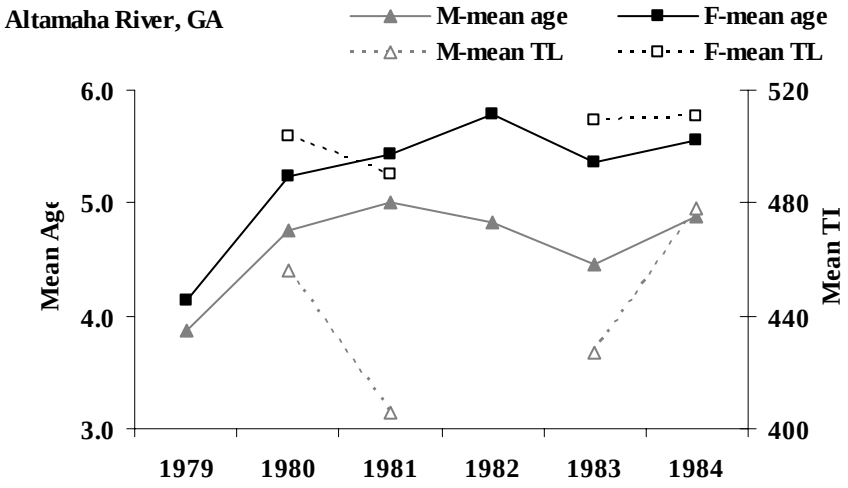
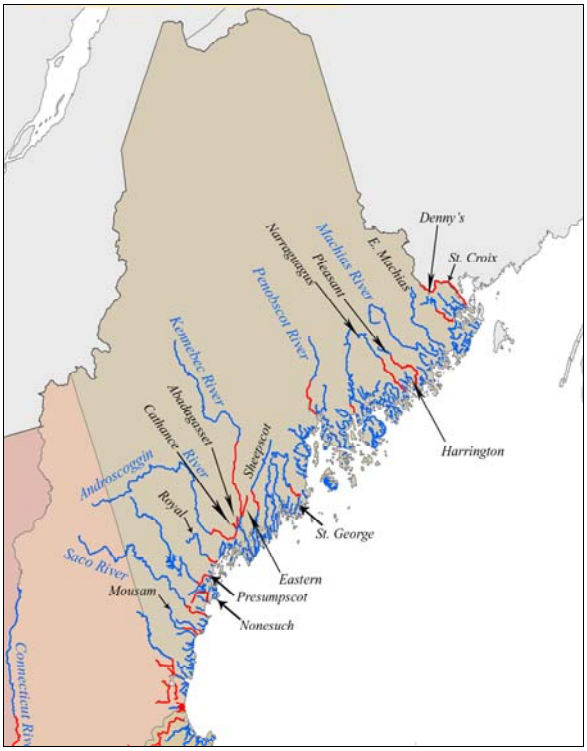


Figure1.3-1. Shad rivers assessed along the Atlantic coast.

Figure 1.3-2 Shad rivers assessed in the northeast region.

Status of American Shad Stocks in Maine



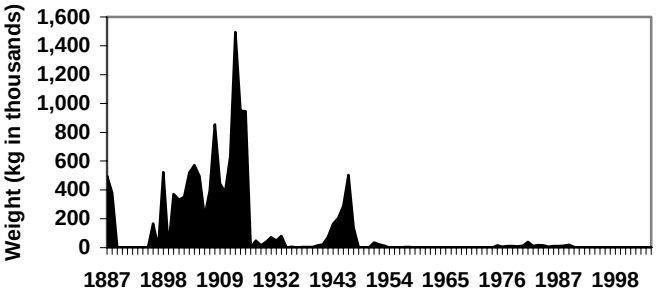
Distribution, Biology and Management

Over 20 coastal rivers in Maine once supported runs of American shad. Since colonial times, overfishing and habitat loss from dam construction and pollution contributed to the disappearance and dramatic declines of shad stocks throughout the state. Current management and monitoring of shad stocks occur in the Saco, Androscoggin, and Kennebec rivers. These and several other spawning rivers are tributaries of the Merrymeeting Bay estuary. Juveniles from all tributaries use the Bay as a nursery area.

Adult American shad enter Maine Rivers from mid-May to the end of June. Peak spawning can occurs during June or as late as July or August. Tagging studies of mature fish indicate that post spawning shad from Maine move as far north as New Brunswick in the summer and south to North Carolina in winter. The stock is iteroparous with the oldest observed fish at age 11. Recent ages ranged from two to nine, but most adult fish are four through seven years old.

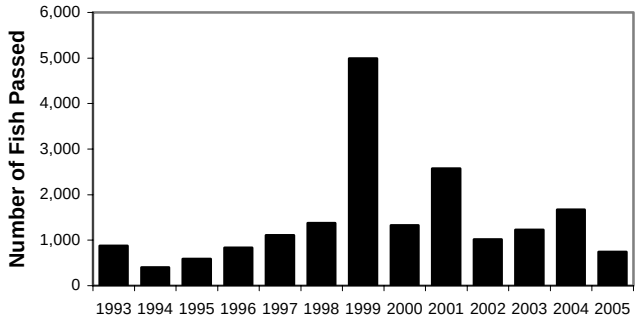
There are seven dams on the Saco River that block migration starting at head-of-tide. The first four dams have upstream passage, but passage at the third dam (1 km above head-of-tide) does not pass shad well. There are currently no downstream fish passage facilities on the Saco River. Three dams on the main stem Androscoggin River block passage starting 10 km above head-of-tide. Spawning is suspected below the lowermost dam. There is ineffective upstream fish passage at the first dam and upstream and downstream passage at the next two dams. The lowermost dam on the Kennebec River was located at head-of-tide; it was removed in 1999, opening 70 km of river, up to the next impassible dam, which does not have fish passage.

The restoration goal is to restore access of shad to historic spawning reaches in the main stem and major tributaries of each system. Restoration targets exceed 200,000 adult for the Saco and Androscoggin Rivers and 725,000 adults for the Kennebec River. Restoration activities include stocking larvae in the Saco River and larvae and pre-spawn adults to the Androscoggin and Kennebec rivers. Stocked larvae have OTC marks. Between two and ten percent of juveniles collected in Merrymeeting Bay had marks (2003-2005); two to 17 percent had marks in the Kennebec (2001-2005).



The Fishery

Shad were historically harvested from all the major rivers along the coast of Maine. Statewide landings peaked at 1.5 million kg in 1912, dropped to mean of 51,400 kg in 1928-1933, and became commercially extinct through 1940. Landings increased to a high of 502,044 kg in 1945 and remained at a relatively low level from 1948 through 1976. From 1978



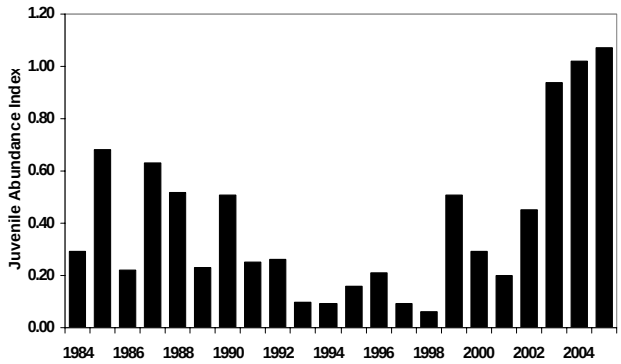
to 1990, landings averaged 14,369 kg. Since the directed fishery closed in 1995, annual landings have been less than 200 kg. A limited recreational fishery occurs in the Saco and several small coastal rivers.

Indices

Adult passage at the lowermost dam on the Saco River peaked in 1998 and has since gradually declined. Passage has remained well below the restoration target.

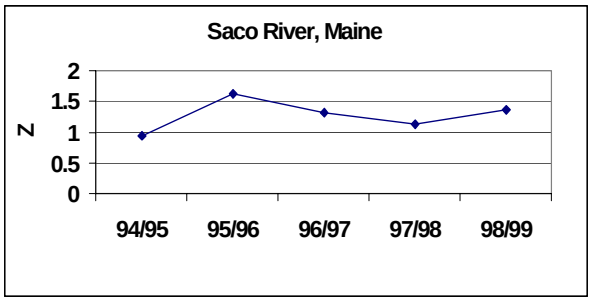
Relative abundance of juvenile American shad from Merrymeeting Bay was relatively high in the 1980s, low during the 1990s and has generally increased since 2000.

Juvenile abundance was positively related to the number of larvae stocked in Merrymeeting Bay tributaries. The increase in juvenile abundance followed the removal of the first dam on the Kennebec River (1999) and coincided with an increase in larval stocking.



Assessment Results

Catch curve estimates of Z for the Saco River population (sexes combined) ranged from 0.94 to 1.63.



Benchmarks

The Z_{30} for New England was Z=0.64. Estimates for the Saco River exceeded this value.

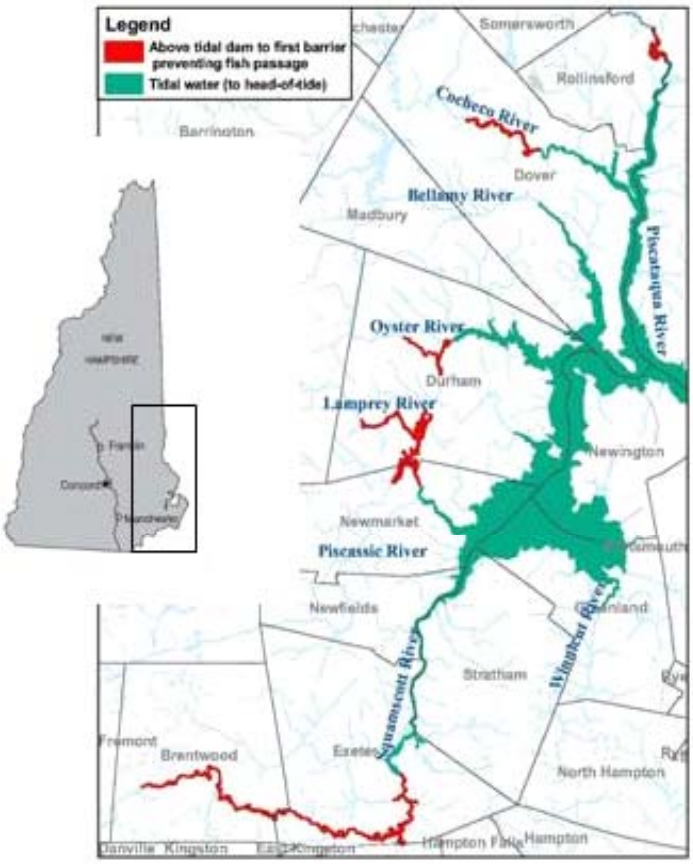
Summary

Abundance of managed stocks of American shad in Maine is well below their historic potential and current restoration goals. Stocks in the Saco and Androscoggin rivers have been denied access to most of the historic spawning reaches for over 100 years. Limited upstream and almost no downstream passage occurs past existing barriers on both rivers. Access to 70 km of spawning habitat was made available for shad of the Kennebec in 1999 with the removal of the first barrier. Stocks are maintained by supplemental stocking of larvae, limited passage on the Saco, and limited spawning below the first dam on the Androscoggin. High estimates of total mortality on the Saco stock are a concern because directed harvest has been banned. The Kennebec stock may increase now that access to some spawning habitat has been restored, but it will not reach full potential until access to the entire spawning reach has been provided. Stocks of the Saco and Androscoggin rivers are not likely to improve until effective upstream and downstream passage have been developed at all barriers within the spawning reaches.

Summary Table

River	Source Data	Year Range	Trend
Saco	Adult trap at fishway	1993-2005	General decrease since 1999
	Total mortality	1993-2005	Stable above Z_{30}
Kennebec	Juvenile abundance index	1984-2005	General increase since 1998

Status of American Shad Stocks in New Hampshire



Distribution, Biology and Management

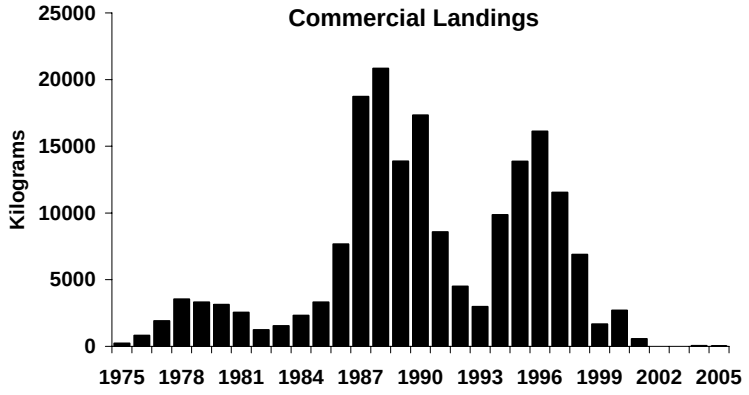
New Hampshire's coastal rivers once supported abundant runs of anadromous fish including American shad, river herring, and Atlantic salmon. All diadromous species have been denied access to historical, freshwater, spawning habitat since the construction of milldams as early as the 1600s but more dramatically during the nineteenth century textile boom. Restoration began with construction of fishways in the late 1960s and early 1970s in the Cocheco, Exeter, Oyster, Lamprey, Winnicut rivers in the Great Bay estuary, and the Taylor River in the Hampton-Seabrook estuary. A downstream passage facility is present on the Cocheco; on all others downstream passage is over the spillway.

Shad are iteroparous and are mature at age five or six for females and four through six for males. The oldest observed fish was age ten; the highest number of repeat spawn marks was four.

Restoration efforts include the movement of fish over barriers and supplemental stocking of adults in the Exeter.

The Fishery

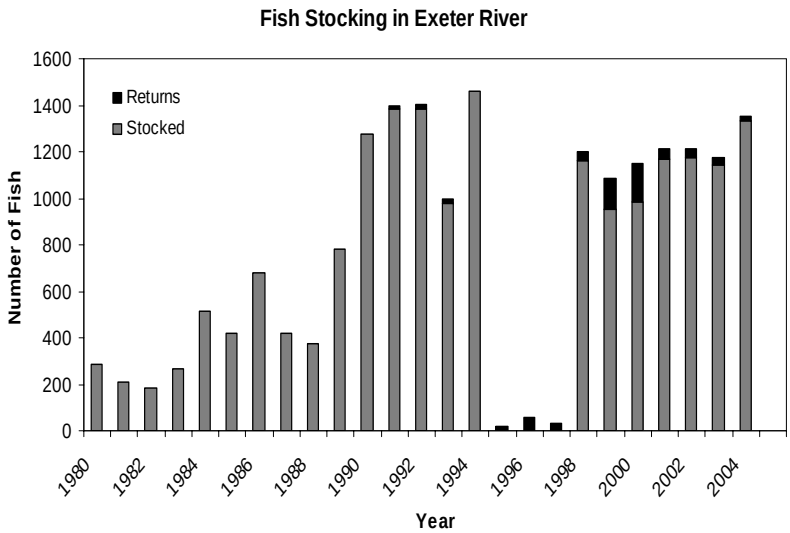
Shad were not reported for New Hampshire waters back to the turn of the 20th century. Recorded commercial harvest available since 1975 are fish of mixed stock origin and are landed from ocean waters outside of state waters in the Exclusive Economic Zone (EEZ) and caught with gill nets or trawls. Peak landings occurred in 1988 and again in 1996. Current landings are minimal. In inland waters recreational catch-and-release fishing is permitted; a two fish take is allowed.

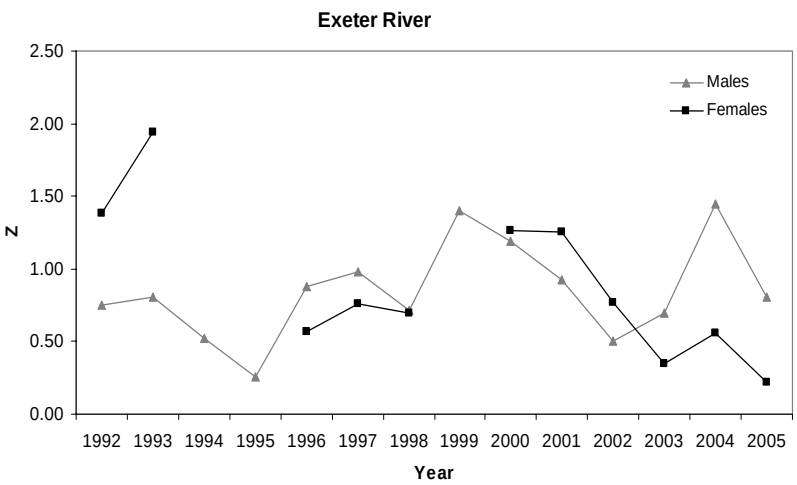


Indices

Recent restoration efforts focus on the Exeter River. Adult return data are poor. A small residual run of shad persists in the Lamprey and Cocheco rivers, although no stocking has occurred in these rivers since 1988. The low number of returns may be

due to difficulties associated with upriver or downriver passage over the dam, increased mortality from other sources, or both. Passage data were not used as abundance indices as many passage changes occurred throughout the times series.





Assessment Results

Total mortality estimates calculated from adult age structure in the Exeter River have varied without trend over the time series.

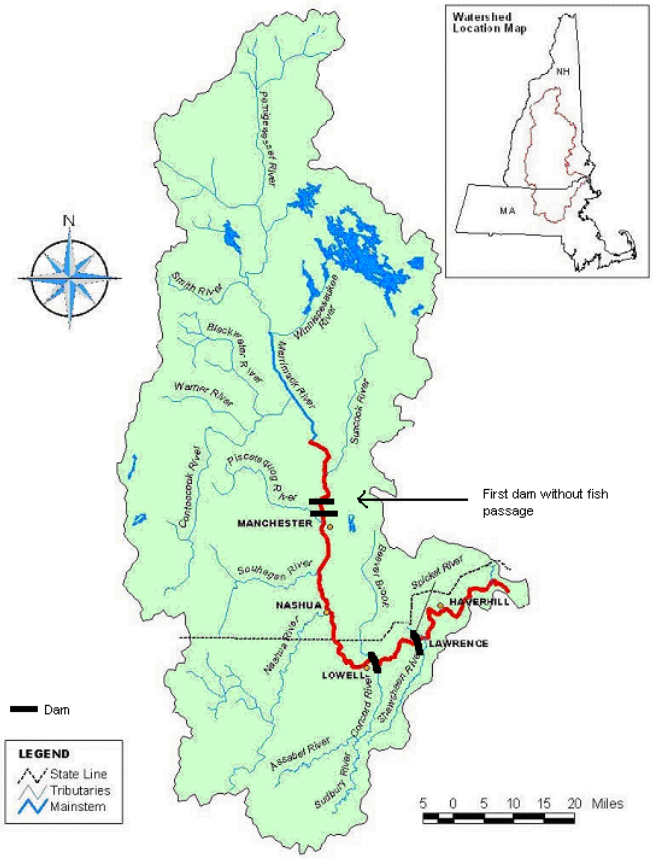
Benchmarks

Sample sizes are too low to make conclusions on total mortality rates relative to a benchmark of Z_{30}=0.64.

Summary

New Hampshire's rivers are under restoration. Returns to the Exeter are extremely small relative to the number stocked five to six years earlier. As restoration activities continue (stocking spawning adults or larvae), efforts should be made to obtain effective upstream and downstream passage at all barriers, and improve water quality. Efforts should also be made to identify and reduce all sources of mortality whether during ocean residency or in-river.

Status of American Shad Stocks in the Merrimack River



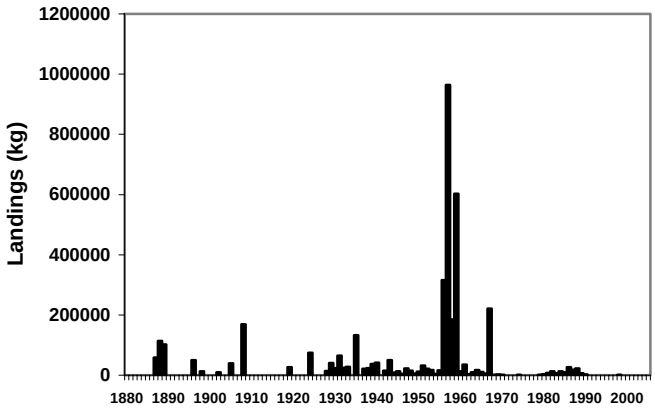
Distribution, Biology and Management

American shad were formerly an important anadromous fish in Massachusetts. Shad were historically abundant in the larger rivers of the Commonwealth including the Connecticut, Merrimack, Neponset, and Charles Rivers, and also in a few smaller rivers including the Palmer and Indianhead. Early historical records indicate fisheries were highly valued as the Commonwealth enacted legislation to protect anadromous runs. Over the last century, however, most runs were extirpated or reduced to extremely small populations due to construction of dams, water pollution at the spawning grounds, and overfishing.

The major coastal run in Massachusetts occurs in the Merrimack River. Shad used to move up the entire Merrimack up to km 185. Presently, the main stem Merrimack has five hydroelectric dams; fish passage is provided on the lower three dams. Recent upgrades at Essex (km 46, #1) and Pawtucket (km 65 #2) dams occurred within the past 25 years. Completion of a passage facility at the Essex Dam occurred in 1982. In 1986, a fish-lift and a modified Ice Harbor ladder were installed at the Pawtucket Dam. For the first time in nearly a century, adult shad were able to reach the Amoskeag Dam (km 120, #3) in New Hampshire. Through cooperative efforts of state and federal agencies, in 1989, a fish ladder was constructed at the Amoskeag Dam. This fishway allows shad access to the Hooksett Dam (km 135, #4). Resolution of problems associated with upstream and downstream passage problems is ongoing at each fishway.

Merrimack shad are iteroparous. Females mature at age five or six, and males at four through six. The oldest observed fish was age ten; the highest number of repeat spawn marks was five for females and six for males.

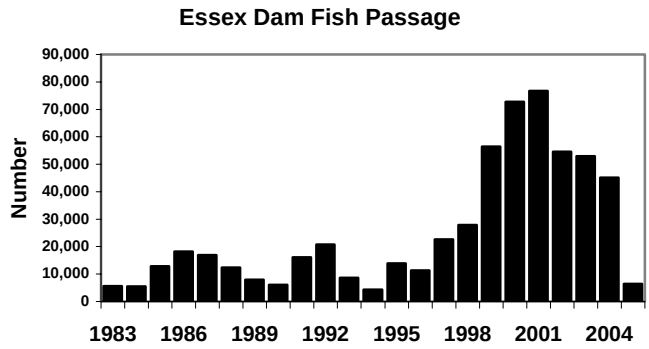
Massachusetts reinstituted a restoration program for the Charles River in 2005 stocking up to three million hatchery raised American shad larvae.

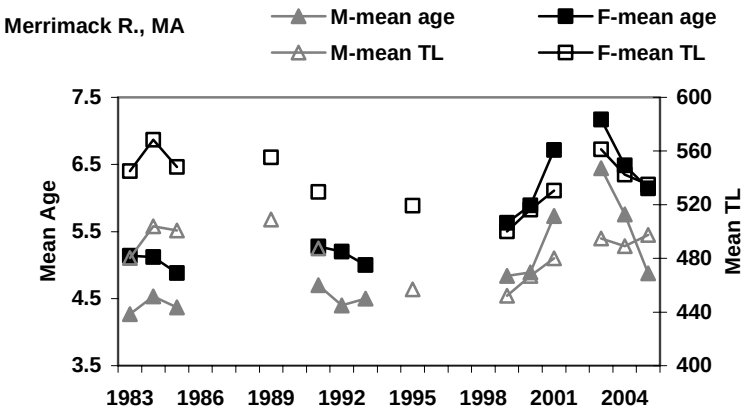


The Fishery

Historical records for commercial landings in Massachusetts begin in the late 1880s. Annual reporting began about 1928. Landing prior to 1945 may be from inland or ocean waters.

Since 1950, all landings were from ocean waters. Total kilograms of fish varied between several thousand kilograms to nearly 133,000 kg. The highest catch of 957,000 kg occurred in 1957, landed by purse seine. This fishery was short lived as the gill net and pound net became the primary gear. After 1967, catches became more sporadic; one exception was a period of increased landings from 1981 to 1989. Since 1987, a moratorium has been in place on commercial shad harvest in all waters of the Commonwealth of Massachusetts.



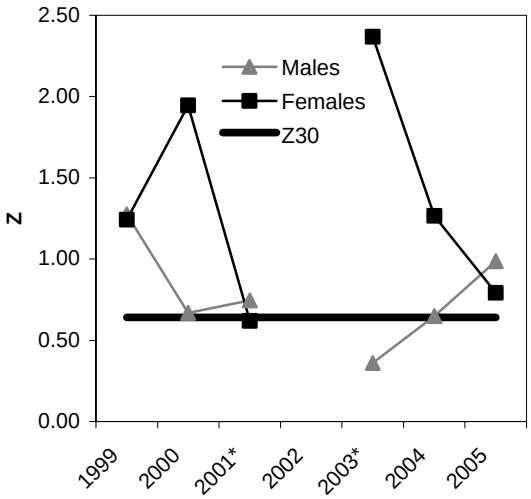


Current landings are minimal and most likely from fisheries in the EEZ. In state waters, a recreational catch of six fish per day by hook and line only is permitted. Most shad fisheries are believed to be predominantly catch-and-release efforts.

Indices

Annual fish passage counts at the first dam at Essex are not indicative of the size of the Merrimack shad population. The number of shad counted at the Essex Dam fish lift varies annually and may be related to environmental conditions, fish passage effectiveness, and the size of the population entering the river and reaching Essex Dam. Adult shad are known to spawn in the river downstream from the Essex Dam. As an example, in 2005 a significant high water event resulted in a closure of the lift for most of the spring season, severely impacting passage.

Samples of mean age and mean total length were obtained infrequently before 1999. Since 1999, a brief spike in larger older fish occurred in 2003.



Assessment Results

Total mortality estimates are only available since 1999 and have been quite variable.

Benchmarks

Sample sizes were adequate in most years. Estimates of total mortality are at or exceed the benchmark of Z_{30}=0.64. Such high estimates of mortality are of concern in a stock in recovery.

The Merrimack River Anadromous Fish Restoration Program developed an interim objective of an average of 35,000 adults. However, the overall target is to develop and maintain a self-sustaining

population of shad in their historical spawning habitat. The interim objective was met for some years (1999 to 2004), but the target is far from being achieved until all passage issues at all dams are resolved.

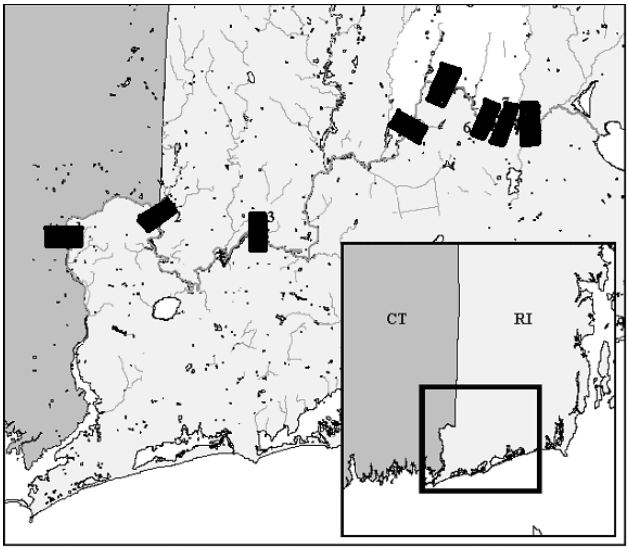
Summary

The Merrimack River shad stock is not recovered, but is subject to periodic restoration stocking events.

Recommendations include:

1. Addressing upstream and downstream fish passage problems at all dams.
2. Improving monitoring of the adult run below Essex dam to develop an index of adult abundance to evaluate passage efficiency.
3. Increasing sample size at the lift to better characterize the run.
4. Developing a juvenile abundance index for this system.
5. Increasing effort to identify and reduce all sources of mortality whether during ocean residency or in-river.

Status of American Shad in Rhode Island

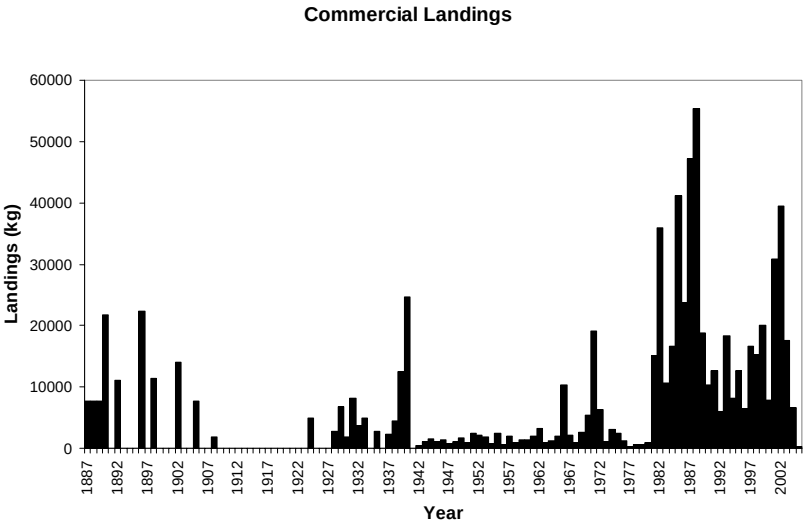


Distribution, Biology and Management

Fisheries in Rhode Island rivers garnered much attention in the post colonial era through the 1700s, but soon lost their importance as the growing textile industry used the river as a source of waterpower. Decreased water quality from factory discharges and increased municipal waste from the growing population accompanied the construction of dams. Anadromous fish runs either disappeared quickly or were heavily fished. A few remnant runs of American shad persist in the Runnins and the Pawcatuck Rivers.

The Pawcatuck River is the only remaining monitored run of American shad in Rhode Island. By 1896, upstream shad passage in the Pawcatuck River was completely blocked by dams (dams are indicated on map with black bars). Shad were extirpated from the Pawcatuck for nearly 100 years. The run was reestablished by stocking efforts that occurred from 1975 through 1985. Since 1986, the stock has relied on wild reproduction.

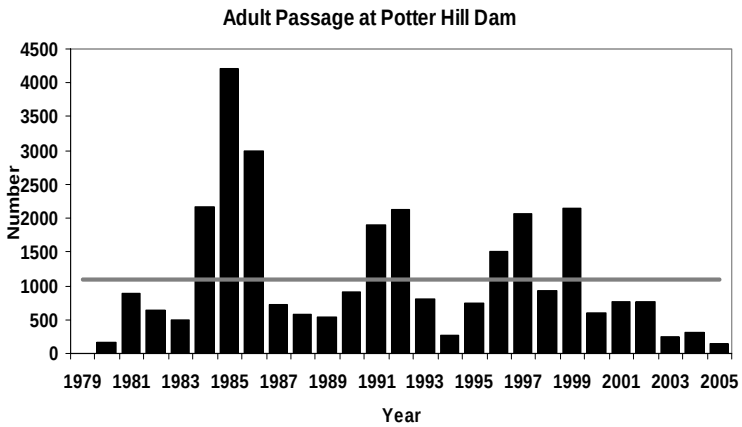
Rhode Island shad are iteroparous. Shad are fully mature at age-5 or 6 for females and 4 through 6 for males. The oldest observed fish was age-8. The occurrence of repeat spawning is very low, which may be due to difficulties associated with upriver or downriver passage over the dam, increased mortality from other sources, or both. Shad are limited to the lower 44 km of river; the first barrier at the Potter Hill Dam (km 22) has a fishway to provide access above the dam. Spawning occurs in the 22km above this dam and perhaps in a portion of the river below.

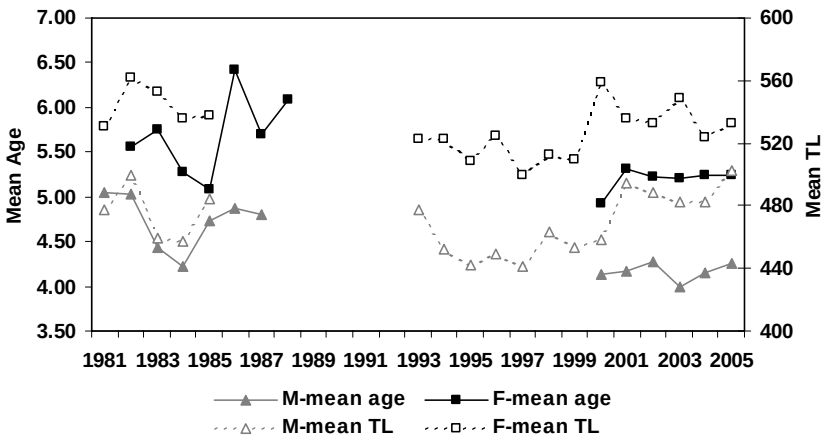


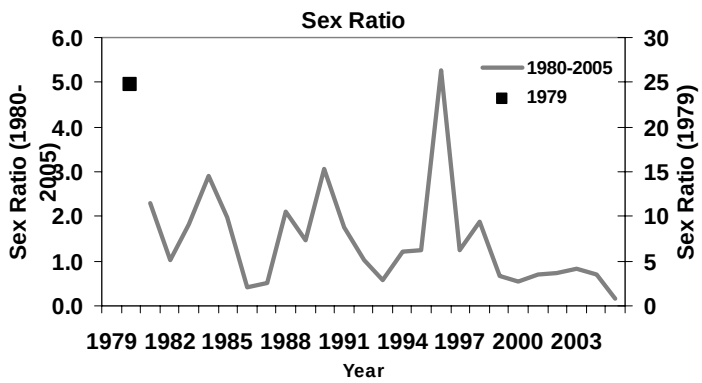
The Fishery

Recorded commercial harvest in Rhode Island waters indicates landings occurred since the turn of the 20th century. All harvest since the 1950s and up to 2005 occurred on mixed stocks in ocean waters. Recreational catch and release fishing is permitted; no take is allowed.

Reported commercial landings of American shad peaked in 1896, and again in 1940 at 24 thousand kg. The fishery took an upswing in 1981 and continued to increase to the peak of 55 thousand kg in 1989, most landings from floating traps. In 1990, landings dropped by two-thirds and remained there until another small peak of 40 thousand kg in 2002. Rhode Island's fishery was included in the closure of directed ocean fisheries as specifed by ASMFC Amendment 1 and landings dropped to near zero by 2005.







Indices

Adult passage data from the trap at Potter Hill Dam on the Pawcatuck River characterize the adult population, but with some uncertainty as not all fish enter the fishway to the trap. A decreasing trend was evident from 1999 to the present.

Other data present conundrums: there is an increasing trend in mean total length, yet a declining trend in mean age. In addition, sex ratio (M:F), once dominated by males, is now dominated by females, inferring that smaller fish are not present in the samples. This lack of smaller fish combined with the small sample size, could cause mean length to increase.

Total mortality estimates calculated from adult age structure were not used as problems were identified with the aging process.

Assessment Results

Examination of most indices indicate a declining trend in the stock.

Benchmarks

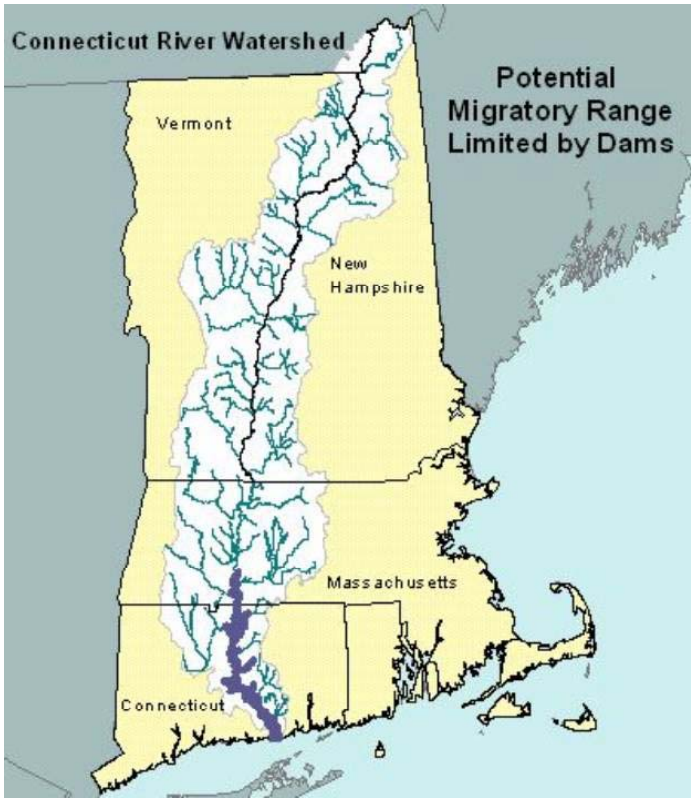
The Pawcatuck River run was nonexistent until 1979. It experienced brief relief in the early 1980s due to stocking efforts to recreate the run. Left on its own, the run has persisted at varying levels since 1986 and relies solely on wild production. The current estimates of the adult run have declined dramatically since 1999 and are far below the long-term average of 1100 fish at the lift.

Summary

The Pawcatuck River stock of American shad is in recovery. The stock relies solely on wild reproduction. Decreasing numbers of shad have appeared at the fishway in the Pawcatuck since 1999. The greatest uncertainty lies in an unknown level of ocean mortality—either from fisheries that could impact the stock (see bycatch section) or possibly predation.

Source Data	Year Range	Trend
Adults Trapped at Fishway	1985-2005	Decreasing over all years
Mean Size	1993-2205	Increasing
Sex Ration (M:F)	1996-2005	Decreasing (favors F)
Mean Age	1981-1987, 2000-2005	Decreasing over all years
BENCHMARK	**1100 adults**	**Currently (151)—well below**

Status of American Shad in the Connecticut River



Distribution, Biology and Management
American shad support sport and commercial fisheries on the Connecticut River. Data on relative abundance, age structure and sex ratio of the run, and the size and extent of the sport and commercial fisheries have been obtained annually since 1974.

The Connecticut River, the largest river in New England, extends about 400 miles from its source in New Hampshire, just south of the Canadian border, to the mouth at Old Saybrook, Connecticut. The river drainage encompasses 11,250 square miles within New Hampshire, Vermont, Massachusetts, and Connecticut. The Connecticut River flow is heavily regulated; there are at least 125 reservoirs within the basin used for power generation and 16 flood control reservoirs.

The Holyoke Dam in Massachusetts is the first barrier to upriver fish migration on the Connecticut River. A fish passage facility began operation at Holyoke Dam in 1955. Major technological improvements to the Holyoke lift were made in 1969, 1975, and 1976. No further improvements were until 2006.

Commercial fishing for American shad occurs in the main stem Connecticut River in the State of Connecticut The commercial season runs from April 1 to June 15 (5" min. stretched mesh). American shad may also be taken commercially in marine waters. In-river effort is restricted by two mandatory rest days per week, as well as gear restrictions. Angling is the only legal method for recreational harvest of American shad in Connecticut. The season runs from April 1 through June 30 in rivers and streams open to fishing all year; otherwise, the season runs from the 3rd Saturday in April through June 30. There is a recreational daily possession limit of six American and hickory shad in the aggregate, per person, in inland and marine waters. There have been no changes to Connecticut Statutes or regulations pertaining to American shad angling since 1999, when the existing six fish recreational creel limit was modified to include hickory shad as an aggregate creel limit for the two species.

Connecticut River American shad are iteroparous. Annual reproductive success is monitored through the collection of juvenile American shad and the calculation of an annual juvenile index of relative abundance.

The Fishery
A commercial gill net fishery and a recreational hook and line fishery have harvested American shad in the Connecticut River since the late 1800s. The commercial shad fishery in the Connecticut River is a spring gill-net fishery (April-June) that extends from the river mouth to Glastonbury, Connecticut (river km 62); landings data date back to 1880. The fishery has changed little since the adoption of outboard-powered vessels, with the exception of the change to drift gill nets from haul seine, fixed gill nets, traps, and pound nets. The number of commercial American shad fishing licenses (effort) has declined since

peaks during and after World War II and is expected to stay low or further decrease as fishermen retire and are not replaced.

There is the potential for significant bycatch losses of American shad in the Atlantic herring fisheries in the Gulf of Maine, which lands annually more than 60 million pounds of herring annually.

Commercial fishermen report in-river commercial landings and effort. Commercial landings (numbers) of Connecticut River shad varied greatly from 1981 to 2005 (Table 1). Commercial landings in the River fell steadily from 1981 through 1999 before rebounding and then declining again. In-river commercial effort declined from 1981 through the present (Table 1). Studies indicate that in-river commercial fishermen might have underreported their landings by 35 to 67% annually from 1966 to 1983.

Recreational American shad landings in numbers were estimated from 1980 to 1996 and periodically thereafter by a roving creel census. No biological samples have been collected since 1978. Prior to 1994, recreational landings comprised up to 82% of annual total in-river landings (Table 1). Recreational landings fell dramatically thereafter and estimates became unreliable and imprecise as reflected by high (>80%) proportional standard errors (PSE). Discard mortality of recreationally caught American shad was assumed to be 100%.

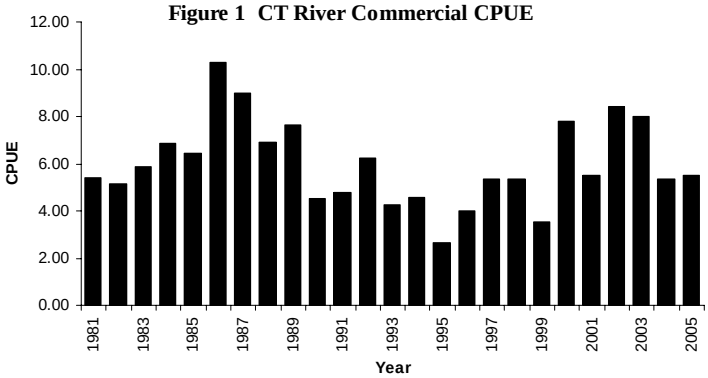
Both commercial and recreational in-river landings remained relatively high from 1981 to about 1992 with peak total landings of 159,000 fish occurring in 1986 (Table 1).

Estimates from the Marine Recreational Fisheries Statistics Survey of American shad harvested in ocean had excessive PSE estimates (>80%) and were considered unreliable.

Indices

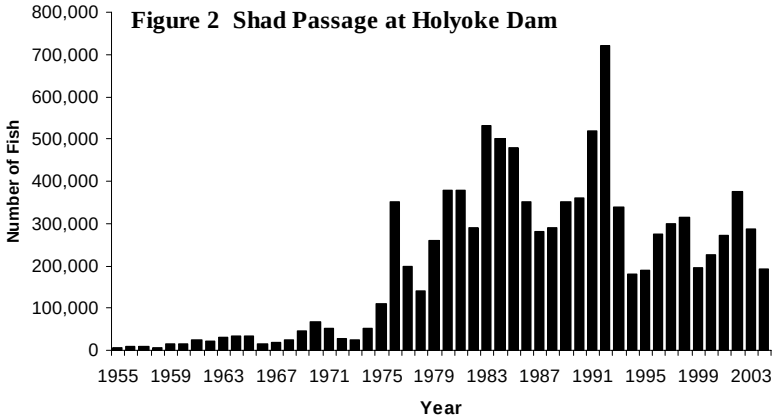
Commercial CPUE (catch per gill net day) peaked in 1986, declined, and then peaked at a lower level in 2003. There was no significant linear trend through this time series (Table 1; Figure 1).

Figure 1 CT River Commercial CPUE



Annual lift counts at Holyoke Dam and Fish-lift generally increased through 1992 when numbers peaked at 720,000 fish (Figure 2). Numbers declined sharply in 1993 and have fluctuated without trend since. A regression of lift numbers on year showed a significant increase from 1976 through 1992, but no trend from 1993 through the present. The fish-lift counts have two biases: (1) since it is at river km 140, all removals from commercial harvest and most removals from recreational downriver of the dam; and (2) the fractions of the population that spawn above the dam and below the dam are not known. The Connecticut River stock of American shad persisted since closure of the Holyoke Dam in 1849 suggesting that spawning occurred below the dam.

Figure 2 Shad Passage at Holyoke Dam



Relative abundance of age zero American shad in the Connecticut River (geometric mean catch per seine haul) has varied without trend since 1981 (Figure 3).

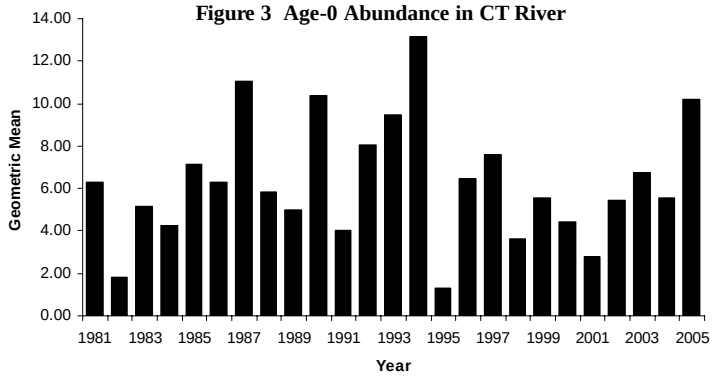


Figure 3 Age-0 Abundance in CT River

Assessment Results

Age structure and spawning history of mature American shad were derived from scale samples collected at the Holyoke fish passage facility in Holyoke, Massachusetts. Males and females were predominately ages four through six (Figures 4 and 5). Age-structure of male and female American shad showed a loss of older fish in recent years. Mean percent of repeat spawners declined throughout the time series (Figure 6).

Figure 4

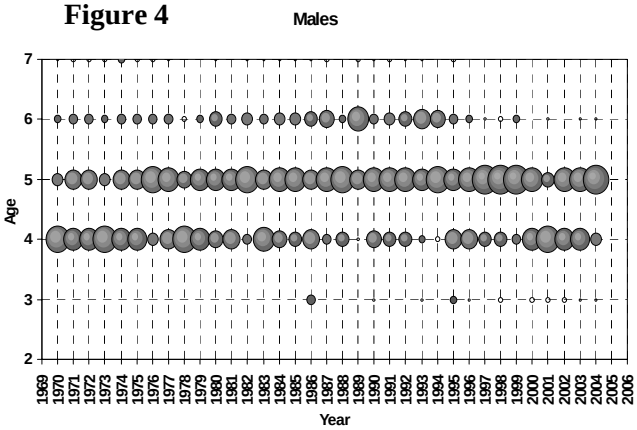
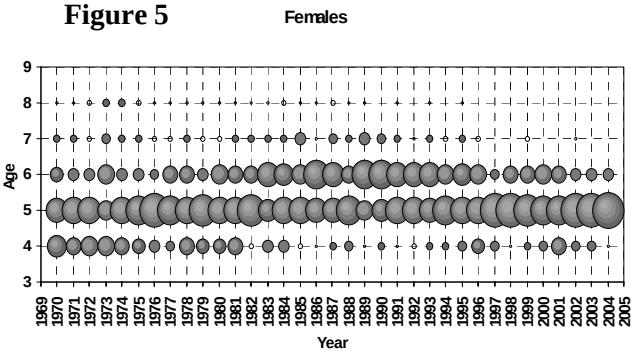


Figure 5



Estimates of total mortality (Z) for adult American shad were determined from age structure as the negative slope of the linear regression of ln percent at age on age. Annual Z-estimates increased throughout the time series for both males and females (Figure 7).

Figure 6

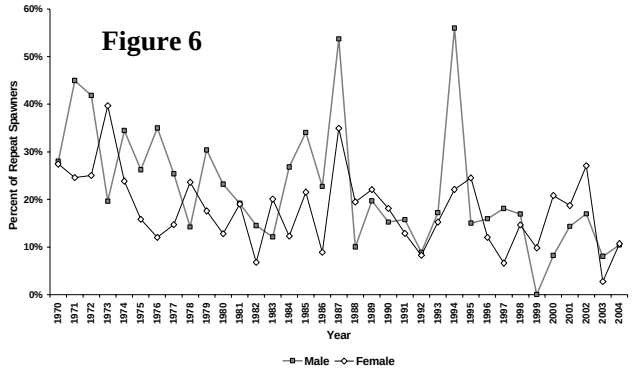
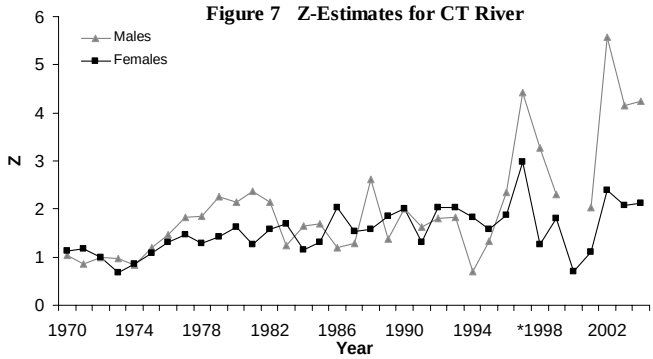


Figure 7 Z-Estimates for CT River



Benchmarks

Annual estimates of Z have exceeded the Z_{30} for the New England of Z = 0.64 for most years since 1970.

Summary

Juvenile indices and commercial CPUE varied without trend since 1981. Lift counts at the first barrier increased through 1992, dropped drastically the following year, and have since varied without trend. In addition, there has been a systematic increase in Z since 1970 (exceeding the reference point in most years), the percentage of repeat spawners returning to the Holyoke fish-lift has decreased, and age-structure has eroded.

Summary Table

Source Data	Year Range	Trend
Adult trap at fishway	1976-2005	Increase to 1992, decline, no trend since 1993
Commercial CPUE	1981-2005	No trend
Adult age structure	1970-2005	Loss of older fish
Total mortality	1970-2005	Increasing and generally above Z_{30}
Age zero index	1981-2005	No trend

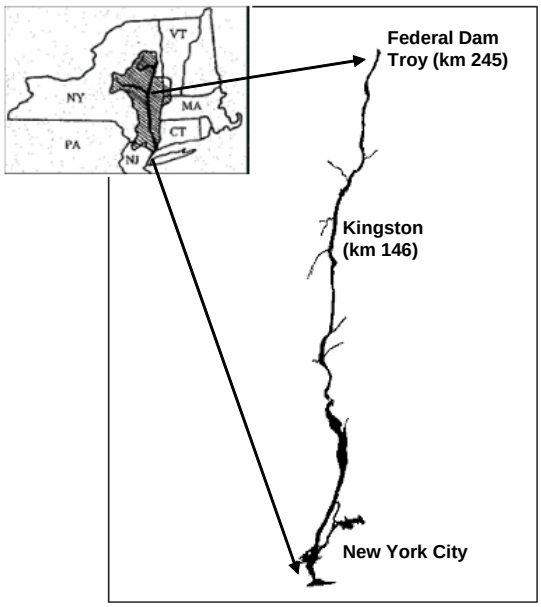
Table 1. Annual losses (numbers in thousands) of Connecticut River American shad.

Year	In-river commercial landings	Commercial Effort[1]	Commercial CPUE[2]	In-river Recreational landings	Total In-river landings	Commercial Ocean landings[3]
1981	49	907	5.4	69	118	33
1982	40.5	790	5.13	44	84.5	42.5
1983	49.5	840	5.89	99	148.5	26.5
1984	39.5	575	6.87	71	110.5	35
1985	38	590	6.44	41	79	41
1986	54	525	10.29	105	159	39.5
1987	31.5	350	9	93	124.5	42
1988	31	450	6.89	53	84	51
1989	30.5	400	7.63	60	90.5	39
1990	22.5	500	4.5	38	60.5	39.5
1991	24	500	4.8	85	109	38.5
1992	25.5	410	6.22	120	145.5	25
1993	17	400	4.25	65	82	27.5
1994	16	350	4.57	45	61	16
1995	10.5	400	2.63	14	24.5	23
1996	12	300	4	11	23	24
1997	16	300	5.33		16	24.5
1998	16	300	5.33		16	30.5
1999	8	225	3.56		8	28
2000	17.5	225	7.78		17.5	17.5
2001	11	200	5.5		11	26.5
2002	21	250	8.4		21	26.5
2003	20	250	8		20	14
2004	12	225	5.33		12	12.5
2005	11	200	5.5		11	4

1 - gill net days, 2 - catch/gill net day*100, 3 - 1995 value may be incomplete

Figure 1.3-3 Shad rivers assessed in the mid-Atlantic region.

Status of American Shad in the Hudson River, New York

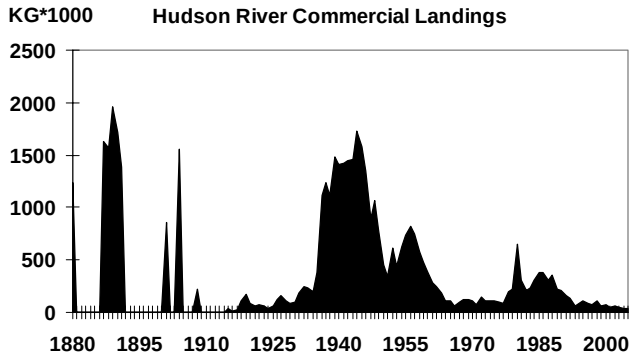


Distribution, Biology and Management

Anadromous fish have been harvested from the Hudson River since the 1600s when the Dutch first colonized the valley. The immigrants brought with them the skill and tools of fishing, and learned from the Native Americans about the numerous fish that arrived every spring. Regulation of the fishery came early, beginning in the mid 1800s. Gear restrictions and the first of the escapement periods were created by the New York legislature in 1868. The Hudson River was also the location of the one of the first American shad hatcheries on the Atlantic coast. Seth Green, a New York fish commissioner and conservationist, worked with Federal biologists, of the then U.S. Bureau of Fisheries, to promote stocking shad to reverse perceived declines in shad stocks on the mid-Atlantic coast. Despite these efforts, the Hudson River American shad stock's demise continued because of an unfortunate series of overfishing events, complicated by anthropogenic impacts that carried on for nearly 140 years.

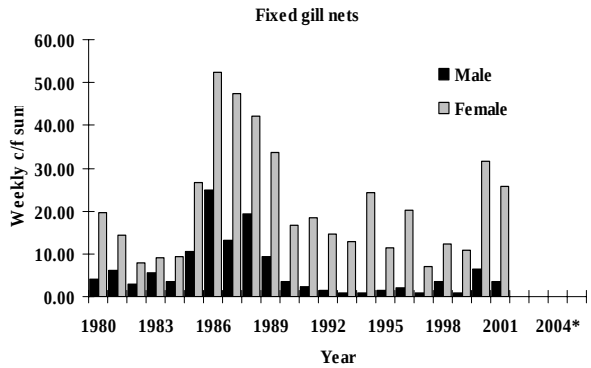
The Hudson is a highly productive system. It is tidal for 254 km to the first impassable barrier. Shad spawn in fresh water in the upper two-thirds of river above Kingston, New York. In ocean waters, the coastal migratory range extends from the Bay of Fundy, Nova Scotia south to coastal waters of Virginia. The oldest American shad observed was age 13. The stock is iteroparous—older fish have up to eight spawning marks. Fish can weigh up to nearly 4.5 kg, but average about 1.2 kg.

Current management is through a cooperative interstate fishery management plan coordinated through the Atlantic States Marine Fisheries Commission.



The Fishery

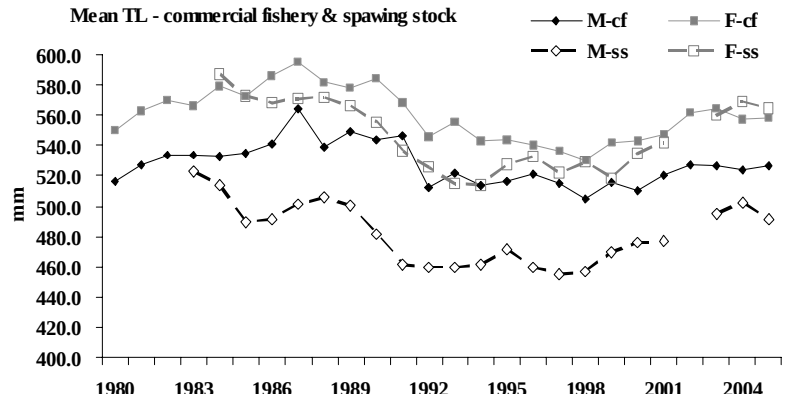
Commercial harvest records begin in the late 1800s. The highest peak of 1.9 million kg occurred in 1889. It is not known if fishing continued in the following five years; however, a second peak occurred in 1904 at 1.5 million kg. From the turn of the 20th century until 1936, landings were relatively low. Over the period 1937-1948, just prior to, during, and after World War II, Hudson shad became a very important commodity on the world's food market. Sustained landings ranged from 1.1 to 1.9 million kg annually. By 1949 and through the 1950s, the stock rapidly collapsed. Fishing slowed for 20 years only to be followed by another resurgence in the 1980s. Landings have declined since. During this last resurgence, a mixed-stock fishery developed in ocean waters (landings not indicated on graph). Two major ocean fishery regulations were implemented after 2000. The first, the Harbor Porpoise Take Reduction Program (HPTRP) forced ocean shad gill netters to use smaller mesh sizes. A regulated 40% decrease in effort occurred in 2002, followed by a complete closure in 2005. Current ocean bycatch remains undocumented.



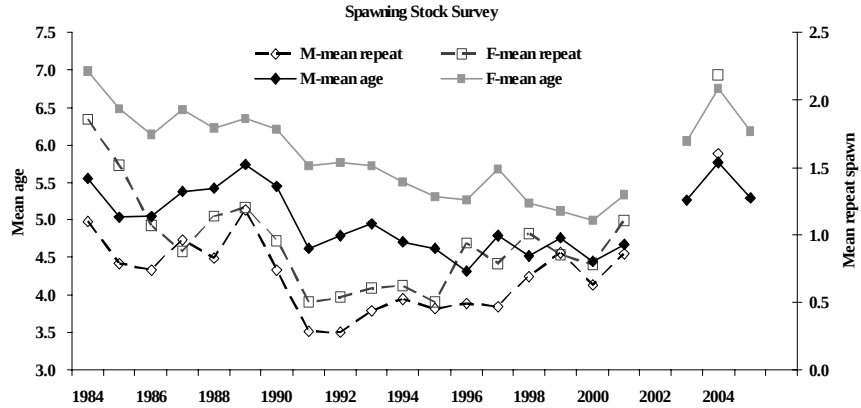
Indices

The in-river fishery is monitored by onboard observers and provides accurate catch-effort data. We used the data from the passive fixed gear gill-net fishery in the lower Hudson. This CPUE series indexes adult shad as they migrate through the lower river to upriver spawning areas. Data are usable until 2001, when sample size became too low to provide confidence in estimates. CPUE declined from a high in 1986 to a low in the late 1990s. Female CPUE spiked in the last two years, coincident with the HTPRP implementation.

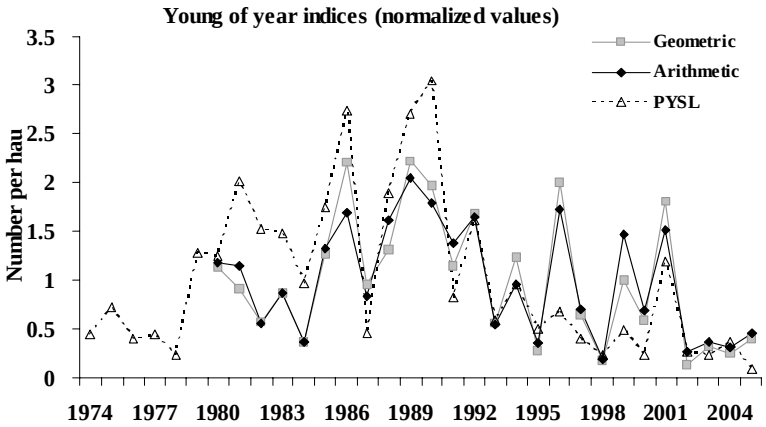
A decline in fish size occurred from the mid-1980s through the late 1990s concurrent with declining CPUE and landings. Samples from the fishery and the independent spawning stock survey indicated fish size was dropping. Larger, older fish disappeared through the late 1980s and mid 1990s. Some larger fish began to appear in 2000 after ocean restrictions banning large mesh gill nets occurred.



In 2004 and 2005, larger fish appeared and smaller, younger fish disappeared, most likely a result of poor recruitment.



Mean age and mean repeat spawning showed the same trend. Mean age and repeats declined until 1994, then stabilized until 2000, with some improvement in 2003 through 2005.



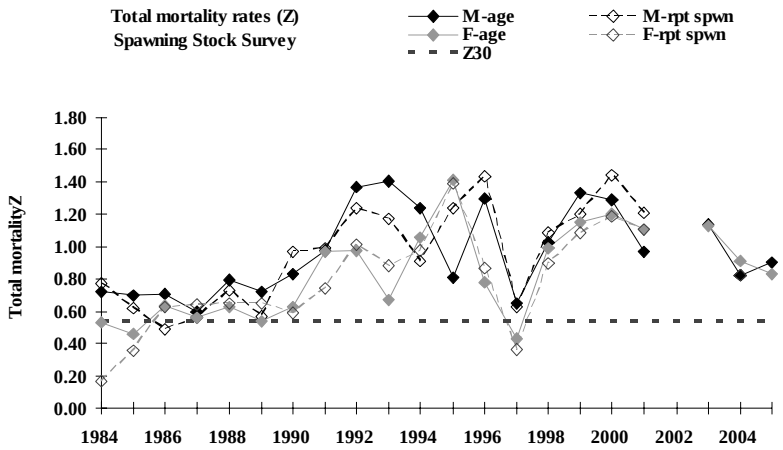
The juvenile abundance indices, (beach seine and post-yolk sac larval), increased through the early 1980s when the spawning stock was high. It has since declined erratically hitting an all time low in 2001. It presently remains at this low level.

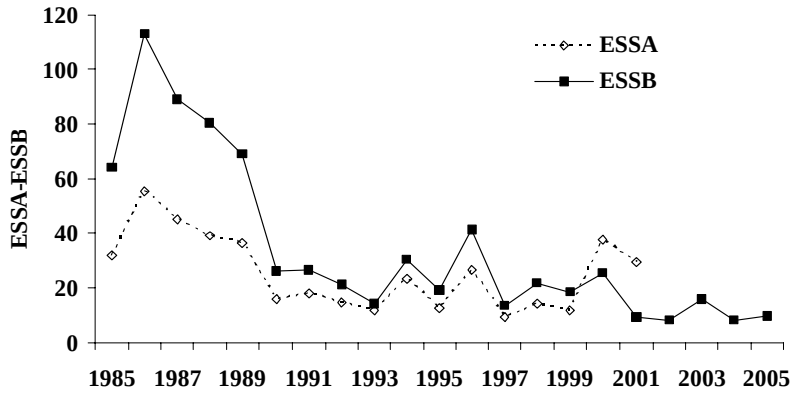
Assessment Results

All indices described above indicate a declining trend in the stock through the late 1980s and the mid 1990s. Recruitment has been poor since 2001.

Total mortality estimates calculated for the spawning stock show that Z for the Hudson River stock was stable in the late 1980s ranging from 0.4 to 0.8. Z began to climb through the 1990s and remained high, but variable, for the rest of the time series.

We also calculated empirical indices of spawning stock abundance (ESSA) and biomass (ESSB). Indices were high in the 1980s, then decreased at a varying rate to the present low. The ESSB is at its lowest level in 20 years.





Benchmarks

We calculated a biological reference point (Z_{30}) from a Thompson-Bell biomass-per-recruit model using Hudson River inputs for weight-, maturity- and vulnerability-at-age, and M=0.3, based on maximum age of 13 observed in the stock. Z_{30} was 0.54. Current Z values are well above this reference point.

Summary

The Hudson River shad stock has experienced a series of major declines over the past 140 years. Current data indicate the stock is at its historic low. The rise in mortality in the last 20 years coincided with a decrease in mean age, mean size, and stock size. Mortality rates on the adult stock remain high, well above reference point. Recent poor recruitment is a major concern. Shad are vulnerable to a host of fisheries on the Atlantic coast during the entire duration of the ocean residency. Total ocean bycatch estimates remain unknown. Mortality on the stock needs to be reduced.

Source Data	Year Range	Trend
Adult Fishery CPUE	1980-2001	Decreasing over all years, small spike in last two years
ESSB	1985-2005	Decreasing
Mean Size	1980-2205	Declined until 1999 with slight increase to present
Mean Age	1980-2005	Declined until late 1990s with slight increase in past three years
Mean Repeat	1980-2005	Decreasing over all years
Juvenile Index	1980-2005	Decline since 1986, past four year at historic low
Z	1984-2005	Increased in the early 1990s and then remained high
Relative Exploitation	1985-2005	Increased in the early 1990s and then remained high
Reference Point	**Z_{30}=0.54**	**Current Z=0.87**

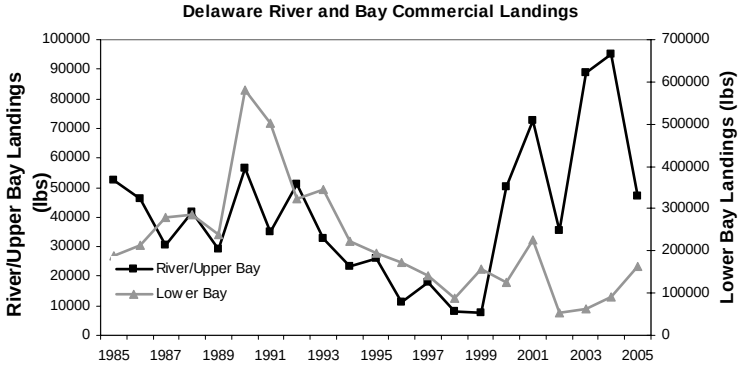
Status of American Shad in the Delaware River

Distribution, Biology and Management

The Delaware River stretches for 330 miles from the East and West branches above Hancock, New York, to the mouth of Delaware Bay. The Delaware Drainage Basin includes the states of Delaware, New Jersey, New York, and Pennsylvania.

New Jersey and Delaware have adopted regulations for limited entry fisheries and gear specific limitations on commercial fishing while Pennsylvania and New York do not permit commercial harvest within the Delaware River Basin. All Basin states have enacted six fish American shad recreational bag limits except the State of Delaware, which has a ten fish limit, combined American and hickory shad.

The Delaware River had the largest annual commercial shad harvest of any river on the Atlantic coast in the late 1890s with estimates ranging up to 19 million pounds in a year. The harvest declined rapidly in the early 1900s due to overfishing, water pollution, and dams on major tributaries, and the shad stock eventually collapsed. Water quality in the Delaware River improved following the passage of the Federal Clean Water Act in 1972. Although the Delaware River shad population had shown signs of recovery during the 1980s into the early 1990s, recent estimates of the adult stock have been well below the target of 750,000 fish.



The Fisheries

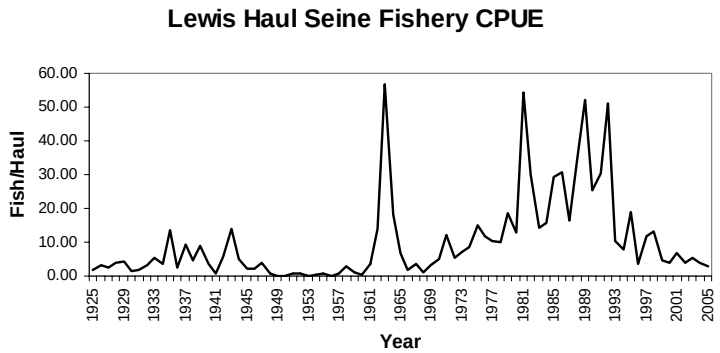
The commercial fishery for American shad in the Delaware River occurs during the spring spawning migration. Landings data should be used with caution since New Jersey landings are likely underreported prior to 1999 and there are no estimates of harvest for the state of Delaware before 1985. Shad harvested in the Delaware River or Upper Bay area are considered to be Delaware stock while those from the Lower Bay areas are mixed stock and the origin of these fish vary annually. Harvest numbers have increased in recent years due to mandatory reporting.

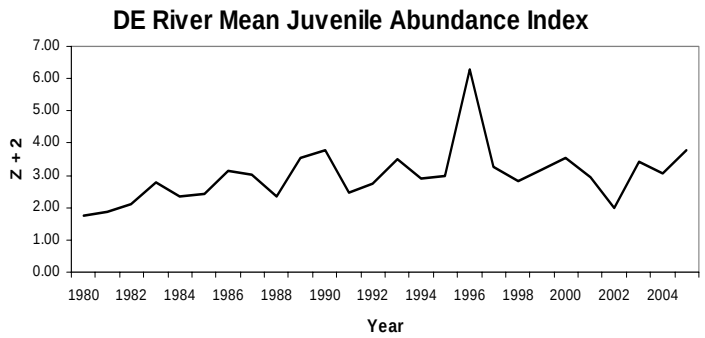
Many recreational surveys have been conducted within the Delaware River since 1965. Recreational catch estimates have fluctuated with a peak in 1992 at 83,141 shad caught throughout the Delaware River. Other recreational fishery data are limited to logbook data during years of population estimates and some recent trends from shad guide fishermen in the upper Delaware River.

Indices

The longest time series of commercial effort is the Lewis haul seine fishery in the non-tidal section of the Delaware River above Trenton, New Jersey. The fishery employs seine nets of different length depending on the water flow and height. Although this may be problematic, the length of the time series still gives a good indication of spawning run strength. The fishery CPUE began steadily increasing from 1969 to 1992 before

dropping off significantly through recent years. Effort data from gill-net catches in Delaware (1989-2005) also show a peak in 1992 with a decreasing trend to low levels in recent years.





Juvenile abundance data are collected in two surveys in non-tidal (upper) and tidal (lower) areas during August, September, and October. Juvenile production has remained fairly stable except for a dominant year class in 1996 and a poor year class in 2002.

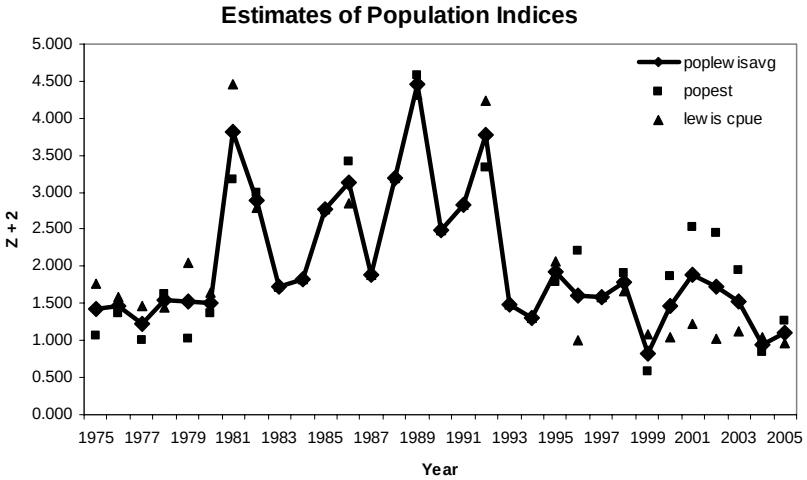
Adult abundance estimates are limited to an index of population derived from mark-recapture studies and a hydroacoustic survey. The population index shows an increase in adult abundance throughout the 1970s and 1980s with a gradual descent from 1989 to 1999. The stock rebounded from 2000 to 2003 but faltered again in recent years.

Assessment Results

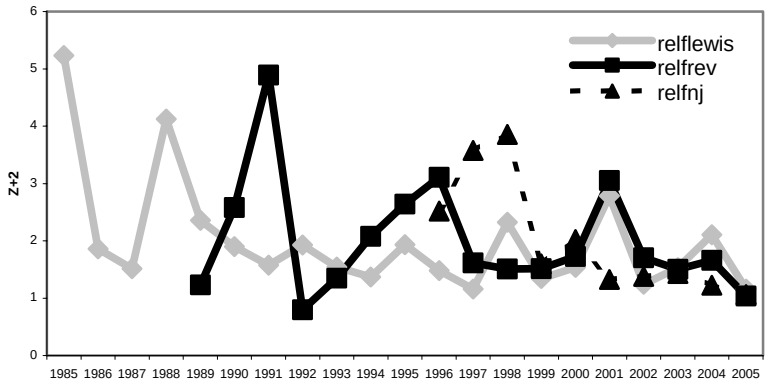
Recent findings have determined that ageing of scales from Delaware River American shad can not be substantiated. While otolith technology is considered better, the principal scientists behind otolith ageing are not satisfied with the process at this time. Without confidence in these ageing techniques, the SASC agreed that alternative methods would be preferred to assess the Delaware River stock of American shad.

Indices were standardized (Z-transformed) with two added to eliminate any negative values. Two estimates of adult shad abundance, the Lewis haul seine fishery CPUE and population index were compared with each other and also averaged together as an indicator of the spawning run. The results show an adult abundance increase from the lows of the late 1970s to a peak abundance level in 1992. This was followed by a significant decrease in abundance through 1994. The adult population has continued to decline and is currently at levels equivalent to the early 1980s.

There does not seem to be recruitment problems with juvenile production within the Delaware River and therefore, based on YOY abundance, the shad population should have remained stable throughout the time series.



Estimates of relative exploitation from commercial fisheries were developed for the 1985 to 2005 time period when reliable in-river estimates of harvest from the Delaware commercial fishery were available to ascertain if potential overfishing occurred during the period of low adult abundance in the early to mid-1990s. The analysis has shown a decrease in relative exploitation since 1985 using the Lewis CPUE data . The other two estimates are from Upper Delaware Bay commercial fisheries and have also shown a general downward trend since the beginning of their respective time series. All three relative exploitation estimates tract fairly well and show that in-river fishing mortality is probably not the cause of any decline of the Delaware River shad stock in recent history.



The analysis has shown an increase in relative exploitation in recent years, beginning in 2000, but the extent of this trend is unknown. In-river exploitation in the Lewis CPUE data varied without trend from 1985 to 1999 but increased significantly in recent years. This increase is likely the result of New Jersey's mandatory reporting enacted in 2000 and not an actual increase in exploitation.

The SASC also looked at potential interactions with striped bass within the Delaware Estuary to determine if the shad decline was a direct result a predator-prey relationship. The analyses indicate that striped bass numbers fluctuate similar to American shad and there is potential for striped bass to be a limiting factor to shad stock growth but there is no evidence that striped bass has caused a decline in the shad population.

Benchmarks

The SASC discussed the development of benchmarks for relaxation of harvest regulations, in the event of stock improvement, and reduction of harvest to prevent recruitment failure, in the event of continued stock collapse. Although there are many potential indices for use as benchmarks the SASC could not come to consensus on which indices would be beneficial at this time. Examples of CPUEs for the Delaware River included in this document:

- Six commercial fishery CPUEs from the Delaware River and Bay
- Three CPUE estimates from the recreational fishery
- Estimates of YOY abundance
- Index of population
- Abundance CPUEs from hydroacoustic monitoring
- CPUE from the Smithfield Beach gillnetting and the Lehigh River fish ladder at Easton

Since the SASC was unable to reach consensus on what could be considered the best scientific benchmark or benchmarks, the SASC considers all options for benchmarks to be on the table and asks that the Peer Review Panel provide comments on the scientific pros and cons of each for use when the Management Board and Technical Committee meet to discuss the issue in the future.

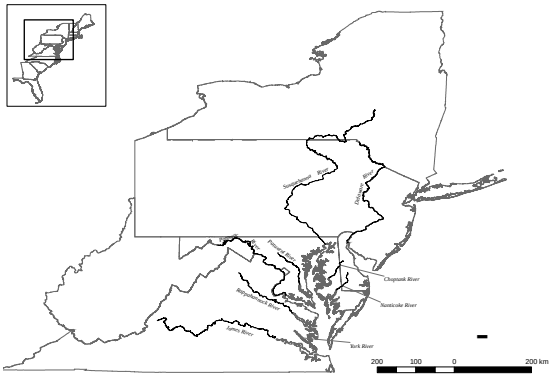
Summary

After evaluating the data on the Delaware River shad stock, the SASC recommends the following:

- No relaxation of the current regulations or sampling requirements take effect until the shad population is estimated to be at least 750,000 fish throughout the entire spawning reach of the Delaware Basin for more than two consecutive years. This recommendation is taken from the original Delaware River Basin Plan and would be dependent on the Delaware Basin States determination of a reliable estimator of the population throughout the entire spawning reach of the Delaware Basin.
- Undertake a more thorough investigation into predator-prey relationships to determine if predation on shad by striped bass or other predators is a significant problem.
- Determine fishing mortality on the Delaware River stock from out of Basin activities including bycatch discard in other fisheries.
- Initiate investigations to ensure that habitat quality and suitability within the Delaware Basin is adequate to restore the American shad stock in the Delaware River and its tributaries.
- Obtain annual estimates of the recreational catch, harvest, and CPUE.
- Require all commercial shad fisheries within the Delaware Basin to sample for hatchery-marked restoration fish.

Status of American Shad in Maryland

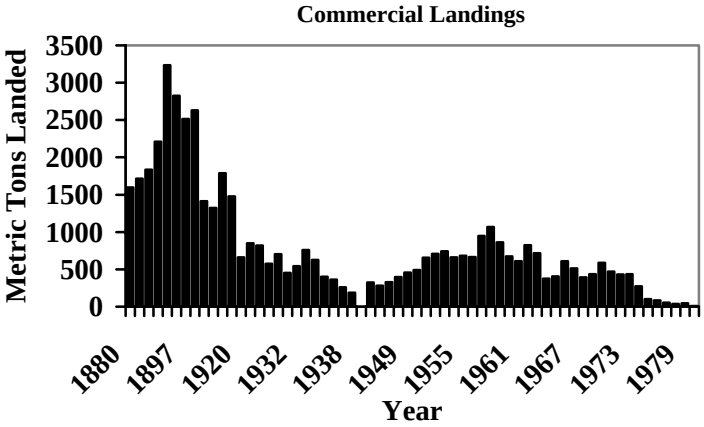
Distribution, Biology, and Management



The Chesapeake Bay is a dynamic estuary with thousands of miles of tributaries that are both tidal and non-tidal. Anadromous species once spawned in every major river system and in most of the smaller tributaries. American shad stocks were a key food source for early settlers and it was not until gear improvements in the late 1800s that stocks took a noticeable decline.

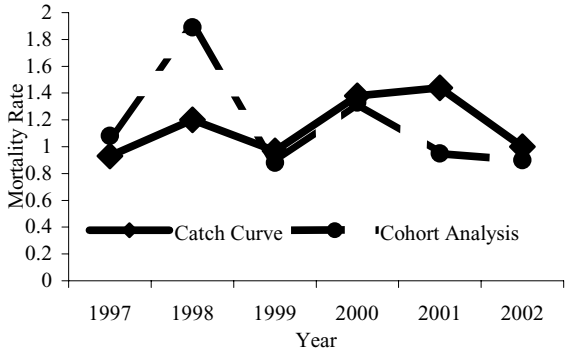
Adult American shad enter the lower Chesapeake Bay in February; peak spawning is during May but may occur through June. This iteroparous stock has spawned up to four times and age structure indicates that most adult fish are four or five years old but age structure ranges from 2-11. Juvenile American shad hatch approximately one week after fertilization and most leave the Bay in late Fall.

The American shad restoration program in Maryland began in 1984 and has focused on restoring historic runs to the major tributaries. Presently, three tributaries are annually stocked with millions of juvenile American shad.



The Fishery

American shad have long been important in the cultural and economic development of the Chesapeake Bay region. Commercial fishing increased beyond a subsistence fishery after the revolutionary war and by the late 1800's, American shad supported the most important commercial fishery in the Chesapeake Bay. American shad landings in Maryland peaked in 1890, declined to the late 1940's, increased through the 1950's and then declined to precarious levels by the late 1970s. The commercial American shad fishery in the Chesapeake Bay was virtually unregulated with only limited gear, area, and time restrictions and was the most important fishery in the Chesapeake Bay until the 1950s.

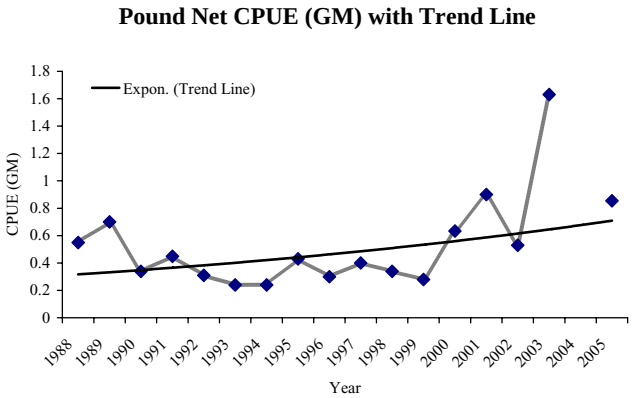


Female American shad were targeted by the fishery because of their roe. The consistent demand for American shad for flesh and roe demand dropped in the 1960s as consumers sought other fish because of the scarcity of American shad. Limited effort during World War II allowed the stock to rebuild but the illimitable commercial fishery depleted stocks until Maryland closed its commercial and recreational fishery in 1980.

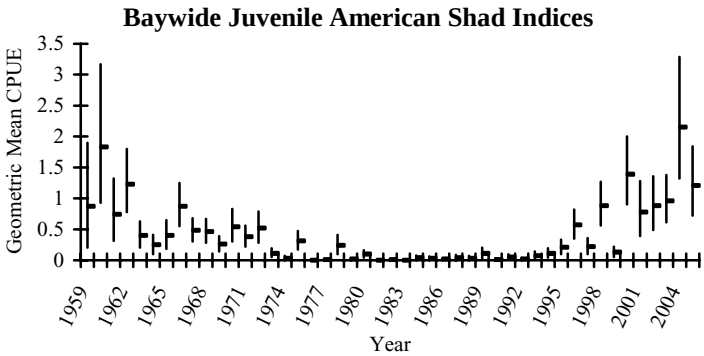
Indices

Limited American shad data exists for the Nanticoke, Choptank, Patuxent, and Pocomoke rivers and the coastal commercial fishery. The lack of absolute abundance estimates, relative abundance indicators, and long-term age-structure only allows index-based assessments for several areas.

The Nanticoke River is the only assessed system in Maryland besides the Susquehanna River that has sufficient data to allow an index-based assessment of adult American shad stocks. The Choptank, Patuxent, and Pocomoke rivers each had viable stocks but overfishing likely caused their decline and these stocks based on limited data, appear to have very low abundance.



Fishery-dependent data from Nanticoke River pound nets 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. Mortality estimates for Nanticoke River American shad based on repeat spawning marks averaged 1.16 (catch curve) and 1.17 (cohort analysis) and there appears to be no trend



Maryland's American shad coastal commercial fishery, closed in 2005, was a mixed stock fishery. Catch-per-unit-effort based on the oceanside commercial gill net fishery dropped dramatically after 1999 when regulations increased and price dropped.

Baywide juvenile American shad indices, although limited in some tributaries of the Chesapeake Bay has increased since the 1990s but has trended down in the last two years if 2006 is included, although this index is heavily weighted by large catches in the Potomac and upper Chesapeake Bay.

In the Nanticoke River, supplemental stocking may have caused a behavioral shift resulting in the lower river being quickly bypassed especially during low spring flows (high salinity) because of the homing to the upper reaches of the river.

Non-hatchery juvenile American shad are prevalent in the upper Nanticoke River and indicate significant natural reproduction. Restoration stocking is also supplementing adult stocks but American shad adult catch by cooperative watermen in the Nanticoke River is well below historical landings.

In over twenty-five years of the American shad recreational and commercial closures and supplemental stocking, stocks have not rebounded to self-sustaining levels for most major tributaries of the Chesapeake Bay (the exception is the Maryland portion of the Susquehanna River). The introduction of hatchery-produced American shad into the Susquehanna, Patuxent, and Choptank rivers had initially rebounded in these systems until 2002 when adult relative abundance indicators declined and this trend has continued into 2006. Recent age and spawning history data showed fewer larger and older fish and a decrease in virgin spawners indicating increased mortality and recruitment failure.

Benchmarks

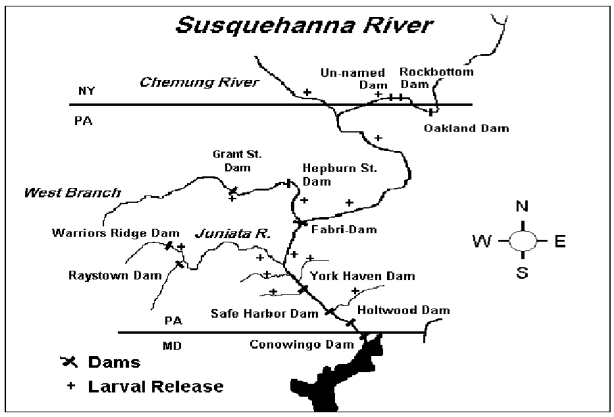
In most years, Z estimates from the repeat spawning marks are higher than benchmark Z_{30} for the mid-Atlantic region. Since there is no directed fishery in the Chesapeake Bay and bycatch mortality is thought to be minimal, evaluation of the causes of increased American shad mortality is essential.

Summary
Landings data from the Nanticoke, Patuxent, Choptank, and Pocomoke rivers and from the main Bay and ocean commercial shad fisheries demonstrate the decline of the American shad stock. Adult indices in the Choptank, Patuxent, and Pocomoke rivers were at historically low levels based on landings data and more recent empirical data suggests that stocks are still depressed. Baywide juvenile indices have increased since the late 1990s indicating increased juvenile survival. Nanticoke River adult indices are low, even though it is supplemented by hatchery fish.

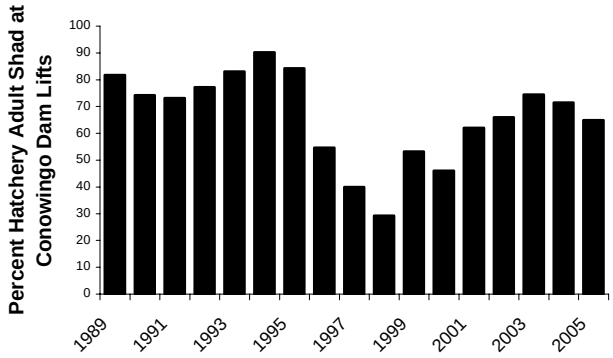
Status of American Shad in the Susquehanna River & Susquehanna Flats

Distribution, Biology and Management

The American shad stock in the Susquehanna River and Flats was spatially restricted by the construction of hydroelectric dams during the early 1900s, blocking access to hundreds of miles of natal habitat in Pennsylvania and New York. Overfishing likely impacted the stock as well. Fish-lifts were retrofitted to the four main stem Susquehanna River dams, beginning in 1972, and have reopened upriver habitat.



Adult American shad enter the Susquehanna River in March; peak spawning is during May but may extend through June. The stock is iteroparous with individuals exhibiting as many as three spawn marks. Spawning fish range in age from 2 to 11, but most adult fish are four or five years old.

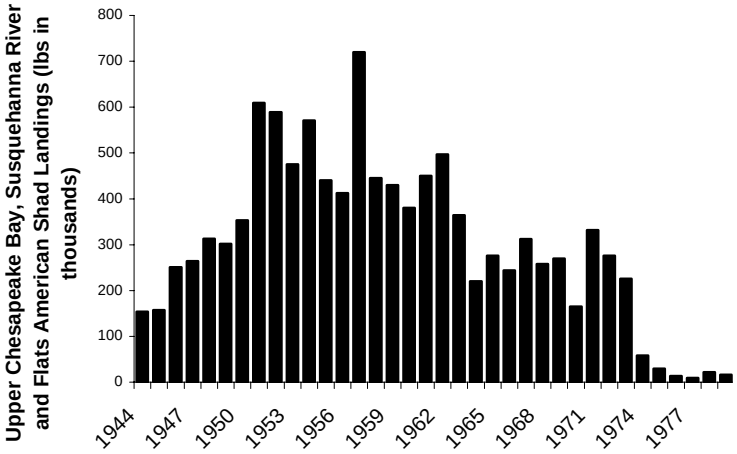


Presently, each of the four main-stem dams has lifts or ladders to pass adult American shad but downstream fish passage is limited to turbine passage or spill.

The annual stocking of millions of juvenile American shad, mainly by Pennsylvania, has driven the recent recovery of the stock as is indicated by the high percentage of hatchery adults collected at Conowingo Dam. However, there is no significant correlation between juvenile abundance indices and returning adults.

The Fishery

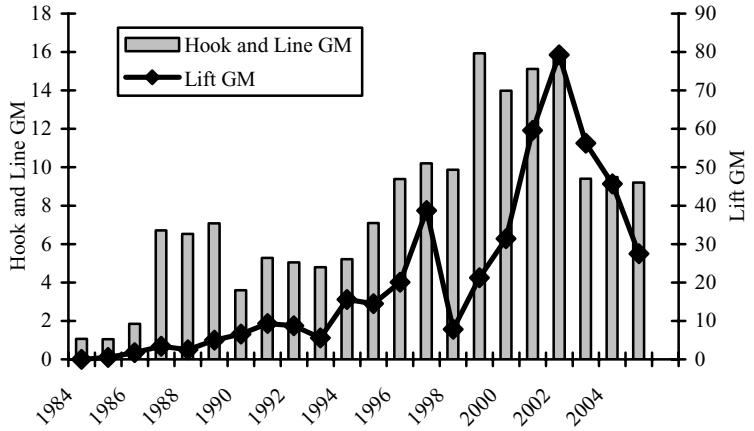
The historic commercial American shad fisheries in the Susquehanna River targeted American shad until Maryland closed the directed fishery in 1980. After 1980, a significant recreational catch-and-release American shad fishery has developed below Conowingo Dam.



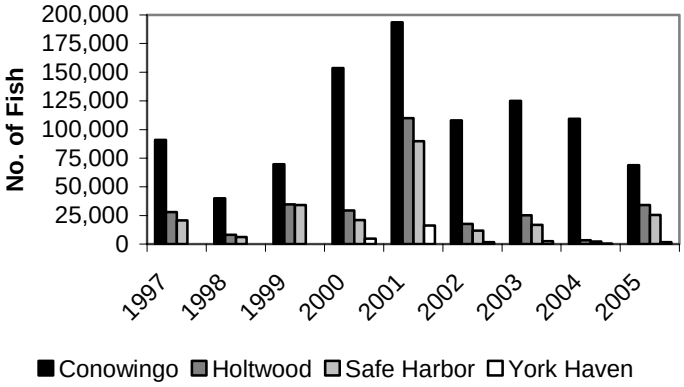
Indices

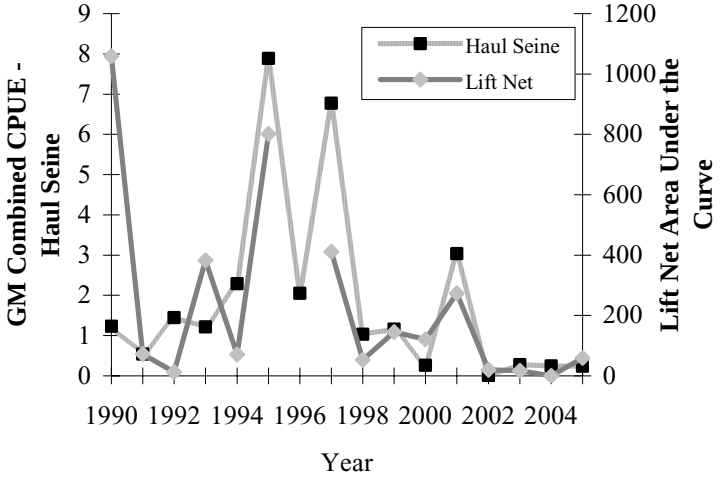
Index-based methods were employed in this assessment. Adult American shad relative abundance indicators—hook and line and Conowingo Dam fish lift counts—had dramatically increased from 1972 to 2002, but have decreased since 2002. Significant changes in attractant flows have occurred at most fish-lifts on the Susquehanna River in order to maximize catchability of American shad.

Cumulative adult shad passage efficiency (the number passed by the fourth dam divided by the number passed at the first dam) is presently less than 3% and the lack of downstream passage for adults minimizes repeat spawning. Fish passage numbers at the three dams above Conowingo Dam indicate that the goal of 2 million American shad will be difficult to obtain unless stocks increase significantly and lift efficiencies are maximized.



Upriver American shad hatchery juvenile abundance indices are not correlated with stocking but wild juvenile production is correlated with adult abundance above Safe Harbor Dam, indicating that access to pristine spawning habitat is limiting upriver reproduction.





Benchmarks

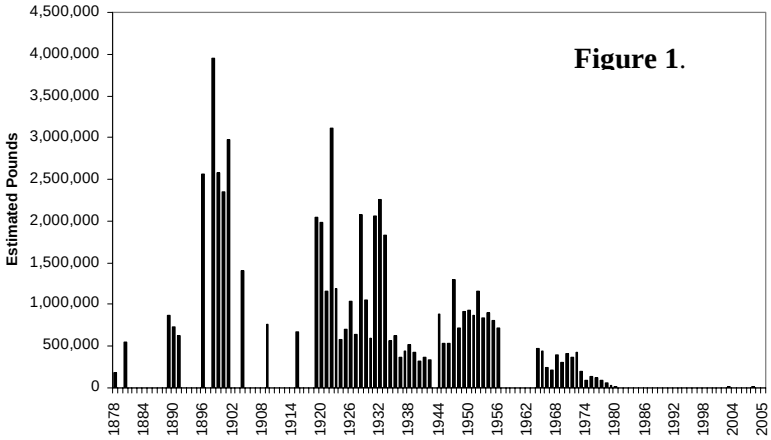
In most years our Z-estimates from the repeat spawning marks are higher than the benchmark Z_{30} for the mid-Atlantic region.

Summary

American shad stocks have rebounded since the closure of the directed fishery in 1980. Pennsylvania established a restoration program that triggered the recovery of the stock until 2002 when abundance began declining. Z-estimates from Susquehanna River stocks are higher than the Z_{30} benchmark and the cause needs to be identified. Fishway efficiency must be significantly improved to support a self-sustaining population. Identification of the factors causing the present decline is critical for recovery of this stock.

Status of the Potomac River American Shad Stock

Distribution, Biology and Management



The Potomac River is a major tributary of the Chesapeake Bay that historically supported a large fishery for American shad (Figure 1). Its watershed ranks fourth in area among all Atlantic east coast rivers. The estuary extends 113 miles from its mouth to just below Little Falls. At Little Falls, a low head dam was built in the 19th century and traditionally had an ineffective fish passage way. A newly installed fish passage now allows shad to extend their range an additional 10 to 12 miles upstream to Great Falls, a natural barrier to all anadromous species. Shad spawning area extends from about Stump Neck, Maryland and Cockpit Point, Virginia upriver to Great Falls, a distance of about 40 miles. Upstream, spawning occurs in a 10 to 12 mile reach between Little Falls and Great Falls. A cooperative restoration program using hatchery-reared larvae began in 1995. During the eight-year stocking phase of the project over 15.8 million shad fry were stocked into the Potomac River. However, the prevalence of adult American shad with hatchery marks has remained very low since 1998, suggesting that the stocking of larvae has not yet influenced run size. The Potomac River serves as a source of brood stock for American shad recovery efforts in the Rappahannock River, other Maryland rivers, and the Susquehanna River.

Since 1963, the Potomac River Fisheries Commission (PRFC) has regulated the American shad fishery in the Potomac River. However, there are five fishery management authorities on the river, each with separate management areas and some with shad monitoring programs. The 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 with authority for the Potomac to the Virginia shore and other waters within D.C.; the Maryland Department of Natural Resources (MD 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 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 with authority for recreational fisheries in the freshwater portions on the Virginia tributaries.

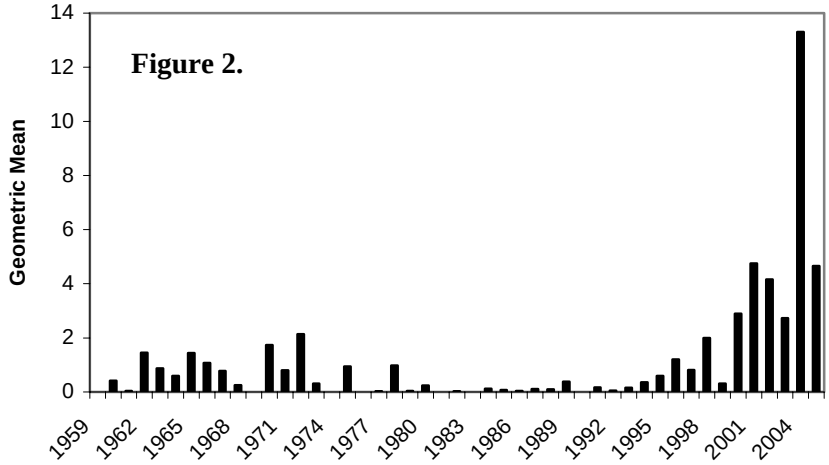
The Fishery

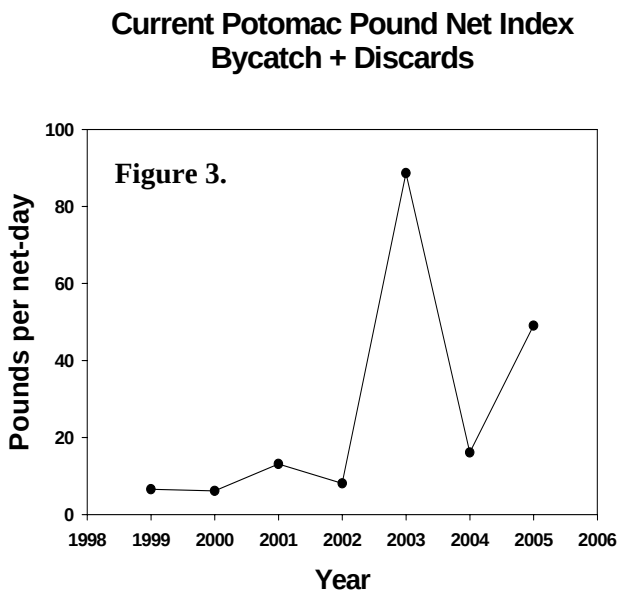
A moratorium on the taking of shad was established in 1982. Currently, bycatch of American shad is permitted by pound nets and gill nets set for other fishes. Fishers are limited to a one bushel (approximately 60 lbs) per licensee, per day. Gill nets are fished from November through March 25 and pound 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. All licensed fishermen are

required to submit reports of their daily harvest of all species by gear type on forms supplied by the PRFC. The recreational fishery for American shad is currently closed.

Survey Indices

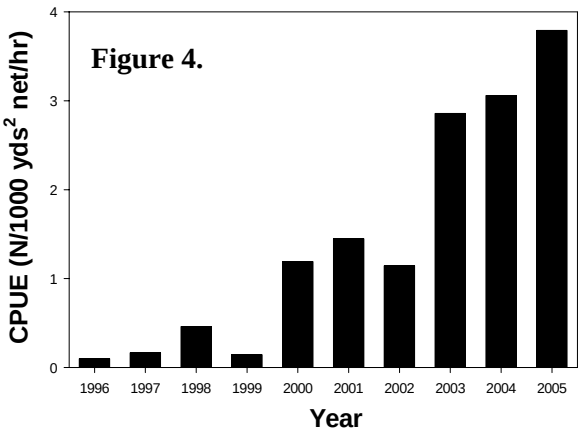
Since 1985, the MD DNR has employed multi-panel drift gill nets to monitor the Chesapeake Bay component of the Atlantic coast striped bass population. The primary objective of this survey is to generate estimates of relative abundance-at-age for striped bass. American shad are caught as bycatch and MD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





Assessment Approaches

We examined trends in estimates of total mortality (Table 1), juvenile abundance (Figure 2), landings plus discards in commercial pound nets (Figure 3), and catches in the MD DNR fishery-independent gill-net survey (Figure 4). To assess stock status and set a management benchmark, we compared current pound net landings during 1999-2005 (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 2).



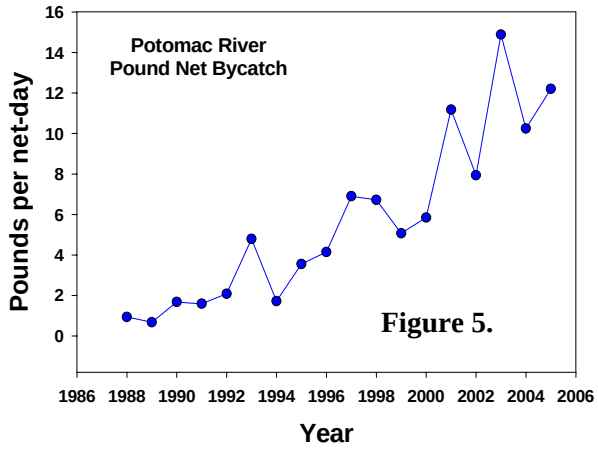
Assessment Results

The gill-net index (Figure 4), the pound net index (Figure 5) and the juvenile abundance index depict strongly increasing trends in relative abundance. Since 2002, estimates of total mortality are declining. Recent total

mortality estimates are within the range of reference values derived from a yield model exercise (Z_{30}= 0.62 to 0.85, depending on the estimate of natural mortality used as input).

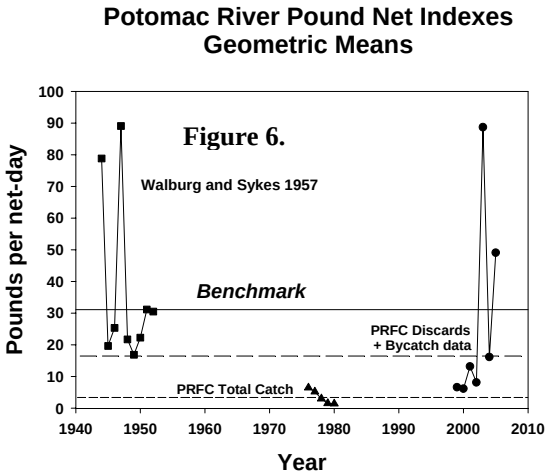
Benchmarks

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 (Figure 6).



Conclusions

Recent total mortality estimates are within the range of reference values derived from a Chesapeake Bay yield model. 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. In the late 1970s, total landings of American shad decreased sharply from 120,000 pounds in 1976 to 16,000 pounds in 1980. 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 1950s average (when catches were sustainable), but is greater than the 1970s average (when landings were not sustainable) and is increasing. Among Chesapeake Bay stocks of American shad, the Potomac River population shows the most promising signs of recovery.



Literature Cited

Walburg, C.H. and J.E. Sykes. 1957. Shad fishery of Chesapeake Bay with special emphasis on the fishery of Virginia. U.S. Fish Wildlife Service, Research Report 48, 26p.

Table 1. 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 2. 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

Status of American Shad Stocks in Virginia

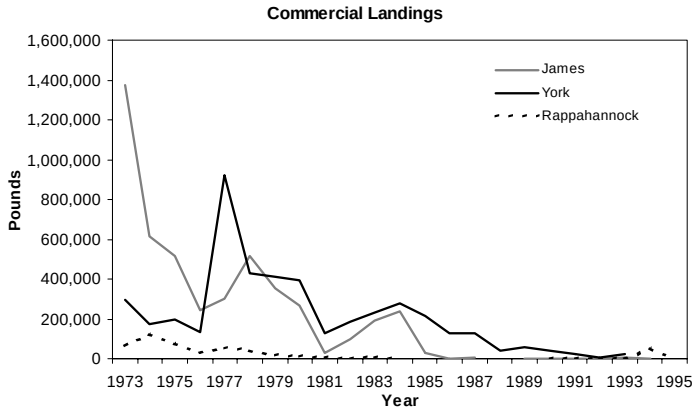
Distribution, Biology and Management

Mixed stocks of American shad enter the lower Chesapeake Bay in late winter-early spring and segregate into river-specific populations. Historical in-river landings data in Virginia are from the three primary spawning runs in the Rappahannock, York, and James rivers. Each river population is considered to represent a unit stock with little or no mixing of other stocks in areas upstream of the river mouth. The York River population migrates to either of two adjacent tributaries (the Pamunkey and Mattaponi rivers). American shad spawn in freshwater portions of the rivers, usually beginning in March and ending in June with peaks in April. The annual spawning run consists of virgin fish 3 to 7 years in age (based on analysis of scales) plus repeat spawners (age-4 through age-12). American shad age-9 and older are rare; maximum age recorded is 12 years. 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. In spring 1994, the Virginia Department of Game and Inland Fisheries and the U.S. Fish and Wildlife Service began hatchery-restocking efforts in the James and Pamunkey rivers. Adult shad from the Pamunkey River are used as brood stock for the James River releases. In spring 2004, stocking was initiated in the Rappahannock River using adult shad from the Potomac River as brood stock. The success of the restoration program in the James River was evidenced by increasing adult catch rates by monitoring gear in 1998 through 2002 as large numbers of mature hatchery fish returned to the spawning grounds.

The Fishery

The Virginia Marine Resources Commission imposed a moratorium on the taking of American shad in Virginia rivers and the Chesapeake Bay in 1994 in response to sharp declines in commercial landings (Figure 1). The ocean-intercept fishery in Virginia coastal waters was closed in December 2004. Drift-net fishing by two Native American tribal governments and the taking of brood stock by the Virginia Department of Game and Inland Fisheries on the spawning grounds of the York River system for stock restoration in the James River are permitted. An active catch and release recreational fishery exists on the James and Rappahannock rivers and to a lesser extent, the York River (especially the Mattaponi River).

Figure 1

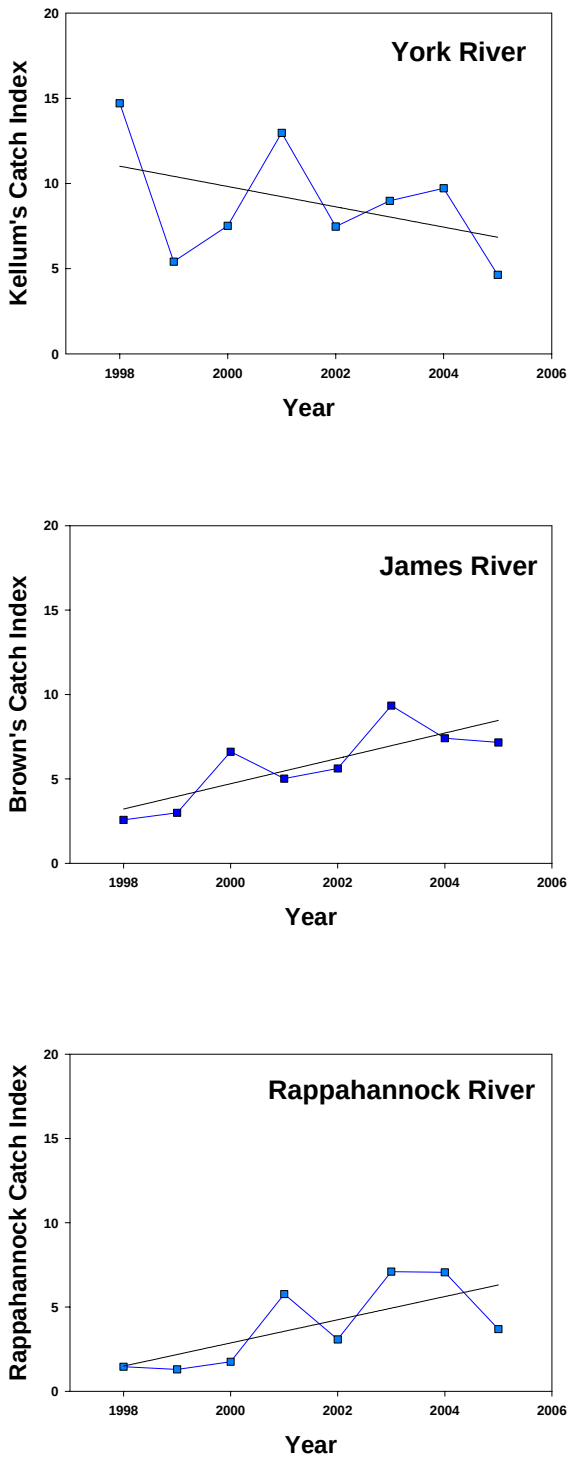


Survey Indices

The primary fishery-independent source of data on adult shad abundance is a staked gill net (SGN) monitoring program in each river. When the in-river fishing moratorium was imposed in Virginia, commercial fishermen who held permits for existing SGN stands were allowed to retain priority rights for the locations of those stands. One of these locations on each river (James, York, and Rappahannock) was selected to monitor catch rates in a sentinel fishery. 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 fish these stands two days in each week in the company of a scientist. 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 longest available time-series of juvenile abundance of American shad results from the Virginia Institute of Marine Science striped bass seine survey (multiple stations in all rivers, 1980-2005).

Figure 2



Assessment Approaches

Assessment approaches are (1) evaluating current status by comparing contemporary catch indexes (the area under the curve of daily catch rates versus time in staked gill-net monitoring) to those recorded in voluntary commercial logbooks of fishers in the 1950s and from 1980 to 1993, and (2) examining patterns of juvenile recruitment and hatchery restoration success (prevalence of hatchery-marked mature fish). A yield-per-recruit model using York River stock-specific growth parameters was constructed for the Native American tribal drift gill-net fishery to provide a benchmark total mortality rate.

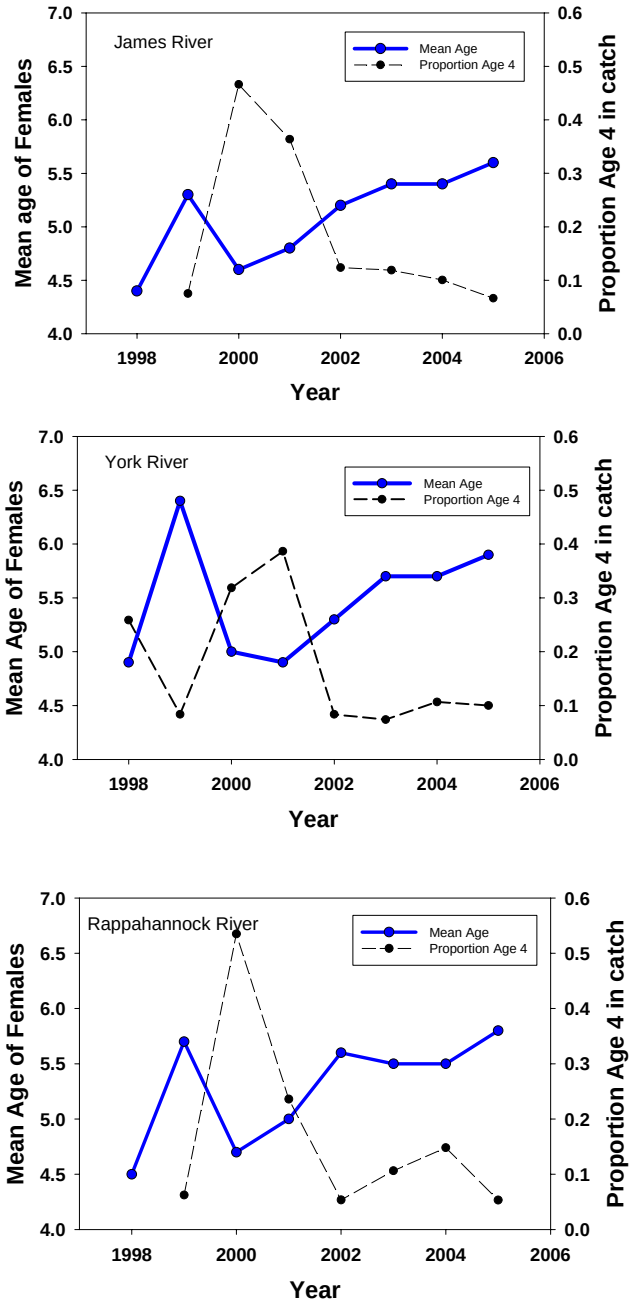
Assessment Results

During the seven years of monitoring on the York River, 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 trend towards decreasing catch rates during the period of monitoring (Figure 2). On the James River, catch index values in 2000 through 2005 are higher than those in 1998 and 1999 (2.57 and 2.99, respectively). This increase in abundance is due to the first influx of mature hatchery fish into the spawning population (Olney *et al*. 2003). The data depict a trend of increasing catch rates during the period of monitoring (Figure 2). The 2003 and 2004 values of the VIMS catch index on the Rappahannock are higher than any previous year of monitoring. The data depict a trend of increasing catch rates since 1998 (Figure 2).

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 3).
On the York River, estimates of total mortality (Table 1) 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).

Figure 3

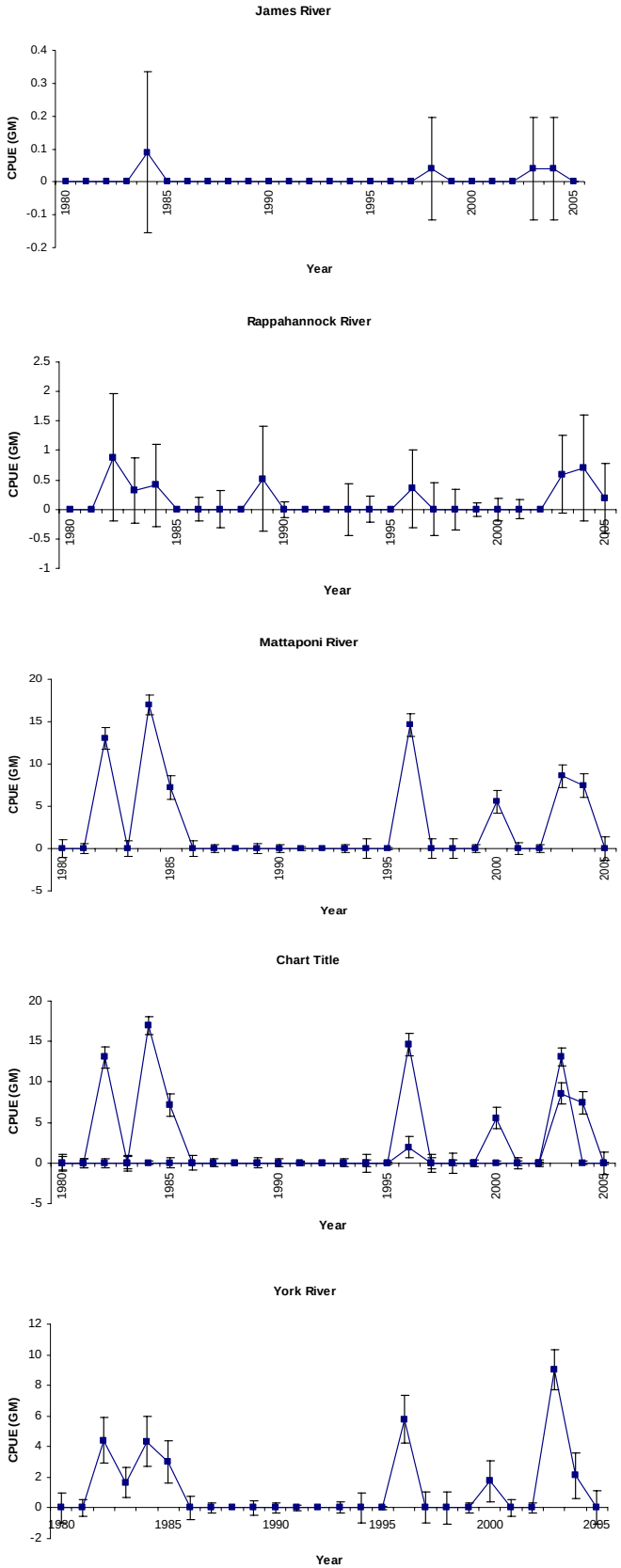


Seine survey data on the James River show no measurable recruitment during most years (Figure 4). With the exception of 2003 data, juvenile abundance index values are consistently higher on the Mattaponi River than they are on the Pamunkey River and the York River (Figure 4, also Wilhite *et a*l. 2003). 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. On the Rappahannock River, the highest juvenile abundance index (JAI) values (>0.5) were recorded in 1982, 1989, 2003, and 2004 (Figure 4). The Rappahannock River time series suggests recruitment failure in 1980, 1981, 1985, 1988, 1991, 1992, 1995, and 2002.

Benchmarks

The benchmark total mortality rate (Z_{30}) ranged from 0.62 to 0.85 depending on the estimate of natural mortality used as input (Table 2). A catch rate benchmark of 17.44 (the geometric mean of the catch index values observed in 1953-1957) is appropriate to assess the York River stock since American shad abundance in the 1980s was insufficient to support the fishery. The geometric means of the catch index values observed between 1980 and 1993 on the James River (6.4) and Rappahannock River (1.45) are not benchmarks but are considered interim targets for restoration. Additional studies are needed to relate current catch rates in the James River to historical data that are available in the form of 1950s commercial logbooks. There are no older logbook data available for the Rappahannock River.

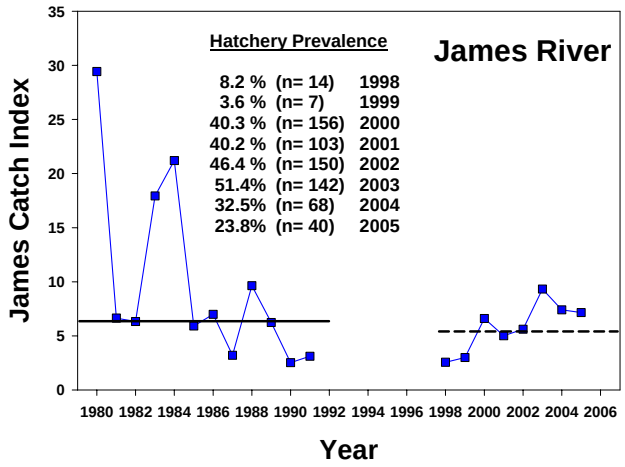
Figure 4


James River
CPUE (GM)
Year
Rappahannock River
CPUE (GM)
Year
Mattaponi River
CPUE (GM)
Year
Chart Title
CPUE (GM)
Year
York River
CPUE (GM)
Year

Conclusions

James River (Figure 5): 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. Current estimates of total mortality (Z) for the stock using catch-at-age and repeat spawning data (Table 1b) are higher than the estimates of Z_{30} generated by the yield model.

Figure 5



York River (Figure 6): 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 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. 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 7) 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 through 1999 has reduced recruitment of young fish to the spawning population in recent years. Current estimates of total mortality (Z) for the stock using catch-at-age and repeat spawning data (Table 1a) usually exceed the estimates of Z_{30} generated by the yield model.

Figure 6

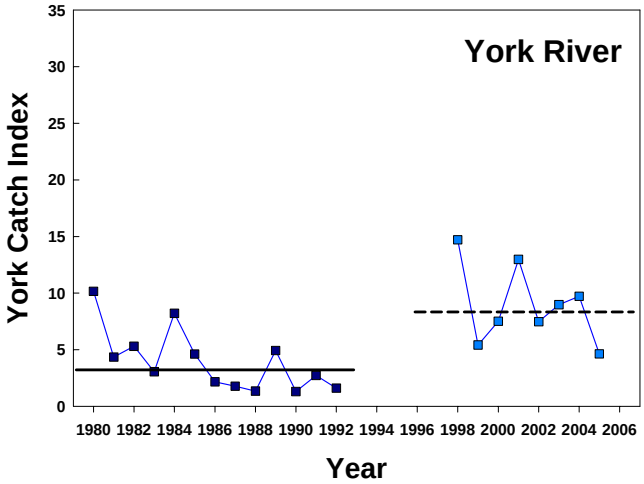
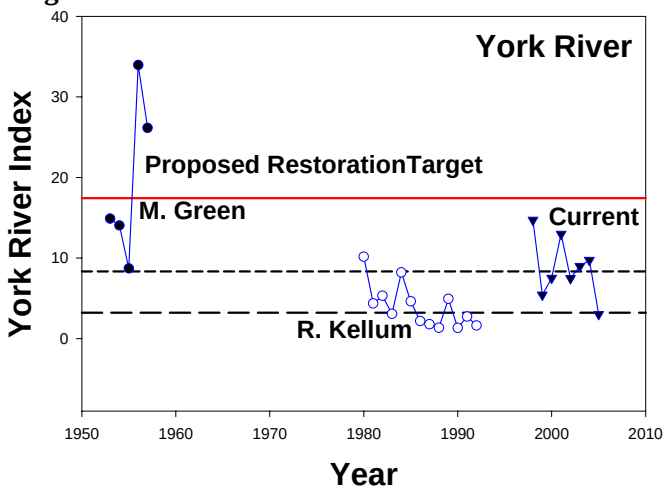
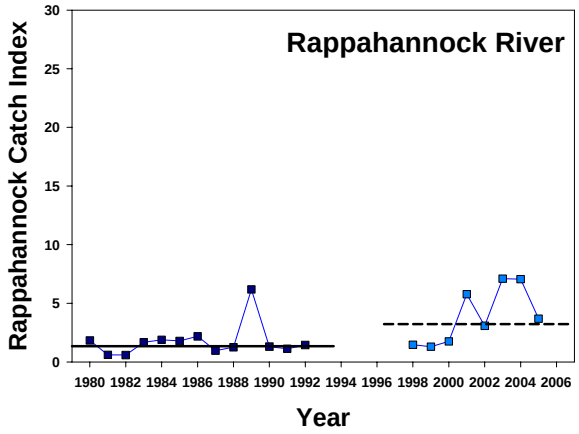


Figure 7



Rappahannock River (Figure 8): The 2003 to 2004 values of the VIMS catch index on the Rappahannock are higher

Figure 8



than all years in the historical data. 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. It should be noted that since the catch index for the Rappahannock River is historically lower than 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 historical and current catch rates, the present status of the Rappahannock River stock is stable with recent evidence of increasing abundance. Current estimates of total mortality (Z) for the stock using catch-at-age and repeat spawning data (Table 1c) usually exceed the estimates of Z_{30} generated by the yield model.

Although harvest of American shad in Virginia has been banned since 1994, the index-based assessment suggests that stock abundance remains low relative to historic logbook data, especially in the James and York rivers. The reasons for this slow recovery are unknown but probably include low levels of recent recruitment, unreported removals and discard mortality.

Literature Cited

Nichols, P.R., and W.H. Massmann. 1963. Abundance, age and fecundity of shad, York River, Virginia, 1953-1959.

Olney, J.E., and J.M. Hoenig. 2001b. Managing a fishery under moratorium: assessment opportunities for Virginia's stocks of American shad (*Alosa sapidissima*). Fisheries 26(2):6-12.

Olney, J.E., D.A. Hopler, Jr., T.P. Gunther Jr., K.L. Maki, and J.M. Hoenig. 2003. Signs of recovery of American shad, *Alosa sapidissima*, in the James River, Virginia. American Fisheries Society Special Symposium 35:323-329.

Table 1
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

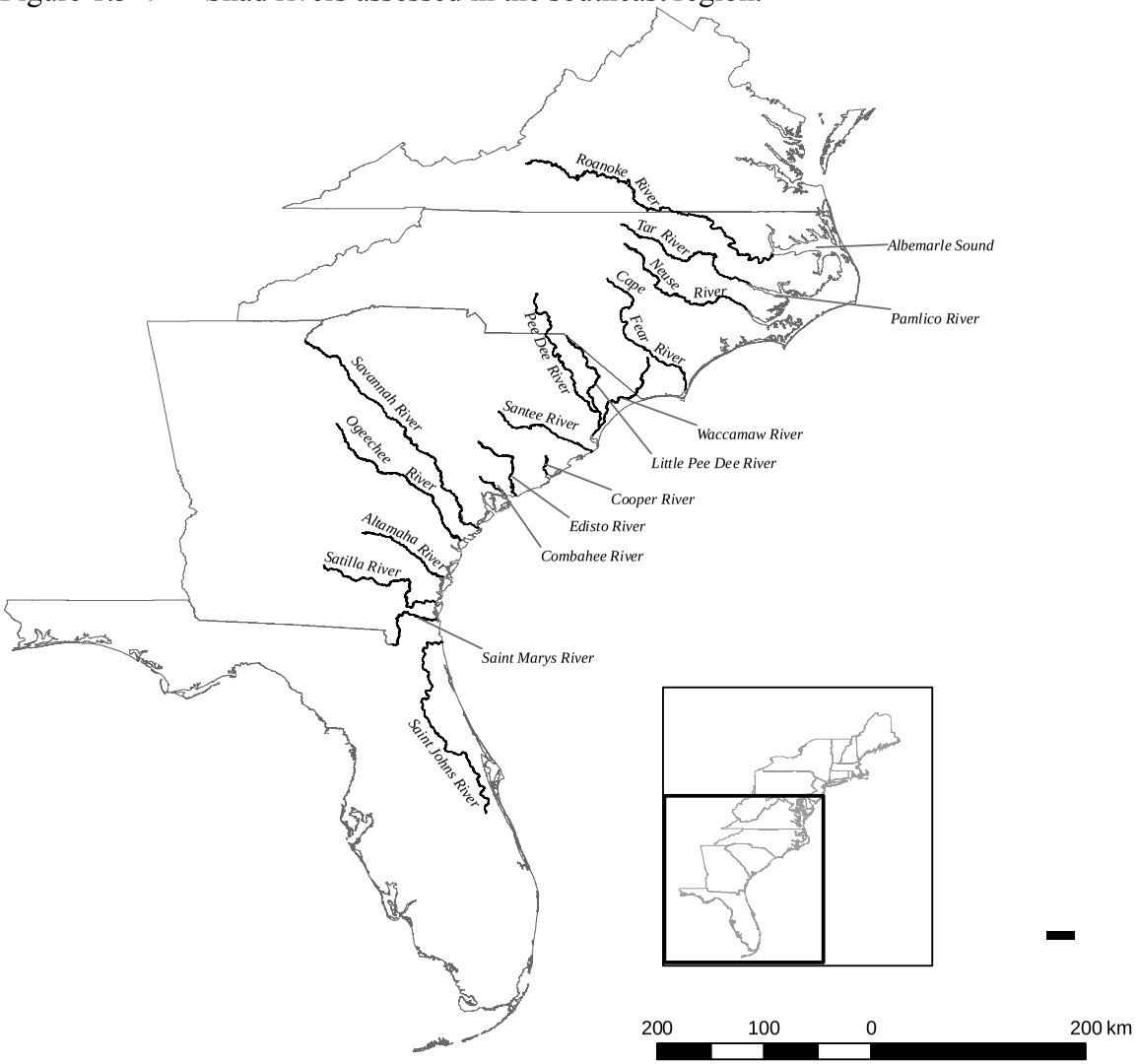
(c)

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 2
F_{30} and Z_{30} yield model estimates for the York River stock using Hudson River and VIMS partial recruitment vectors.

Age	M	F_{30}			Z_{30}		
		Benchmark Values	Hudson Recruitment Vector	VIMS Recruitment Vector	Benchmark Values	Hudson Recruitment Vector	VIMS Recruitment Vector
12	0.35	0.27	0.27	0.3	0.62	0.62	0.65
10	0.42	0.29	0.29	0.32	0.71	0.71	0.74
8	0.53	0.32	0.33	0.36	0.85	0.86	0.89

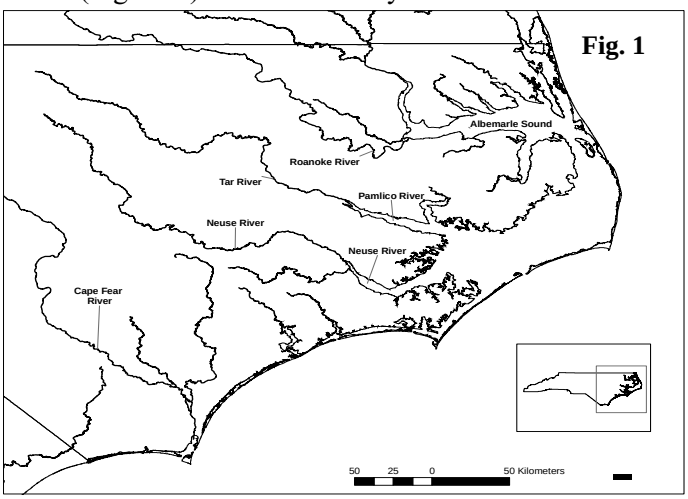
Figure 1.3-4 Shad rivers assessed in the southeast region.



Status of American Shad Stocks in North Carolina

Distribution, Biology and Management

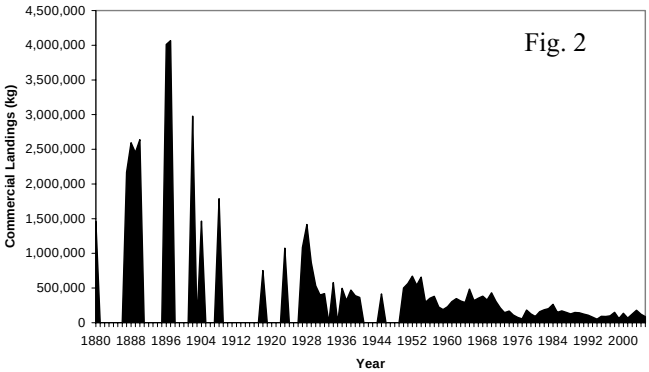
American Shad ascend all coastal rivers in North Carolina and are most abundant in Albemarle and Pamlico sounds and the Roanoke, Chowan, Tar-Pamlico, Neuse, Northeast Cape Fear, and Cape Fear rivers (Figure 1). The life history of shad from Albemarle Sound tends to closely mirror those stocks to the north. American shad populations in North Carolina river systems south of Albemarle Sound form a region where stocks transition from the iteroparous stocks of the north to the semelparous stocks seen in the south. American shad are fully mature at ages 7 or 8 in Albemarle Sound, while shad in other North Carolina systems reach full maturity at ages 6 or 7.



Prior to 1987, few limits were placed on commercial fishing (e.g., no mesh size or yardage limits, seasons, or closed areas). In 1988, an area closure was instituted for a portion of Albemarle Sound, along with gill net mesh restriction in other areas. In 1995, further rules were adopted that made it unlawful to take American shad for commercial purposes by any method from April 15 through January 1. North Carolina's ocean-intercept fishery was closed in 2005. Recreational fishermen can harvest up to 10 shad per person per day by hook and line.

The Fishery

North Carolina landings of American shad peaked in 1897 at at four million kg and decreased to 0.7 million kg by 1918 (Figure 2). 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 from 1973 to 2005.

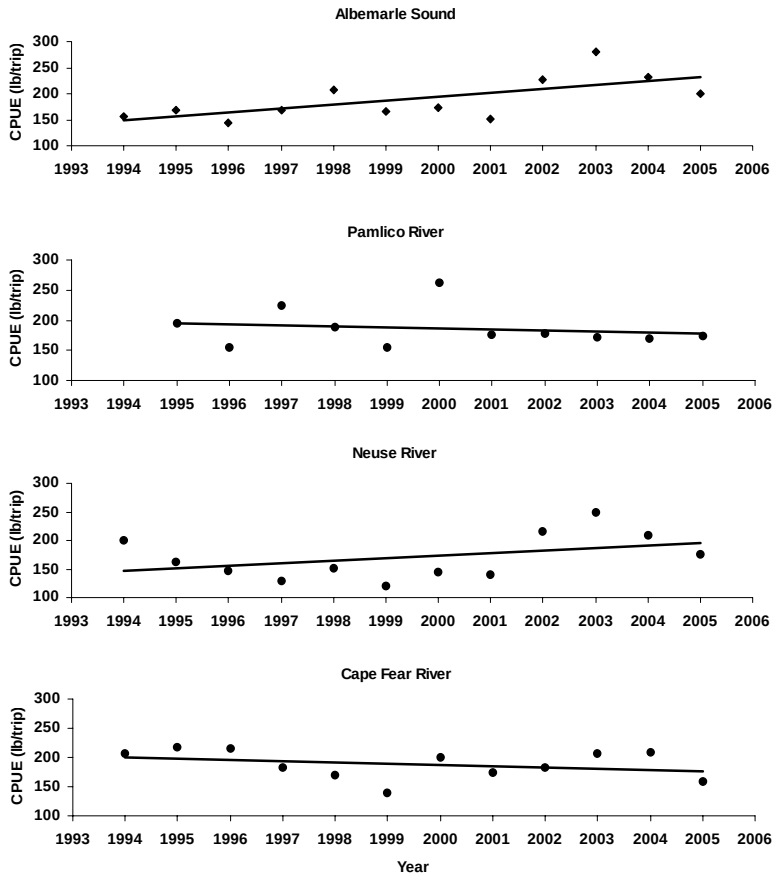


Pound nets were a large component of the commercial harvest in the 1970s but now the vast majority of shad are harvested with gill nets. Landings fluctuate greatly over time, but are currently around the long-term average of 58,263 kg for Albemarle Sound and 13,167 kg for the Neuse River. Current landings are below the long-term averages for the Pamlico River (mean = 10,494 kg) and the Cape Fear River (mean = 13,568 kg). Landings have been declining for the past 3 to 4 years for all systems except the Pamlico River, which remains low but consistent (Table 1).

Indices

Commercial gill-net catch-per-unit-effort (CPUE) data for directed shad trips (>100 lbs) were available after the inception of the North Carolina Trip Ticket Program (1994 to 2005; Figure 3). These CPUEs showed an increasing trend for Albemarle Sound but were without trend for the Pamlico, Neuse, and Cape Fear Rivers.

Fig. 3



Increasing trends were evident in the fishery-independent CPUE estimates from the NCDMF gill-net survey in Albemarle Sound as well as the NCWRC electrofishing survey in the Roanoke River (Figure 4). No trends were evident from NCWRC electrofishing surveys from any other systems (Figure 5). Fishery-independent survey indices are not available for any systems other than Albemarle Sound prior to 2000. A summary of all indices is given in Table 2.

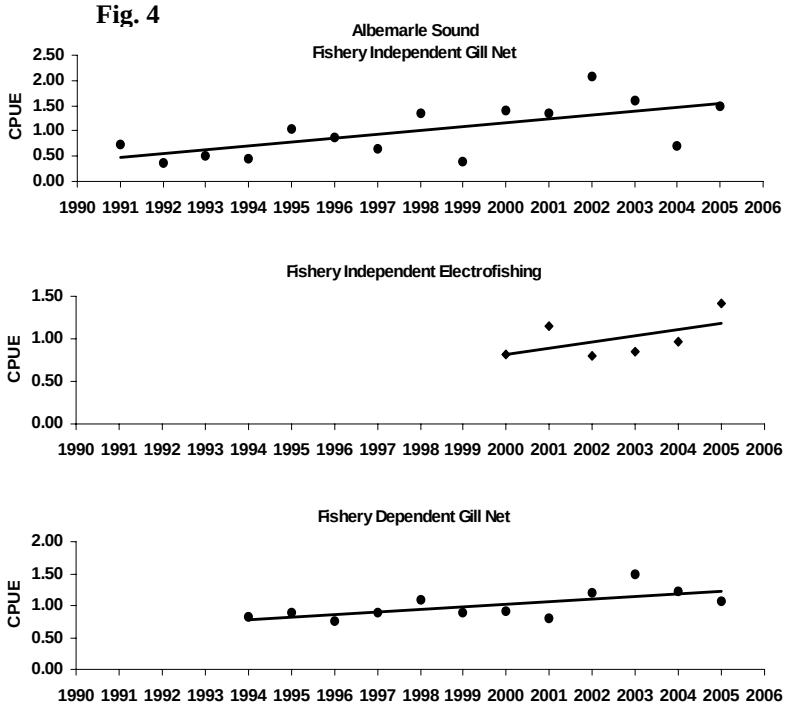
Assessment Results

For all systems, catch curve estimates of total mortality rates (Z) were highly variable and generally ranged from 1 to 2 for both males and females (Figure 6 Albemarle Sound commercial gill net, Figure 7 Albemarle Sound commercial and fishery independent gill, 2000-2005, and Figure 8 Roanoke River fishery independent electrofishing; Tables 3-6; please the North Carolina source document (§13) for figures of Z-estimates from the other systems).

Benchmarks

Catch curve estimates of total mortality rate were higher than the recommended level (Z_{30}) for Albemarle Sound. Adequate data were not available to calculate reference points for any other systems.

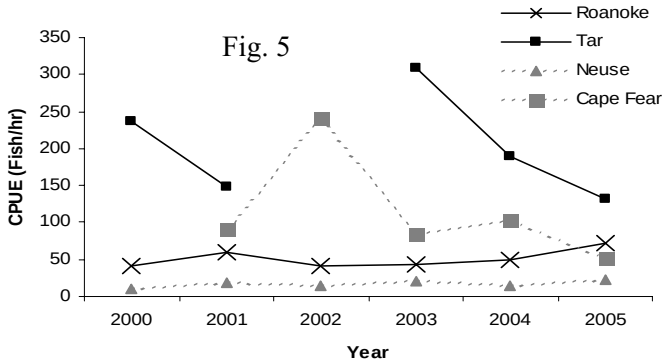
Fig. 4

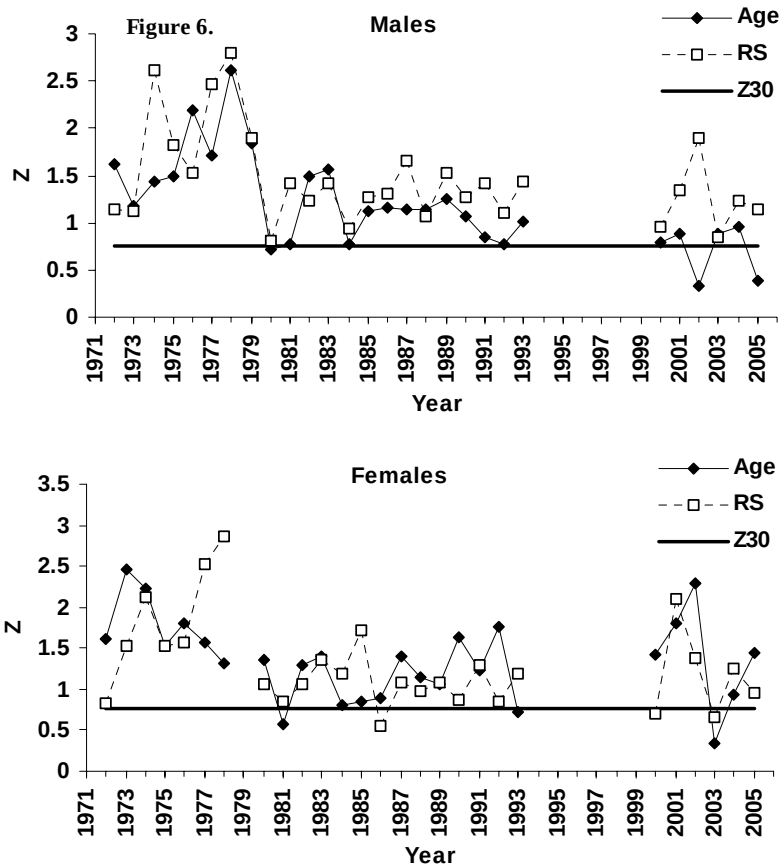


Summary

Albemarle Sound/Roanoke River: 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

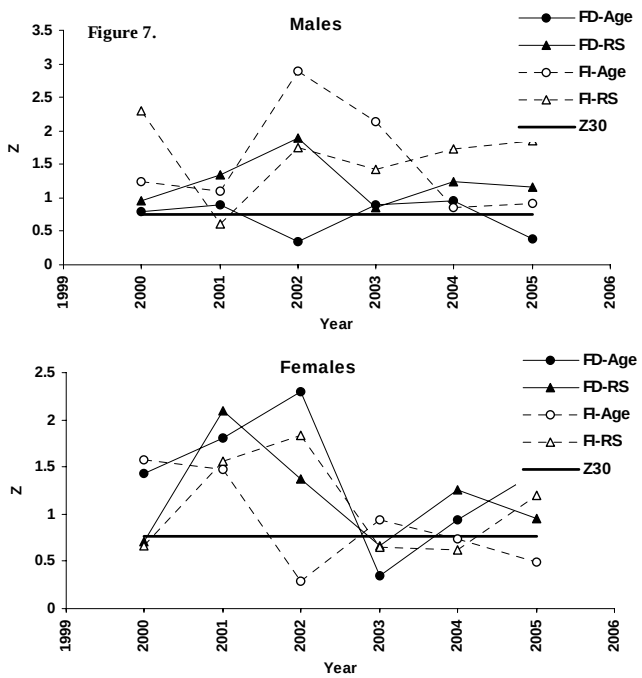
from the Albemarle Sound fishery have made up a significant portion of statewide landings since the late 1980s, it is reasonable that current abundance in Albemarle Sound and its tributaries is well below the historic potential for these stocks. Current landings are much less than the MSY of 1-2 million 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.





Tar-Pamlico: 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 North Carolina 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.

Neuse River: 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 are 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.



Cape Fear River: 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.

Fig. 8

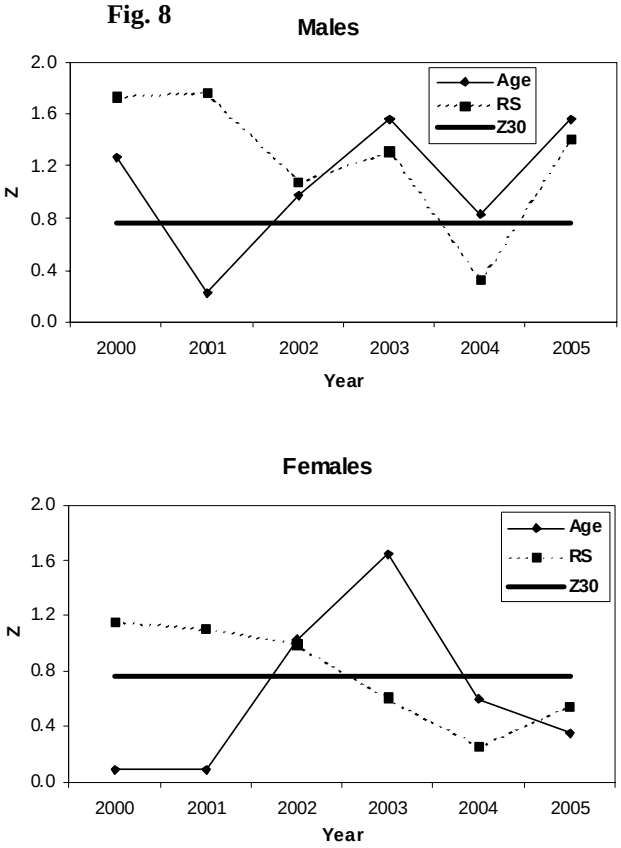


Table 1 North Carolina commercial landings (kg), 1995–2005. Landings were prohibited from April 15 to December 31 of each year.

Year	Atlantic Ocean	Albemarle Sound	Pamlico Sound	Pamlico River	Neuse River	Cape Fear River
1995	46714	27,648	2,373	4,342	6,945	5,071
1996	26385	29,916	4,135	3,934	11,086	12,165
1997	44594	28,844	7,264	5,392	9,891	7,069
1998	53533	76,406	2,272	5,306	5,314	5,055
1999	14955	31,784	2,746	3,139	3,501	3,086
2000	50307	58,779	7,173	9,708	4,182	5,034
2001	5370	43,094	4,440	2,911	4,842	5,708
2002	3800	79,427	6,306	6,792	18,224	8,702
2003	5677	127,320	5,174	7,838	16,379	15,667
2004	3050	82,362	741	7,819	15,257	12,667
2005	101	57,557	2,479	6,667	11,014	7,852

Table 2 Summary of abundance trends by river system. FI = fishery-independent.

System	Source Data	Year Range	Trend
Albemarle	Commercial gill net	1994-2005	Increasing
	FI gillnet	1991-2005	Increasing
Roanoke	FI electrofishing	2000-2005	Increasing
Tar-Pamlico	Commercial gill net	1994-2005	No Trend
	FI electrofishing	2000-2005	No Trend
Neuse	Commercial gill net	1994-2005	No Trend
	FI electrofishing	2000-2005	No Trend
Cape Fear	Commercial gill net	1994-2005	No Trend
	FI electrofishing	2000-2005	No Trend

Table 3 Total instantaneous mortality estimates for American shad in the Albemarle Sound, NC. Age = catch curve from ages, RS = catch curve using repeat spawn 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 4 Total instantaneous mortality estimates for American shad in the Pamlico River, NC. Age = catch curve from ages, RS = catch curve using repeat spawn 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 5 Total instantaneous mortality estimates for American shad in the Neuse River, NC. Age = catch curve from ages, RS = catch curve using repeat spawn 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 6. Total instantaneous mortality estimates for American shad in the Cape Fear River, NC. Age = catch curve from ages, RS = catch curve using repeat spawn 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

Status of American Shad Stocks in South Carolina

Distribution, Biology and Management

Commercial fisheries for American shad occur in Winyah Bay and the Waccamaw, Pee Dee, Black, Santee, Edisto, Combahee, and Savannah rivers, while the Lynches River, Sampit River, Ashepoo River, Ashley River, and Cooper River no longer support large, if any, commercial fisheries (see map of southeast U.S. rivers for overview of South Carolina's major rivers). Recreational fisheries exist in the Cooper, Savannah, Edisto, and Combahee rivers, as well as the Santee River Rediversion Canal. Data were available to assess trends in fishery and stock status of American shad for the following river systems in South Carolina: Winyah Bay and its major tributaries (i.e., Waccamaw and Great Pee Dee rivers), Santee River, Cooper River, Edisto River, Combahee River and Savannah River. Georgia Department of Natural Resources (GADNR) provided additional data for the Savannah River.

The South Carolina Department of Natural Resources (SCDNR) manages its commercial shad fisheries using a combination of seasons, gear restrictions, and catch limits. All licensed fishermen were required to report their daily catch and effort to the SCDNR beginning in 1998. South Carolina has a 10-fish aggregate daily creel limit in recreational fisheries for American and hickory shad in all rivers except the Santee River, which has an aggregate creel limit of 20-fish per day.

American shad returning to South Carolina rivers are generally believed to be semelparous. 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; however, a low degree of repeat spawning was reported in 1985 (3% for males and 2% for females).

The Fishery

The commercial gill-net fishery targets females. SCDNR has collected landings data by river system since 1979 and instituted mandatory catch and effort reporting in 1998; however, mandatory reporting has not been fully implemented. Questions remain 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.

Historical commercial shad landings data from the National Marine Fisheries Service (NMFS) are available for South Carolina back to 1880 with the highest reported landings occurring in 1896 (304,819 kg). NMFS port agents compiled landings data until 1979. Landings generally declined from the late 1800s throughout the twentieth century reaching a low in the 1970s (11,022-28,305 kg). Total American shad landings in South Carolina decreased from 191,098 kg in 2004 to 92,194 kg in 2005 (Table 1). From 1979 to the middle 1990s, ocean-intercept landings were typically greater than in-river landings. Since then, the ratio of ocean landings to in-river landings has declined, culminating with the ocean fishery closing in 2005. In 2000, 2,727 commercial shad fishing trips were reported to SCDNR, decreasing to 2,132 trips in 2005. With the ocean-intercept fishery closure in 2005, the Santee River and Winyah Bay are now the largest commercial shad fisheries in South Carolina, with Santee River landings comprising 58% and Winyah Bay landings 38% of the 2005 statewide total.

Winyah Bay (Waccamaw, Great Pee Dee, Little Pee Dee, Lynches, Sampit, and Black rivers): Winyah Bay 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 Winyah Bay fishery was not included in the closure of the ocean-intercept fishery. Shad gillnetting on the Sampit River was generally limited to the first 16 km of the river above its confluence with the Winyah Bay. Most American shad fishing occurs in the lower 97 km of Black River. Gillnetting for American shad on the Great Pee Dee River occurs to rkm 105, with activity up to at least

rkm 240. Fish migrating to the Little Pee Dee and Lynches Rivers must have successfully by-passed fisheries in the Great Pee Dee before entering their respective tributary streams at approximately rkm 72 and rkm 113, respectively. Shad gillnetting is generally restricted to the lower 32 km of the Little Pee Dee River. The Lynches River shad fishery is prosecuted in the lower 24 km.

Winyah Bay landings averaged 37,695 kg a year since 1979, with a period of below average landings from 1987 to 2000 (Table 1). American shad landings reached 114,104 kg in 1981. Recent peaks in landings came in 2002 and 2004. Winyah Bay landings (32,797 kg) were below average for the time series in 2005. Landings for the major tributaries of Winyah Bay (Waccamaw River and Pee Dee River) are available since 1999. Reported landings for the Pee Dee River averaged 11,935 kg from 1999 to 2005. Reported landings for the Waccamaw River averaged 11,935 kg from 1999 to 2005. The smaller shad fisheries of other Winyah Bay tributaries have not faired well. By 1960, the Sampit River no longer supported a commercial shad fishery. Shad fisheries in both the Lynches River and Black River have experienced large declines since 1960.

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 inland 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 until 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 the Santee dam are closed to gill nets.

American shad landings on the Santee River were 5,183 kg in 1896 and 24,610 kg in 1960. Since 1979, Santee River commercial shad harvest has averaged 42,260 kg a year, with 53,901 kg landed in 2005 (the lowest since 1995; Table 1). Note that the landings include "before and after" Rediversion landings, where annual harvest averaged 2,554 kg from 1979 to 1985; however, since the completion of the Rediversion Canal in 1985 landings have averaged 56,157 kg a year. Annual fishing effort has averaged 710 trips since 1999. The number of trips in 2005 dropped to 577 from 696 in 2004.

A recreational creel survey conducted by SCDNR in the Santee River before and after completion of the Rediversion Canal showed that total annual effort for all species targeted in recreational fisheries increased by 52.1% in the post-Rediversion survey, while landings increased by 77.5% from the earlier period.

Cooper River: The Cooper River is navigable for approximately 80 km and is impounded by the Pinopolis Dam, which was part of the original Santee-Cooper Project, at approximately rkm 88. The Cooper River likely supported a small shad stock before the creation of the lakes and rerouting of the Santee River. Hook and line is the only legal gear on the Cooper River.

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 (Table 1). The Cooper River supports an active recreational fishery below the Pinopolis Dam tailrace in the late winter to early spring. A recreational creel survey conducted by SCDNR on the Cooper River estimated shad catch (in numbers) from 2001 to 2005 to be 3,864, 3,199, 6,856, 5,529, and 14,629. A recreational creel survey investing all recreational fisheries on the Santee River and Cooper River conducted by SCDNR before (1981 to 1982) and after (1991 to 1993) completion of the Rediversion Canal showed that, although effort increased slightly after Rediversion on the Cooper River, landings of all fish decreased over 50% from the earlier period.

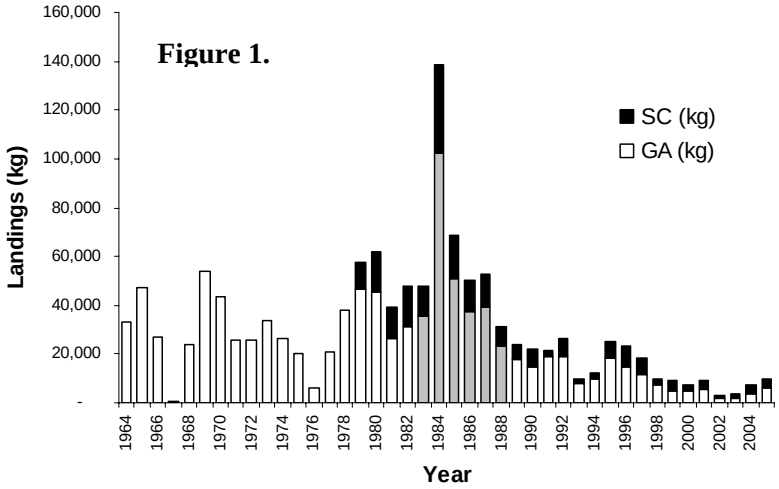
Edisto River: The Edisto River is approximately 356 km long and is open to the shad gill-net fishery (both set and drift nets) for its entirety, and continues to support a gill-net fishery to approximately rkm 161. The Edisto River has supported commercial shad fishery for over 100 years and a recreational fishery since the late 1960s. Historically, commercial fishing effort was concentrated between rkm 30 and 50, with gillnetting, 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.

The magnitude of the Edisto River commercial fishery has declined since 1896 when landings were 58,732 kg. Landings dropped to 15,145 kg in 1960 and from 1979 to 2005 Edisto River commercial shad landings averaged 2,934 kg a year (Table 1). The lowest landings in the time series occurred from 1994 to 1997. Since 2000, landings have averaged 2,211 kg a year with 1,686 kg landed in 2005. This assessment does not account for an unknown recreational harvest.

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 approximately rkm 40 and rkm 80. There is a very small recreational hook and line (trolling) fishery. Drift nets are rarely, if ever, used on the Combahee River.

In 1896, 6,419 kg of shad were harvested on the Combahee River; landings dropped to 878 kg in 1960. The Combahee has supported a small fishery that has landed an average of 715 kg shad per year since 1979 (Table 1). Since 1998, landings have been below the time series average, but have been stable, and, in 2005, 403 kg of American shad were landed.

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 used primarily in tidal portions of the river, but set nets are the principal gear used throughout the river.



American shad harvested from the Savannah River are landed in both Georgia and South Carolina. Landings decreased by an order of magnitude from 1896 (94,074 kg) and 1960 (74,671 kg) to 2005 (9,766 kg). From 1964 to 1979, annual landings in Georgia averaged approximately 30,000 kg. South Carolina shad landings were stable from 1979 to 1987 averaging 16,689 kg per year, but have decreased with landings not exceeding 10,000 kg since 1997 and reaching a time series low of 1,150 kg in 2002 (Table 1; Figure 1). Savannah River shad landings for South Carolina in 2005 were 3,407 kg. Georgia landings have accounted for 71% of Savannah River shad landings when both states have reported landings. A recreational creel survey provides a snapshot of estimated recreational catch and effort for 1999.

Indices

Overview of Indices: SCDNR identified a group of "reliable" fishermen who volunteered their catch and effort data on female American shad during investigations into South Carolina's commercial American shad fishery from 1979 to 1985. These records were used to develop fishery-dependent catch-per-unit-effort (CPUE) from 1979 to 2000 and were collected from fishermen from Winyah Bay and Waccamaw, Pee Dee, Santee, Edisto, Combahee, and Savannah rivers. With the initiation of mandatory reporting in 1998, SCDNR decided to use the mandatory reporting records from these "reliable" fishermen to continue the CPUE time series beginning in 2001 to maintain consistency with data from earlier years.

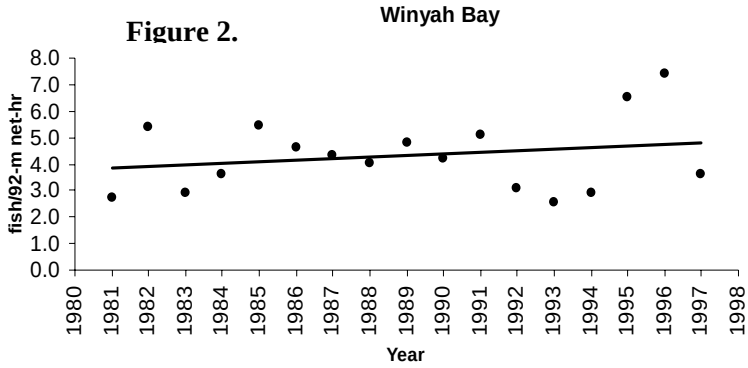
The CPUE data collected from the "reliable" fishermen throughout the state are used only to make general observations on changes in "perceived stock status" since 1979. Many variables, such as water temperature, water levels, flow rates, and fuel and shad prices affect observed CPUE values and these parameters are highly variable between seasons and might have substantial impacts on catchability, and even effort, particularly in certain rivers.

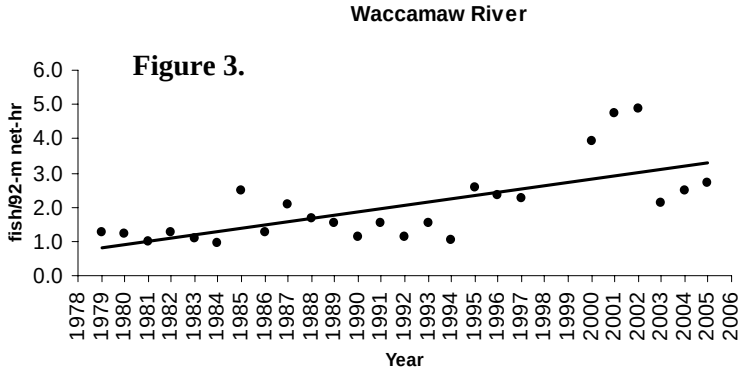
Fish passage at the St. Stephen Dam was monitored by hydroacoustic sampling from 1986 to 1987, real-time human counts from 1988 to 1994, and time-lapse video recording from 1994 to 2005. Since the proportion of Santee River American shad that entered the Rediversion Canal and the efficiency of the Fish Lock both are unknown and appear to vary among years, fish passage at this facility can only be used to document general abundance trends.

Relative exploitation of American shad on the Santee River was estimated using commercial gill-net landings data and fish-lift counts from the St. Stephen fish-lift. A minimum population bound was calculated by summing landings and fishway counts in numbers for each year. This is considered a minimum bound because commercial landings are and do not include recreational removals, and fish passage is unknown. Relative exploitation rates were estimated by dividing catch by the minimum population bound for the year.

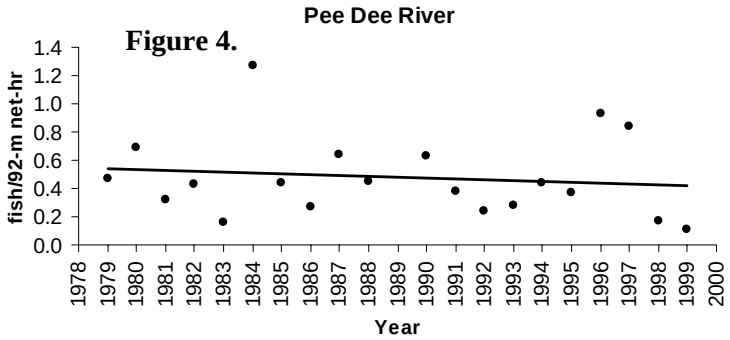
The Cooper River supports an active recreational fishery below the Pinopolis Dam tailrace in the late winter to early spring. SCDNR has conducted a creel survey from 2001 to 2005 to estimate catch, harvest, and CPUE in this recreational fishery.

Winyah Bay: Data from the volunteer fishermen in the drift gill-net fishery in Winyah Bay produced a continuous dataset from 1981 through 1997. Fish moving through the lowermost portion of this complex system may be bound for any Winyah Bay tributary (i.e., a mixed stock). The CPUE fluctuated without trend throughout the time series (Table 2; Figure 2). No data were collected from 1998 through 2000. The cooperating fisherman who provided drift-net catches for this area switched to set nets beginning in 2001.

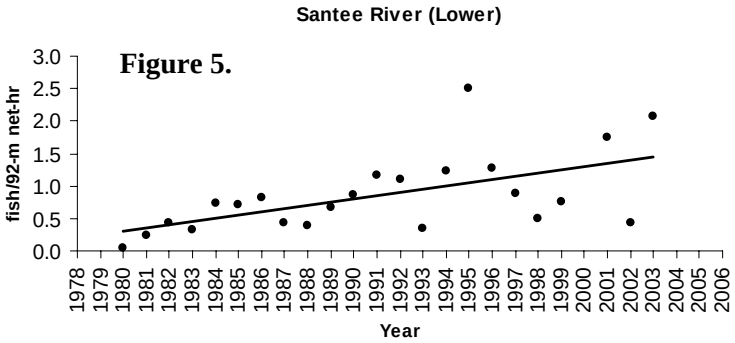




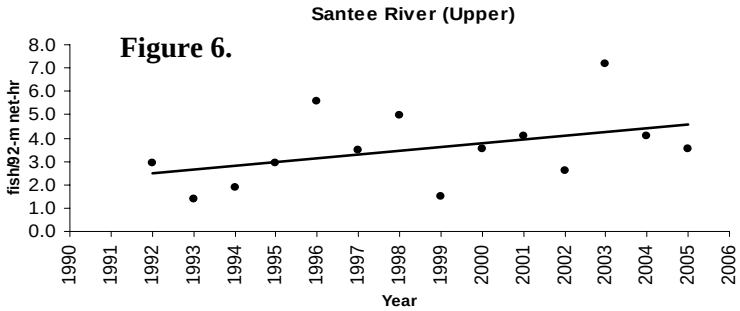
The commercial drift gill-net CPUE in the lower Waccamaw River had a significant increasing slope (Table 2; Figure 3). CPUE data for the Pee Dee River did not show a significant trend over the years 1979 to 1999 (Table 2; Figure 4).



Santee River: CPUE records for commercial gill net fisheries on the Santee include a lower drift gill-net series and upper set-net series (Figures 5 and 6). Both CPUE series increase with time, but only the lower set-net CPUE trend is significant (Table 2). The lower set gill-net fishery consistently increases over the whole time series including the years before completion of the Rediversion Canal.



From 2001 to 2005, the St. Stephen fish-lift passed 965,804 American shad into the Santee-Cooper lake system. Annual American shad passage decreased during this time compared to the previous six years. 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.

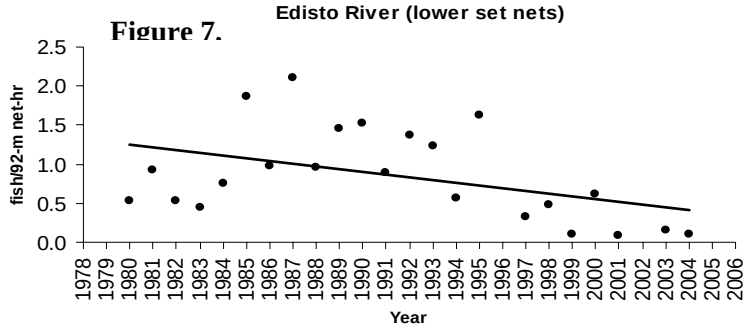


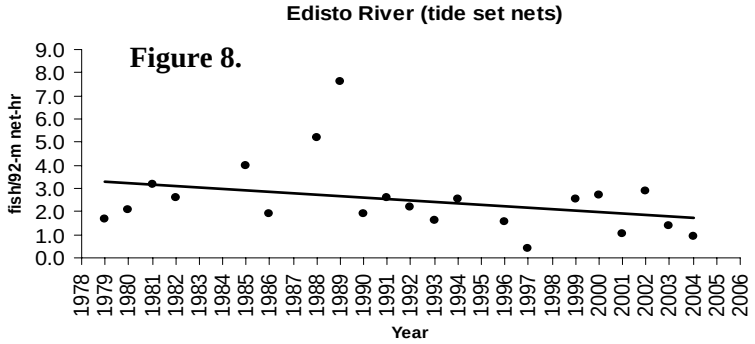
The relative exploitation estimates, derived from the commercial landings and fish count data, peaked in 1988 and 1989 when minimum population size was at its lowest. This might partially explain catch increases in the lower set nets, if shad were more "catchable" those two years. Relative exploitation 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.

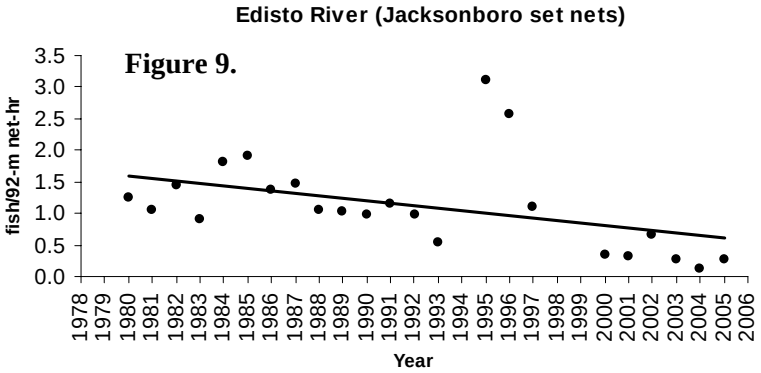
Cooper River: Recreational catch-per-man-hour (CPMH) averaged 0.96 and ranged from 0.59 in 2002 to 1.60 in 2005. CPMH increased slightly during the five-year period. The 10-fish per day creel limit has been in effect for the duration of this study. Twenty-two percent of the catch was released in 2005.

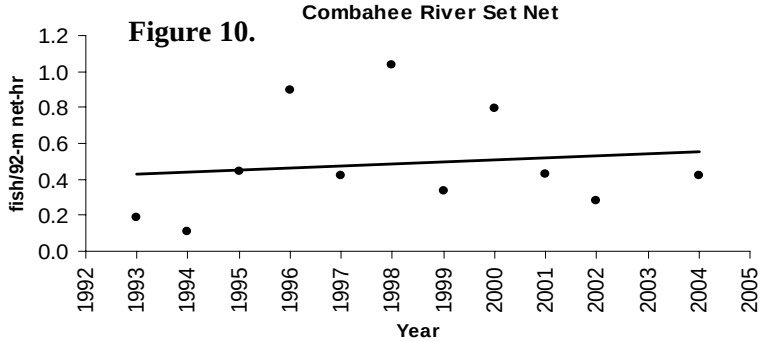
Edisto River: Three CPUE time series are available for the Edisto River: the lower 24-hour set gill net, the tide set gill net, and the Jacksonboro set gill net—each has declined (Figures 7-9) with significant negative slopes for both the lower 24-hour set gill net and the Jacsksonboro set gill net datasets (Table 2).

Combahee River: CPUE data for the Combahee River set gill-net fishery had no discernable trend (Table 2; Figure 10).







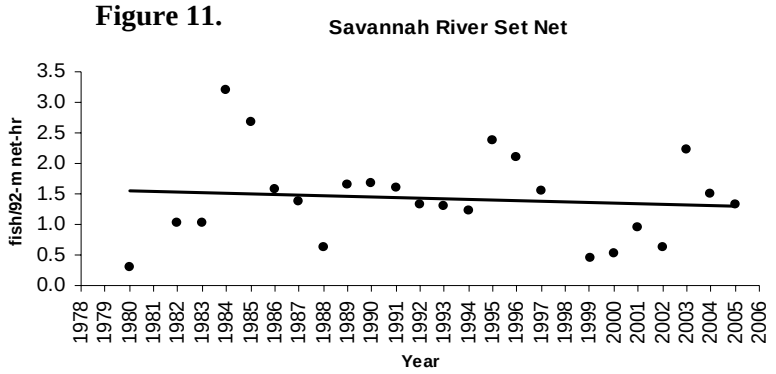


Savannah River: The SCDNR commercial set gill-net CPUE series for the Savannah River did not show a discernable trend (Table 2; Figure11). GADNR effort data show that an average 66.7 drift gill-net trips per year were made on the Savannah River since 2000. Earlier effort records from GADNR were not reliable, because records for individual trips often included records from multiple trips or from partial trips. CPUE was not calculated from GADNR catch and trip records for set gill nets because the number of reported trips fluctuated inconsistently since 2000 (from 1 to 52 trips per year) and the time series is short.

Other Studies: SCDNR has also conducted tag-return studies in the gill-net fisheries for several rivers. 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). The ASMFC American Shad Stock Assessment Subcommittee did not use these exploitation rates to evaluate the American shad stock status in South Carolina because no data were available to determine if the following assumptions of tag-return studies were violated: (1) no tag loss, (2) 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 up river and do not stop their migrations after tagging.

Juvenile Surveys: Trawl sampling studies were conducted for juvenile American shad in the fall of 1985 in the Edisto River and Winyah Bay. These programs were discontinued after a single sampling season.

Figure 11.



Assessment Results

Winyah Bay Conclusions: 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 and Pee Dee rivers, 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, fisheries prosecuted in Winyah Bay may hinder the rebuilding of American shad populations in these rivers. The available evidence suggests that the larger shad stocks in Winyah Bay have remained stable or increased slightly since the late 1970s, but these trends cannot be substantiated for the status of the smaller tributaries.

Santee River Conclusions: The Santee River American shad stock appears to have increased since the completion of the Rediversion Canal (Table 2); however, the large decrease in American shad counts at the St. Stephen fish-lift since 2000 is cause for concern. Decreases could indicate a reduction in stock size or a reduction in the proportion of fish entering the diversion 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 increase, then there could be cause to closely monitor this American shad stock, especially if effort is redirected to the Santee River from the closed ocean-intercept fishery.

Cooper River Conclusions: The recreational creel survey provides a short time series of harvest and catch rate estimates (2001-2005) and provides evidence that the river has been able to sustain the current level recreational harvest. The recreational fishery appears to be healthy and the increasing catch-per-man-hour (CPMH) observed in the creel survey may indicate that the population can withstand current harvest levels without any decline; however, additional years of the survey will be need to confirm these observations.

Edisto River Conclusions: Recent estimates of commercial CPUE have declined in all three available time series, significantly for two of them (Table 2), and landings have been below the time series (1979-2005) average for 13 of the last 15 years. Given the low landings and declining commercial set gill-net CPUE, continued harvest of Edisto River American shad could prolong the recovery of this stock or lead to continued stock declines.

Combahee River Conclusions: 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 Combahee River American shad showed no significant trend since 1993 (Table 2). 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 Conclusions: 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 harvest levels (Table 2).

Other Rivers: There is a little or no information on the shad stocks of the Lynches, Black, Sampit, Wateree, Catawba, Wando, Ashley, Ashepoo, and Coosawhatchie rivers and Bull Creek that provide insights on stock status. Since these stocks are perceived as small, removals from these stocks could prolong or prevent successful rebuilding of these stocks. Threats to small stocks harvested within the Winyah Bay mixed stock fishery are discussed above.

Benchmarks

No benchmarks were established for evaluating American shad status in South Carolina's rivers.

Summary

Available information on the river specific stocks shows different states of stock status. The largest stocks (Winyah Bay (mixed stock), Waccamaw River, and Santee River) appear stable or to have increased since the late 1970s; however, in the case of the Winyah Bay mixed stock this cannot be substantiated for its smaller tributaries (Lynches River, Black River and Sampit River). The Santee River fishery and stock appears to have increased since completion of the Rediversion project. Recent decreases in fish-lift counts, declines in mean age and size, and the potential for increased effort suggests that continued monitoring of this stock is warranted to ensure the long-term health of the Santee River stock. The Cooper River appears to be able to support current recreational harvest levels, and continuing the creel survey to monitor this fishery is advised. On the Savannah River, there has been no trend in commercial CPUE since the late 1970s.

The decline in commercial CPUE and low landings on the Edisto River provides evidence of a declining, if not depleted, American shad stock. Similarly, the Combahee River American shad stock is likely depressed, but the only available catch and effort index for the stock begins in 1993. There is a lack of information on the American shad stocks of other rivers in South Carolina. These stocks are perceived as small and removals from these stocks could prolong or prevent successful rebuilding of these stocks.

Table 1. American Shad landings by river in South Carolina since 1996.

Year	Winyah Bay Complex	Santee River	Cooper River	Edisto River	Combahee River	Savannah River (SC)	Total In-river	Ocean-Intercept	Statewide (All Waters)
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 2. Summary of abundance trends in from commercial gill net CPUE in South Carolina by river.

System	Dataset	Gear	Years	Mixed Stock*	Slope	*P*-value	R-square	Conclusion
Winyah Bay		Drift Gill Net	1981-1997	Yes	0.060	0.390	0.050	No discernable trend in dataset
Waccamaw River		Drift Gill Net	1979-2005	No	0.095	<0.001	0.476	Significant positive slope
Pee Dee River		Set Gill Net	1979-1999	No	-0.006	0.580	0.017	No discernable trend in dataset
Santee River	Upper Santee	Set Gill Net	1979-180,1986, 1992-2005	No	0.160	0.137	0.175	No discernable trend in dataset
	Lower Santee	Drift Gill Net	1980-2003	No	0.049	0.004	0.329	Significant positive slope
Edisto River	Lower	Set Gill Net	1980-2004	No	-0.035	0.040	0.186	Significant negative slope
	Tide Set Net	Set Gill Net	1979-1982,1985,1986,1988-1994, 1996,1997,1999-2000	No	-0.062	0.169	0.097	No discernable trend in dataset
	Jacksonboro	Set Gill Net	1980-2005	No	-0.040	0.041	0.184	Significant negative slope
Combahee River		Set Gill Net	1989, 1993-2004**	No	0.012	0.683	0.019	No discernable trend in dataset
Savannah River		Set Gill Net	1980-2005	No	-0.010	0.632	0.011	No discernable trend in dataset

* 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

Status of American Shad Stocks in Georgia

Distribution, Biology and Management

The Georgia Department of Natural Resources (GADNR) manages American shad by river system. The Altamaha, Ogeechee, and Savannah rivers each support commercial American shad fisheries (see map of southeast U.S. rivers). There are small shad runs in the Satilla and St. Marys rivers, and no commercial landings have been reported from these rivers since the 1980s. In addition to 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) and the Savannah River assessment is included in Chapter 14.

Commercial set and drift gill-net fisheries are conducted in the Altamaha, Ogeechee, and Savannah rivers, with regulations including mesh size and lead length restrictions, and closed season. The Altamaha River has the largest commercial shad harvest in Georgia followed by the Savannah River and then the Ogeechee River. Before 1980, a shad license was required to fish commercially for American shad and hickory shad in Georgia, since then commercial shad fishing has been covered by a general commercial fishing license. The commercial shad season is open each year from January 1 to March 31. Each river has weekly closures in effect. Set and drift gill nets are the only legal commercial gear for American shad in Georgia. Set gill nets were banned in the lower Savannah River in 1990. All sturgeon, catfish, and non-shad gamefish must be immediately released. There is no commercial shad fishing on the St. Marys River, due to the Florida net ban enacted in 1995.

Recreational fisheries currently exist in the Ogeechee and Savannah rivers, with a creel limit in both rivers of 8 fish per angler. Shad are infrequently caught as bycatch in Altamaha River recreational fishery. 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.

Shad in Georgia are believed to be semelparous. There are no records of repeat spawning marks in 1,311 male specimens and 2,452 female specimens examined by GADNR that were collected from the 1960s to recent years.

The Fishery

Studies in the late 1970s and the 1980s of the commercial fishery for American shad documented substantial underreporting, as shad that were sold to inland dealers or kept for personal use were not included in National Marine Fisheries Service landings data. Mandatory catch and effort reporting was instituted in 2000. Before mandatory reporting, catch and effort data were required, but were not always collected due to difficulties in enforcement and reported individual “trips” were often summaries of multiple trips or represented partial trips. Underreported landings and a short time series of mandatory effort reporting, limit the extent that commercial fishery data can be used in this assessment.

Statewide records of American shad landings in Georgia date back to 1880 and peaked in the early 1900s. In the 1960s, landings reached a second peak of consistently high landings, sustaining average annual harvests of nearly 200,000 kg. 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. Landings from 1996 to present for each river are in Table 1.

Reported landings of American shad in the Altamaha River peaked in 1968 at 213,963 kg and then declined steadily to the early 1980s. From 1983 through 1988, landings average 122,150 kg before declining to an average of 44,675 kg from 1989 to 1994. Landings increased briefly from 1995 to 1998, averaging 106,646

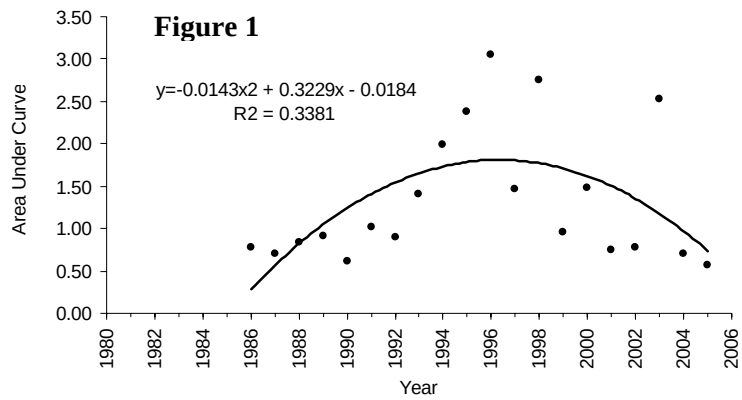
kg annually and then declined to a mean of 30,535 kg a year from 1999 to 2005. Landings in 2005 were 25,653 kg. A roving commercial gill-net survey was conducted by GADNR from 1982 to 1991 to collect catch and effort for the entire Altamaha River shad fishery. Catch and effort data were available for the commercial drift gill-net fishery since 2000.

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. 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. Recreational harvest of American shad and hickory shad in the Ogeechee River was estimated through an access creel survey conducted in 1996 (1,239 fish), 2000 (295 fish), and 2005 (442 fish).

Historically, harvests greater than 10,000 kg per year occurred on both the Satilla and St. Marys rivers; however, no commercial harvest has been reported from either river since the late 1980s.

Indices

An area under the curve index (AUC) of daily catch (numbers) of drift gill nets per net (ft)-hour. for Altamaha River spawning runs of American shad was developed for each season since 1986 using data collected by GADNR during collections for their tag-return study (Figure 1). The AUC approach was utilized because it accounts for both the magnitude of daily catch rates and season duration.



The tag-return study on the Altamaha has been used by GADNR to develop estimates of exploitation and population size. The ASMFC American Shad Stock Assessment Subcommittee (SASC) did not use these exploitation rates to evaluate the Altamaha River American shad stock status because no data were available to determine if assumptions of tag-return studies were violated: (1) no tag loss, (2) 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 up river and do not stop their migrations after tagging.

GADNR conducts a recreational creel survey on the Ogeechee River every five years to estimate the harvest and effort. There are no monitoring efforts on either the Satilla River or St. Marys River.

A juvenile survey was conducted from 1982 to 1991 in the Altamaha, but was discontinued because the juvenile abundance index did not relate to the subsequent adult spawning stock or the parent stock that produced it. A juvenile survey was conducted from 1982 to 1985 on the Ogeechee River.

Assessment Results

The lone CPUE series spanning sufficient time to provide insight of recent population trends was from the GADNR tag-return study collections and was used to develop an area under the curve estimate of the seasonal catch in numbers per net (ft)-hour. 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 (Figure 1). Other indices are of short duration (recent commercial drift gill-net CPUE) or were terminated in the early 1990s (roving commercial gill-net survey and did not have significant trends. In summary, the Altamaha River American shad fishery and stock are at depressed levels compared to 1960s and earlier. Data are insufficient to quantitatively assess the Ogeechee, Satilla, and St. Marys rivers.

Benchmarks
No benchmarks were developed by the SASC for Georgia rivers.

Summary
The Altamaha River American shad fishery and stock are at depressed levels compared to the 1960s and earlier. The AUC index indicates a brief increase in the stock from 1995 through 1998, before decreasing to current low levels. The American shad fishery on the Altamaha River and other Georgia rivers is believed to be declining. Until signs of increased abundance are evident, either from the decline in commercial effort within the river and from the closure of the ocean-intercept fishery, harvest of American shad should not be increased on the Altamaha River. Developing a benchmark based on a desirable level of the AUC index might be challenging, since the fishery is declining and the long history of underreporting harvest.

Increased harvest of American shad on the Ogeechee River, and harvest Satilla and St. Marys rivers, is not warranted until usable indicators of stock status can be developed to guide further management activities. Continued harvest of shad on Georgia's shad producing rivers may prolong successful rebuilding of their natal shad runs.

Table 1. American Shad landings by river in Georgia since 1996.

Year	Total Landings	Altamaha River	Savannah River	Ogeechee River	Satilla River	St. Marys River
1996	120,781	50,750	14,859	1,789		
1997	106,484	42,763	11,680	1,058		
1998	148,540	44,733	52,557	350		
1999	50,752	14,383	4,983	442		
2000	66,029	18,730	4,657	434		
2001	60,704	18,150	5,750	351		
2002	30,813	8,491	1,729	351		
2003	38,798	11,916	1,780	17		
2004	29,416	13,648	3,410	134		
2005	41,529	11,636	6,366	69		

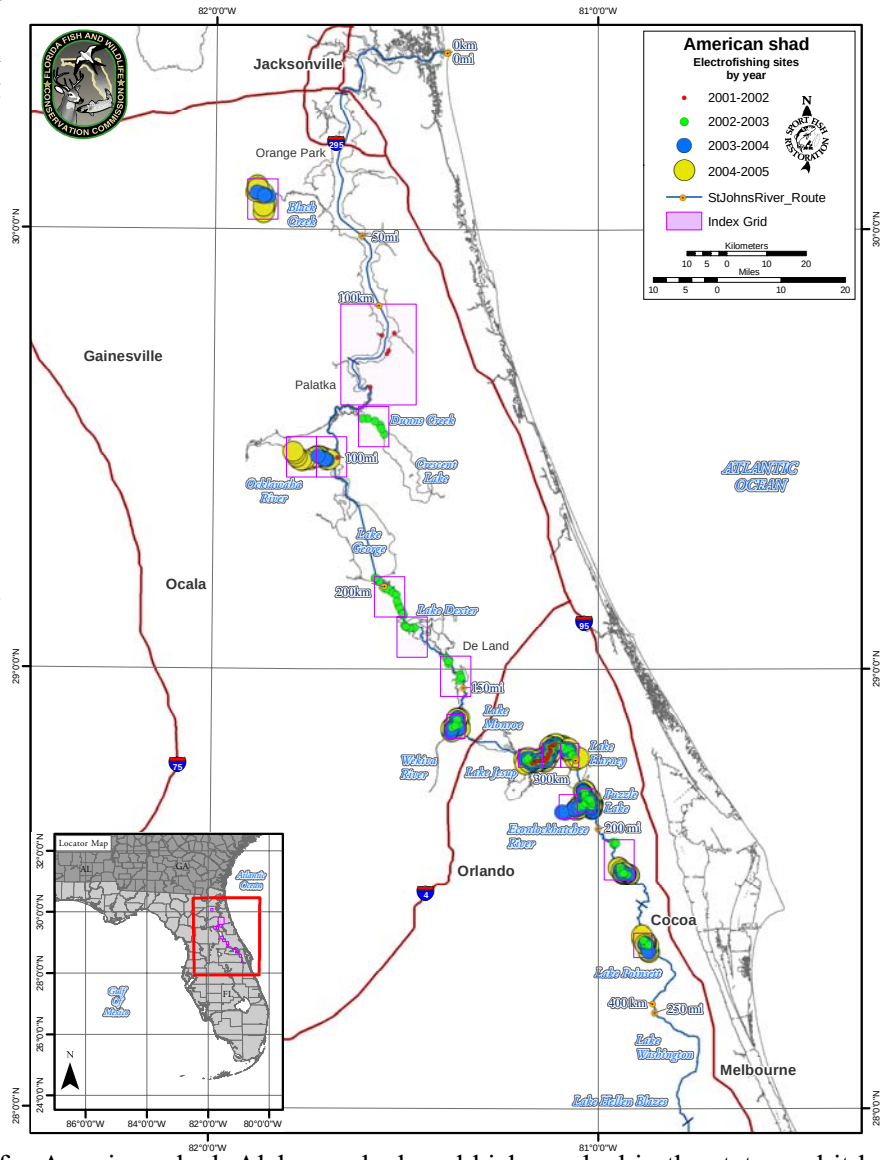
Table 2. Summary of abundance trends for the Altamaha River in Georgia.

System	Index	Gears	Years	Slope	P-value	R-square	Conclusion
Altamaha River	AUC	Drift Gill Net	1986 to 2005	a= -0.0143, b= 0.3229, c= -0.0184	a= 0.0121, b= 0.0091, c= 0.9708	0.3381	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

Status of American Shad Stocks in Florida

Distribution, Biology and Management

American shad occur in the St. Johns, Nassau, and St. Marys rivers of northeast Florida, and each are considered a separate stock. Only the St. Johns River has sufficient data to conduct a stock assessment and it is defined as a separate management unit for American shad. Adults are present during the winter and spring (November to May) and juveniles occur from the spring to autumn and into 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). Available evidence supports that American shad native to Florida rivers are semelparous.



Florida's commercial shad landings were severely reduced after January 1, 1992, by a regulation to increase mesh size, as well as adding net-tending and soak-time regulations to the ocean-intercept shad fishery (Williams 1996). An amendment to Florida's Constitution, which took effect in July 1995, prohibited the use of entangling nets within 3 miles of the Atlantic coast, effectively eliminating shad fishing within state waters. Since January 1, 1997, hook and line has been the only allowable fishing gear for American shad, Alabama shad, and hickory shad in the state, and it has been unlawful to possess more than 10 fish of any combination of these species. Historical regulations are covered in detail in Chapter 16.

The St. Johns has only a 9.1 m elevation change over its entire length (499 km). There is one dam on the main stem of the St. Johns River, at Lake Washington, and its tributary, the Oklawaha River, is dammed. The primary concerns regarding habitat on the St. Johns River are the competing demands for water resources between human development and wildlife and fisheries needs.

The Fishery

Florida's shad landings peaked in the late 1800s at 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. 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.

In the late 1800s, Florida's shad were caught primarily in drifting gill nets, secondarily in haul seines, and thirdly in anchored or staked gill nets. By the 1950s, most landings of American shad were made by haul seine followed by gill nets. Haul seining was discontinued during the early 1970s in the St. Johns River, and gill nets were used into the 1990s. Commercial shad fishing grounds have also shifted geographically. 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) and, by the early 1990s, nearly all the shad harvested came from gill nets fished in coastal waters offshore of Mayport, Florida. The Marine Recreational Fisheries Statistics Survey does not appear to intersect with the American shad recreational fishery on the St. Johns River, because the fishery is concentrated well upstream. Today, Florida's shad fishery is composed primarily of recreational anglers fishing on the spawning grounds and most anglers practice catch and release.

Fishing Year	Ocean Landings (pounds)	Total Landings (pounds)
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
2000-2005	0	0

Indices

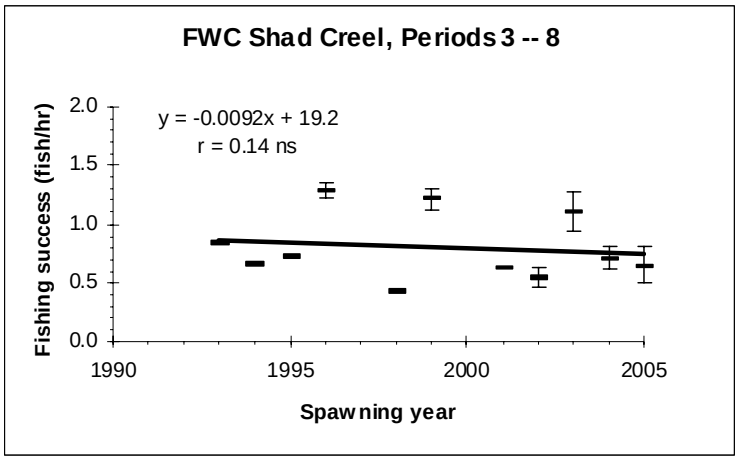
A roving creel survey was conducted to monitor catches of American and hickory shad during 11 years of the 13-year period from 1992 to 2005. Angler interviews were completed together with instantaneous counts of the number of anglers along an 11.9 km stretch of the river between the mouth of Lake Jessup and the north end of Lake Harney. 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. Anglers within the creel survey area caught from 1,260 (2004-2005) to 12,592 (1998-1999) American and hickory shad each year and averaged 5,879 shad per year (+ 3,676 s.d.; n=11 years). Catch and release is commonly practiced in this fishery, with 79% of the catch released in 2001-2002, 77% in 2002-2003, 71% in 2003-2004, and 79% in 2004-2005.

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. 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, covering several key areas of the shad spawning grounds and bracketing the full spawning period for American shad.

Assessment Approach

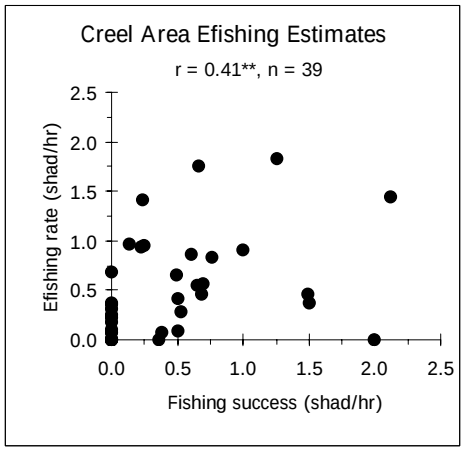
This assessment examines catch and effort data, using a falsification approach to test the following hypotheses:

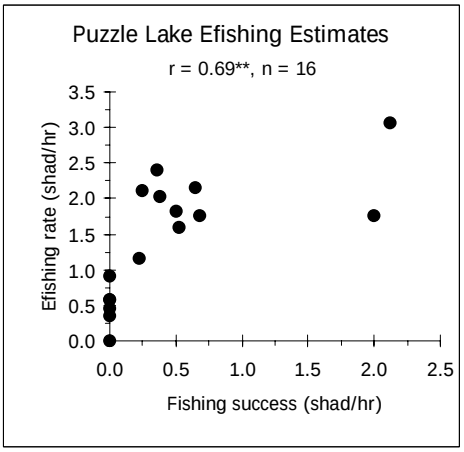
1. H_o: Fishing success (i.e., angler catch rates) is not related to fisheries-independent (i.e., electrofishing) estimates of abundance. This hypothesis will be tested by correlating fishing success (ratio-of-mean estimates from the creel survey) and geometric mean abundance (shad collected by fisheries-independent electrofishing), in order to validate that creel survey catch rate estimates are 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.
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.



Assessment Results

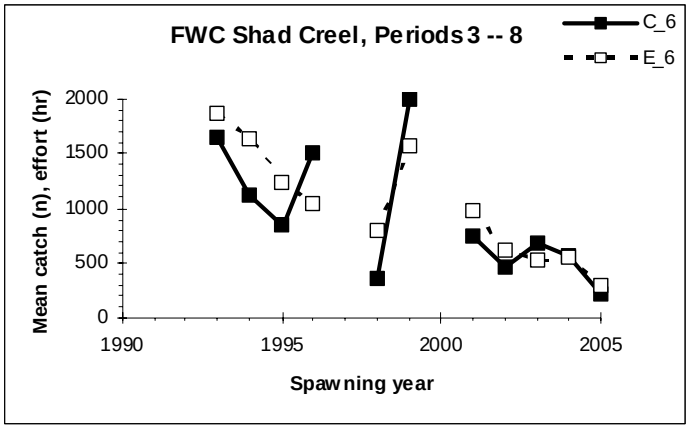
There was a statistically significant and positive relationship between shad abundance measured by electrofishing versus that measured by a roving creel survey. This was observed when the creel survey estimates were correlated to electrofishing in either the creel areas (i.e., Lake Monroe to Lake Harney; 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), demonstrating 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 does not show a statistically significant trend over time, 1993 to 2005. These relatively stable estimates of catch rate have occurred during a period of generally declining effort in the recreational shad fishery. Today's (2001-2005) male American shad were about five percent shorter and the females were about eight percent shorter than 50 years ago.

The proportions of females, relative to females and males combined, have changed notably in the last several decades. During the complete 1957- 1958 spawning run, females were only slightly more abundant than males (n=63,692; prop. females=0.53). During recent (2001-2005) spawning runs, females were considerably less abundant compared to males throughout the year. Across all years, males dominated the catch (n=1,786; prop. females=0.36).



Benchmarks

The benchmark 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.

Summary

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.

1.4 CONCLUSIONS AND RECOMMENDATIONS

1.4.1 Conclusions

This section contains conclusions based on observations from the overview of the coast-wide summary materials presented in this introductory section. Stock specific conclusions are contained in individual state sections (Sections 2-16) and in Section 1.4 – Stock Assessment Summaries.

- Ocean mixed stock harvest has been a large component of total American shad harvest over the last 25 years and since the late 1980s it was the dominant component of shad harvest from north of Virginia. Some segments of the American shad harvest remain unknown (e.g., inland commercial, recreational harvest, under-reporting for each segment, and unreported bycatch), likely resulting in underestimated landings. However, reported landings still provide valuable insight into the general magnitude and trends of harvest along the U.S. Atlantic coast. The expected benefits resulting from the ocean intercept fishery closure were not obvious in this assessment and might take one or more generations of American shad before they are realized.

- Available total mortality estimates generally exceeded Z_{30} for most years in rivers where data were suitable for catch curve analysis and where data supported SSBPR modeling. There is some evidence in these data, in conjunction with other data summarized in this assessment, that these Z values have affected characteristics of some stocks.

- Data on annual number of fish passing upriver at dams on several Atlantic coastal rivers exhibited a coast-wide pattern of an increase followed by a decrease. Interestingly, most fish passage numbers declined at about the same time (late 1990s to early 2000s). This synchronous decline suggests a coast wide change in environmental conditions or mortality factors that affected stocks from South Carolina to Maine within the last five years.

- Continuous fishery dependent and independent catch-per-unit-effort series generally only provide insight into recent stock dynamics, except for the Delaware River Lewis haul seine index.

- Trends in juvenile production do not show consistent patterns coast-wide; however, regional patterns and some local trends were noteworthy:

    - Recruitment has increased in the upper Chesapeake Bay, including the Potomac River, and Merrymeeting Bay, Maine in recent years.
    - Recruitment patterns in the lower Chesapeake Bay (James, York, and Rappahannock rivers) and in Albemarle Sound have been similar.
    - Relatively low young-of-year production was observed in all New England juvenile surveys in 1998 and 2001
    - There has been consistent low recruitment in the Hudson River since 2002

1.4.2 Recommendations

While some of the recommendations made in this assessment are specific or applicable to one system only, the recommendations listed below are applicable coastwide. They were developed as themes emerged in the assessment of all 31 rivers. Here we classify them according to whether they relate to fisheries and fishery assessments or to habitat. Please note that they are not prioritized.

Recommendations for Fisheries and Fishery Assessments:

1. Do not increase directed fisheries for American shad.
2. Restrict fisheries operating on stocks where total mortality is increasing and relative abundance is decreasing.
3. Identify all fisheries where bycatch occurs, then quantify the amount and disposition of bycatch. In fisheries where bycatch is allowed, quantify the discards.
4. Employ observer coverage to verify the reporting rate of commercial catch and harvest as well as bycatch and discards.
5. Identify directed harvest and bycatch losses of American shad in ocean and bay waters of Atlantic Maritime Canada.
6. Employ microchemistry techniques to identify stock composition in mixed stock harvest.
7. Spatially delineate between mixed stock and Delaware stock areas within the Delaware system.
8. Collect annual estimates of recreational catch, total harvest, CPUE, age, size, and sex composition of fish in each fishery.
9. Do not continue in-river tagging programs (conducted in Georgia, South Carolina, and Maryland) used to estimate exploitation and population size unless methods to identify reporting rate, tag mortality and loss, and movement (fallback), which are needed to estimate exploitation, are developed.
10. Continue tagging using Brownie-type models to estimate survival.
11. Monitor juvenile production in semelparous stocks. Such monitoring may indicate when recruitment failure has occurred.
12. Mark stocked larvae with OTC marks that allow age and year-class identification in mature fish. This is critical for verification of various aging techniques.
13. Characterize passage-associated efficiency, mortality, migration delay, and sub-lethal effects on American shad at hydroelectric dams.
14. Annually update all summary data tables of on-going data collection for use in the next assessment in the format used in this stock assessment for use in ASMFC stock assessments only.

Recommendations for Habitat

1. Develop safe, timely and effective upriver and downriver passage for adults and downriver passage for juvenile at all barriers within spawning reaches.
2. Maintain water quality and suitable habitat for all life stages of American shad in all rivers with shad populations. Refer to Amendment 1 for habitat issues pertaining to American shad and the ASMFC Anadromous Species Habitat Source Document (*in prep*).
3. In rivers with flow regulation, maintain flows at levels that ensure adequate fish passage, water quality, and habitat protection.
4. All rivers systems assessed in this document should have shad management (e.g., recovery and restoration) plans. Review and update these plans on a regular basis.

1.5 CAUSES OF DECLINE: HYPOTHESES

Results of data summarized elsewhere in this document suggest declines in many Atlantic coastal stocks of American shad, especially in the mid-Atlantic and southern New England states. Many causes for this decline have been suggested. They include bycatch in ocean fisheries, former mixed stock harvest from coastal and estuarine locations, increased predation on juvenile and adult shad by piscine and mammalian predators, and losses from down river passage at dams and hydroelectric facilities. This section explores two of these potential causes: losses from mixed stock harvest and predation. Papers included in this section used creative analyses and complex models to provide coastwide and stock specific perspectives on these two hypotheses. This section does not provide definitive answers, but does set the stage for crafting future analyses and investigations.

1.5.1 Coastwide Perspective

Papers in this section include:

A. American Shad Stock Contributions in Mixed Stock Fisheries Along the Atlantic Coast—an Update
B. Relative Rates of Exploitation in Three Atlantic Coastal American Shad Stocks
C. Striped Bass Predation on Adult American Shad: Occurrence and Observed Effects on American Shad Abundance in Atlantic Coastal Rivers and Estuaries

A. *American Shad Stock Contributions in Mixed Stock Fisheries Along the Atlantic Coast—an Update*

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Introduction

In Section 1.1.7, we summarized available data on commercial in-river and ocean and mixed stock (OMS) fishery landings of American shad along the U.S. Atlantic coast. Clearly, ocean harvest was large and cannot be ignored in any assessment of American shad stock change over the last 20 years. To be most useful, ocean harvest needs to be partitioned to source stock. Available techniques for partitioning harvest include otolith chemistry, tag release recapture analyses, and DNA methodology. Otolith chemical signature analysis is a new and promising technique (Walther *et al.*, in press), but no data on ocean shad stock composition have been produced. Published and unpublished tag release recapture studies of American shad have been conducted at several locations along the U.S. Atlantic coast with tag release locations in both spawning estuaries and in mixed stock locations along the coast. There have also been a few DNA studies of stock composition of the OMS harvest. Both tag release recapture and DNA studies provide some insight on stocks that might have contributed to the mixed stock harvest. Tag release recapture studies were available from the late 1950s through the present. DNA studies were conducted in 1991-1995. A few studies of ocean harvest stock composition are available from the early 1990s. Hattala et al. (1998) attempted to partition ocean landings to stock using available tag release – recapture and DNA data available at the time. We updated that study through 2005 using additional and more current tag recapture data.

Methods

We used tag recapture data from studies that released tagged fish in mixed stock areas and DNA data sampled from mixed stock fisheries harvest to develop estimates of stock composition in these fisheries. We partitioned the mixed stock fisheries into regions such that each region had either a tag release location or a DNA study. Regions were also based on timing of fisheries along the coast and the stocks that were potentially affected by them. Percent recapture from given states or rivers (stock) were then applied to total annual mixed stock harvest within region. Stock composition within region remained constant among years because tag-recapture studies only occurred at discrete intervals through the time period.

Regions

Mixed stock landings came from Section 1.1.7. Landings were grouped into the following regions: southern (South Carolina and North Carolina), mid-Atlantic (Virginia to Maryland), Delaware Bay, the New Jersey Coast, and northern (New York through New England; Table A1). Percent contributions of the affected stocks were developed as follows:

North and South Carolina: Stock and state percent compositions in this region were derived from two tagging studies conducted in ocean waters off North Carolina (Parker 1992; Supplemental Table A1[1]) and South Carolina (McCord 1986-1988; Supplemental Table A2). Estimates of percent recaptured by state or river were averaged among years and between studies

Maryland and Virginia: MtDNA studies were used to apportion harvest in this region (Supplemental Tables A3 and A4). The DNA data were used rather than tagging data because the tagging study conducted in ocean waters off Maryland and Virginia (Jesien 1992; Supplemental Table A5) was limited by access to fishing vessels through the season. Subsequent tag releases were not distributed evenly over the fishing season.

For the 1980-1988 period, percentages in Table A1 represent an average of three sample areas over two years: the 1992 and 1993 harvests from Virginia fisheries off Rudee Inlet and Wachapreague and the 1993 Ocean City, Maryland harvest of coastal shad. For 1989 to present, percent composition is based on average stock composition determined for the 1992 and 1993 Wachapreague fishery and 1992 Ocean City fishery (three sample areas).

Delaware Bay and New Jersey Coast: Results from the most recent tagging study, conducted in 1995 through 2005 in lower Delaware Bay, were used for this region (Supplemental Table A6). We refined the estimates for the Delaware and Hudson stocks for this assessment by readjusting the harvest that was assigned to the Delaware-New Jersey portion of the mixed stock fishery made by Hattala *et al*. (1998). This newer version (as compared to the 1998 version) segregates Delaware ocean and Delaware Bay landings from that of New Jersey ocean landings. We allowed a higher percentage of New Jersey ocean harvest to be attributed to the Hudson stock (Table A1) since shad caught along the coast were assumed to be headed north, and not south to the Delaware or other southern rivers. This agrees with the migratory pattern described by Dadswell *et al*. (1987). We recognize that the resulting attributed harvests may be biased higher but they provide a reasonable upper bound on estimated harvest.

New York and New England: The only data available for this region were from early studies conducted in the New York Bight (Talbot and Sykes 1958, summarized in Dadswell *et al*. 1987, Supplemental Table A7).

[1] Supplemental Tables immediately follow Section 1.5.1 tables.

Apportionment to Affected Stocks

The apportionment of mixed stock fishery landings occurred in a step-wise progression. Percents attributed to affected stocks were calculated from tagging or mtDNA studies, as described above (Table A1). Landings (Table A2) of American shad include those from mixed stock fisheries only (see Section 1.1.7). Annual landings from each state's fishery were totaled within region (i.e., South Carolina and North Carolina were added to form the "SC-NC" group; Table A3). The affected stock's (or group's) estimated portion was calculated by multiplying each percent listed in the column under each affected stock (Table A1) by the landings harvested by each of the five groups (Table A3). The total harvest for an affected stock was the sum of the regional harvest estimates attributed to that stock (Table A4).

Landings in the earlier 1998 version were adjusted for underreporting of 50 percent. We chose not to adjust landings for this assessment since the 1998 under-reporting rate was a "best guess." No study on reporting rate in the mixed stock fishery has ever been conducted.

Results

Losses to the mixed stock fishery tended to be highest for stocks in North Carolina, South Carolina, the Delaware River, the Hudson River, and the Connecticut River. Losses to rivers in Chesapeake Bay and New England were much smaller.

Discussion

There were several problems associated with the methodology used in this section. However results do provide a general overview of stock, or state, specific losses to the mixed stock fishery. Better estimates will have to await data from additional tagging, DNA, or other (otolith micro-chemistry) studies from mixed stock areas. Although the ocean-intercept fishery closed in 2005, the issue remains relevant because ocean bycatch continues. A summary of problems with the methodology used in the present analysis follows.

Within regional stock composition, percents were kept constant within and among years. This is probably an unrealistic assumption. Stock composition in a given area likely varies seasonally as shad from different stocks migrate through the area. Changes in stock size may also have occurred for some or all stocks for the period 1980 to the present and such changes would have altered stock composition among years. Stock composition of harvest probably also changed over time as fisheries altered timing and location of operations.

Estimates of stock composition were also affected by the studies used to partition harvest. DNA stock identification studies on American shad are still in their infancy and need work on verification and refinement. Tag-recapture methods were affected by poorly known recapture effort, unknown reporting rates, and small recapture sample sizes. However, use of tag release recapture data remains valuable because data from many studies are available and two studies have been ongoing for over ten years. Moreover, tag-recapture locations and times are generally reliable.

Conclusion

We did not preclude the usefulness of past tagging or DNA studies to examine the composition of the mixed stock fishery. We use the data only to attempt a first order approximation of potential fishing pressure of the mixed stock fisheries on a particular stock or region.

In the Relative Exploitation discussion, we illustrate the possible impact of the estimated harvest on individual stocks.

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Table 1.5.1-A1 Estimated American shad stock contributions (percent) in the mixed stock Atlantic coast fisheries, based on DNA and tag-recapture programs.

Mixed Stock Fishery Area	**Affected Stocks**									
	FL	**GA**	**SC**	**NC**	**VA**	**MD**	**Delaware R.**	**Hudson R.**	**Connecticut R.**	**New England - Canada**
SC-NC	1.00%	7.20%	54.30%	37.50%						
VA-MD (1980-1988)	1.00%		23.60%	20.20%	16.40%	2.60%	11.50%	3.40%	6.40%	14.60%
VA-MD (1989-present)	**1.00%**		**31.70%**	**26.70%**	**9.30%**	**4.30%**	**11.00%**	**11.00%**	**3.00%**	**3.00%**
Delaware Bay						2.10%	39.00%	42.00%	15.00%	2.10%
NJ Coast							13.00%	70.00%	15.00%	2.00%
NY-NE					0.50%	0.50%	1.00%	6.00%	50.00%	42.00%

Table 1.5.1 -A2 American shad landings reported for mixed stock fisheries (kg*1000; Sources: NMFS and state reports). Note: inland landings are not included (see Section 1.1.7).

Year	SC	NC	VA	MD	DE	NJ	NY	RI	MA	NH	ME
1980	70.3	1.8	43.5	0.0	40.7	54.3	51.5	0.9	3.8	3.1	12.7
1981	67.8	48.7	125.0	0.0	83.7	59.3	26.4	14.2	7.6	2.5	41.1
1982	111.2	29.0	125.6	0.0	148.5	126.9	33.4	36.0	13.3	1.2	11.7
1983	93.2	1.7	94.2	9.1	98.8	88.9	15.0	10.7	6.1	1.5	17.6
1984	178.2	6.1	292.3	8.7	93.3	94.8	15.2	16.6	13.5	2.3	15.2
1985	62.4	1.4	150.7	68.1	78.2	97.6	42.5	41.2	10.1	3.3	7.3
1986	102.3	28.6	161.3	57.3	96.1	71.2	33.1	23.8	27.3	7.7	10.4
1987	163.1	18.7	179.3	54.1	111.6	83.7	5.3	47.1	18.5	18.7	12.0
1988	117.2	22.7	194.5	120.0	132.0	105.9	7.0	55.3	23.0	20.8	14.5
1989	103.5	17.5	181.3	221.3	98.3	181.1	10.3	19.0	6.2	13.9	21.1
1990	73.2	16.8	147.5	128.7	215.4	203.8	2.4	10.3	2.5	17.3	5.4
1991	65.4	8.7	181.3	106.1	231.5	174.3	11.9	12.6	0.3	8.6	0.9
1992	49.5	10.9	196.0	90.2	124.3	129.6	9.6	6.0	0.1	4.5	0.7
1993	29.5	12.8	220.8	35.3	134.3	145.2	3.5	18.4	0.2	3.0	0.0
1994	32.6	15.4	171.4	15.3	102.5	98.4	2.7	8.1	0.1	12.8	0.5
1995	60.0	46.7	68.5	27.5	86.7	127.0	6.6	12.7	0.2	13.9	0.2
1996	100.7	26.4	108.0	60.2	120.2	95.3	11.5	6.5	0.1	16.1	0.5
1997	51.4	44.6	162.3	75.4	74.2	102.3	17.1	16.7	0.3	11.5	0.1
1998	30.6	53.5	157.6	54.1	94.6	105.7	41.4	15.2	0.8	6.9	0.2
1999	8.8	15.0	105.0	27.7	102.7	118.4	31.1	20.1	0.1	1.7	0.1
2000	40.3	50.3	74.5	16.3	75.4	97.0	11.6	7.9	0.1	2.7	0.1
2001	41.9	5.4	114.6	26.0	127.9	91.2	14.2	30.8	0.5	0.4	0.2
2002	38.3	3.8	69.1	18.7	55.2	110.5	27.6	39.6	0.2	0.0	0.0
2003	16.8	5.7	23.4	4.9	40.0	68.8	11.1	17.5	0.5	0.0	0.0
2004	20.8	3.0	25.1	3.8	78.9	57.0	6.8	6.7	0.0	0.0	0.0
2005	0.0	0.1	0.0	0.0	55.8	20.0	2.0	0.0	0.0	0.0	0.1

Table 1.5.1-A3 Landings (kg*1000) from Table 1.5.1-2 summed by area grouping (see Table 1.5.1-1).

Year	SC-NC	VA-MD	Delaware Bay	NJ Ocean	NY-NE
1980	72.1	43.5	63.7	31.3	72.0
1981	116.6	125.0	114.4	28.6	91.9
1982	140.2	125.6	208.8	66.6	95.7
1983	94.9	103.3	121.1	66.5	50.8
1984	184.4	300.9	112.3	75.8	62.8
1985	63.8	218.7	100.4	75.4	104.4
1986	130.9	218.5	125.1	42.2	102.2
1987	181.8	233.4	161.2	34.1	101.6
1988	139.9	314.6	168.7	69.3	120.6
1989	121.0	402.6	125.7	153.6	70.5
1990	90.0	276.2	312.8	106.4	38.0
1991	74.1	287.4	299.7	106.2	34.3
1992	60.4	286.2	176.1	77.8	20.9
1993	42.2	256.1	190.3	89.2	25.1
1994	48.0	186.6	121.2	79.6	24.3
1995	106.7	95.9	114.6	99.0	33.5
1996	127.1	168.2	128.2	87.3	34.6
1997	96.0	237.7	89.8	86.6	45.7
1998	84.1	211.7	101.1	99.2	64.5
1999	23.7	132.7	140.3	80.8	53.0
2000	90.7	90.8	110.8	61.5	22.4
2001	47.3	140.6	140.1	78.9	46.0
2002	42.1	87.8	62.3	103.4	67.4
2003	22.5	28.2	42.9	66.0	29.2
2004	23.9	28.9	81.4	54.6	13.5
2005	0.1	0.0	74.6	1.2	2.0

Table 1.5.1-A4 State stock estimates of harvest by mixed stock fisheries (kg; Table 1.5.1-3 landings * Percent in Table 1.5.1-1). Estimates are not adjusted for under-reporting.

Year	FL	GA	SC	NC	VA	MD	Delaware R.	Hudson R.	Connecticut R.	New England - Canada
1980	1.2	5.2	49.4	35.8	7.5	2.8	34.6	54.5	53.0	38.6
1981	2.4	8.4	92.8	69.0	21.0	6.1	63.6	77.8	75.4	59.8
1982	2.7	10.1	105.8	78.0	21.1	8.1	105.5	144.3	97.2	64.2
1983	2.0	6.8	75.9	56.5	17.2	5.5	68.3	104.0	60.2	40.3
1984	4.9	13.3	171.1	129.9	49.7	10.5	88.9	114.2	78.9	74.2
1985	2.8	4.6	86.3	68.1	36.4	8.3	75.2	108.7	92.6	79.4
1986	3.5	9.4	122.6	93.2	36.4	8.8	80.4	95.7	90.2	78.3
1987	4.2	13.1	153.8	115.3	38.8	10.0	95.2	105.6	95.0	80.8
1988	4.5	10.1	150.2	116.0	52.2	12.3	112.2	137.3	116.1	101.5
1989	5.2	8.7	193.3	152.9	37.8	20.3	114.0	208.9	89.2	47.4
1990	3.7	6.5	136.4	107.5	25.9	18.6	166.6	238.5	90.2	32.9
1991	3.6	5.3	131.4	104.5	26.9	18.8	162.6	233.9	86.7	31.5
1992	3.5	4.3	123.5	99.1	26.7	16.1	110.5	161.2	57.1	22.6
1993	3.0	3.0	104.1	84.2	23.9	15.1	114.2	172.0	62.1	24.0
1994	2.3	3.5	85.2	67.8	17.5	10.7	78.4	128.6	47.9	19.9
1995	2.0	7.7	88.4	65.6	9.1	6.7	68.5	130.0	51.7	21.3
1996	3.0	9.2	122.3	92.6	15.8	10.1	80.2	135.5	54.7	24.0
1997	3.3	6.9	127.5	99.5	22.3	12.3	72.9	127.2	56.5	30.0
1998	3.0	6.1	112.8	88.1	20.0	11.5	76.3	139.1	68.7	37.6
1999	1.6	1.7	55.0	44.3	12.6	8.9	80.4	133.3	63.7	30.8
2000	1.8	6.5	78.0	58.2	8.6	6.3	61.4	101.0	39.8	15.7
2001	1.9	3.4	70.3	55.3	13.3	9.2	80.8	132.3	60.1	28.1
2002	1.3	3.0	50.7	39.2	8.5	5.4	48.1	112.2	61.2	34.3
2003	0.5	1.6	21.2	16.0	2.8	2.3	28.7	69.1	31.8	15.3
2004	0.5	1.7	22.1	16.7	2.8	3.0	42.1	76.4	28.0	9.4
2005	0.0	0.0	0.1	0.0	0.0	1.6	29.3	32.3	12.4	2.5

Supplemental Table A1 Tagging studies conducted off the coast of North Carolina.

Study:	**J. Parker 1992, Ocean Tagging Study - Southeast NC**									
Release Location:	Southeast NC*		S.E. NC (Wrightsville)		**TOTAL**					
Release Period:	January-March		December 1989-April							
Year:	1989		1990							
N-caught:					**320**					
N-tagged:					**301**					
% tagged:					**94%**					
River & State(s)	Returns	% Returned	Returns	% Returned	**Returns**	**% Returned**	**Group**	**1989**	**1990**	**Average**
NC - Ocean	7	17.10%	6	37.50%	**13**	**22.80%**	**NC**	73.20%	75.00%	**74.10%**
NC - Albemarle Sound										
NC- Neuse River										
NC- Cape Fear River	23	56.10%	6	37.50%	**29**	**50.90%**				
SC - Waccamaw-Pee Dee R.	8	19.50%	3	18.80%	**11**	**19.30%**	**SC**	24.40%	18.80%	**21.60%**
SC - Santee R.										
SC - Edisto R.	2	4.90%			**2**	**3.50%**				
GA - Savannah-Ogeechee R.	1	2.40%	1	6.30%	**2**	**3.50%**	**GA**	2.40%	6.30%	**4.30%**
Total returns	**41**		**16**		**57**	**0.18937**				
% of releases	**13.60%**		**5.30%**		**18.90%**					
Additional information:										
Mean TL:	484.9		494.9							
Gill Net Mesh Size (in):	5.5									
Percent-at-age:										
4	15.6		4.4							
5	76.6		53.2							
6	7.8	one repeat	42.4							

*Southeast NC = south of Pamlico Sound and near the Cape Fear River.

Supplemental Table A2 Tagging indices conducted off the coast of South Carolina.

Study:	**W. McCord, SC Ocean Tagging**									
Release Location:	SC Ocean		SC Ocean		SC Ocean		SC Ocean			
Release Period:										
Year:	1986		1987		1988		All years			
N-tagged:	485	24.70%	125	31.20%	275	24.70%	885	25.60%		
River & State(s)	Returns	% Returned	Returns	% Returned	Returns	% Returned	Returns	% Returned	**Groups**	**% Returned**
NC- Cape Fear R.					1	1.50%	1	0.40%		
NC - Ocean	1	0.80%					1	0.40%	NC	0.90%
SC - Ocean	4	3.30%	5	12.80%	4	5.90%	13	5.70%		
SC - Waccamaw-Pee Dee R.	82	68.30%	25	64.10%	37	54.40%	144	63.40%		
SC - Georgetown			1	2.60%	1	1.50%	2	0.90%		
SC - Santee R.	9	7.50%			9	13.20%	18	7.90%		
SC - Cooper R.	1	0.80%			1	1.50%	2	0.90%		
SC - Edisto R.	4	3.30%	1	2.60%	3	4.40%	8	3.50%		
SC - Savannah R.	6	5.00%	1	2.60%	3	4.40%	10	4.40%	SC	86.80%
GA - Ogeechee R.	2	1.70%					2	0.90%		
GA - Altamaha R.	11	9.20%	6	15.40%	4	5.90%	21	9.30%	GA	10.10%
FL - St. Johns R.					4	5.90%	4	1.80%	FL	1.80%
Unknown					1	1.50%	1	0.40%		
Total Returns	**120**		**39**		**68**		**227**			**99.60%**

Supplemental Table A3 Summaries of genetic DNA studies (presented as percent of sample from river origin) conducted off the coasts of Virginia and Maryland (Brown and Epifano 1994) and New Jersey (1996).

Study:	**Brown & Epifano 1994 (Table 11)**						
Sampling Location:	Rudee Inlet, VA			Wachpreague, VA			Ocean City, MD
Year:	1992*	1993		1992	1993		1992
River of Origin:	%	%	mean	%	%	mean	%
St. Lawrence R.	30	0	15.0	0	0	0.0	
Shubenacadie R.	0	0	0.0	7	0	3.5	
St. John R.	23	2	12.5	0	11	5.5	
Connecticut R.	17	6	11.5	3	6	4.5	
Hudson R.	0	0	0.0	14	3	8.5	
Delaware R.	4	15	9.5	0	12	6.0	23
Susquehanna R.	0	0	0.0	13	0	6.5	
Rappahannock R.	10	8	9.0	0	0	0.0	
Pamunkey R.	0	7	3.5	0	0	0.0	
York R.	10	0	5.0	0	11	5.5	0
James R.	4	15	9.5	0	17	8.5	
Chowan R.	0	0	0.0	1	35	18.0	44
Cape Fear R.	0	21	10.5	0	0	0.0	
Santee R.	0	23	11.5	9	0	4.5	0
Savannah R.	0	0	0.0	49	5	27.0	32
St. John's R. (FL)	2	0	1.0	3	0	1.5	0

Summary of Composition:							
Study:	Brown & Epifano 1994 (Table 11)				Brown 1996		
Year:	1992-1993	1992-1993	1992	1991	1994	1995	
Sampling Location:	Rudee	Wachpreague	Ocean City	Virginia	New Jersey Coast		
River of Origin:	%	%	%	%	%	%	mean
Canadian	27.5	9.0			21	47	34.0
Connecticut R.	11.5	4.5		32			
Hudson R.	0.0	8.5			21	22	21.5
Delaware R.	9.5	6.0	23	9			
Susquehanna R.**	0.0	6.5		31	55	31	43.0
VA Rivers	27.0	14.0		2	3		1.5
NC Rivers	10.5	18.0	44	5			
Santee R.	11.5	4.5		19			
Savannah R.	0.0	27.0	32				
St. Johns (FL)	1.0	1.5		2			

%- max. likelihood estimates of proportion

* trace amounts of other systems: Columbia (of Hudson origin in 1870s) and Nanticoke

* *NOTE: most shad returning to the Susquehanna River are of Hudson River or Delaware River parent broodstock.

Supplemental Table A4 Estimated stock composition (% by state/area) of American shad harvest for the 1992 and 1993 ocean-intercept fisheries off Maryland and Virginia, based on mtDNA studies (Brown and Epifano 1995).

State/Area Affected	Time Period	
	1980-1988	**1989-1996**
Florida	1.0	1.0
South Carolina	23.6	31.7
North Carolina	20.3	26.7
Viginia rivers	16.4	9.3
Maryland rivers	2.6	4.3
Delaware River	11.5	11.7
Hudson River	3.5	5.7
Connecticut R.	6.4	3.0
Canadian rivers	14.6	6.0

Supplemental Table A5 Tagging studies conducted off the coasts of Maryland and Virginia.

Study	**Jesien (1992 Report to State of MD) Ocean Tagging Study, MD & VA**									
Release Location:	Rudee Inlet, VA		Ocean City, MD		Rudee Inlet, VA		**TOTAL MD-VA**		**TOTAL MD-VA**	
Release Period:	February-March		March-April		March-April					
Year:	1991		1992		1992		**1992**		**1991 & 1992**	
N-caught:	3199		648		3127		**3775**		**6974**	
N-tagged:	569		260		430		**690**		**1259**	
% Tagged:	18%		40%		14%		**18%**		**18%**	
River & State(s)	Returns	% Returns	Returns	% Returns	Returns	% Returns	**1992 Returns**	**% Returns**	**1991-1992 Returns**	**% Returns**
MA - Merrimack R.					1	5.00%	**1**	**2.60%**	**1**	**1.72%**
CT, MA - Connecticut R.	1	5.30%	1	5.30%			**1**	**2.60%**	**2**	**3.45%**
NY,NJ - Hudson R.	2	10.50%							**2**	**3.45%**
PA, DE, NJ - Delaware R.	2	10.50%	9	47.40%	2	10.00%	**11**	**28.20%**	**13**	**22.41%**
DE, NJ - Delaware Bay			2	10.50%			**2**	**5.10%**	**2**	**3.45%**
DE - Ocean			1	5.30%			**1**	**2.60%**	**1**	**1.72%**
NJ - Ocean					1	5.00%	**1**	**2.60%**	**1**	**1.72%**
MD - Chesapeake Bay	1	5.30%							**1**	**1.72%**
VA - Chesapeake Bay rivers	9	47.40%			2	10.00%	**2**	**5.10%**	**11**	**18.97%**
VA - Ocean	1	5.30%	4	21.10%	5	25.00%	**9**	**23.10%**	**10**	**17.24%**
NC - Ocean	3	15.80%	1	5.30%			**1**	**2.60%**	**4**	**6.90%**
NC - Albemarle Sound					3	15.00%	**3**	**7.70%**	**3**	**5.17%**
NC- Neuse R.					1	5.00%	**1**	**2.60%**	**1**	**1.72%**
NC - Cape Fear R.					2	10.00%	**2**	**5.10%**	**2**	**3.45%**
SC - Waccamaw-Pee Dee R.			1	5.30%			**1**	**2.60%**	**1**	**1.72%**
SC - Santee R.					1	5.00%	**1**	**2.60%**	**1**	**1.72%**
GA - Savannah-Ogeechee R.					2	10.00%	**2**	**5.10%**	**2**	**3.45%**
Total Returns	**19**		**19**		**20**		**39**		**58**	
% of Releases	**3.30%**		**7.30%**		**4.70%**		**5.70%**		**4.60%**	
Additional Information:										
Mean TL	513		541		517					
Gill net mesh	5.5		6		5.5					

Supplemental Table A6 American shad tagging studies conducted in lower Delaware Bay and the Hudson River.

Study	**Hattala & Allen, Cooperative American Shad Tagging Program**							
Time Period:	1995-present. Data summarized and reported in annual ASMFC reports.							
	Recaptures by Release Location					Releases		
Lower Delaware Bay	N	%	**Hudson R. NY**	N	%	Year	Lower DE Bay	Hudson R.
Ocean	49	20.70%	Delaware Bay	5	3.00%	1995	107	2648
CT - Connecticut R.	34	14.30%	NY - Hudson R.	148	89.20%	1996	294	1579
Delaware Bay	56	23.60%	NS - Ocean	1	0.60%	1997	509	2046
DE, NJ, PA - Delware R.	38	16.00%	RI - Ocean	1	0.60%	1998	555	249
NY - Hudson R.	44	18.60%	MD - Ocean	2	1.20%	1999	764	413
NC - Cape Fear R.	1	0.40%	NJ - Ocean	5	3.00%	2000	430	493
Chesapeake Bay	2	0.80%	VA - Ocean	3	1.80%	2001	663	542
DE - Indian R.	1	0.40%	NJ - Raritan Bay	1	0.60%	2002	273	66
PA - Lehigh R.	1	0.40%				2003	170	604
RI - Pawcatuck R.	1	0.40%				2004	51	766
NB - Petitcodiac R.	1	0.40%				2005	220	519
SC - Santee R.	1	0.40%						
NB - Shubenacadie R.	1	0.40%						
QB - St.Lawrence R.	1	0.40%						
MD - Susquehanna R.	5	2.10%						
MA - Westfield R.	1	0.40%						
Total	**237**			**166**				

Supplemental Table A7 American shad tagging studies summarized by Dadswell et al. (1987), conducted in the Connecticut River, Hudson River, New York Bight, Delaware River, and Chesapeake Bay.

Studies:	**Talbot and Sykes 1958**				**Miller 1982**		**Leggett (unpublished)**	
Release Location:	Hudson R/NY Bight		Rudee Inlet/Ches. Bay		Delaware		Connecticut	
N-tagged:	11579		4775		2920		18374	
River & State(s)	Returns	% Returns	Returns	% Returns	Returns	% Returns	Returns	% Returns
CAN - St. Lawrence R.					2	1.50%		
CAN - Miramichi R.					4	3.00%		
CAN - Bay of Fundy	13	0.70%	3	2.60%	18	13.30%		
Gulf of Maine	9	0.50%	5	4.30%	3	2.20%		
MA - Cape Cod	7	0.40%	4	3.50%				
MA - Merrimack					1	0.70%		
CT, MA - Connecticut R.	146	7.90%	21	18.30%	36	26.70%	311	83.40%
NY - Ocean	23	1.30%	5	4.30%	2	1.50%	19	5.10%
NY, NJ - Hudson R.	1582	86.10%	31	27.00%	25	18.50%		
PA, DE, NJ - Delaware R.					45	33.30%		
DE, NJ - Delaware Bay	20	1.10%	9	7.80%			2	0.50%
DE - Ocean					1	0.70%		
NJ - Ocean	13	0.70%	5	4.30%			4	1.10%
MD - Chesapeake Bay	10	0.50%						
VA - Chesapeake Bay rivers	7	0.40%					2	0.50%
VA - Ocean					1	0.70%	10	2.70%
NC - Ocean	5	0.30%	14	12.20%	3	2.20%	23	6.20%
NC - Rivers	2	0.10%	16	13.90%			1	0.30%
SC - Rivers			1	0.90%				
GA - Rivers			1	0.90%			1	0.30%
Total Returns	**1837**	**15.90%**	**115**		**135**		**373**	
% of Releases	**15.90%**		**2.40%**		**4.60%**		**2.00%**	

Aggregation Areas: Summer – off Fundy, St. Lawrence estuary, off Newfoundland and Labrador
Winter – off Florida, Middle Atlantic Bight, Scotian Shelf, and Gulf of Maine

B. *Relative Rates of Exploitation in Three Atlantic Coastal American Shad Stocks*

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Introduction

Rates of total mortality have increased in several American shad stocks along the U.S. Atlantic coast in recent years (Section 1.2.3). In many of these stocks, concurrent declines in abundance, mean age, and mean size have occurred. Understanding the causes of increased mortality is important to managing stocks currently in decline. Total mortality reflects the combined impact of fisheries, spawning mortality, predation, and mortality associated with downstream passage at hydroelectric dams. Recent interest has focused on effects of predation on American shad stocks (Section 1.5, Savoy and Crecco 2004). Earlier interest focused on effects of fishing and in particular, effects from the growing harvest of American shad from ocean waters (ASMFC 1998).

Commercial harvest of American shad occurs within natal rivers and in various mixed stock fisheries in ocean waters and bays. Harvest from ocean waters has been a growing component of Atlantic coastal shad harvest over the last 25 years. Growth of this fishery was most pronounced in the region from Virginia through Maine. Ocean harvest in this region increased substantially from 1970 through the late 1980s and early 1990s (Section 1.1.7). It then declined through 2005 when directed harvest from ocean waters was closed. Natal river harvest in this region declined through the entire time series. Ocean harvest exceeded natal river harvest from the late 1980s through 2004.

In this section, we use trends in relative exploitation to evaluate the possibility that increased mortality observed in coastal shad stocks was caused by increased fishing mortality. We confined our analyses to American shad of the Delaware, Hudson, and Connecticut rivers because stocks in these rivers have been well studied for many years and all of them show some effects of the rise in mortality. Moreover, most of the ocean harvest from these three stocks occurred in the region from Maine through Virginia where the mixed stock harvest was large (Section 1.1.7).

Methods

We calculated relative exploitation rates as total annual harvest (kg) divided by river specific annual indices of adult abundance. Exploitation rates were developed from in-river harvest alone and from in-river harvest plus that part of the mixed stock ocean harvest attributed to the stock (termed total stock harvest). Stock composition of the ocean harvest was developed in Section 1.5.1. River specific adult abundance indices and estimates of total mortality came from river specific assessments in this volume Specifics of the adult indices used are given in Table B1.

Results

Annual patterns of relative exploitation differed somewhat among stocks.

<u>Delaware River</u>: Relative exploitation rates for the Delaware River stock based on total stock harvest increased gradually from 1970 through 2005 (Table B2; Figure B1). CPUE in the Delaware River commercial gill net fishery declined from 1990 through the present. Relative exploitation rates for in-river harvest (i.e., not including any mixed stock harvest) are given in Sections 1.5.2 and 8.

Hudson River: Relative exploitation rates from in-river harvest suggested a peak of relatively high exploitation in 1980 followed by a decline and then fluctuation at low values through the present (Table B3; Figure B2). Rates from total stock harvest suggested the same peak in 1980, a low period through the rest of the 1980s, an increase in 1990, followed by fluctuation at a relatively high level from 1990 through the present (Table B3; Figure 2). Patterns of change in rates were similar using either adult abundance index. Estimates of total instantaneous mortality (Z) for the Hudson River stock (Section 7) were relatively low in the mid to late 1980s, climbed in the early 1990s, and have fluctuated at relatively high levels since that time (Table B3; Figure B2).

Connecticut River: Relative exploitation rates for Connecticut River shad from in-river harvest and total stock harvest and based on lift counts generally declined from the late 1970s through the present (Table B4; Figure 3B). Relative exploitation rates from total stock harvest and based on CPUE in the river fishery generally declined from 1981 through the present (Table B4; Figure 3B). Estimates of Z for the Connecticut River stock generally increased from 1970 though the present (Table B4; Figure B). The increase was most pronounced in males.

Discussion

The increase in relative exploitation for the Delaware River stock suggests a rise in fishing rate. Since the increase was coincident with the rise in mixed stock harvest and relative exploitation from in-river fishing did not increase (Sections 1.5 and 8), mixed stock harvest appears to have been the more important source of fishing mortality in recent years. The decline in CPUE in the Delaware River commercial fishery since 1990 suggests that increased fishing rate on this stock may have affected abundance. Age data were not available for estimates of Z so it is not known if changes in relative exploitation rates were related to changes in total mortality.

As in the Delaware River, in-river rates of relative exploitation remained relatively constant in the Hudson River stock while rates from total stock harvest increased. This again suggests some influence of ocean harvest on fishing rate. The spike in relative exploitation rate in the Hudson stock from in-river and total stock harvest that occurred in 1980 appeared to be driven by in-river harvest because ocean harvest was still a small component of total stock harvest at that time. The rise in relative exploitation rate from total Hudson harvest is coincident with the rise in Z suggesting that fishing may have been an important factor in the rise in Z in this stock.

Fishing did not appear to be a factor in the increased total mortality in the Connecticut River stock. In the Connecticut River, relative exploitation rate from in-river harvest and from total stock harvest declined as the mortality rates increased.

Results of these analyses suggest that the rise in mixed stock harvest that occurred in the 1980s may have increased fishing rates on the Delaware and Hudson River stocks of American shad. Conversely, fishing in general does not appear to have been a factor in the changing age structure and abundance of American shad in the Connecticut River. The directed fishery for American shad was closed in all Atlantic coastal states in 2005. Results of these analyses suggest that the closures may have been warranted for some stocks.

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Table 1.5.1-B1. Indices of adult abundance used in calculating relative exploitation for American shad of the Delaware, Hudson, and Connecticut Rivers.

River	Index	Years Evaluated	Source
Delaware	CPUE in the commercial Lewis Haul seine fishery	1970 - 2005	Allen et al. (Section 8, this volume)
	CPUE-revised in commercial gill net river fishery	1989-2005	
Hudson	ESSB - combined fishery independent / dependent index	1985 - 2005	Hattala and Kahnle (Section 7, this volume)
	EGG - fishery independent index of egg abundance	1974 - 2005	
Connecticut	Holyoke Dam fish lift passage	1976 - 2005	SAC (Section 6, this volume)
	In river commercial gill net CPUE	1981 - 2005	

Table 1.5.1-B2. Commercial harvest, adult abundance indices, and relative exploitation for the Delaware River American shad stock.

	Commercial Landings (kg)			Adult Index		Relative Exploitation
Year	**Estimated Delaware R. Portion of OMS***	**In-river Delaware R.**	**Total Delaware R.**	**Lewis Seine CPUE**	**Delaware R. Com. Fishery CPUE (revised)**	**Total Delaware R Harvest/ Lewis CPUE**
1970	7606	2223	9829	4.9		2.0
1971	5162	1179	6341	12.3		0.5
1972	7031	953	7983	5.4		1.5
1973	5804	726	6529	7.2		0.9
1974	6923	680	7603	8.5		0.9
1975	11647	862	12509	14.9		0.8
1976	12138	0	12138	12.0		1.0
1977	23491	1542	25034	10.2		2.5
1978	23014	0	23014	10.1		2.3
1979	21052	0	21052	18.7		1.1
1980	34634	2815	37449	13.0		2.9
1981	63626	5785	69411	54.2		1.3
1982	105493	10761	116254	29.8		3.9
1983	68276	8776	77052	14.4		5.3
1984	88904	9807	98711	15.7		6.3
1985	75170	23767	98937	29.3		3.4
1986	80445	21012	101457	30.7		3.3
1987	95167	13898	109066	16.5		6.6
1988	112166	18921	131087	35.6		3.7
1989	113992	13177	127169	52.2	56.4	2.4
1990	166592	25574	192165	25.3	30.5	7.6
1991	162640	15788	178428	30.4	11.1	5.9
1992	110472	23139	133611	51.0	78.6	2.6
1993	114237	14769	129006	10.5	53.3	12.3
1994	78396	10620	89016	7.9	34.9	11.3
1995	68457	11841	80298	19.0	26.5	4.2
1996	80196	5078	85274	3.7	15.6	23.3
1997	72899	8039	80938	12.0	27.8	6.8
1998	76254	3684	79939	13.2	28.6	6.1
1999	80365	3504	83869	4.6	7.3	18.2
2000	61438	22755	84193	4.1	20.8	20.7
2001	80847	33011	113858	6.8	5.8	16.6
2002	48075	15992	64067	3.8	7.7	16.7
2003	28707	40346	69052	5.2	17.0	13.2
2004	42141	43132	85273	4.1	9.6	20.9
2005	29256	21419	50675	2.9	3.9	17.5

*OMS - Ocean mixed stock fishery

Table 1.5.1-B3. Commercial harvest, adult abundance indices, relative exploitation, and total mortality estimates for the Hudson River American shad stock. ESSB is a fishery dependent index of ages 5-7 expanded to all ages by fishery independent age data and mean weight at age. Egg is an annual index of eggs per 1000 m^3 from river-wide sampling.

	Commercial Landings (kg)			Adult Indices		Relative Exploitation				Total Mortality	
Year	Estimated Hudson R. Portion of OMS*	In-river Hudson	Total Hudson	ESSB	Egg	In-river Harvest/ ESSB	Total HR Harvest/ ESSB	In-river Harvest/ Egg	Total HR Harvest/ Egg	Male Z	Female Z
1974	15609	110678	126288		0.097			114.1	130.2		
1975	26255	114806	141061		0.060			191.3	235.1		
1976	27398	98930	126328		0.037			267.4	341.4		
1977	52964	94167	147132		0.036			261.6	408.7		
1978	51903	206207	258110		0.044			468.7	586.6		
1979	47583	232833	280416		0.045			517.4	623.1		
1980	54488	595622	650110		0.046			1294.8	1413.3		
1981	77838	281323	359161		0.161			174.7	223.1		
1982	144343	171869	316212		0.123			139.7	257.1		
1983	103989	208384	312372		0.356			58.5	87.7		
1984	114242	318155	432397		0.472			67.4	91.6	0.72	0.53
1985	108684	342951	451635	64.3	0.262	53.3	70.2	130.9	172.4	0.70	0.46
1986	95678	362321	457999	112.9	0.770	32.1	40.6	47.1	59.5	0.68	0.63
1987	105597	310345	415942	89.3	0.349	34.8	46.6	88.9	119.2	0.60	0.56
1988	137284	355138	492422	80.2	0.259	44.3	61.4	137.1	190.1	0.79	0.63
1989	208860	220314	429174	69.2	0.327	31.8	62.0	67.4	131.2	0.72	0.54
1990	238521	210257	448777	25.9	0.270	81.1	173.2	77.9	166.2	0.83	0.63
1991	233884	149401	383286	26.6	0.086	56.1	143.9	173.7	445.7	0.98	0.97
1992	161160	120475	281635	20.9	0.075	57.5	134.5	160.6	375.5	1.37	0.98
1993	172047	62692	234739	14.2	0.120	44.0	164.7	52.2	195.6	1.41	0.67
1994	128638	90072	218710	30.1	0.227	29.9	72.6	39.7	96.3	1.24	1.06
1995	130010	112885	242895	19.1	0.121	59.0	127.0	93.3	200.7	0.81	1.42

Year	Commercial Landings (kg)			Adult Indices		Relative Exploitation				Total Mortality	
	Estimated Hudson R. Portion of OMS*	In-river Hudson	Total Hudson	ESSB	Egg	In-river Harvest/ ESSB	Total HR Harvest/ ESSB	In-river Harvest/ Egg	Total HR Harvest/ Egg	Male Z	Female Z
1996	135536	83690	219226	41.5	0.262	20.2	52.8	31.9	83.7	1.29	0.78
1997	127247	67799	195047	13.6	0.036	49.8	143.4	188.3	541.8	0.65	0.43
1998	139083	105484	244567	21.5	0.086	49.1	113.8	122.7	284.4	1.03	0.99
1999	133268	66501	199769	16.6	0.085	40.0	120.2	78.2	235.0	1.33	1.15
2000	100962	69555	170517	25.3	0.119	27.5	67.5	58.4	143.3	1.29	1.20
2001	132345	45997	178341	9.3	0.039	49.6	192.2	117.9	457.3	0.97	1.11
2002	112240	59242	171482	8.3	0.034	71.5	207.1	174.2	504.4		
2003	69057	49998	119055	15.9	0.072	31.5	75.0	69.4	165.4	1.13	1.13
2004	76355	33040	109395	8.1	0.033	40.9	135.4	100.1	331.5	0.80	0.91
2005	32286	23807	56093	9.9	0.042	24.1	56.8	56.7	133.6	0.90	0.83

*OMS - Ocean mixed stock fishery

Table 1.5.1-B4. Commercial harvest, adult abundance indices, relative exploitation, and total mortality estimates for the Connecticut River American shad stock.

	Commercial Landings (kg)			Adult Indices		Relative Exploitation			Total Mortality	
Year	**Estimated Connecticut R. Portion of OMS***	**In-river Connecticut**	**Total Connecticut**	**In-river Com. CPUE**	**Holyoke Lift**	**In-river Ct/H lift**	**Total Ct/H Lift**	**Total Ct/In-river CPUE (1000s)**	**Male Z**	**Female Z**
1970	6720	78518	85238		66000				1.03	1.14
1971	3742	109182	112924		53000				0.85	1.17
1972	6198	113037	119236		26000				0.99	1.00
1973	4191	116847	121039		25000				0.98	0.67
1974	4207	112130	116337		53000				0.83	0.87
1975	6995	75071	82065		110000				1.21	1.07
1976	7779	177811	185590		350000	0.51	0.53		1.47	1.30
1977	14241	150777	165017		200000	0.75	0.83		1.83	1.46
1978	14136	138938	153074		140000	0.99	1.09		1.84	1.29
1979	14336	93804	108141		260000	0.36	0.42		2.27	1.42
1980	53045	140843	193888		380000	0.37	0.51		2.15	1.61
1981	75402	147284	222686	5.40	380000	0.39	0.59	41.22	2.37	1.27
1982	97182	128369	225551	5.13	290000	0.44	0.78	44.00	2.14	1.58
1983	60181	193234	253414	5.89	530000	0.36	0.48	43.00	1.24	1.70
1984	78873	180896	259769	6.87	500000	0.36	0.52	37.81	1.64	1.15
1985	92586	182347	274934	6.44	480000	0.38	0.57	42.69	1.68	1.31
1986	90192	146059	236251	10.29	350000	0.42	0.68	22.97	1.20	2.02
1987	95036	151457	246493	9.00	280000	0.54	0.88	27.39	1.29	1.53
1988	116144	85776	201920	6.89	290000	0.30	0.70	29.31	2.61	1.59
1989	89246	82147	171393	7.63	350000	0.23	0.49	22.48	1.37	1.84
1990	90171	117675	207846	4.50	360000	0.33	0.58	46.19	2.00	2.01
1991	86663	67722	154386	4.80	520000	0.13	0.30	32.16	1.63	1.31

	Commercial Landings (kg)			Adult Indices		Relative Exploitation			Total Mortality	
Year	**Estimated Connecticut R. Portion of OMS***	**In-river Connecticut**	**Total Connecticut**	**In-river Com. CPUE**	**Holyoke Lift**	**In-river Ct/H lift**	**Total Ct/H Lift**	**Total Ct/In-river CPUE (1000s)**	**Male Z**	**Female Z**
1992	57120	65454	122575	6.22	720000	0.09	0.17	19.71	1.81	2.02
1993	62137	43845	105982	4.25	340000	0.13	0.31	24.94	1.82	2.02
1994	47860	47174	95034	4.57	181000	0.26	0.53	20.79	0.69	1.82
1995	51660	27931	79591	2.63	190000	0.15	0.42	30.32	1.34	1.57
1996	54660	30281	84941	4.00	276000	0.11	0.31	21.24	2.35	1.87
1997	56468	41279	97747	5.33	299000	0.14	0.33	18.33	4.42	2.98
1998	68666	40526	109192	5.33	316000	0.13	0.35	20.47	3.28	1.25
1999	63674	20219	83893	3.56	194000	0.10	0.43	23.59	2.30	1.81
2000	39783	48724	88507	7.78	225000	0.22	0.39	11.38		0.69
2001	60086	26869	86955	5.50	273000	0.10	0.32	15.81	2.02	1.11
2002	61182	49034	110216	8.40	375000	0.13	0.29	13.12	5.56	2.39
2003	31756	50407	82163	8.00	287000	0.18	0.29	10.27	4.14	2.07
2004	28028	30086	58115	5.33	191290	0.16	0.30	10.90	4.24	2.12
2005	12390	32626	45016	5.50	117756	0.28	0.38	8.18		

*OMS- Ocean mixed stock fishery

Figure 1.5.1-B1. Relative exploitation of the Delaware River American shad stock using total harvest (ocean/mixed stock and in-river harvest) and the Lewis CPUE as a measure of stock abundance.

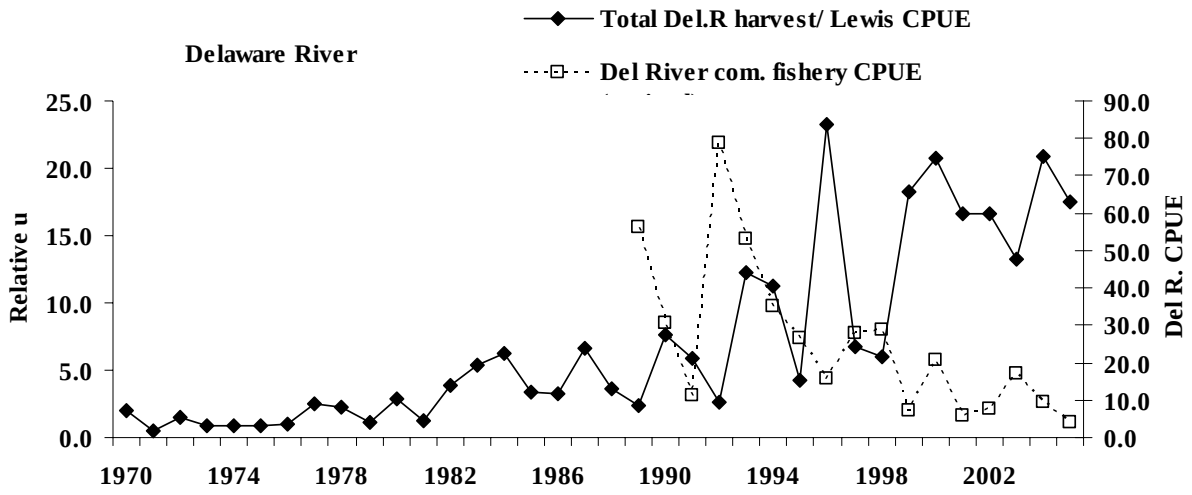


Figure 1.5.1-B2. Relative exploitation of the Hudson River American shad stock using total harvest (ocean/mixed stock and in-river harvest) and ESSB and Egg indices as a measure of stock abundance. ESSB is a fishery-dependent index of ages 5-7 expanded to all ages by fishery independent age data and mean weight at age. Egg is an annual index of eggs per 1000 m^3 from river-wide sampling.

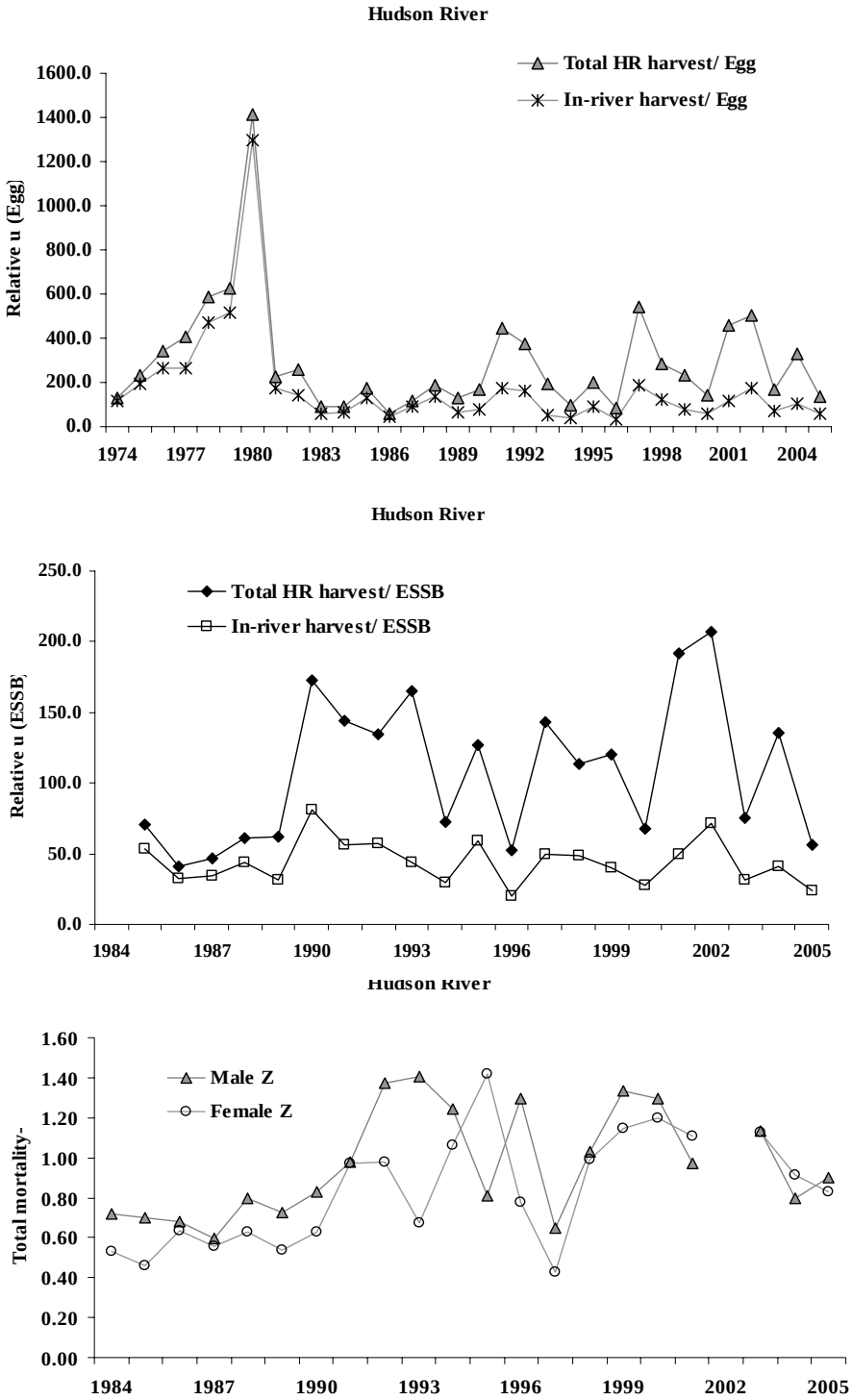
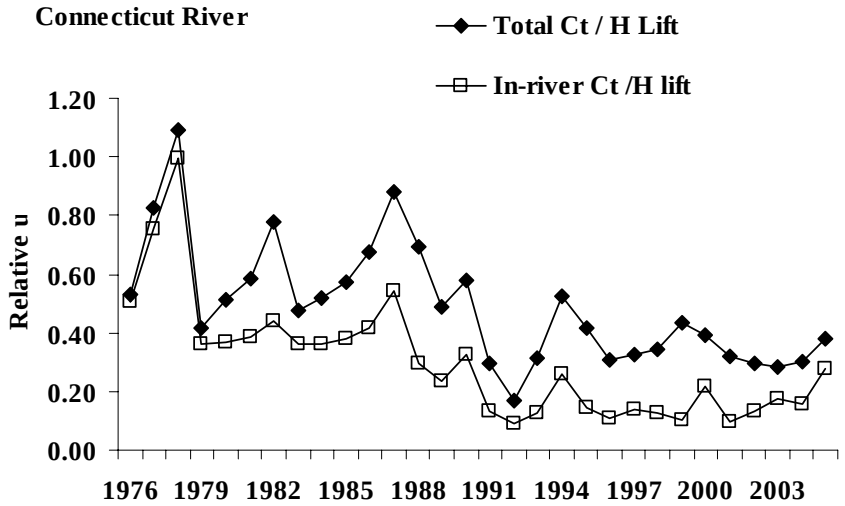
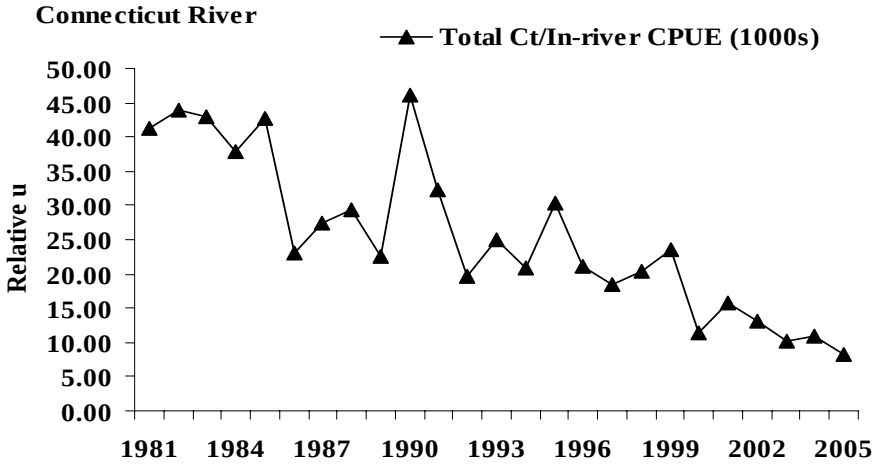
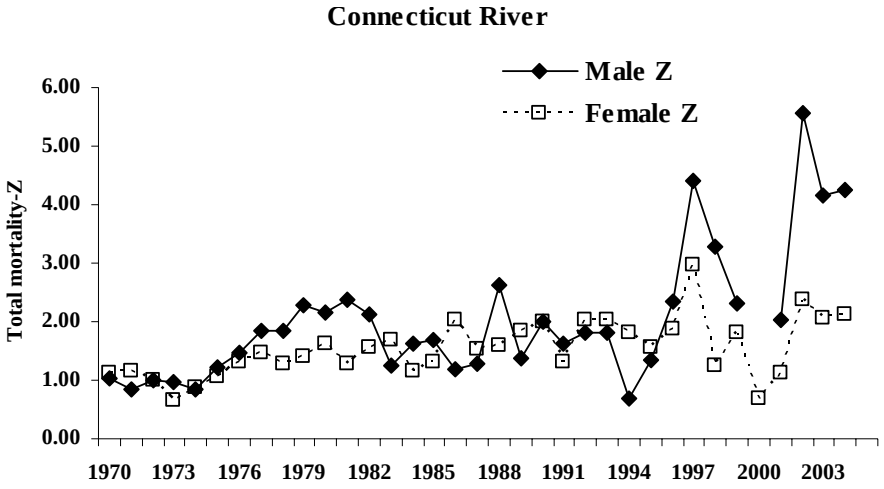


Figure 1.5.1-B3 Relative exploitation of the Connecticut River American shad stock using total harvest (ocean/mixed stock and in-river harvest) and the Holyoke Lift and in-river CPUE as measures of stock abundance.







C. *Striped Bass Predation on Adult American Shad: Occurrence and Observed Effects on American Shad Abundance in Atlantic Coastal Rivers and Estuaries*

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Introduction

The possibility that increased striped bass abundance could negatively affect American shad and other potential prey has been discussed for some time (Walter *et al*. 2003). As mortality mortality rates of mature American shad have increased, researchers have focused on the possibility that mature striped bass could be preying on mature American shad. Clearly mature bass and mature American shad overlap in time and space in spawning rivers and along the Atlantic coast. Large striped bass (>90 cm TL) do prey on small mature American shad (Crecco *et al*. 2007, this volume) and such predation could affect American shad abundance. We evaluated the potential for adult predation by evaluating diet data for adult striped bass in the Hudson River estuary and inspecting the relationship between abundance indices of mature American shad and striped bass in selected coastal rivers.

Methods

Hudson River Diet Data

We collected approximately 200 mature striped bass annually from the Hudson River estuary from 1990 through 2006 for contaminant analyses. Fish were taken by electrofishing, haul seine, and fishery-independent and dependent gill nets in spring, summer, and fall. Fish were generally placed in a cooler of ice shortly after collection. Most fish were collected in the spring during the spawning migration. In the laboratory, fish were measured to the nearest millimeter total length (TL). Stomachs were removed and contents were identified to the lowest taxonomic level possible and enumerated. Contents were not preserved. Diets were summarized as frequency of occurrence (number and percent of stomachs containing a given item) by season and general diet category (crabs, fish, other, and empty) and by taxon for the entire sample, all seasons combined. We added diet summaries for striped bass >900 mm TL because that size striped bass was proposed by (Crecco *et al*. 2007, this volume) as being the size most likely to prey on adult American shad.

Striped Bass and American Shad Abundance (Selected Rivers)

We obtained indices of abundance for mature American shad and striped bass for the Connecticut River, Hudson River, Delaware River, Susquehanna River and upper Chesapeake Bay, Potomac River, and Albemarle Sound. Indices came from a variety of fishery independent and dependent sample programs conducted by state natural resource agencies and published in agency or interstate reports (Table C1). Sampling occurred in spring. The two species were generally collected from within the same geographic area within each river or estuary, but by different sample gears within system. It was our working hypothesis that in systems where striped bass and American shad abundance consistently varied in opposite directions, striped bass may have affected the abundance of American shad. Abundance correlations between the two species were tested by a simple linear regression of annual abundance of American shad on annual abundance of striped bass.

Results

Hudson River Striped Bass Diet

We examined stomachs from 1,859 mature striped bass in the Hudson River during the 16-year study period, of which 1,646 came from spring collections (Table C2). Fish up to 1165 mm TL were taken, but modal length interval was 650 to 700 mm TL (Figure C1). Forty-seven fish (2.5%) were greater than 900 mm TL. Most stomachs were empty (84 % of total, 74 % of fish >900 mm TL; Table C3). Of stomachs containing food items, those with fish predominated in the total sample (66%) and in bass >900 mm TL (100%; Table C3). The two most common food items in stomachs were unidentified fish (36 % of total, 42 % of bass over 900 mm TL) and herring (18 % of total, 33 % of bass over 900 mm TL; Table C3). American shad were observed in the stomachs of two striped bass (<1% of total, 17 % of bass over 900 mm TL) and both of these striped bass were greater than 1000 mm TL.

Striped Bass and American Shad Abundance (Selected Rivers)

There was some indication in some systems that abundance of mature striped bass and American shad was inversely correlated, at least for short periods of time (Table C4; Figure C2). In the last few years in the Connecticut River, it appears that shad abundance declined when striped bass abundance went up. A similar pattern occurred in the late 1980s in the Hudson River, and in the last few years in upper Chesapeake Bay. However, there were no long stretches of time in any system in which striped bass increased and American shad decreased. On the contrary, there were long stretches of time in almost all systems when abundance of the two species appeared to change in the same direction. This was most apparent in the Delaware River where data suggested a concurrent decline over the time series, in the Hudson River during the 1990s, and in the Potomac River where data suggested a concurrent increase. A simple regression of shad abundance on bass abundance was significant for the entire time series in the Delaware River ($r^2 = 0.44$, slope = 2.02, $P = 0.04$; Figure C3) and in 1990 to 2001 in the Hudson River ($r^2 = 0.74$, slope = 0.47, $P = <0.01$.). Regressions were not significant between species abundances in any other system.

Discussion

Hudson River Striped Bass Diet

Results of our diet analyses indicated that mature striped bass of the Hudson River Estuary do prey on river herring and mature American shad; however, American shad were only observed in the largest striped bass and only in two fish during the 16-year study period. Results of our study differed somewhat from those observed in a recent study of striped bass diet in the Connecticut River (Crecco *et al*. 2007, this volume). In the Hudson study, two of 47 striped bass >900 mm TL contained American shad. In the Connecticut study, 19 of 28 striped bass >900 mm TL contained American shad. American shad were not an important prey item in Connecticut River American shad less than 900 mm TL and not prey at all in smaller Hudson River striped bass. Only the smallest mature shad were consumed by striped bass in the Connecticut River. Sixteen percent of the striped bass in the Hudson had food items in their stomachs, while fifty one percent of the bass in the Connecticut study had food items.

Differences in percent full stomachs and frequency of American shad predation between striped bass of the Hudson and Connecticut rivers might be explained by differences in biota of the two systems. Striped bass spawn in the Hudson River, but not in the Connecticut River, so one would expect striped bass present in the Connecticut to be more focused on feeding. Furthermore, striped bass in any abundance are a new addition to the Connecticut River and prey, including American shad, may not have adjusted to the presence of such a large predator. Mature striped bass and American shad have occupied overlapping habitats in the Hudson River for hundreds of years and could be expected to have developed coping

strategies. Finally, it is likely that large striped bass of the Connecticut River have shifted to American shad as blueback herring abundance decreased as suggested by Savoy and Crecco (2004).

In any diet study of fish, the observed frequency of a given food item may be affected by rate of digestion rendering the item unrecognizable. This is most likely to occur with small, soft-bodied foods. We did not consider this for mature American shad in the Hudson and Connecticut River striped bass diet studies because mature shad are relatively large compared to their predators and because the relatively cool water temperatures during spring when most fish were collected would have slowed digestion.

It should be pointed out that striped bass >900 mm TL are a relatively minor component of striped bass present in Atlantic coastal rivers in spring. In haul seine sample of Hudson River striped bass spawning stocks, fish >900 mm TL made up an average of 2.5% of the males and 3.1% of the females in 1985 through 2006. These proportions compare favorably with the 2.5% of the Hudson River diet sample that were >900 mm TL. Size composition of mature striped bass in the Connecticut River is not known. About 6.1% of striped bass in the diet study in that river were >900 mm TL.

Mature American shad do not appear to be an important food item for striped bass along the Atlantic coast. Walter *et al*. (2003) surveyed over 35 published and unpublished reports on striped bass diets in Atlantic coastal rivers, estuaries, and ocean waters. They found that menhaden, anchovies, river herring, and Atlantic herring were reported as dominating the diets of striped bass older than age one. The review summary was not detailed enough to identify if American shad had been identified as a minor prey item by any author.

Striped Bass and American Shad Abundance (Selected Rivers)

We did not find strong evidence from adult abundance data over the last 20 years that increased abundance of striped bass concurred with decreased abundance of American shad. Both American shad and striped bass are relatively long-lived fish with several age classes in their spawning populations. If striped bass fed on the smallest and youngest American shad, one would expect to see reduced recruitment to the shad spawning population and slow erosion of shad abundance as bass abundance remained high or increased. We did not see evidence of such long-term changes in available abundance data. Short-term increases in bass occasionally coincided with short-term declines in shad, but such change would not likely be caused by predation on recruiting fish unless only a few age classes of prey were present. More importantly, there were several datasets in which both American shad and striped bass changed in the same direction for all, or part of, the time series. Such concurrent changes suggest change in environmental conditions or mortality factors that affected both species in a similar manner.

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Table 1.5.1-C1. Relative abundance indices for adult American shad and striped bass in Atlantic coastal rivers and estuaries

River	Species	Data Source
Connecticut	American Shad	Total annual lift numbers at the Holyoke Dam on the Connecticut River (Savoy 2005).
	Striped Bass	Relative adult abundance from annual electrofishing collections (Crecco *et al*. 2007, this volume).
Hudson	American Shad	Adult index based on index of egg abundance and age structure in the haul seine fishery-independent sampling (Hattala and Kahnle 2007, this volume).
	Striped Bass	Adult index based on index of egg abundance and age structure in the haul seine fishery-independent sampling.
Delaware	American Shad	Catch per haul in commercial haul seine collections (Allen *et al*. 2007, this volume).
	Striped Bass	Electrofishing CPUE for ages 3-13 (ASMFC 2006).
Susquehanna	American Shad	Catch per angler hour in fishery-independent sampling in the Conowingo Dam tailrace (Sadzinski *et al*. 2007, this volume).
	Striped Bass	Index of spawning biomass March - May (B. Sadzinski, pers. comm.).
Potomac	American Shad	Pounds per net day in commercial pound (Carpenter *et al*. 2007, this volume).
	Striped Bass	Index of spawning biomass March-May (B. Sadzinski, pers. comm.).
Albemarle Sound	American Shad	Pounds per trip in commercial gill net (Burgess et al. 2007, this volume).
	Striped Bass	CPUE in spring fishery-independent gill net survey (Burgess, pers. comm.).

Table 1.5.1-C2. Number and mean total length striped bass collected from the Hudson River examined in diet analyses, 1990-2006.

Season	Primary Food Item	N	Mean TL	SD	Min	Max
All Fish						
Spring	Crabs	39	666.5	79.1	535	875
Fall	Crabs	2	525.5	30.4	504	547
ALL		**41**	**659.6**	**83.1**	**504**	**875**
Fall	Fish	32	579.2	114.7	356	815
Spring		140	691.3	122.3	476	1165
Summer		26	661.9	88.9	484	838
Unknown		2	568.0	9.9	561	575
ALL		**200**	**668.3**	**123.5**	**356**	**1165**
Fall	Other	1	672.0			
Spring		59	624.1	89.7	467	995
Summer		2	586.0	35.4	561	611
ALL		**62**	**623.6**	**88.0**	**467**	**995**
Fall	Empty	74	621.4	113.3	390	935
Spring		1408	649.6	94.8	425	1006
Summer		51	667.7	153.8	368	1054
Unknown		21	588.9	66.4	496	727
ALL		**1554**	**648.0**	**98.3**	**368**	**1054**
		Fish > 900 mm TL				
Spring	Fish	12	980.0	73.9	900	1165
Fall	Empty	1	935.0			
Spring		30	947.0	35.1	902	1006
Summer		4	956.8	67.8	904	1054
ALL		**35**	**947.8**	**38.3**	**902**	**1054**

Table 1.5.1-C3. Stomach contents of striped bass collected from the Hudson River Estuary, 1990-006.

Category	All Fish		Fish > 900 mmTL	
Total number of stomachs examined	1859		47	
Empty	1555	83.6%	35	74.5%
Total with food items	304	16.4%	12	25.5%
Food Items	**N-Stomachs**		**N-Stomachs**	
Crab, blue	41	13.5%	-	
Crab, Mud	2	0.7%	-	
Crab, unidentified	6	2.0%	-	
TOTAL Crabs	**49**	**16.1%**	**0**	
Fish, Unidentified	108	35.5%	5	41.7%
American eel	3	1.0%	0	
American shad	2	0.7%	2	16.7%
Atlantic menhaden	14	4.6%	-	
Catfish/bullhead	3	1.0%	1	8.3%
Cunner	1	0.3%	-	
Herring, total	55	18.1%	4	33.3%
Alewife	(7)		-	
Blueback herring	(12)		(1)	
Needlefish	2	0.7%	-	
Pipefish	1	0.3%	-	
Sand lance	1	0.3%	-	
White perch	11	3.6%	-	
TOTAL Fish	**200**	**65.8%**	**12**	**100.0%**
Amphipods	3	1.0%	-	
Arthropod	4	1.3%	-	
Crustacean	1	0.3%	-	
Grass shrimp	1	0.3%	-	
Isopods	13	4.3%	-	
Miscellaneous*	14	4.6%	-	
Rocks	4	1.3%	-	
Squid	3	1.0%	-	
Unidentified digested material	22	7.2%	-	
TOTAL-Other	**48**	**15.8%**	**0**	

* Sticks, worms, bones, bologna sandwich, mollusk parts, clam shell, plastic straw, mussel

Table 1.5.1-C4. Relative abundance indices for adult American shad and striped bass in Atlantic coastal rivers and estuaries.

	Connecticut River		Hudson River		Delaware River		Upper Bay		Potomac River		Albemarle Sound	
Year	Holyoke Shad Lift (N*1000)	Striped Bass Electro CPUE	American Shad Adult Index	Striped Bass Adult Index	Shad FD Haul Seine CPUE	Striped Bass Electro CPUE	Shad Catch Per Angler hr	Striped Bass SSB	Shad Pound Net CPUE	Striped Bass SSB	Shad FD Gillnet CPUE	Striped Bass FI Gill Net CPUE
1985			31.82	0.42			2.1	64.9		25.9		
1986			55.40	0.72			3.0	152.0		45.7		
1987			45.03	1.51			3.7	400.5		88.8		
1988			39.30	1.34			6.0	250.3	0.9	63.6		
1989			36.57	3.93			6.5	120.3	0.7	80.5		
1990			15.60	4.67			5.0	98.4	1.7	62.5		
1991			17.83	5.69			5.7	109.4	1.6	138.7		1.2
1992			14.49	4.43			6.1	275.0	2.1	379.4		0.5
1993	720	11	11.95	5.25			5.6	278.5	4.8	420.9		0.3
1994	181	44	23.23	5.45			5.6	87.3	1.7		156.8	0.2
1995	190	13	12.63	2.60			7.4	547.7	3.6	293.8	169.5	1.0
1996	276	86	26.75	11.06	3.7	3.4	10.1	347.9	4.1	391.6	144.8	0.7
1997	299	142	9.12	3.40	12.0	4.1	10.5	256.9	6.9	369.6	167.8	0.9
1998	316	110	13.87	4.04	13.2	3.7	14.2	157.4	6.7	217.0	206.6	1.0
1999	194	59	11.79	9.90	4.6	2.6	15.8	161.4	5.1	275.2	166.8	1.2
2000	225	198	37.71	17.84	4.1	2.1	20.4	169.9	5.8	301.8	172.9	0.9
2001	273	126	29.08	14.17	6.8	1.9	14.8	490.2	11.2	273.2	151.9	1.0
2002	375	113			3.8	1.6	13.5	266.4	7.9	380.7	226.1	0.9
2003	287	162	6.26	4.89	5.2	2.5	11.2	566.2	14.9	118.5	280.6	0.4
2004	191	203	34.90	4.43	4.1	2.9	12.2	389.8	10.3	578.8	232.9	1.0
2005				5.12	2.9	0.0	7.1	469.7	12.2	196.1	201.0	0.7

Figure 1.5.1-C1 Length frequency of striped bass, collected in the Hudson River, and used in diet analysis.

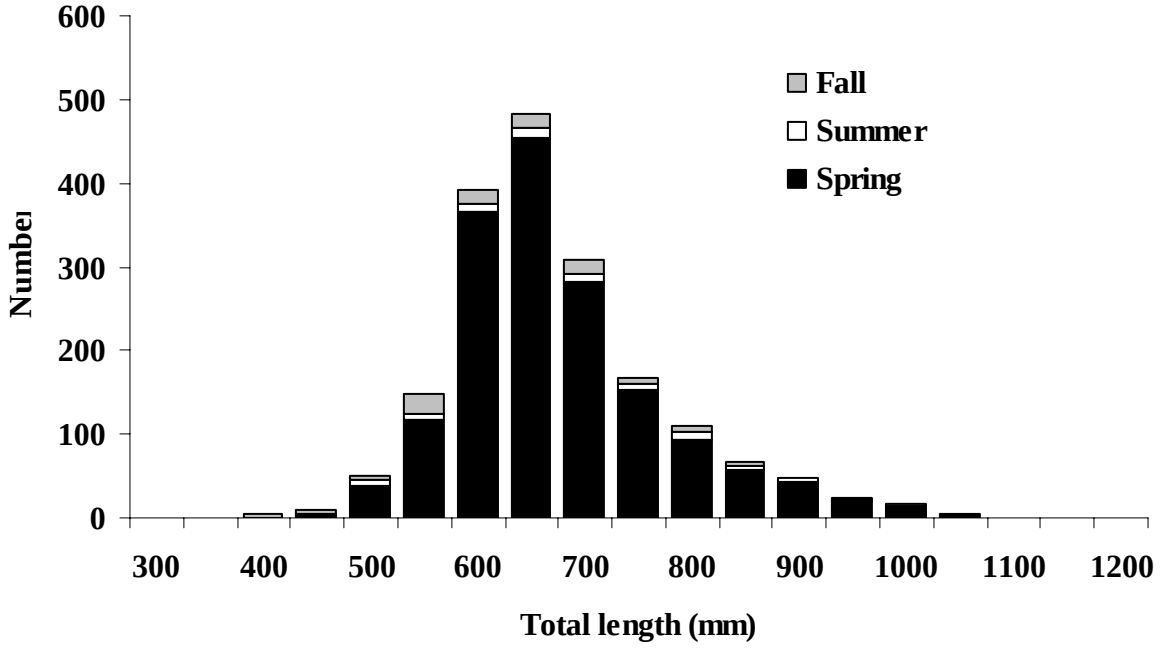


Figure 1.5.1-C2 Relative abundance of American shad and striped bass in Atlantic coastal rivers and estuaries.

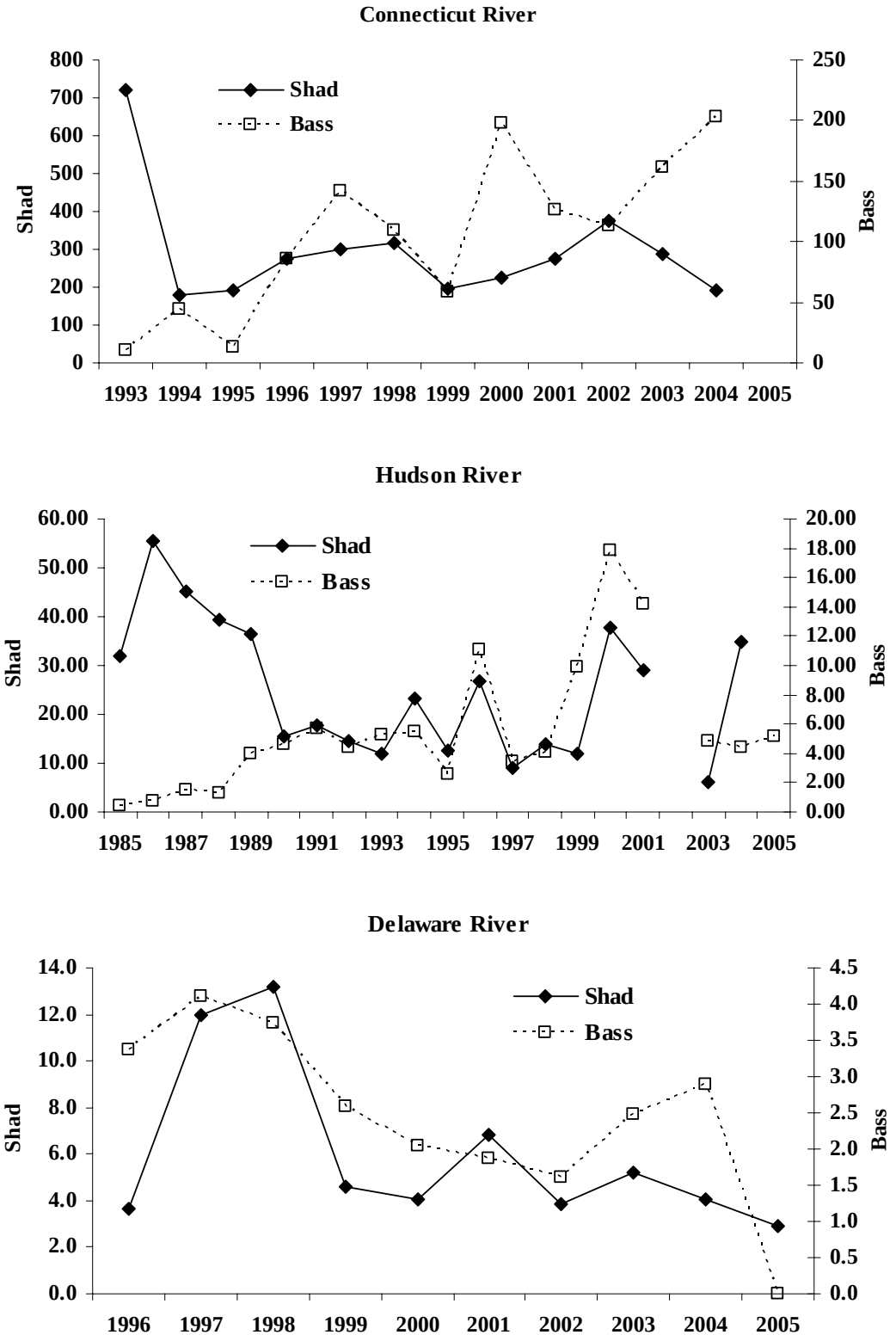
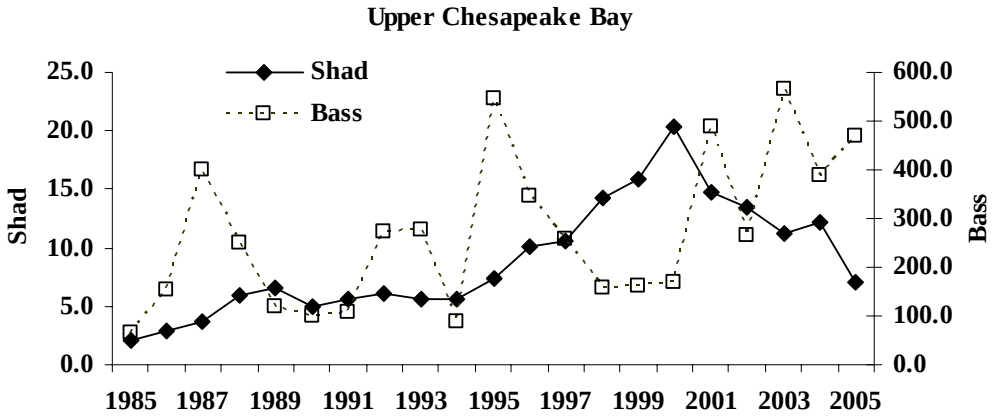
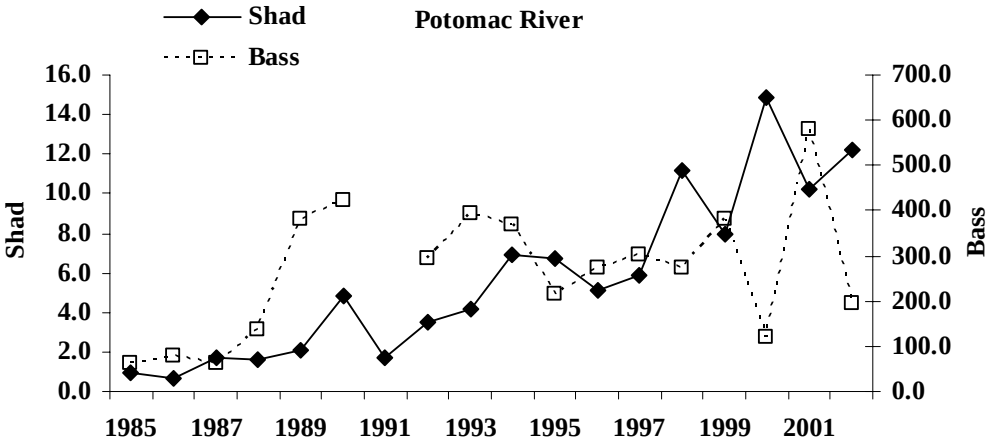


Figure 1.5.1-C2 (cont.) Relative abundance of American shad and striped bass in Atlantic coastal rivers and estuaries.





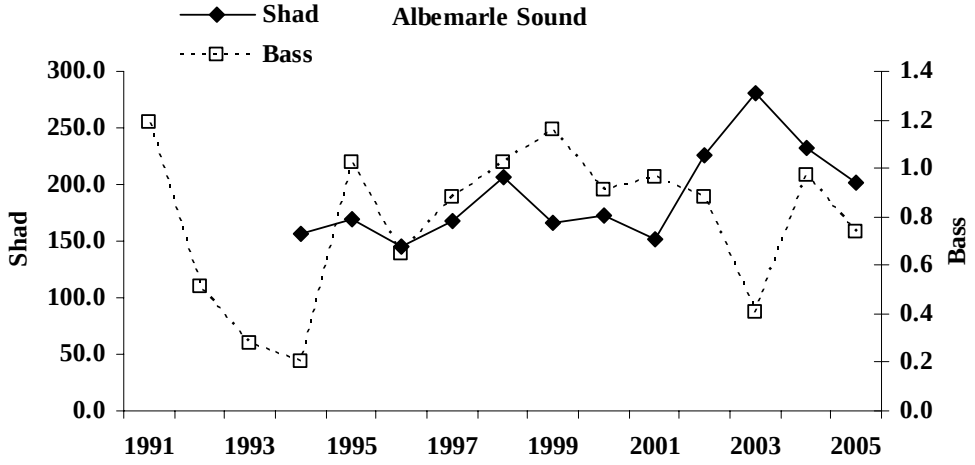
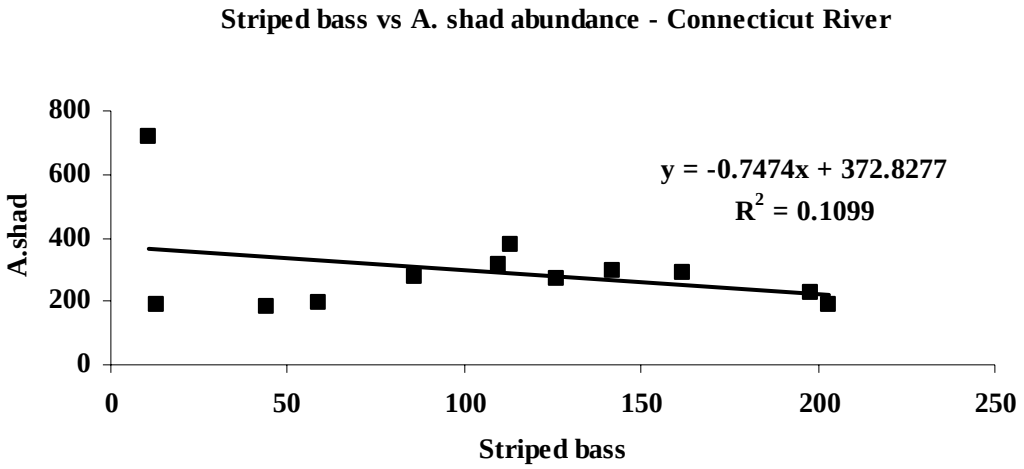
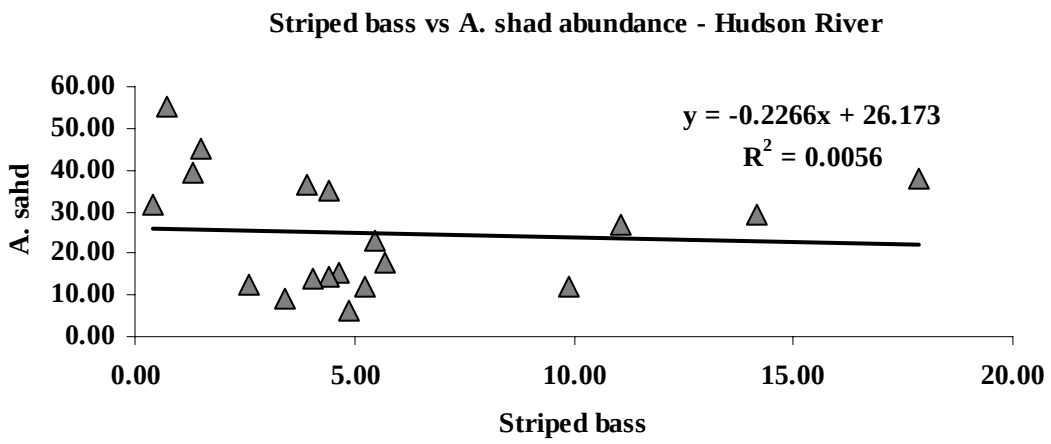


Figure 1.5.1-C3 Relationship between relative abundance of mature striped bass and mature American shad in Atlantic coastal rivers and estuaries.





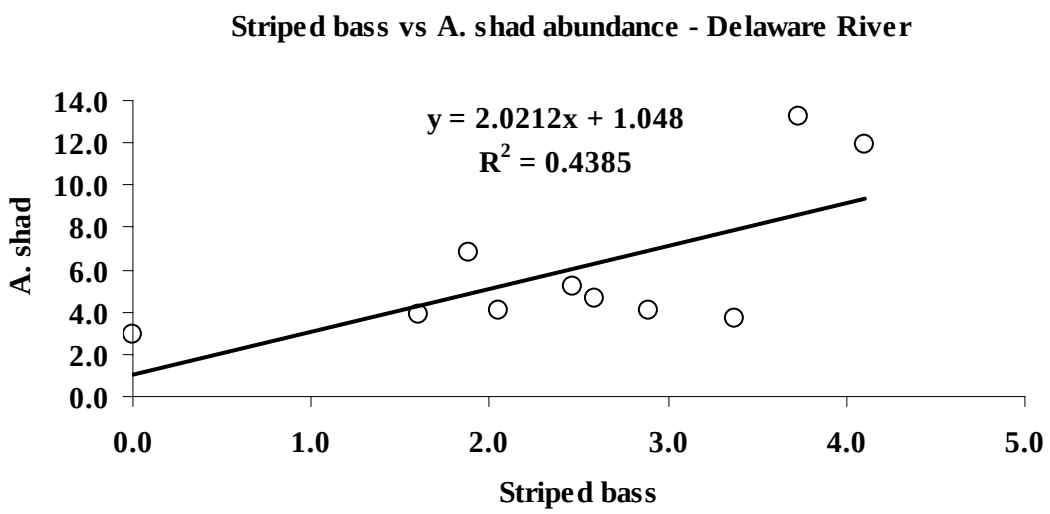
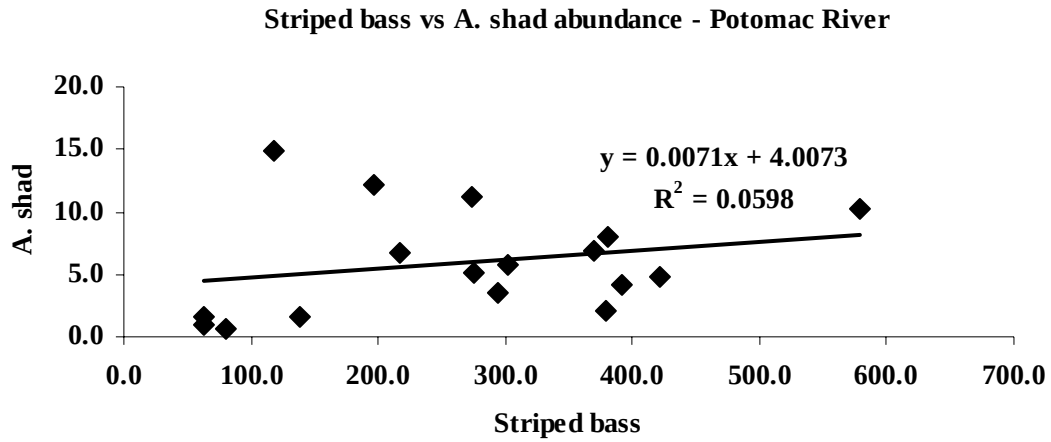
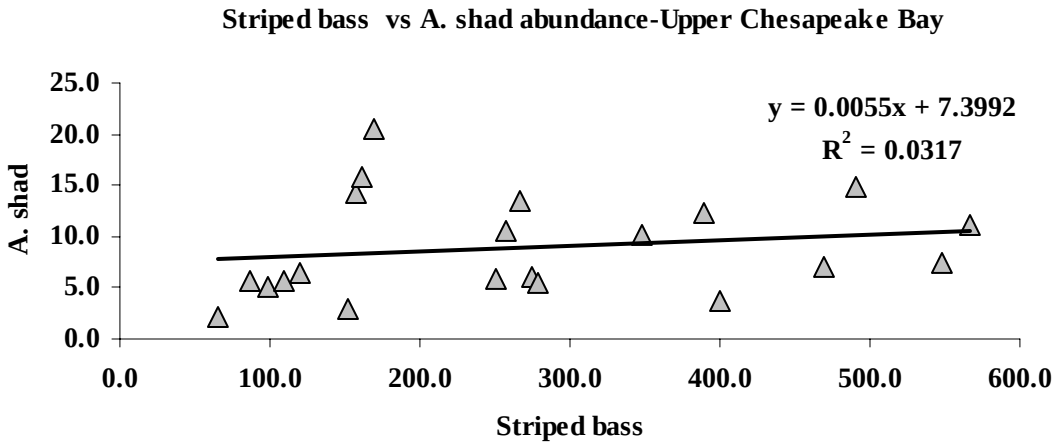
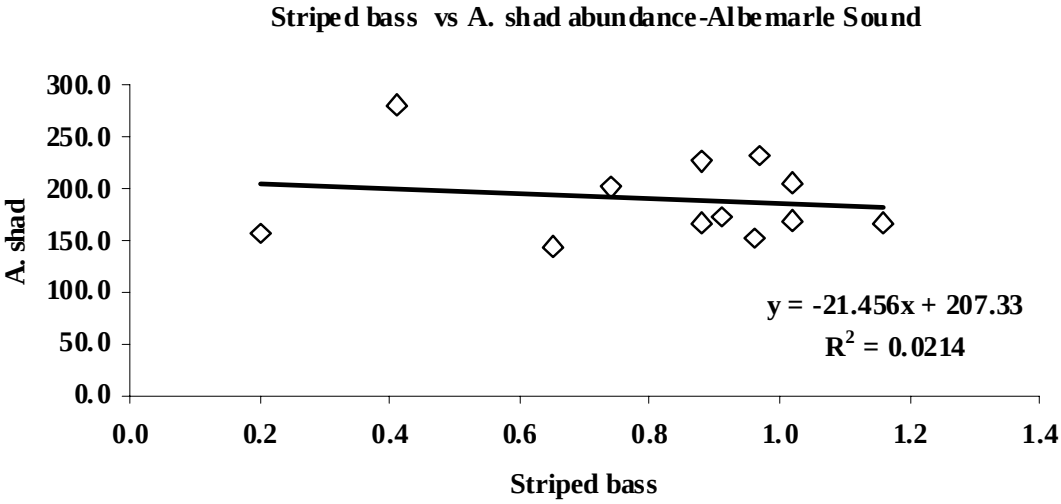


Figure 1.5.1-C3 (cont.) Relationship between relative abundance of mature striped bass and mature American shad in Atlantic coastal rivers and estuaries.







1.5.2 Stock-Specific Perspectives

A. *Delaware River*

The SASC examined data to determine if the decline in adult shad abundance during the1990s was caused by overfishing. In the 1998 assessment, estimates of fishing mortality were determined based on landings data and stock estimates derived from landings and population estimates. Controversy arose due to lack of confidence in the population estimates and the probability of their accuracy to perform such calculations.

Estimates of relative exploitation were developed from commercial CPUE data to ascertain if potential overfishing occurred during the period of low adult abundance in the early to mid-1990s. Relative exploitation estimation is a basic approach with minimum assumptions that reveals trend in exploitation (annual harvest divided by an index of relative abundance) rather than absolute estimates of fishing mortality. The SASC developed estimates from the New Jersey and Delaware gill-net fisheries as well as the Lewis haul seine fishery. For this assessment, estimates of relative exploitation were developed by dividing annual in-river harvest (river and upper bay commercial landings) by the CPUE.

Relative exploitation rates were developed for the 1985 to 2005 time period when more reliable in-river estimates of harvest are available (see Section 8, Figure 8.19). All estimates were standardized (Z-transformed) with a value of two added to eliminate any negative numbers for easier comparison. All estimates of relative exploitation were fairly similar throughout the 1990s. The analysis has shown an increase in relative exploitation in recent years beginning in 2000 but the extent of this trend is unknown. This increase may be a direct result of the mandatory reporting enacted by New Jersey starting in 2000 and might not be an actual increase in exploitation but rather an increase in reported harvest. Alternatively, the increase may be a result of current low population size and could be potentially harmful to stock restoration. Further study is needed to determine if recent trends in exploitation are of a magnitude to necessitate concern.

To test the hypothesis of the mandatory reporting effect on relative exploitation, the analysis was repeated using only State of Delaware landings instead of all in-river landings. The results of this analysis indicate that the relative exploitation has actually decreased in recent years (see Section 8, Figure 8.20). This is also no indication that overfishing was a major factor in any adult population decline in the 1990s.

Two estimates of relative exploitation of American shad were calculated (see Section 8, Figure 8.21) using the CPUE from the Lewis fishery combined with harvest data from the Delaware Estuary (1954-2005) and in-river fisheries (1985-2005). All estimates were standardized (Z-transformed) with a value of two added to eliminate any negative numbers for easier comparison. Although Estuary landings data are potentially biased with mixed stock landings from the lower Delaware Bay area, they are considered useful in determining how current estimates compare in magnitude to those of the past. Estimates of relative exploitation from the estuary harvest were very high from 1954 to 1968 when compared to the 1990s, as well as when compared to estimates of in-river relative exploitation in the 1990s.

The relative exploitation derived from the Lewis fishery varied without trend from 1985 to 1999, but increased dramatically in recent years. Again it is likely that this increase is a direct result of the mandatory reporting enacted by New Jersey starting in 2000 and is not an actual increase in exploitation, reinforcing the need to explore exploitation, if not actual harvest, within the Delaware River Basin.

Since overfishing did not seem to be a major factor in stock decline during the 1990s, other data were analyzed to determine the potential cause. The SASC also looked at potential interactions with striped bass within the Delaware Estuary to determine if the shad decline was a direct result of a predator-prey

relationship. Analysis of American shad young-of-year (YOY) and age 1+ indices were compared to various striped bass indices from 1980 to 2005 including:

- NJ seine age 1+, arithmetic and geometric means (1980-2005)
- NJ seine YOY (1980-2005)
- Delaware Bay (DE) trawl 2-8 aggregate (1982-2005)
- Delaware River spawning stock—ages 2-8 separate and 3-12 aggregate (1996-2004)

The only significant correlation found was between the Delaware River striped bass spawning stock age-3 and the upper Delaware River American shad YOY ($r^2 = 0.5747$) with no time lag. When lagged, there is no correlation ($r^2 = - 0.0009$). Because the DE trawl did not catch many striped bass from 1982 to 1990, the SASC looked at the DE trawl compared to the averaged Delaware River YOY for the period 1991 to 2005 (see Section 8, Figure 8.22). The resulting correlation ($r^2 = 0.5488$) was exceeded only by the age-3 Delaware River spawning stock analysis.

After eliminating recent years to determine if there was any correlation in the 1990s when shad abundance was declining, a stronger correlation ($r^2 = 0.7415$) was found from 1991 to 2000 (see Section 8, Figure 8.23). Analyses with the YOY indices and Delaware Bay trawl striped bass indices were not time lagged due to fact that the Delaware Bay trawl is an aggregate index. An important detail to note is that the relationship is dominated by the 1996 year-class of American shad, which may have an effect on all assumptions of striped bass-American shad interactions.

The striped bass-American shad analyses show that when shad YOY production is high, there are ample striped bass present in the Delaware system of the 2-8 year-old age classes and the opposite seems to be true if shad YOY production is low. For both species this seems to be dictated by environmental conditions. This may mean that striped bass was a limiting factor during the 1990s in years when shad production was high. Additional empirical evidence, such as stomach content analysis, is necessary to determine if the correlation has a factual basis or is just due to the opposing directions in which the two species have been heading in the Delaware since the mid-1990s.

B. *Connecticut River*

American shad landings and run sizes have fallen steadily in the Connecticut River since 1993 despite relatively high and persistent juvenile production since 1990. Several analyses have been conducted to determine the effects of fishing and predation on the recent stock decline of Connecticut River shad that have incorporated both ocean recreational shad landings and ocean commercial discards in the development of fishing mortality estimates. In addition, equilibrium and non-steady state overfishing thresholds (F_{msy}, N_{msy}) were estimated for Connecticut River shad.

Connecticut Department of Environmental Protection (CTDEP) estimates of fishing mortality on American shad declined after 1995, which did not support the hypothesis that the drop in shad run size since 1993 was due to overfishing. Additionally, trends in juvenile production have been at or above the long-term median index despite the persistent drop in adult stock size from 1996 to 2005, providing evidence that there has been a recruitment bottleneck in the Connecticut River American shad stock. This scenario led CTDEP to hypothesize that this recent failure in shad productivity was largely due to a systematic rise in striped bass predation on adult shad in the River (Savoy and Crecco 2004).

An age-aggregated Steele and Henderson (S-H) production model was constructed on data for the Connecticut River stock of American shad. Results indicated that striped bass consumption rates on adult

shad rose in the River four-fold after 1994, coincident with a steady rise in striped bass abundance. Estimates of annual adult shad consumption by striped bass from 1999 to 2005 were 5 to 15 times greater than the in-river landings (sport plus commercial) during those years. The approximate equilibrium F_{msy} level of 0.39 for shad based on the S-H model easily exceeded the total fishing mortality levels on adult shad in all years from 1989 to 2005. Non-equilibrium F_{msy} levels approached 0.50 in most years from 1981 to 1993, but annual F_{msy} levels fell steadily thereafter to 0.02 in 2004 following a steady rise in striped bass consumption rates. Statistical and empirical evidence given here strongly suggest that the recent emergence of a recruitment bottleneck and the subsequent decline in adult shad run size in the Connecticut River were linked mainly to predation effects from striped bass.

For the complete analysis of the Connecticut River predation hypothesis, please see the Appendix A: Stock Assessment of American Shad in Connecticut (Minority Opinion).

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C. *Hudson River*

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Introduction

Currently the Hudson River American shad stock is at its lowest point in its 125-year history since record keeping began. The Hudson is not alone in this position; other stocks, from the Mid-Atlantic states to Maine, are there too. So how did the Hudson stock get here, and more importantly, why?

The sections preceding this have outlined the sporadic history of data collection on shad stocks, including those with coastwide consequences for many stocks: the inadequate knowledge of bycatch in coastal fisheries, the unknown component of shad in bait fisheries, and stock composition in known current and past fisheries. This lends a level of uncertainty to any analyses to quantify the effect of fishing. However, the trends observed in the Hudson stock over the past 25 years led us to one conclusion.

Methods

To realistically estimate the effects of fishing on the Hudson shad stock, we cannot ignore the harvest from the ocean mixed stock fishery. Effects of mixed stock harvest on selected individual stocks were debated during preparation of the last assessment (ASMFC 1998). We updated estimates of stock composition of mixed stock harvest in Section 1.5.1.

During the mid-1980s we noticed several changes in the Hudson River stock. Fewer shad were returning (change in CPUE in the in-river fixed gill-net fishery, see Section 7), plus older fish were disappearing.

Mixed stock harvest combined with in-river harvest make up most of the removals for a single stock. An unknown, and unaccounted, bycatch kill adds to the uncertainty of the total kill amount. Once total harvest is estimated it can then be compared to a spawning stock index of the affected population. We attempt to draw this comparison to estimate the effect of mixed stock and in-river harvest on the Hudson stock.

Spawning Stock Abundance and Biomass Indices

Spawning stock abundance (SSA) and biomass (SSB) indices can be approached in two ways. The first is an empirical approach, the calculation of an index that measures the current spawning stock equivalent to the annual production. The methods for the calculating our empirical spawning stock abundance and biomass indices (ESSA/ESSB) are described in Section 7. Here we include a second approach that predicts future stock potential. This approach begins an abundance index at age zero, then uses a process that "grows them up" to generate an estimate of current or future spawning stock abundance and biomass. We developed both empirical and predictive indices to compare expected versus observed returns of adults.

Potential Production Index

Our approach begins with an abundance index at age zero, growing them up over their lifetime time to estimate each year-class's potential contribution to the spawning stock. For the measure at age zero, we chose the PYSL index because the long times series of available data includes most of the year-classes present at the adult ages in the spawning population.

Each annual age-0 measure was decremented by assumed annual survival rates for pre-recruits from age zero through age four, then by survival derived from annual mortality rates observed in the adult stock for ages five through 14. Values used were S=0.19 for age zero to age one, S=0.37 for ages one and two, and S=0.74 (from M=0.3) for age three to recruitment to the fishery (ASMFC 1998). Estimates of S for the adult stock for 1974 to 1983 are from Deriso *et al.* (2000). S for 1984 to 2005 are from the annual mortality rates calculated from the spawning stock age structure (Table C1). A maturity schedule is then applied to each age of each year-class. The annual estimate of the forward projection of the PYSL to spawning stock abundance (PSSA) equals the sum of year-classes from ages three through ten predicted to be present each year. Ages three through ten represent most of the adult spawning population with ages greater than age ten comprising a small number of the adults present. To calculate the biomass index (PSSB), the fraction at-age is multiplied by observed annual weight-at-age (WAA in kilograms, Section 7 appendix) before summation. Available data on age zero allowed the calculation of the PSSA and PSSB from1984 through 2008.

Estimates of Current F

We attempted to use several modeling approaches as well as catch-curve analyses (Section 7) to estimate current F on the Hudson stock. These techniques included attempts at using virtual population analysis (VPA), statistical catch-at-age, and surplus production models. The goal was to arrive at some convergence in model-generated mortality rates with mortality estimates calculated from catch-curve or tag based methods. We also developed a stock reconstruction model, which utilized all available stock data. The Hudson River American shad stock has relatively long data series, unlike most other east coast shad stocks. We made an effort to try a variety of models to understand the nuances of model behavior and to find useful tools in our assessment. Convergence of model outputs would, at minimum, increase the level of confidence in estimates of F.

Surplus Production

The most commonly used surplus production model used in east coast fisheries is ASPIC, available from its author Dr. Michael Prager (2005) at the NMFS Beaufort Laboratory. NMFS staff, at Woods Hole, offers a Windows based version of Dr. Prager's model, for those not versed in running DOS based software (NOAA 2005). Prager (2005) developed this model for use when accurate age data is lacking. Primary model inputs include a long-term data series of catch and effort or CPUE. With these inputs, the model attempts to calculate a series of exploitation rates, and estimates population growth parameters (K and r) and fishing mortality rates, MSY, etc., along with diagnostic tools (residuals).

For the Hudson shad stock, in-river catch data was available from 1915 to the present. Several effort data series are available. Talbot (1954) estimated fishing effort for the period 1915 to 1951 in standard fishing units. A SFU equals the number of licensed nets in both New York and New Jersey waters, multiplied by the allowed fishing hours per week. The number of nets for New Jersey is adjusted by a correction factor of five as Talbot (1954) calculated that their fishing power was five times greater than nets in New York. Using his methodology and data up until the present, we input data from the entire time series from 1915 to 2005. Another effort data series available was calculated by Klauda *et al.* (1976). It is similar to Talbot's, but instead uses the total amount of square yard hours of net multiplied by allowable fishing hours. We also calculated this time series for the last 25 years so the complete times series is from 1931 to 2005 (see Section 7).

Virtual Population Analysis

We attempted to fit Hudson River catch-at-age data to two different VPA models, the ADAPT version produced by Woods Hole (NOAA 2005) and the ICES VPA versions (G. Shepherd, pers. comm.). Use of a VPA requires accurate catch-at-age data from all sources of fishing mortality along with indices of abundance at various life stages for tuning.

The only accurate catch-at-age data for known harvest of Hudson River stock is from the in-river harvest of American shad. Ocean catch-at-age was impossible to generate as little data has been collected to describe age-structure of the catch, let alone stock composition. In order to work in a VPA, multiple year age data summaries would need to be generated, summarized by each individual fishery (both directed and bycatch) and stock. To keep things simple, we used the method described in Section 1.5.1 as a first order approximation of the Hudson River component of ocean catch. Then we applied the age structure observed in the Hudson River to the estimated ocean catch.

The only indices of abundance that exist to tune the VPA are those that are measured in the Hudson at adult ages and at age zero (see Section 7).

Age Structured

We also input the data described above into ASAP (Age Structured Assessment Program, NFT version, NOAA 2005). ASAP is a forward projecting model that requires age based catch data, the same as described for the VPA above.

Stock Reconstruction

The stock reconstruction model is the result of cooperative work of the authors and Dr. C. Walters (pers. comm.) and Dr. R. Deriso (pers. comm.). This model builds an annual age structured population in biomass over a series of years of available data, 1915 to the present. The model begins with an estimated natural recruitment rate (millions of age ones), and then applies a survival rate generated from a constant M to

recruitment-at-age for ages one through 14. Weight-at-age data is input to generate a vulnerable stock size in biomass. Inputs for this model are the same as those used for the Hudson in Section 1.1.5.

Another input to the model is losses to the stock. This includes in-river and (1915 to the present, see Section 7), and estimated ocean harvest (1970 to present, see Section 1.5.1) of adults which are used to estimate annual exploitation from the calculated vulnerable stock size.

Maturity, fecundity and vulnerability-at-age are applied to the numbers-at-age to calculate annual egg production, which is also decremented by annual exploitation. The resulting annual egg production, as proxy for the adult stock, is used in a Beverton-Holt stock recruitment (S-R) function to estimate annual recruit production. Included in the S-R are estimated entrainment losses (1952 to present) at age zero (see Sections 1.1.5 and 7).

The user is allowed to select other input parameters: proportion of entrainment mortality before compensation, future harvest (exploitation) rate, future entrainment mortality rate (proportion of larvae lost), and annual natural survival rate (exp(-M)). The model estimates recruitment efficiency (proportion of natural biomass needed for one half the normal recruitment), the natural (unfished) recruitment rate (millions of age ones) and the ratio of 1915 (beginning year) recruitment to unfished recruitment.

The stock production model is set up as a Microsoft Excel spreadsheet for ease in use and can be tuned to observed data in two different ways using the SOLVER function. Observed data measured over the past 25 years are used as tuning indices: PYSL, YOY, adult relative abundance indices and mortality rates (see Section 7). One tuning method uses a maximum likelihood function that attempts to fit the model to the observed data series. The second method tunes the model to past and present exploitation rates using least squares analysis. Comparisons can also be made to using observed versus model generated age structure.

This model was further refined (Deriso *et al.* 2000). It utilized a similar approach as the stock production model, but in a much more detailed method that includes the use of age and repeat spawn data to calculate estimates of survival and impact of entrainment loss.

The stock-recruitment function allows for a predictive component to estimate the effects of future management strategies.

Assessment Results

Overfishing Definition

In Section 1.1.5, we selected a $Z_{30} = 0.54$, using age invariant natural mortality (M=0.3), a Type I fisheries, and a simple biomass per recruit (BPR) analysis. For this section however, we converted the benchmark to an F_{30}=0.24 (BPR) by subtracting M (Table C2).

Spawning Stock Abundance and Biomass

Potential SSA and SSB

The forward projection or potential spawning stock abundance index (PSSA) attempts to predict what the spawning stock should be, based on production of young that occurred previously. The index was relatively low in 1984, then increased to high level for the period 1987 to 1990 (Table C3; Figure C1). The index began to decrease in stepwise drop/increase fashion until 1997 after which the index dropped and continued to decline through the present. The predicted outlook is bleak, as the index remains low through 2008. A

similar pattern occurred for the potential spawning stock biomass index (PSSB), but the patterns of high and low are much more pronounced than for the PSSA (Figure C1).

Comparison of the Empirical versus Potential

The abundance indices (ESSA or PSSA) correlated with their respective related biomass index (ESSB or PSSB; Figure C2). However, when the potential index is compared to the empirical index a gap appears through the years 1990 to about 1998 (Figure C2). Focusing on the biomass indices, we compared the ESSB to the in-river harvest. As expected, the two track each other well (r^2=0.84, *P*=6.06E-09). They both measure what returned to the Hudson (Figure C3). We also compared the PSSB to the total harvest (estimated ocean mixed stock fishery harvest plus in-river harvest) for the Hudson (Figure C4). The estimated total harvest correlates well (r^2=0.70, *P*=1.2E-06; Figure C4) with the PSSB. These correlations suggest that the ocean harvest may have come from the predicted stock that did not return to the river.

Current F

Given that Z = M + F, estimates of Z from catch curve analyses of age (Section 7) and assumed values of M can be used to generate estimates of F. Using the age invariant estimate of M=0.30, estimates of F for females remained relatively low (range of 0.16 to 0.33) for the period 1984 to 1990 (Figure C5). F estimates based on spawning marks were similar for the same period. From 1991 through 1995, values of F increased and peaked at 1.12 in 1995. F varied, but remained high, with the exception of the drop in 1997, until 2003. The last two years F declined to 0.53. A similar pattern in F occurred for males, but was higher than females in most years.

Deriso *et al.* (2000) found fishing mortality rates (F) for older shad of 0.4 to 0.5 for the period 1974 to 1992, with rates higher for female shad than for males. Average exploitation was 0.33 (F=0.4) for the same period. These estimates of F, and those generated from recent estimates of Z (see Section 7), exceed all estimates of overfishing we recommend in our analyses (Figure C5). It should be noted that the beginning of the decline in the PSSB coincides with the increase in F beginning in 1991.

Model Estimates

Surplus Production

Several model runs were made with ASPIC. Each run resulted in an error where *r*, the intrinsic rate of stock growth, was forced to the minimum constraint making results trivial. Examination of the effort residuals suggests that effort was underestimated during periods of the peak harvest (e.g., WWII; Figure C6). The catch data series also includes a period where dramatic changes were taking place in stock size, from record peak harvests (high stock size) of approximately 1.4 million kg per year in the 1940s to a record low catches (low stock size) of less than 90,000 kg per year in the last 10 years.

Surplus production models require that all mortality to a stock be included. This presents a problem when trying to include a more accurate estimate of ocean catch. Our estimate of ocean catch is only a first order approximation of kill. This model also requires a corresponding estimate of effort, which is not available. This precludes the model's usefulness of as an effective tool if only one component of catch and effort (for the Hudson River) is included and the ocean kill and associated effort is left out.

Virtual Population Analysis

We were unable to obtain good VPA results in several attempts to run either the ADAPT or ICES version. VPA modeling requires a large amount of detailed catch-at-age data, and abundance indices for all ages:

age one to the assumed oldest age, which is 13, for Hudson River American shad. In order to get either model to run, a series of adjustments to the input data were necessary. These included collapsing of age structure data from age three to 13 down to ages three to 8+, and realigning age zero data to reflect abundance at age one and two.

Interpretation of results proved just as problematic. The two VPA types varied widely in resulting F estimates. Patterns of residuals suggested bias. Most all of these problems can be attributed to the lack of necessary catch-at-age data, collapsing the age structure data for model input, the assumption of applying the Hudson River age structure to the estimated ocean catch, and the lack of tuning indices. Only five tuning indices are available for shad, all of which are from observed data in the Hudson. In contrast, the VPA for striped bass uses nearly 50 tuning indices covering ages zero to 15+ during both in-river and ocean residency (ASMFC 2005). The VPA method is not worth pursuing for American shad further until detailed catch-at-age data are available.

Statistical Catch-at-Age

The ASAP did not fare any better than either the VPA or ASPIC models. The same problems occurred in that there are no age data to associate with ocean mixed stock harvest. We suspect there may be an issue with fishery selectivity. In addition to no age data for the mixed stock harvest, there are no estimates of effort or fishery selectivity. We tried several times series of data (1915 to present, 1931 to present and 1970 to present). Residuals were extremely skewed, with very low estimates of F, a result that is counterintuitive given other measures of F (see above).

Stock Reconstruction

After exploring the use of the models above, many problems were identified. Most were on the input side of incomplete records of effort and/or accurate data of catch and kill-at-age. Little data were recorded when the mixed stock/ocean fisheries operated leaving wide margins for error. We attempted to simplify assumptions by using a model that did not require a high level of detailed data. The stock reconstruction approach uses general life history data, as would be included in a yield model and complements it with observed fishery dependent and independent programs.

Dramatic changes in stock size occurred for the Hudson River stock over the past nearly one hundred year period from 1915 to the present. The long sustained high harvest from 1936 to 1955 indicates that the Hudson River shad stock size was several orders of magnitude larger than anything observed since then. In looking at all long-term data, the stock reconstruction model estimated initial stock size at nearly 11.3 million kg (Figure C7.A). The recent estimated vulnerable stock size (mature fish) for the Hudson averages, for 2001 to 2005, about 475,000 kg or about 245,000 fish (Figures C7.B and C7.C), lower than the range of the 1995 and 1996 population estimates reported by Hattala *et al.* (1998).

Both model fits, least squares fit of patterns of observed exploitation and use of maximum likelihood function tuned to recent observed indices are similar. The model fit to the exploitation patterns of the1950s and 1974 to 2005 tracks the trend in the observed indices of egg, PYSL and YOY abundance, CPUE of returning adults and exploitation rates (Figure C8). However, the maximum likelihood estimation (MLE) fit tends to exacerbate patterns of exploitation that occurred in the years preceding the collection of the observed indices. The MLE model fits the years from 1974 to 2005 reasonably well, but estimates excessive, and unrealistic, exploitation rates (exceeding100%) during the late1950s.

The stock reconstruction model estimates equilibrium yield of the stock to be approximately 590,000 kg at a μ_{msy} = 0.22 (Figure C9), equivalent to F_{msy} of 0.25. This is essentially equal to the overfishing definition value F_{30}=0.24 (BPR) from the Thompson-Bell model results. Estimated exploitation rates increased during

the early 1980s, peaked in the late 1990s and have since declined (Figure C8). Exploitation rates exceeded μ_{msy} starting in the mid 1980s.

Discussion

Z-Estimates

The most recent observed estimates of Z are higher than those observed in mid 1980s and result in F values that exceed our over fishing definition at most reasonable values of M. The possible weakness in our Z estimates is that they are based on age composition generated from scale samples. Ageing of scales remains an art and estimates have not been verified by known age fish. However, the same staff and methods have been used to age shad for the entire time period. Thus any bias should be consistent. The reduction in average age led to increased mortality estimates regardless of size of bias. Our estimates of current Z (see Section 7) and F are close to those generated by Deriso *et al.* (1995) by a stock reconstruction analyses.

Estimates of M used in the last coastwide assessment (ASMFC 1998) are considerably higher than what we suggested in this assessment (See Section 1.1.5). Estimates of Z in ASMFC (1998) were derived from cohort-based survival estimates from the age structure of fish collected only in the Connecticut River (Savoy and Shake 1993, 1994 and Savoy 1995). F was estimated from exploitation (the in-river commercial fishery harvest divided by an estimated population size). F was then subtracted from Z to obtain M. However, it should be noted that these M estimates included all other sources of mortality other than the in-river fishery harvest of the Connecticut. The population estimate for the Connecticut stock has not been verified since the mid 1980s (see Section 6).

Ocean Harvest

There are no data to estimate reporting rates for ocean harvest. Moreover, few sampling programs were conducted to directly identify stocks in the mixed stock harvest. We used tag data and knowledge of east coast migratory habits of shad for a first order approximation of harvest composition (see Section 1.5.1). The resulting numbers are not, and will never be, without uncertainty, but they do provide a general perspective on stocks that were affected by mixed stock harvest.

Our potential spawning stock index suggests that losses occurred between the juvenile and adult stage. Certainly, the mixed stock harvest is one possible source of such losses. This possibility is strengthened by the fact that differences between the predicted and observed Hudson River adult abundance indices increased at about the same time that the size of losses to the mixed stock harvest increased.

The PSSB we calculated is a relative measure of potential spawning stock biomass, an estimate of expected return to the Hudson. Over the course of the last fifteen years, dramatic increases in mortality occurred on the Hudson River's adult shad stock. The ESSA bears out the difference observed between what returned to the Hudson versus what was expected (Figure C2). The two indices are in general agreement for the first two years, 1985 and 1986, but then the indices begin to diverge slowly, then more dramatically through the mid to late 1990s. The divergence of the indices suggests that the mortality occurred in ocean waters. The PSSB closely tracks the combined estimated ocean and Hudson River harvest - the "missing" difference being ocean harvest.

An easy mistake that can be made is under-estimating the effects of what could be considered a "small" amount of fishing. Total harvest of American shad from the mid-Atlantic to New England was barely 140,000 kg in 2005. Ocean harvest made up greater than 50% of the total harvest from 1988 to 2005. From Virginia to Maine only three systems, (Delaware, Hudson and Connecticut rivers) support in-river fisheries,

all other states allow no harvest. With stocks at historic lows, even "small" amounts of harvest have the ability to continue to drive stocks lower.

Other investigators (Savoy and Crecco 2004) suggested the major change in returning adults to the Connecticut River shad was due to increased predation by striped bass on the adults as they returned to the Connecticut each spring. We agree that predation could be a factor increase, but we feel it would be on young fish and not adults. The size of an adult American shad would mean that the predator on the order of 40 to 50 pounds or more to be able to consume a four to five pound fish as prey. Analyses conducted in Section 1.5.1-c indicated that adult American shad were only a minor dietary component of striped bass in the Hudson River and that there was no evidence for a long-term decline in adult shad abundance that coincided with an increase in striped bass.

Predation cannot explain the disappearance of older adult shad as observed in the Hudson. However, predation on young, over time could erode recruitment into the adult population. Crecco and Savoy (2004) observed that relative survival of juvenile shad to recruitment as virgins declined as striped bass abundance increased. They concluded that the decline was caused by predation on pre-recruits.

Herring are a more likely target and well-known prey item of striped bass. The blueback herring run dropped precipitously in the Connecticut system, prompting a closure on all take in 2002. The states of Massachusetts and Rhode Island closed their herring fisheries in 2006 due to decline in their runs. In the Hudson River and the Chesapeake Bay, changes in herring have only been recently recorded. The fish-lift counts of blueback herring at the Conowingo Dam fish-lift increased until 2001, but have since declined (R. Sadzinski, pers. comm.).

Bycatch

Another area of high uncertainty is the kill that occurs on immature, sub-adult fish that become part of the Atlantic coast's "bait" fishery. Removals of American shad at early ages (ages one through three) still remain unaccounted for. Hattala (memo to the ASMFC Shad & River Herring Technical Committee) reported to the shad technical committee that vessel trip reports obtained from NMFS more often have no shad listed as bycatch. Small shad landed as bait in state waters essentially disappear into any (NMFS) database recording unclassified bait. Given the amount of known bycatch of more lucrative species (i.e. striped bass) in various fisheries on the coast, the likelihood of shad bycatch being equal to zero is low.

Stock Characteristics

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

Size and mean age decreased and remained low after 1991, relative to that in the mid 1980s. These changes could be caused by changes in year class production resulting in more young fish or in decreased survival of older fish. Increased fishing is the logical cause of any survival decrease. We tested effects of year class fluctuation on age structure by normalizing catch-at-age data by relative abundance of the same cohort at age zero. Resulting mean age (Section 7, Figure 7.13) continued to be lower in the most recent data suggesting that change was caused by actual losses of older fish rather than on year class fluctuation. A size-at-age decrease is one of the classic signs of overfishing where the fastest growing fish of each age class are removed, reducing overall size at a particular age (Hilborn and Walters 1992).

The changes in mean size-at-age is not limited to the loss of older fish, but also the result of fishing pressure over time altering what remains available at age. Fishing, especially gill-net fisheries, which are the primary

means of harvest of shad on the Atlantic coast, tend to remove the larger of any fish from a group of individuals. Weight-at-age data from the commercial fishery indicated a shift at age to smaller fish, the same shift in size was much more pronounced in spawning stock samples (see Section 7, Figures 7.11 and 7.12). If current data are used, the importance of river specific data, as used in yield modeling, becomes complicated by the greater over-whelming influence exerted by chronic fishing pressure that continually alters stock characteristics.

Future Projections

Examples of an "Unexploited Shad Stock": The Columbia River

One real world example of stock growth of American shad is available from the Columbia River, on the Pacific coast. In 1871, Seth Green, a New York fish culturist, transported Hudson River American shad larvae across the United States and released the fingerlings into the Sacramento River (Ebbesmeyer and Hinrichsen 1997). The establishment, expansion and colonization of American shad along the Pacific coast is not all that well documented. However, shad reached the Columbia River system by about 1880.

Consistent record keeping has occurred from 1938 to the present for fish passage numbers at the major dams on the Columbia (ACOE and www.fpc.org). In addition to fish passage records, we also obtained data on the Columbia commercial fishery for shad (R. Hinrichsen and R. Beamesderfer pers. comm.), which allowed us to do some estimation of stock exploitation and growth. Figure C10 shows that from 1938 though 1960 the fishery sustained a fairly high level of exploitation on the stock, u~ 0.89 kept the stock at very low levels. Shad were actually shipped east and sold as Atlantic shad, during the time period when most east coast stocks were declining after being over-fished during WWII (McPhee 2002). In the early sixties, salmon became a more popular item in the markets and fishing pressure eased on shad.

The most dramatic increase in the Columbia shad stock occurred in the 1970s and 1980s as exploitation declined. We used the fish passage counts at the two major dams on the Columbia River, Bonneville and the Dalles Dams, to calculate the growth rate of the Columbia shad stock that use the upper river. The growth rate was about 6 percent per year and the passage numbers have grown to nearly three million fish. Shad increasingly became known as the "trash fish" compared to the more lucrative salmon.

The dynamics of this west coast shad stock are poorly known. Shad are considered an exotic nuisance with most all resources focused on native salmon runs. Water temperatures increase slowly from 7ºC through 21ºC from April through early August and the runs can last three to four months, quite unlike the east coast. Passage counts give us an estimate of numbers of fish that utilize the upper Columbia, above Bonneville Dam. However, below the dam is approximately 215 km of river in which shad could possibly spawn. The number of shad spawning in the lower river (below Bonneville Dam) is unknown. It is also not clear how many adult shad get out, or if they get out, of the Columbia's dammed upper river. If adult fish do not get out, this may be part of the reason why the growth rate is so low.

One thing is for certain, the stock did not respond (in growth) until exploitation was reduced to a very low level. The current age structure of the Columbia stock might also provide a clue how old shad can get in a lightly unexploited population, if the fish are iteroparous and allowed to repeat spawn, and get out of the Columbia system after spawning.

Response of Hudson River Shad

It is not known if the Hudson River shad stock will respond in a similar way as the Columbia stock did when exploitation was decreased. The Columbia stock's response was slow, but may be dependent on a host of unknown factors about fish passage issue (i.e., downstream return of Columbia stock mentioned above).

Clupeid stocks are notorious for lack of response to restrictions in fish management changes (Hilborn and Walters 1992).

Conclusions and Recommendations

We feel that the Hudson River American shad stock was overfished during the late 1980s and early 1990s and that this overfishing altered stock characteristics and reduced abundance. Moreover, overfishing appeared to be caused by the ocean mixed stock harvest that occurred beginning in the early 1980s. The Hudson River American shad stock is a shared resource along its entire migratory range, from North Carolina to Maine and Canada. As long as fisheries continue to operate in coastal waters, decisions on the fishery, and the direction it will take are also a shared process.

We recommend that fisheries that potentially affect the Hudson be restricted to reduce further damage to this stock. These fisheries include those in the Hudson River, both commercial and recreational take, as well as known remaining mixed stock fisheries outside of the Hudson River system. The remaining mixed stock fisheries include those in lower Delaware Bay. Other known bycatch fisheries should be regulated to minimize catch of American shad and a concerted effort made to identify bycatch in the other numerous fisheries that are implicated (e.g. Atlantic herring fishery).

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Table 1.5.2-C1. Survival estimates used as model inputs for Potential spawning stock abundance index for the Hudson River American shad stock.

Pre-recruits		Recruits	
Age	**S at age**	**Year**	**S for Age 5+**
1	0.19	1974	0.41
2	0.37	1975	0.35
3	0.74	1976	0.36
4	0.74	1977	0.43
		1978	0.43
		1979	0.44
		1980	0.37
		1981	0.43
		1982	0.44
		1983	0.44
		1984	0.59
		1985	0.63
		1986	0.53
		1987	0.57
		1988	0.53
		1989	0.58
		1990	0.53
		1991	0.38
		1992	0.38
		1993	0.51
		1994	0.35
		1995	0.24
		1996	0.46
		1997	0.65
		1998	0.37
		1999	0.32
		2000	0.30
		2001	0.33
		2002	0.33
		2003	0.32
		2004	0.40
		2005	0.44

Table 1.5.2-C2. F_{30} based on Egg (EPR) or Biomass (BPR) per recruit for the Hudson River shad stock.

			Type 1		**Type 2**	
			F_{30}		**F_{30}**	
Type of model run	**M**	**Fmax**	**EPR**	**BPR**	**EPR**	**BPR**
Hudson River						
max age =14	0.30	0.20	0.22	**0.24**	0.23	0.25
Age specific		0.18	0.19	0.21	0.20	0.22

Table 1.5.2-C3. Various relative indices of spawning stock abundance for American shad of the Hudson River Estuary.

Year	Sum of weekly CPUE	CPUE			Spawning stock abundance								
		Age five	Age six	Age seven	Age Five	Age six	Age seven	Ages 5&6	ESSA Age (5-7)	ESSB Age (5-7)	ESSB est*	PSSA (3-10)	PSSB (3-10)
1980	19.59	7.62	7.70	2.74									
1981	14.47	3.50	5.38	2.93									
1982	8.02	2.19	2.28	1.71									
1983	9.16	3.16	2.95	0.94									
1984	9.49	2.03	3.53	1.71								1.17	2.05
1985	26.65	6.95	8.17	5.19	40.82	28.45	28.71	33.05	31.82	64.3		1.92	3.47
1986	52.27	15.84	16.57	8.92	55.74	50.23	67.62	52.78	55.40	112.9		2.28	4.28
1987	47.37	8.22	13.57	9.66	25.47	55.76	73.01	38.49	45.03	89.3		2.51	4.89
1988	42.22	9.03	12.86	10.42	30.52	37.58	56.59	34.30	39.30	80.2		2.33	4.71
1989	33.79	7.47	12.24	8.88	25.83	46.36	38.88	35.62	36.57	69.2		2.36	4.85
1990	16.61	3.54	5.14	4.05	10.84	22.91	15.25	15.76	15.60	25.9		2.61	5.04
1991	18.31	5.27	5.54	4.02	16.15	15.47	27.27	15.80	17.83	26.6		1.96	3.82
1992	14.61	6.25	4.86	2.15	16.05	13.09	13.95	14.61	14.49	20.9		1.43	2.65
1993	13.02	3.36	4.83	2.31	8.43	13.49	18.99	10.82	11.95	14.2		2.04	3.65
1994	24.24	6.46	10.62	5.54	10.16	43.04	60.95	19.34	23.23	30.1		2.14	3.64
1995	11.49	4.35	4.43	1.89	9.12	15.14	25.04	11.41	12.63	19.1		1.32	2.02
1996	20.25	8.80	6.96	2.39	20.23	40.02	34.30	25.89	26.75	41.5		1.36	2.01
1997	7.11	3.28	2.05	0.87	7.69	11.82	10.88	8.88	9.12	13.6		1.87	2.84
1998	12.23	5.75	3.20	1.29	11.50	17.36	23.93	13.08	13.87	21.5		1.22	1.83
1999	10.81	4.77	3.44	1.28	8.17	22.74	18.21	11.17	11.79	16.6	18.5	0.74	1.09
2000	31.61	14.29	10.40	3.40	24.28	79.84	130.57	34.35	37.71	58.0	25.3	0.51	0.73
2001	25.74	9.97	9.01	3.82	24.49	31.74	41.06	27.47	29.08	43.7	9.3	0.43	0.59
2002*											8.3	0.31	0.47
2003*											15.9	0.27	0.39
2004*											8.1	0.32	0.45
2005*											9.9	0.45	0.64

*Data from 2002-2005 insufficient to generate ESSA index, see Section 7

Figure 1.5.2-C1. The potential spawning stock abundance (PSSA) and biomass (PSSB) indices for Hudson River American shad.

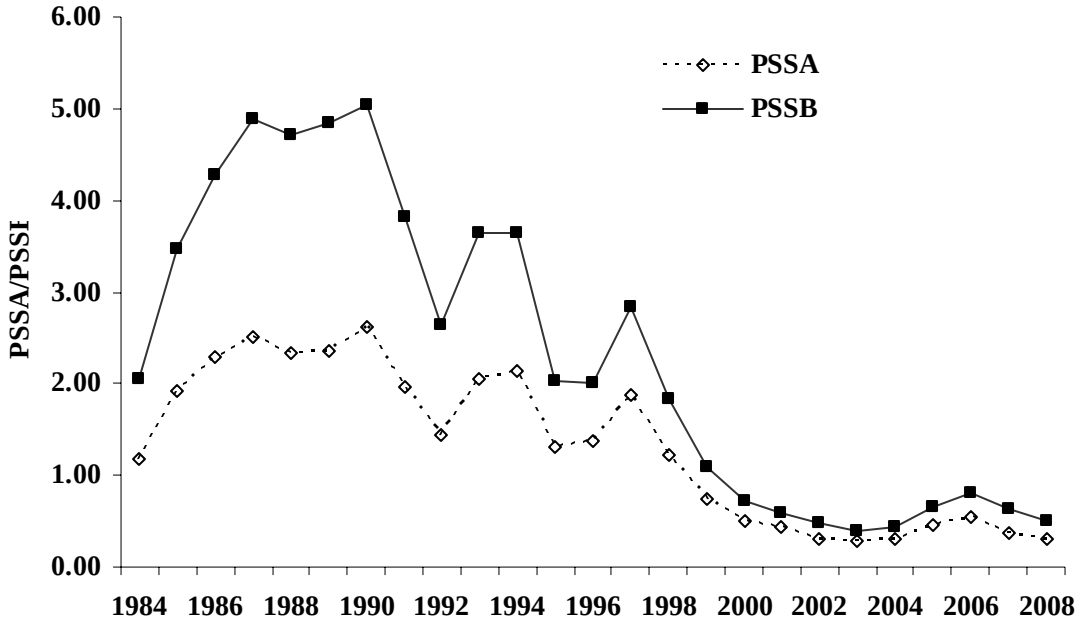


Figure 1.5.2-C2. Comparison of the Hudson River empirical (ESSB) and potential (PSSB) spawning stock biomass indices.

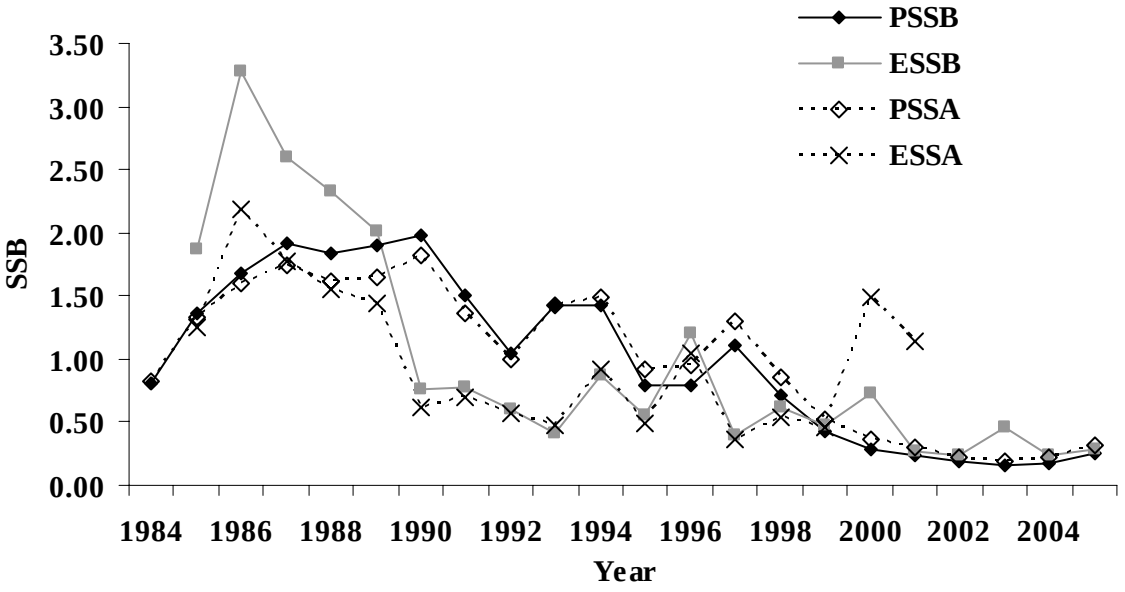
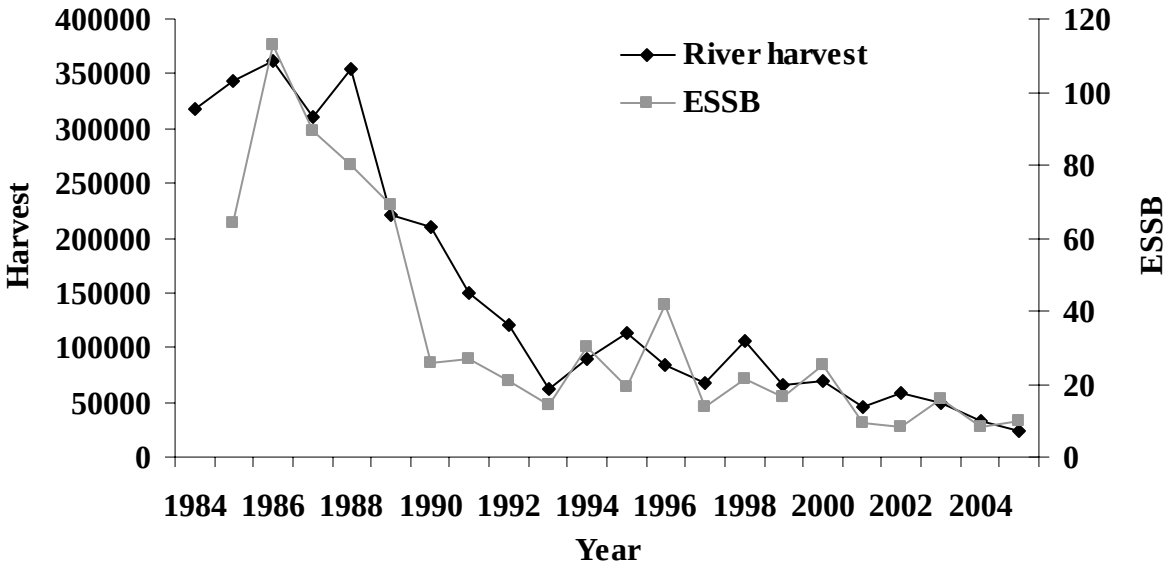


Figure 1.5.2-C3. Comparison of the Hudson River empirical (ESSB) spawning stock biomass index with in-river harvest.



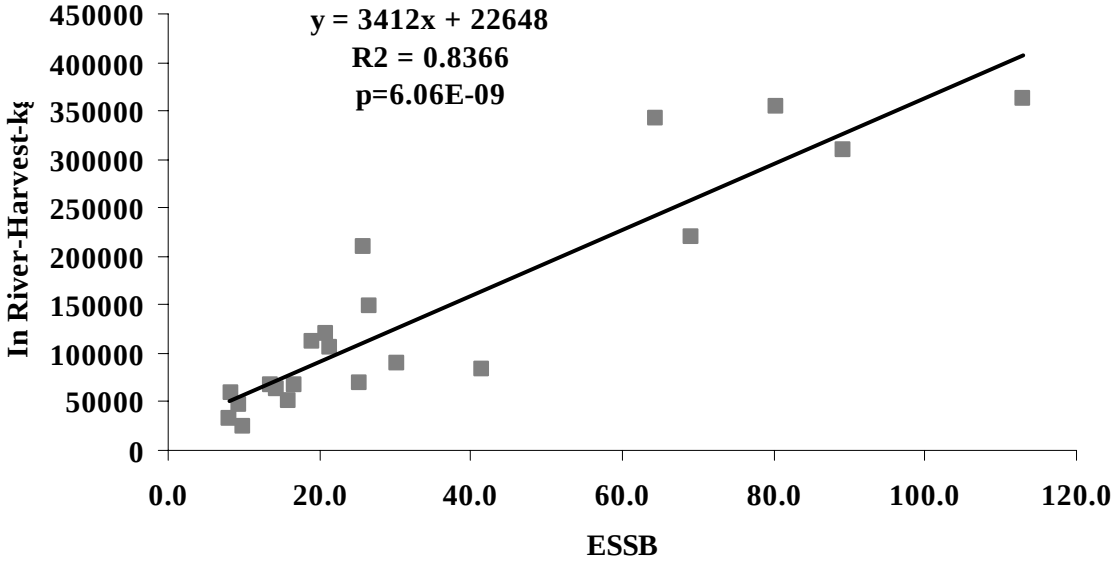
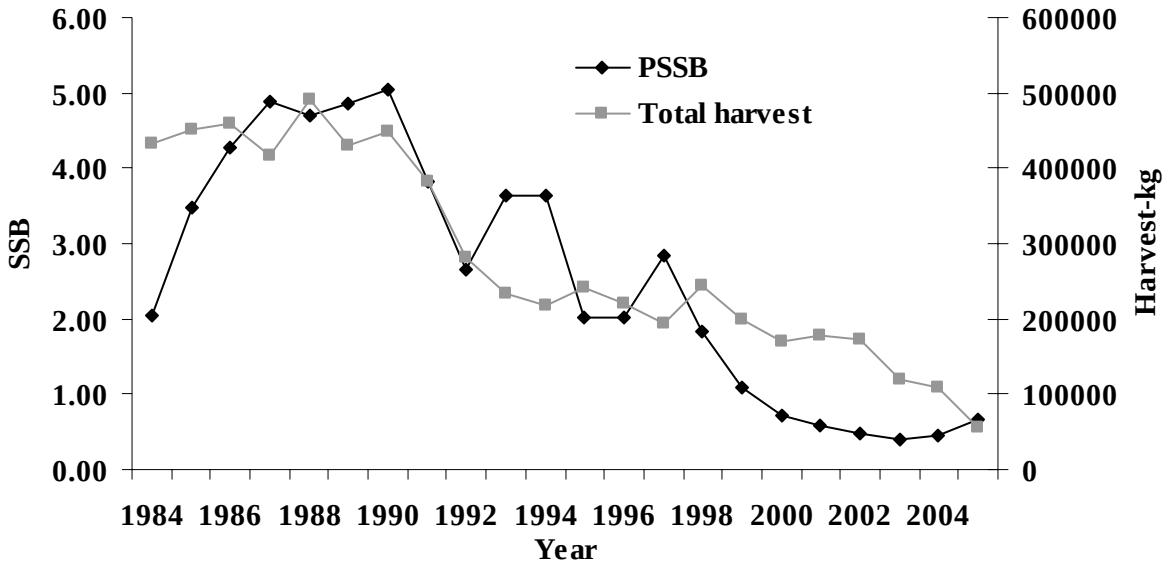


Figure 1.5.2-C4. Comparison of the Hudson River potential (PSSB) spawning stock biomass index with estimated total (river and mixed stock) harvest, with correlation between the PSSB and harvest.



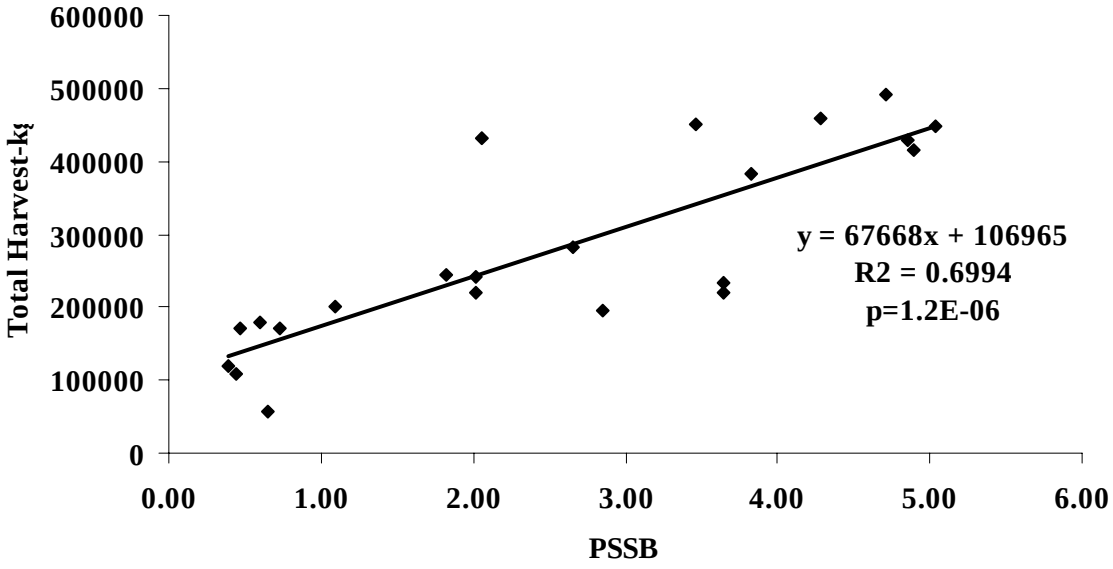
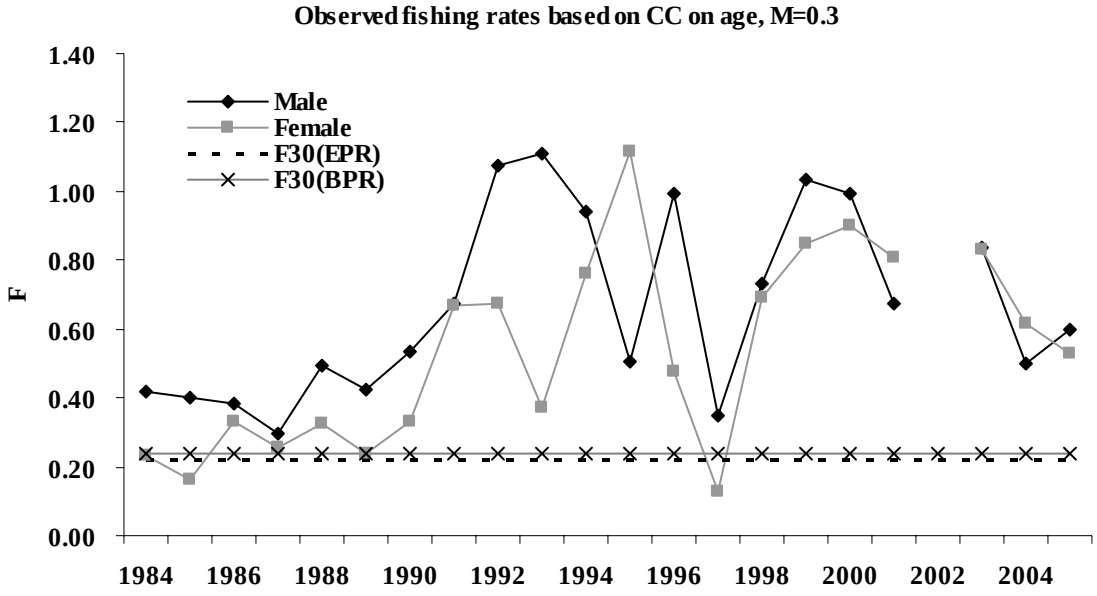


Figure 1.5.2-C5. Comparison of observed fishing mortality rates based on catch curve on age and catchcurve on repeat spawning versus selected overfishing rate.



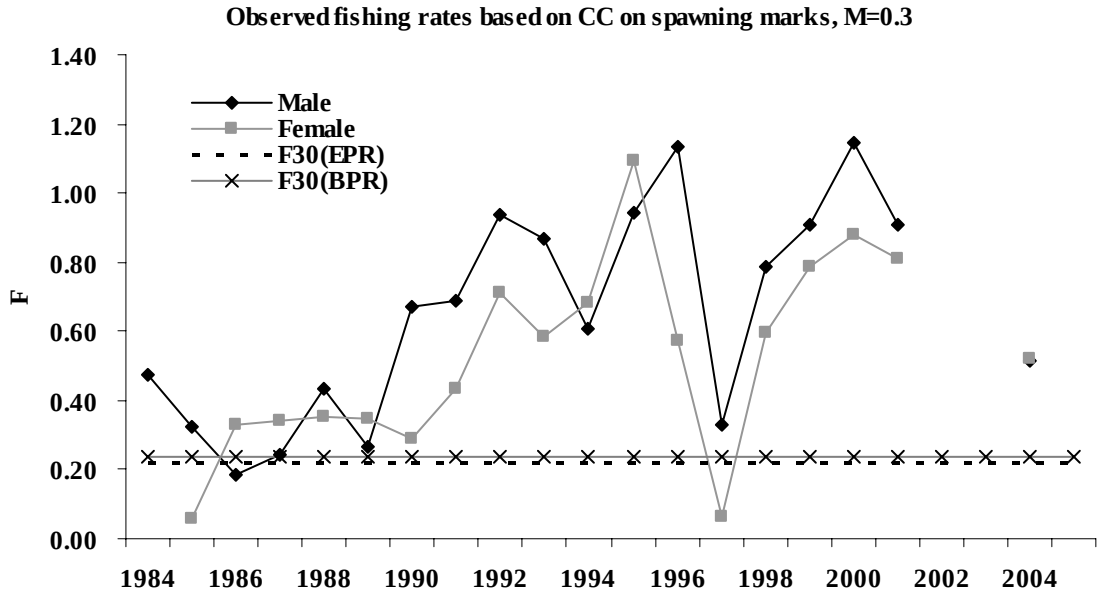


Figure 1.5.2-C6. Outputs of ASPIC (surplus production) model run for the Hudson River American shad stock.

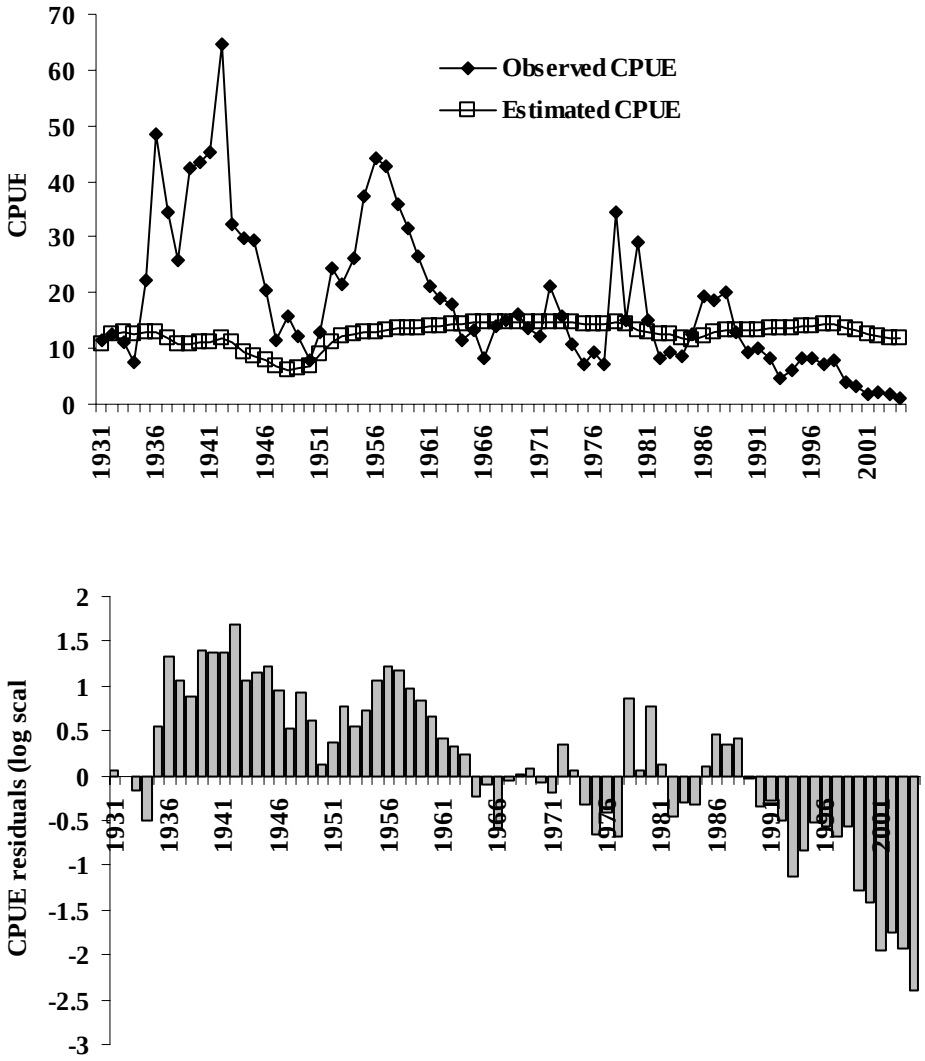


Figure C7. Estimated a) stock size and harvest (kg-millions) of Hudson River American shad 1915-2005; b) 1970-2005; c) estimated stock size (N) 1970-2005.

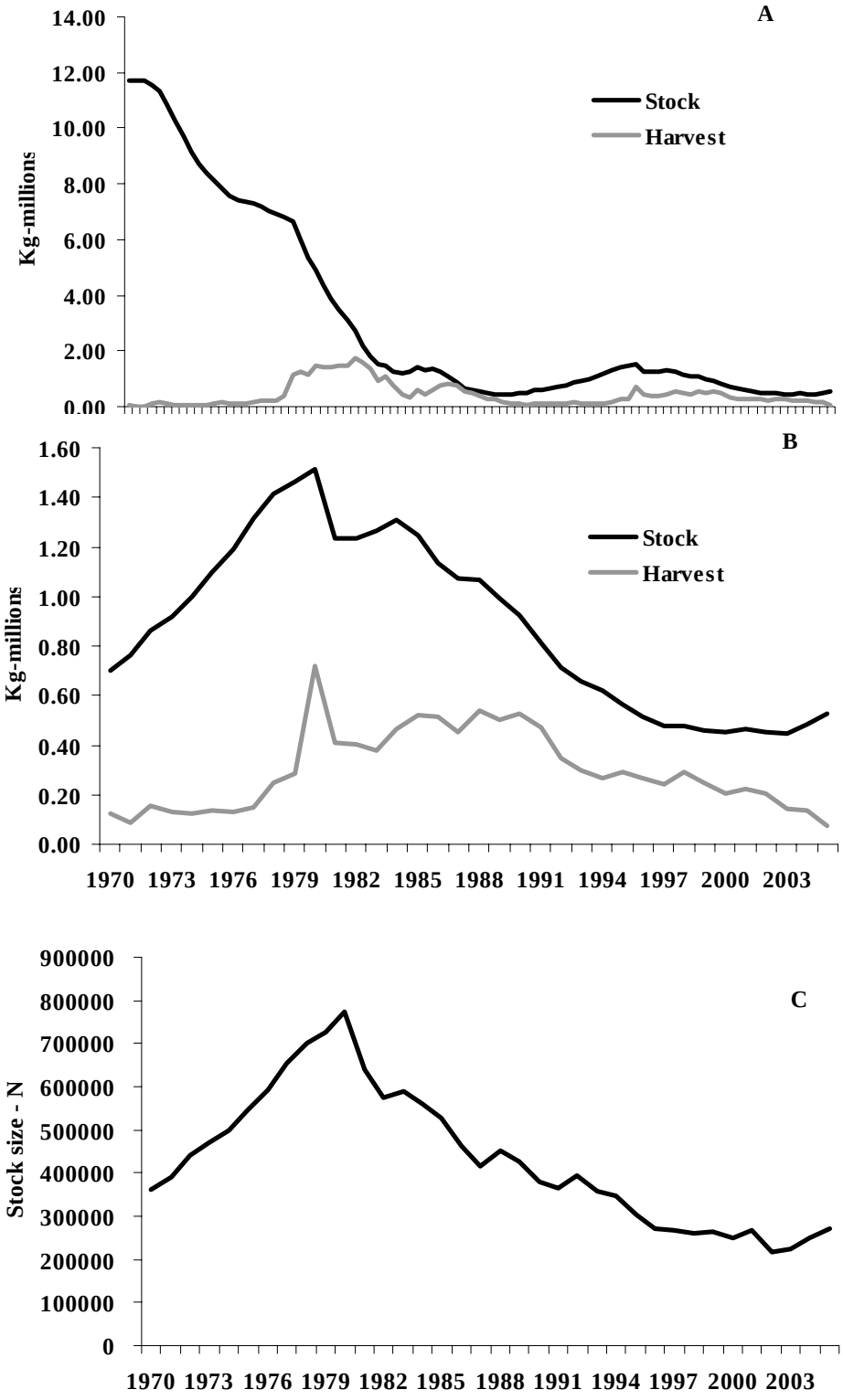


Figure 1.5.2-C8. Observed data and stock reconstruction model predictions of abundance of eggs, YOY, predicted stock and CPUE, and exploitation rate for Hudson River American shad.

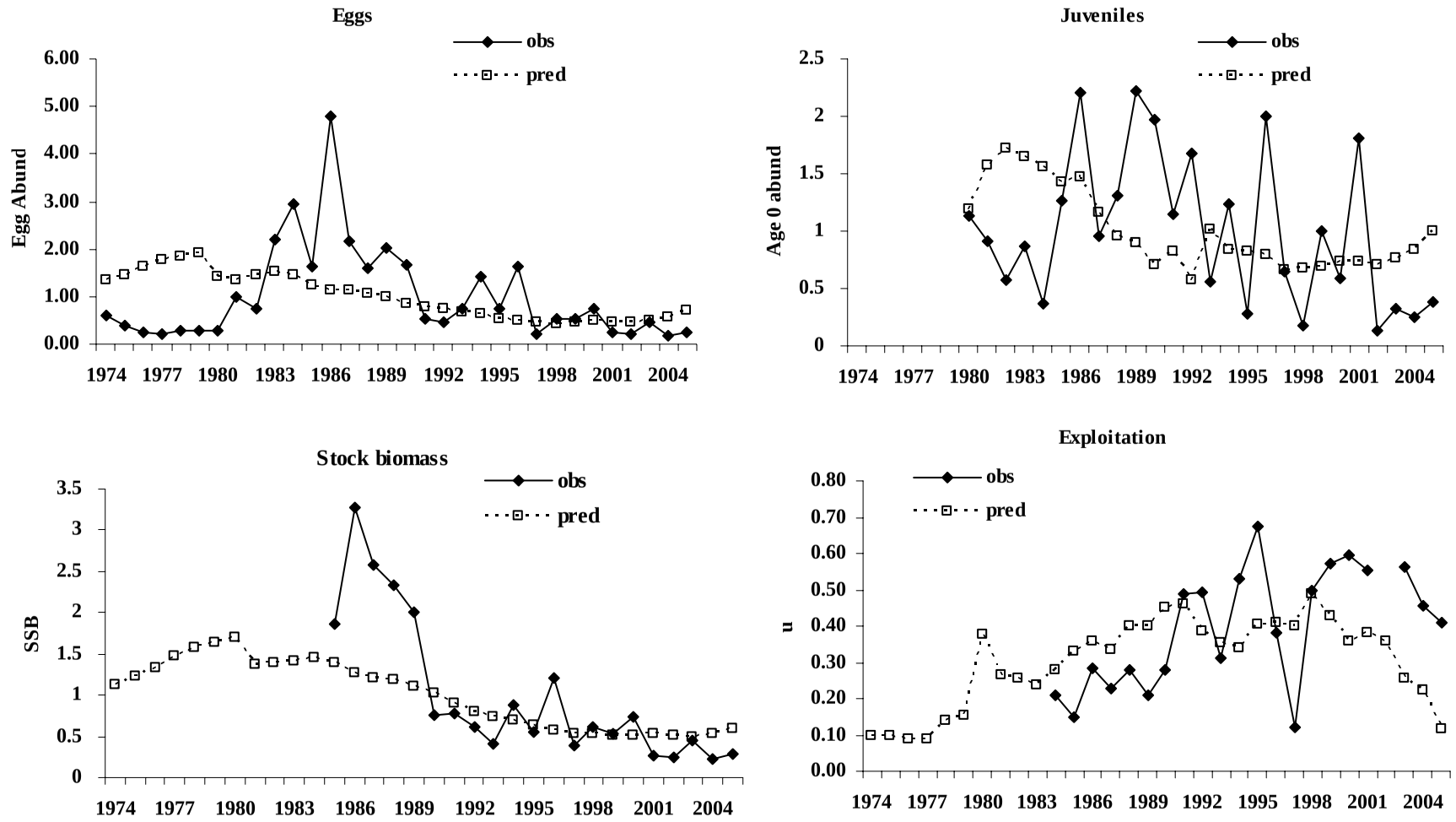


Figure 1.5.2-C9. Equilibrium catch versus exploitation rate of Hudson River American shad.

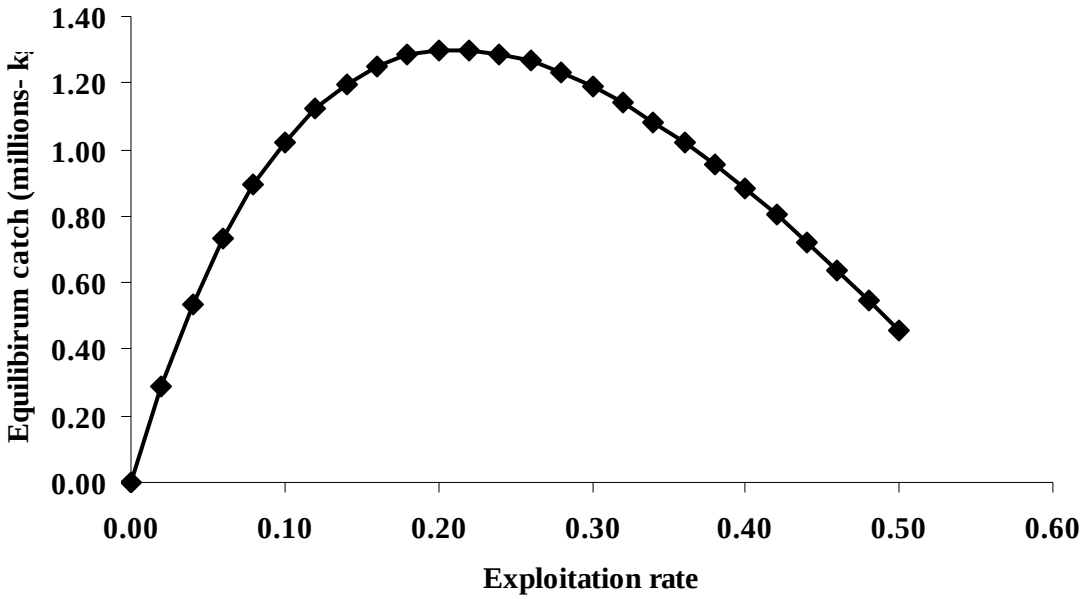
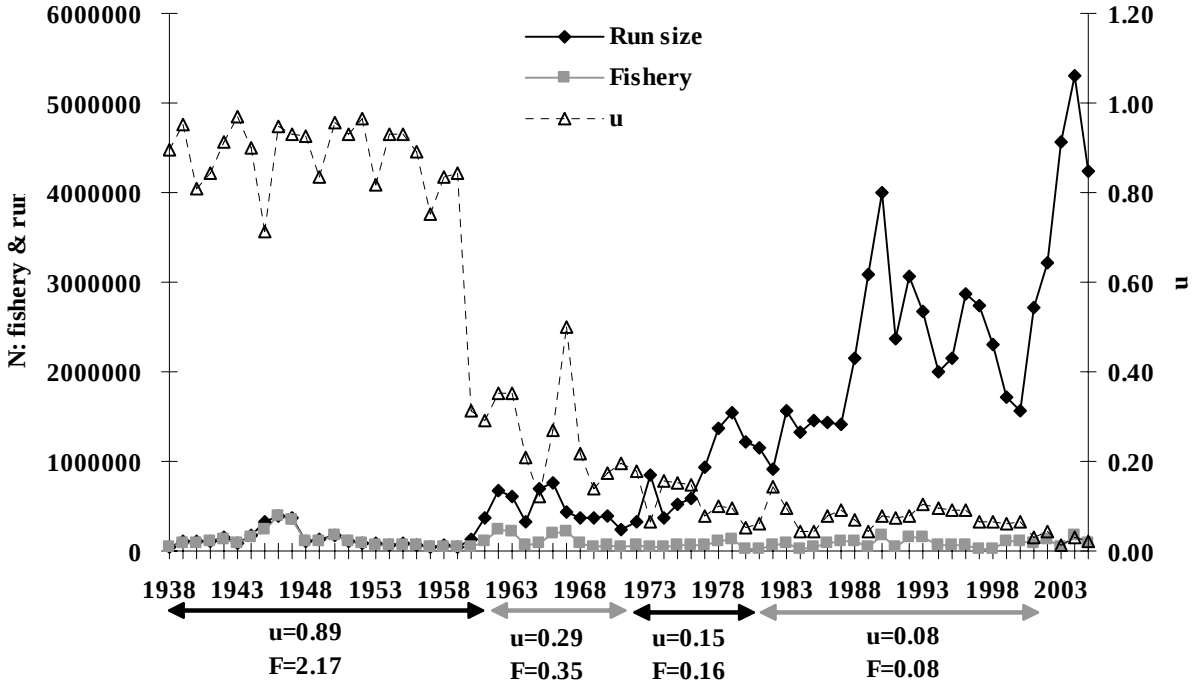


Figure 1.5.2-C10. Comparison of fisheries harvest versus run size of American shad in the Columbia River, Oregon and Washington.



APPENDIX I

Formulae Used in Biomass Model Analyses

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The Thompson Bell Yield- per-recruit (YPR) model, modified for biomass-per-recruit with the addition of weight-at-age and fecundity for egg-per-recruit, was calculated as follows:

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

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

Mortality was modeled using:

$$N_{j+1} = N_j * \mu$$

Where:
- N_{j+1} = Number of fish alive at age j+1
- N_j = Number alive at age j

Exploitation, μ, was calculated as follows:

Type 1 fishery: $\mu = =1\text{-exp}(-F_j)$

Type 2 fishery: $\mu = (F_j * A_j) / Z_j$

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

Vulnerability to the fishery was age based, calculated from observed data obtained from various river systems.

Age invariant natural mortality was obtained from the formula from Hoenig (1983):

$$\text{Log}_e M = 1.46 - 1.01 * \text{Log}_e (TMAX)$$

Where:
- M = instantaneous rate of natural mortality
- TMAX = maximum age of the fished stock

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

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

The model was run at fishing rates (F_j) of zero to 0.7 in 0.01 increments.

Number harvested-at-age was converted to weight by multiplying numbers by weight-at-age. Weight-at-age was estimated using the various growth functions. Gompertz (Hudson only):

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

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

Egg-per-recruit (EPR) was calculated as:

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

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

Biomass-per-recruit (BPR) was calculated as:

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

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

Maturity schedule for female American shad were calculated from observed age and or repeat spawning data, to estimate proportion mature-at-age.

APPENDIX II

York River, Virginia Partial Recruitment Vector Analyses

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Introduction

There are two types of recruitment vectors, or selectivity values, that can be calculated. The first calculation is a relative selectivity that estimates the selectivity of the gear for each age group with respect to the most abundant age group, so that the age group caught with the greatest frequency has a selectivity of 1 and all other groups are some fraction of that. An absolute selectivity value can be determined by correcting for the effects of mesh size on the relative proportions of the different age groups. This selectivity value is calculated using catch-at-age data from a selective gear, drift gill net (DGN), and a non-selective gear, pound net (PN), determining the proportion-at-age for each age group in each gear, dividing each age group's proportion in the selective gear by the proportion found in the non-selective gear, and finally, dividing each age group's "corrected" proportion-at-age by the value of the group with the highest value.

Datasets

Concurrent York River DGN and PN data were available for 1998-2000. Drift gill-net samples were obtained from tribal fisherman on the Mattaponi and Pamunkey Rivers, which constitute the headwaters of the York River system. Mattaponi and Pamunkey samples were combined within years to represent an overall York River sample since it is unclear if the stocks are separate down to the tributary level. Pound net samples were obtained from Mr. Green at the mouth of the York River. Mr. Green fished five separate pound nets at the mouth of the York River, but all nets were within the same river kilometer. Catches from all five nets were combined within years to represent an overall Green pound net sample for that year. One caveat of using Mr. Green's nets was the possibility of mixed stock catches. These nets were located at the mouth of the York River where it empties into the main stem Chesapeake Bay and upper Bay stocks could possibly be caught along with York River fish as they migrate past the nets to more northern rivers. Since the drift gill-net mesh sizes target maturing female fish, only female fish were used from the pound net samples.

None of our DGN or PN samples were aged so an age-length key was developed for each of the gears. As much as possible, care was taken to select datasets for the keys from gears that were located in spatially and temporally similar conditions to those of the samples to which they were being applied. Fork length was used instead of total length since total length can be greatly affected by fin injury and degradation.

Age-length key

To determine whether fork length of fish varied by year, necessitating individual analyses by year, a 1-way ANCOVA was run for the years 1998 to 2003 on the female York River stake gill-net monitoring data.

Table AII.1 One-way ANCOVA results for York River American shad fork length (mm) versus year. Dependent variable=year, independent variable=fork length (mm), covariate=ScaleAge.

Source	DF	Seq SS	Adj SS	Adj MS	F	*P*
ScaleAge	1	12802	8452	8452	14.86	0.000
Year	5	99193	99193	19839	34.89	0.000
Error	2172	1235119	1235119	569		
Total	2178	1347115				

After removing the effects of varying age structure on size ($P<0.0005$), the 1-way ANCOVA was significant for year effects ($P<0.00005$). Due to significant year effects, age-length keys were created for each year separately.

We developed individual age-length keys for 1998, 1999, and 2000 York River Indian DGN samples using VIMS stake gill-net (SGN) data from the same years. Stake gill-net samples were collected downriver from the DGN sites at the VIMS monitoring net and aged by one reader. In some cases, fish were dropped from the DGN sample when age-length values were not available in the SGN key. Additionally, when the age-length key required a DGN sample to be separated into more age groups than there were fish in the sample, we attempted to allocate the samples between the most abundant age groups. If age groups had the same abundance, the older age group was preferred. Since mesh sizes of nets used in the drift gill-net fishery were the same in 1998 through 1999 (5.5" mesh), but not 2000 (5.25"), selectivity values for 2000 should not be used alongside or combined with the 1998 and 1999 values.

Since no aged pound net samples were available from 1998, 1999, and 2000, a pound net age-length key for Mr. Green's PN samples was developed from aged samples collected in Mr. Kellum's PN in 2001 and 2002. Mr. Kellum's PN samples were collected upriver from Mr. Green's PN samples, had two different scale readers (2001=Maki, 2002=Watkins), and since Mr. Kellum's samples were from different years than Mr. Green's samples, they were combined to generate the key values applied to Mr. Green's samples. Again, some fish were dropped when age-length values were not available in the key and when the age-length key required a sample to be separated into more age groups than there were fish in the sample, we attempted to allocate the samples between the most abundant age groups; if age groups had the same abundance, the older age group was selected.

The age-length keys were applied to the Indian drift gill-net samples and the Green pound net samples from 1998 to 2000 and age-frequencies were determined for each gear and year.

Selectivity

Relative selectivity- The first selectivity calculation involved determining the percent contribution of each age class to the total sample and then dividing that value by the maximum of those values, so that the age class constituting the highest proportion of the catch had a selectivity value equal to 1 and all other age classes were some fraction of that:

Table AII.2 Number-at-age for the Mattaponi and Pamunkey River combined drift gill-net dataset. Mesh size of the DGN is included in parentheses next to the year.

Year	**Age (years)**							
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1998 (5.5")	0	29	38	18	9	6	1	0
1999 (5.5")	2	17	88	48	10	4	0	0
2000 (5.25")	9	113	158	108	21	1	1	1

Table AII.3 Proportion-at-age for the Mattaponi and Pamunkey River combined drift gill-net dataset. Mesh size of the DGN is included in parentheses next to the year.

Year	**Age (years)**							
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1998 (5.5")	0	0.29	0.38	0.18	0.09	0.06	0.01	0
1999 (5.5")	0.01	0.10	0.52	0.28	0.06	0.02	0	0
2000 (5.25")	0.02	0.27	0.38	0.26	0.05	0	0	0

Table AII.4 Partial recruitment vector values for the York River drift gill-net fishery, by age class and year. Mesh size of the DGN is included in parentheses next to the year. (Figure B1)

Year	Age (years)							
	3	4	5	6	7	8	9	10
1998 (5.5”)	0	0.76	1.00	0.47	0.24	0.16	0.03	0
1999 (5.5”)	0.02	0.19	1.00	0.55	0.11	0.05	0	0
2000 (5.25”)	0.06	0.72	1.00	0.68	0.13	0.01	0.01	0.01

Absolute selectivity- The second selectivity calculation involved correcting the drift gill-net proportion-at-age values for gear mesh size selectivity using concurrent, non-selective pound net data. The proportion-at-age for all age classes present in the Green pound net data was calculated:

Table AII.5 Number-at-age for Mr. Green’s York River pound net data. Mesh size of the DGN is included in parentheses next to the year.

Year	Age (years)							
	3	4	5	6	7	8	9	10
1998 (5.5”)	0	69	88	40	29	3	0	0
1999 (5.5”)	0	168	272	159	96	11	0	0
2000 (5.25”)	0	24	41	28	16	2	0	0

Table AII.6 Proportion-at–age for Mr. Green’s York River pound net data. Mesh size of the DGN is included in parentheses next to the year.

Year	Age (years)							
	3	4	5	6	7	8	9	10
1998 (5.5”)	0	0.30	0.38	0.17	0.13	0.01	0	0
1999 (5.5”)	0	0.24	0.39	0.23	0.14	0.02	0	0
2000 (5.25”)	0	0.22	0.37	0.25	0.14	0.02	0	0

For a given age class, the proportion-at-age from the DGN sample was divided by the proportion-at-age from the PN sample to adjust the DGN proportions to the non-selective proportions found in the pound net samples:

Table AII.7 Corrected proportion-at-age for the York River drift gill-net fishery, calculated by dividing the DGN proportion-at-age by Green’s PN proportion-at-age. Mesh size of the DGN is included in parentheses next to the year. “-” indicates no value due to lack of age class in pound net sample.

Age	Age (years)							
	3	4	5	6	7	8	9	10
1998 (5.5”)	-	0.95	0.98	1.02	0.70	4.53	-	-
1999 (5.5”)	-	0.42	1.35	1.26	0.44	1.52	-	-
2000 (5.25”)	-	1.27	1.04	1.04	0.35	0.13	-	-

A final, “corrected” selectivity value was determined by dividing each of the adjusted proportion-at-age values by the maximum of those values, so that the age group constituting the highest proportion of the catch was equal to 1 and all other age classes were some fraction of that (Table B8). Note the absence of values in the smallest and largest age classes due to truncation of the sample during the age-length key conversion.

Table AII.8 Absolute selectivity values for the York River drift gill-net fishery, by age class and year. Mesh size of the DGN is included in parentheses next to the year. "-" indicates no value due to lack of age class in pound net sample. (Figure B1)

Year	Age (years)							
	3	4	5	6	7	8	9	10
1998 (5.5")	-	0.21	0.22	0.23	0.16	1.00	-	-
1999 (5.5")	-	0.28	0.89	0.83	0.29	1.00	-	-
2000 (5.25")	-	1.00	0.82	0.82	0.28	0.11	-	-
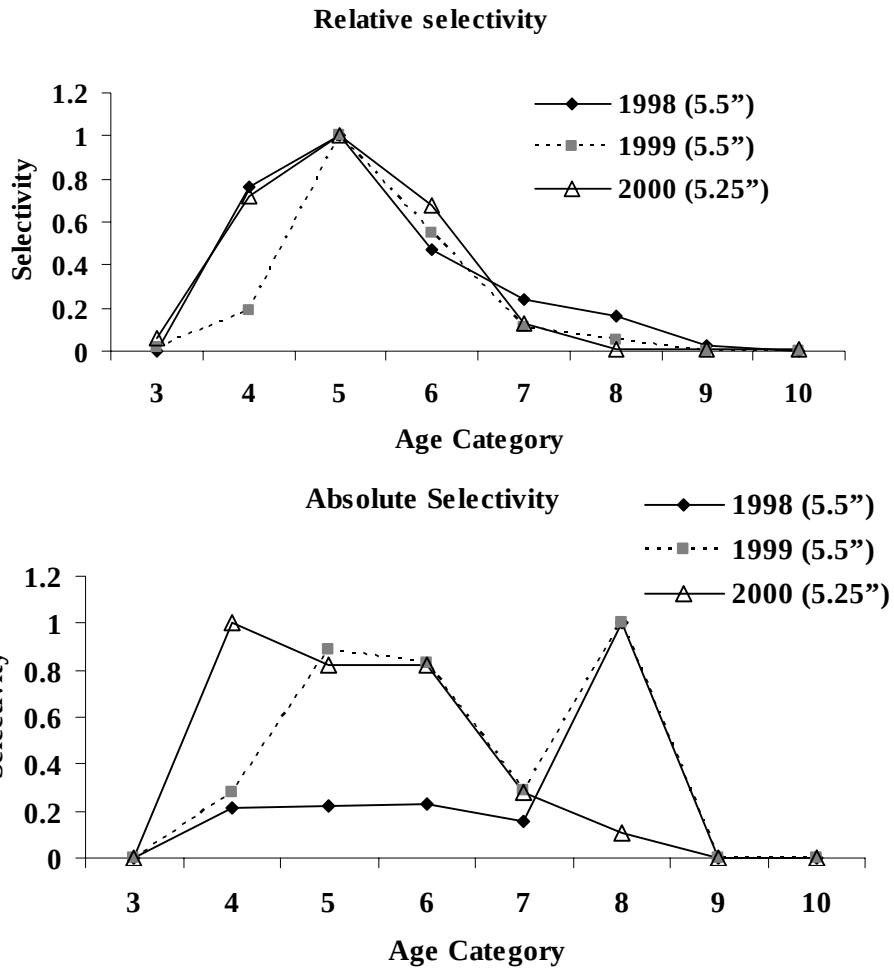
Figure AII.1 Relative and absolute selectivity values for the York River drift gill-net fishery using year specific age-length keys for ageing samples.