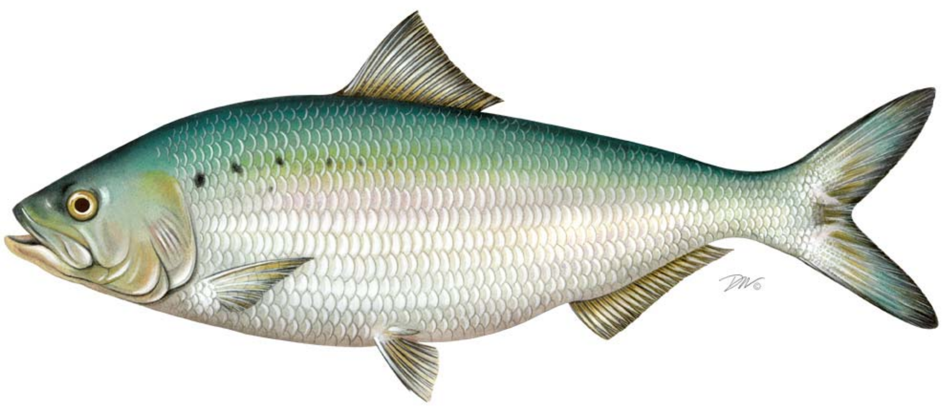
Stock Assessment Report No. 07-01 (Supplement)
of the

Atlantic States Marine Fisheries Commission

American Shad Stock Assessment Report for Peer Review

Volume II



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 II

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

TERMS OF REFERENCE

1. Compile and determine adequacy of available life history data for each stock.

2. Compile and determine adequacy of available fishery-dependent and/or independent data as indices of relative abundance for each stock.

3. Determine most appropriate method of estimating natural mortality.

4. Determine which assessment analyses are most appropriate to available data for each stock.

5. Assessment methods will range from simple trend analysis to more complex models.

6. Estimate biological reference points for each stock where possible.

7. Determine current status of each stock where possible.

8. Develop recommendations for needed monitoring data and future research.

9. Describe the locations and amounts of shad and river herring bycatch in commercial fisheries for mackerel, sea herring, and other pelagic species and estimate the contribution of that bycatch to fishing mortality.

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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 2
Status of American Shad Stocks in Maine

Contributors:

Michael Brown
Maine Department of Marine Resources
21 State House Station, Augusta, Maine 04333

Andrew Kahnle and Kathryn Hattala
Hudson River Fisheries Unit, New York State Department of Environmental Conservation
21 S. Putt Corners Road, New Paltz, New York 12561

2.1 INTRODUCTION

The Maine Department of Marine Resources (MDMR) manages American shad by river system. Three Maine rivers are currently under active restoration. The Saco, Androscoggin, and Kennebec rivers are historical American shad rivers that have the best potential to support significant American shad runs. The majority of the smaller coastal rivers in Maine that contain American shad are under passive restoration (Table 2.1; Figure 2.1). The State of Maine does not sample or assess shad populations classified as "under passive restoration." When resource agencies collect data, they are stored at the Department's headquarters in Hallowell, Maine.

In 1951, Taylor conducted a limited assessment of shad populations in and around Merrymeeting Bay. The Merrymeeting Bay estuary is a unique fresh water tidal ecosystem. Six rivers empty into the estuary: the Kennebec, Androscoggin, Cathance, Abbagadasett, Muddy, and Eastern. Each river once had spawning populations of shad. Using historical landings data recorded by county and historical accounts of fishing activities, he attempted to assess why shad numbers were stable in the Eastern River and declining in others. Taylor concluded that the free flowing Eastern River had maintained a healthy spawning population of shad for two reasons, the absence of dams and industrial pollution.

The larger rivers, the Kennebec and Androscoggin, were an important part of Maine's industrial history. Industrial pollution severely affected the water quality of both rivers. Taylor (1951) concluded that the Androscoggin deposited pollution in the Cathance, Muddy, and Abbagadasett through the tidal action of the bay and this prevented recruitment to these systems. The Kennebec River, in addition to limited amounts of industrial pollution, had a large number of sawmills as well as a dam located at head-of-tide in Augusta. Taylor (1951) believed sawdust affected spawning habitat in the river below Augusta. The Eastern River flows into the upper section of the bay and escaped many of the problems associated with dams and industrial pollutants of the time. Taylor (1951) believed that these were the reasons the shad fisheries of the Eastern River remained stable as commercial fisheries in the other rivers of the bay declined.

It is likely that a combination of overfishing and habitat loss from dam construction beginning in colonial days through the early 1800s contributed to the disappearance and dramatic declines of shad stocks in the State of Maine (Flagg *et al*. 1976).

Flagg *et al*. (1976) used a combination of harvest change following dam construction and drainage area historically available for shad spawning to estimate potential historical spawning stock size of American shad in Maine. According to Atkins (1887), the completion of the Edwards Dam in Augusta in 1837 resulted in a 50 percent decline in the shad catch of the lower Kennebec. Therefore, the 8,268 square kilometers of the upper Kennebec previously accessible to shad apparently produced 50 percent of the commercial harvest. During the 12-year period from 1903 to 1914, the lower Kennebec yielded an average annual harvest of 308,370 kg. This then equaled the harvest produced from 8,268 square kilometers of accessible drainage area in the upper Kennebec. Excluding the New Hampshire portion of the Androscoggin and Saco River drainages, the total land area of Maine that drains into Maine coastal waters approximates 64,200 square kilometers. Historically, approximately 33,280 square kilometers of this drainage was accessible to American shad. Based on historical harvest from the Kennebec, this would have generated a potential yield of 1,215,000 kg of Maine-produced fish. If we assume a harvest of 30 to 80 percent of the total run that is characteristic of commercial shad fisheries in southern New England areas, the total Maine historical run size would have ranged from 1,518,750 kg to 4,050,000 kg. Assuming a mean weight of 1.8 kg, the total historical population would have been 850,000 to 2,250,000 adult fish (Flagg *et al.* 1976).

2.2 MANAGEMENT UNIT DEFINITION

All of Maine's active restoration efforts focus on three rivers: the Saco, Androscoggin, and the Kennebec. Maine currently manages shad stocks in each river system as separate management units.

2.3 REGULATORY HISTORY

Historically, fisheries managers used a number of regulatory processes to manage American shad fisheries in Maine. Many of these regulations applied to the commercial American shad fisheries in the Kennebec, Androscoggin, and Merrymeeting Bay areas from the late 1800s through the 1940s. Several of the smaller coastal rivers had additional river-specific harvest regulations. Maine reduced commercial shad catches through mesh size and lead length restrictions for shad anglers using gill nets and weirs. Closed seasons allowed additional escapement of spawning fish. By the end of the 1940s, the effects of pollution and over fishing depleted many of the coastal river fisheries to the point where it became economically infeasible to continue commercial fishing operations. Generally, commercial shad catches after the 1940s resulted from herring and groundfish fishing operations in near shore and offshore locations.

The effects of pollution on stock size were as important as the commercial fishery. Pulp and paper, textile mills, and logging drives had devastating effects on shad habitat in the lower sections of many of Maine's shad rivers, which reduced the returning shad's ability to reproduce successfully. The state closed commercial fishing for American shad effective May 1998.

In 1998, Maine established a recreational two fish possession limit for American shad caught in coastal waters and limited recreational fishermen to hook and line only.

2.4 ASSESSMENT HISTORY

2.4.1 Formal Assessments

Current data collected by the MDMR are limited to fish passage counts, juvenile indices, and tagging studies. The majority of these data were collected since 1970. Maine does have limited amounts of historical data collected during the commercial shad fisheries of the late 1800s and early 1900s. The Atlantic States Marine Fisheries Commission reviewed Maine's American shad populations when it conducted two coastwide assessments in ASMFC (1988) and ASMFC (1998). The earlier assessment used a multiple regression model based on F_{msy}, river latitude, and flow variability for twelve known rivers to predict the sustainable fishing rate for Maine, as well as other east coast rivers (ASMFC 1988). Estimates of F_{msy} were 0.21 and 0.45 for the Penobscot and Kennebec populations, respectively. However, confidence in the F_{msy} estimates was poor. The 1998 assessment examined juvenile abundance indices (JAIs) and coastal commercial landings data for the period 1979 to 1997. There were no conclusions drawn on either data series.

2.4.2 Historical Perspective

Maine had an incredibly rich history of over 20 rivers that once supported shad runs. Clyde C. Taylor conducted a survey of Maine's historical shad rivers in 1951 and his paper is the most comprehensive report available in terms of a historical perspective. Included in his report are a number of river-specific regulations and catch and effort data for Maine's small coastal rivers. A summary of this information is provided below.

Nonesuch River, Scarborough

Taylor walked the Nonesuch River on August 22, 1950, from the ocean to Thurston's Mills, approximately 28.8 km inland. The falls at Thurston's Mills were the inland limit of shad in this system. Based on discussions with commercial fishermen targeting shad in the Nonesuch he determined shad were found in the river May through June. The estimated total catch in a night's worth of fishing was 20 fish per night with an estimated total season catch of 200 to 400 shad. Taylor observed as many as 40 fishermen on a single night. Fishing gear was a dip net 1.5 to 1.8 m in diameter. Fishing gear was restricted to the tidal portions of the river and dip or bag nets not exceeding 5.7 m in circumference. The total daily catch limit was five fish (State of Maine 1949;Taylor 1951).

Presumpscot River, Portland

Although the Presumpscot River did have a shad run, spawning was limited to the river below Presumpscot Falls, 1.6 km above salt water. In 1868, shad migrated as far up as Cumberland Falls, 14.4 km above tidewater (Atkins 1868). A 2.7-m high dam at Cumberland Mills prevented farther passage. A survey of river and stream conditions in 1930 (Walker 1930), indicated that at least one point between Westbrook, Maine and the sea had a dissolved oxygen content below 3 ppm attributable to sapphire wastes from pulp production. Poor water quality from pulp and paper industries accelerated the shad decline in the Presumpscot.

Stroudwater River, Portland

No historical information.

Royal River, Yarmouth

No historical information. Falls 0.4 km above tidewater may prevent upstream passage. Current data suggests that wild shad are spawning in the Royal River. In the 1980s, field staff captured juvenile shad below the first set of falls at head-of-tide while sampling for alosines.

Kennebec River and Tributaries

The Kennebec River supported a shad fishery for many years after the decline of shad in many of Maine's smaller rivers. Historically, shad migrated 109 river kilometers (rkm) inland from tidewater. Dams erected on the Sandy, Sebasticook, and Cobboseeconte, tributaries to the Kennebec, prevented shad from accessing spawning habitat. The Sandy River was dammed in 1804, the Sebasticook in 1809, and the Cobboseeconte in 1787. Shad fisheries still existed for a limited period below the dam on the Sebasticook River. A historical account (Atkins 1868) reports the following:

> In 1814, the town (Benton) obtained an act authorizing them to control the fisheries and the first year after cutting away this dam, the fishery was leased to one James Ford, he agreeing to pay yearly 200 fish to each man, woman and child in Benton, and to sell as many more as he wanted at a fixed price. From this time, the fishery increased rapidly and the town began to sell the fishery yearly at public auction. The price varied from $500 to $1,200-1,500; the purchaser being bound to distribute gratis to the poor and to sell to all the townspeople at a fixed price. The year of the closing of the Augusta dam, the fishery sold for $225. One or two years before it had sold for $500.

Once the Edwards Dam at Augusta was finished, it prevented shad from ascending above head-of-tide Sometime between 1855 and 1867 a fishway was incorporated at the dam site, the exact date is not known.

Although the Edwards Dam had a fishway, its effectiveness was poor. The decline, and eventual disappearance, of shad from the lower Kennebec appears to have been a gradual process. The total catch figures, both for the Merrymeeting Bay area and the entire Kennebec River, did not reflect the decline that was occurring. Atkins cites the catch of a single weir in this district that apparently did show a decline in catch associated with the closing of the Edwards Dam: "Mr. Brown's weir produced in the ten years ending in 1835 an average of 5,961 shad yearly. In the twelve years from 1837 to 1848 the average catch was 3,120 per year, a little more than half the former yield" (Atkins 1887).

In 1860, fishermen in Augusta noted declining shad numbers. Seines fished in the area in 1822 caught as many as 700 shad per day. About 1857, one seine harvested 3,000 shad and 20,000 alewives during the season. In 1867, the shad fishery was a total failure (Atkins 1868).

> The most productive shad weirs were those of the Merrymeeting Bay and its vicinity. Of the 140,000 shad taken in the Kennebec in 1880, 108,000 were taken in the Merrymeeting Bay district, 5,800 above Richmond, 16,744 between the bay and Bath, and only 10,00 below Bath, including the Sasanca or eastward arm, between Woolwich and Arrowsic. In the bay district, 44 weirs averaged 2,048; below Bath 29 weirs averaged 345 shad. All included in the above statement are breeding shad, called by the fishermen "river shad" or "spawn shad." (Atkins 1887)

During 1851 and 1852, seine weirs began to replace the less effective shallow water weirs. These seine weirs could be fished at locations where traditional weirs were impractical.

Androscoggin River, Brunswick

Harvest records indicate that commercial fishermen regularly fished the first 8 km of the Androscoggin River, from Brunswick down to Merrymeeting Bay starting in 1887 continuing until the late 1950s. The falls at Lewiston were a barrier to upstream migration.

Cathance River, Bowdoinham

There was a commercial fishery for shad in the upper and middle sections of the river, approximately 2.0 km above Bowdoinham to the bay. The last good catch of shad occurred in the spring of 1918, after that, the fishery collapsed. One fisherman put a drift gill net into the River to show how the fishery historically caught shad in the river (Squiers, pers. comm.). To his surprise, he caught six shad the first night he fished. He fished the River for four more years. His catch never exceeded 13 fish in one night. Once the nets fell into disrepair he did not feel it was worth the cost to replace them.

Abbagadasett River, Bowdoinham

This is a small tidal river approximately 1.5 km long. Although there is no direct historical reference to the River, it is believed to have contained shad. Maine's juvenile index survey conducted in the Abbagadasett the past 20 years indicates the presence of juvenile American shad.

Eastern River, Dresden

The Eastern River is a 16 km long tidal river that enters the Kennebec River on the eastern side of Swans Island. Historically the River was one of the most productive rivers in the Merrymeeting Bay area. Historical accounts provide evidence of how important the Eastern River was, and may still be, to reestablishing Maine's American shad runs. "In the Eastern River thirty years ago, there were eight or nine weirs, each of which took 6,000 to 8,000 shad per year and about the same amount was taken by seines and drift nets, indicating a catch of 100,000 shad annually" (Stevenson 1898).

Sheepscot River, Alna

The Sheepscot never had a large shad run according to historical references. An estimate of average annual run size was 1,000 fish (Taylor 1951). Through the 1940s, commercial fisherman, Rockwell Riddle, fished the River. Two shad caught and measured at that time were a male 47 cm, 0.9 kg, and a female the same length that weighed 1.4 kg. During the 1950s, three commercial fishermen fished for shad using gill nets but only a few fish were caught. In recent years, 2002 through 2005, the Maine Atlantic Salmon Commission did capture adult shad in the rotary screw smolt traps set at head-of-tide. The trap captured 12 American shad in 2002, 8 in 2003, and 14 in 2004.

Penobscot River, Bangor

Historically the Penobscot had large runs of American shad but these runs soon declined after the construction of dams to power sawmills began in 1771. After construction, the numbers of all anadromous species declined. Dams on the tributaries and the main stem of the River excluded all shad from historical spawning habitats. Accounts of the time indicate that shad were numerous and an important resource to townspeople.

> Fish, too, began to be a marketable commodity. The streams were full of them. Salmon, shad, and alewives were taken under lover's leap, at the mouths of the Mantawassuck, Segeundedunk and Sowadabscook streams and at Penobscot Falls. No record was made of the quantity or value of fish taken in any one year, but between thirty and four hundred barrels of shad and alewives were taken at one tide at each of the several places or –eddies—the average would be from 75 to 100 barrels. At Treats Falls sometimes 40 salmon were taken in a day. (Ford 1882)

Describing events in Bangor for the year 1827, Ford (1882) wrote:

> Some opinion may be formed in regard the immense quantities of fish in the Penobscot at the head-of-tide, when it is understood that 7,000 shad and 100 barrels of alewives were taken in one haul of the seine, about the middle of May this year. This was an unusual fish year. Shad were sold

> at Old Town at 5 cents a hundred, and alewives were deemed hardly worth saving.

By the time construction of the Bangor Dam was complete (1877), the American shad fishery had ceased to exist. Because brackish reaches Bangor, and there are no suitable spawning areas for shad between the Bangor Dam and the sea. The Bangor Dam no longer exists and the next upstream barrier is the Veazie Dam, in Veazie, Maine, just north of Bangor. The breaching of the Bangor Dam opened approximately 1.6 rkm of spawning habitat to American shad.

Narraguagus River, Cherryfield

This River still has a small native run of shad. The alewife fisheries at Cherryfield, and the Atlantic salmon trap located there, routinely capture American shad. MDMR conducted a tagging study from 1968 to 1971 to determine where these fish went after they spawned. MDMR tagged 583 pre-spawn shad over a four-year period. Fishermen recaptured eleven tagged shad. Returns from Saint John, New Brunswick, North Carolina, Virginia, and Maine indicate that Maine shad were susceptible to ocean-intercept fisheries as they migrated up the east coast.

Pleasant and Harrington rivers, Columbia Falls

Historically commercial fishermen harvested shad, alewives, and Atlantic salmon in late May and early June. Two to three fishermen would drift net the rivers and sell shad, alewives, or salmon they captured locally. There are no estimates on the numbers of fish taken each year.

Chandler River, Jonesboro

Historically the Chandler River had shad but there is no recent evidence that there are American shad still in the River.

Machias and East Machias Rivers

Neither of these rivers produced significant numbers of shad. A gorge on the river likely prevented passage up the Machias River. The East Machias is principally an alewife river and according to historical records, and never produced more than a 20 shad annually.

Denny's River, Dennysville

Shad were caught in the river until the construction of a dam in 1846. There are no documented sightings of shad since 1846.

St. Croix River, Calais

Historically there were great numbers of shad in the river. Historical accounts stated, "The numbers of shad were almost incredible" (Atkins 1868). Dams constructed in 1825 caused the fishery to decline. Obstructions and a series of impassable dams beginning just above head-of-tide prevent upstream passage.

2.5 STOCK-SPECIFIC LIFE HISTORY

2.5.1 Growth

In Maine, the average weight of male American shad is 1.35 kg while females average 1.8 kg. Older fish may exceed 5.4 kg and 75 cm in length (Flagg *et al*. 1976). Maine has not developed growth curves or age-length keys for American shad because available data on length-at-age are limited to a few age classes.

2.5.2 Reproduction

Depending on weather conditions, adult shad normally enter Maine rivers from mid-May to the latter part of June. Most spawning in the Kennebec River occurs during June with some spawning extending into July and August (Bigelow and Schroeder 1953). Female shad carry from 20,000 to 60,000 eggs depending on the size, age, and river of origin (Flagg *et al*. 1976). Most Canadian shad produce from 20,000 to 150,000 eggs per female, which is probably representative of the fecundity of Maine shad (Liem and Scott 1966). Fecundity data specific to Maine American shad are not available.

Eggs are spherical, about two millimeters in diameter, and slightly heavier than water. The adults spawn in riverine areas with current velocities ranging from 0.3 to 0.9 m per second and at water depths ranging from 0.9 to 6.0 m. River currents carry fertilized eggs for several kilometers downstream from spawning locations. Viable eggs are located on river bottom types ranging from fine sand to coarse rubble and ledge, but never on silt or mud bottoms. The eggs hatch from 12 to15 days at 11.0 °C and 6 to 8 days at 17.0 °C (Bigelow and Schroeder 1953). The larvae are ten mm long at the time of hatching and are slender. Some drift down to brackish water shortly after hatching while others remain in the fresh water throughout the summer months. In the fall, when shad reach 5.0 to 7.5 cm, the young fish leave the rivers as water temperatures decline below 12.0 °C (Stira and Smith 1976).

2.5.3 Ocean Migration

During the fall and winter migration period, all east coast American shad populations mix in the Atlantic Ocean. Tagging studies, conducted in Maine, indicate that the New Brunswick, Virginia and North Carolina ocean-intercept fisheries catch shad native to Maine (Table 2.2). One interesting exception was a fish tagged in June and recovered in July well upriver in the Petitcodiac River in New Brunswick. The timing and location of returns suggested that Maine shad move as far north as New Brunswick in the summer and as far south as North Carolina in winter.

2.5.4 Genetic Information

Each river system may have its own genetic stock. Analyses that identify river-specific stocks may affect current management strategies implemented by the State of Maine. The Maine Department of Marine Resources collects genetic samples from shad ascending the Brunswick fishway on the Androscoggin River. Analysis of the samples in storage will help determine the origin of the American shad within the estuary.

2.6 HABITAT DESCRIPTIONS

Dams and pollution have reduced watershed area in Maine that is accessible and suitable for American shad to about 1787 square kilometers or 5 percent of historic habitat (Flagg *et al*.1976). Current habitat varies among river systems. Habitats in the Saco, Androscoggin, and Kennebec rivers are described below. The Merrymeeting Bay Estuary is the largest contiguous section of American shad spawning habitat available in Maine. Entrepreneurs dammed many of Maine's coastal rivers at the head-of-tide during the industrial revolution, preventing shad from reaching suitable spawning habitat. Tidal sections of the Penobscot River remain free flowing up to Veazie, Maine but the amount of spawning habitat available remains a question. Besides a few smaller rivers, such as the Eastern and Narraguagus, spawning habitat in Maine is permanently altered.

2.7 RESTORATION PROGRAMS

Restoration activities for American shad in the river systems under restoration include improving or implementing upstream and downstream fish passage facilities at all dams within the historic range in each system, restricting recreational and commercial harvest, and stocking fry and adults into historic spawning reaches. The Waldoboro shad hatchery began raising American shad fry for restoration stocking in 1992. Stocked larvae are usually 7 to 21 days old. Maine obtained broodstock from the Merrimack, Connecticut, and Saco rivers after 1997. During the period 1984 through 1996, Maine collected adult shad from the Cathance, Connecticut, and Narraguagus rivers to stock the Androscoggin and Kennebec rivers. Lary (1999) developed the restoration targets for the Saco, Androscoggin, and Kennebec rivers. Restoration targets are 2.3 shad per 100 square yards of surface area in river reaches within the historic range within each river system. The Maine Department of Marine Resources bases its restoration goal numbers on upstream passage numbers and returns in subsequent years at the Holyoke Dam on the Connecticut River during the 1980s.

2.7.1 Saco River

The Saco River is the smallest Maine river currently under active restoration. The Saco is 120 km long, drains 4,428 square kilometers, and has an annual mean discharge of 8.2 x 10^6 cubic meters per day. The historic range of American shad in the Saco River includes the main stem and tributaries up to Hirum Falls. There are currently seven dams on the Saco that block upstream passage. The first dams are located at head-of-tide in Saco, one on each side of an island located in the middle of the river. The first four dams all have upstream passage, but passage at the third dam, located 1 km above head-of-tide, does not pass shad well enough to allow shad to reach the majority of the spawning habitat. Florida Power and Light Energy (FLPE) trucks shad from the Cataract Dams and releases them above the second dam to continue their upstream migration. There are currently no downstream fish passage facilities on the Saco River. State fisheries agencies are currently negotiating with FLPE for upstream and downstream fish passage at all dams on the Saco.

The restoration goal for the Saco River is to restore American shad to the main stem and tributaries up to the Hirum Falls Dam. The river and tributaries include an estimated 90,868 habitat units, 100 square yards each. The Saco River could potentially support a run of 208,997 adult American shad. The numbers of fish passed upstream, at each of the first three dams on the Saco River will be used to measure the success of the restoration program

Restoration stocking on the Saco River involves only the introductions of larvae hatched from Saco River brood stock and raised at the Waldoboro Shad Hatchery. The MDMR released larvae in the Saco annually from 1997 through 2001 (Table 2.3)

2.7.2 Androscoggin River

The Androscoggin River is Maine's third largest watershed, draining 8,970 square kilometers. The Androscoggin discharges an annual mean of 14.4 x 10^6 cubic meters per day. The first natural barrier to upstream migration of American shad on the main stem Androscoggin occurs at Lewiston Falls, 35.4 km above tidewater. Shad had access to an additional 56.3 km of habitat in the Little Androscoggin River that joins the main stem just below Lewiston Falls. Access to the main stem Androscoggin River stopped in 1809 with the construction of a dam at head-of-tide at Brunswick 9.6 km above its confluence with Merrymeeting Bay. There are two additional dams upstream of Brunswick and below Lewiston on the main stem Androscoggin. In 1982, Central Maine Power Company constructed a vertical slot fishway at the dam at Brunswick. In 1987, developers expanded the Pejepscot Hydropower Project and followed with the Worumbo Hydropower Project in 1988. The Federal Energy Regulatory Commission (FERC) required upstream fish-lifts and downstream passage facilities at the Pejepscot Project, the second upstream dam, and at the Worumbo Project, the third upstream dam.

The restoration goal for the Androscoggin River watershed is to restore American shad to their historic range in the main stem upstream to Lewiston and in the Little Androscoggin to Biscoe Falls. There are 10,217,391 square yards of shad habitat within river reaches targeted for restoration. Lary (1999) estimated that the Androscoggin watershed could support a run of 235,000 adult shad annually. Fisheries staff measure restoration progress in terms of successful upstream passage at the first three dams on the Androscoggin River, which includes all historical habitat on the main stem of the Androscoggin River.

Restoration activities on the Androscoggin River involve developing fish passage facilities, stocking shad larvae, and transferring pre-spawn adults from other river systems. Maine released larvae from the Waldoboro Shad Hatchery to the Androscoggin from 1999 through 2005 (Table 2.3). Adult transfers occurred from the Cathance River in 1984 and 1985, from the Connecticut River in 1988 to 1997 and in 1999, and from the Merrimack River in 2002 to 2004 (Table 2.4).

2.7.3 Kennebec River

The Kennebec River is Maine's second-largest river based on drainage area and average daily discharge. The river is 368 km long, drains 15,262 square kilometers, and discharges 19.8 x 10^6 cubic meters per day. The historic range of American shad in the Kennebec River extended up the main stem and main stem tributaries as far as Madison (rkm 125). The first barrier to upstream movement was the Edwards Dam at Augusta. This dam, removed in 1999, opened the River to shad up to the Lockwood Dam in Waterville, 70.4 rkm from tidewater. The management plan for the Kennebec River includes upstream and downstream fish passage facilities for each dam within the river reaches targeted for restoration (Squiers 1986).

The restoration goal is to restore American shad to the main stem Kennebec up to Madison and to the Sebasticook River, Sandy River, Seven Mile Stream, and Wesserunsett Stream. These river and stream reaches include 31,510,241 acres of shad habitat and would support and estimated 725,000 adult American shad if there was no dam induced mortality during downstream migration of juveniles. A 10 percent mortality rate during downstream migration at each hydropower facility would reduce the potential production of American shad to 519,759.

Restoration of American shad to the Kennebec River involves developing fish passage facilities, stocking of shad larvae, and transferring pre-spawn adults from other river systems. Maine stocks shad larvae from the Waldoboro Shad Hatchery into the main stem Kennebec and Sebasticook rivers (Table 2.3). Fisheries personnel transferred adults from the Connecticut and Narraguagus rivers and Sagadahoc Bay to the Kennebec River from 1987 through 1997 and again in 1999 (Table 2.4). Adult American shad transfers from the Merrimack River occurred from 2002 through 2004.

2.7.4 Hatchery Evaluation

The Waldoboro Shad Hatchery uses oxytetracycline (OTC) to mark the larvae otoliths to differentiate hatchery-reared fish from wild reproduction. Starting in 2000, field staff began collecting adult shad that died in fish passage facilities for OTC mark analysis. Fisheries staff also collected dead adult fish from Androscoggin and Saco rivers to look for OTC marks on returning shad (Brown and Ryder 2001). Adult shad were not intentionally killed for this study. Juvenile shad for this study were collected from fish passage operations on the Androscoggin and Kennebec rivers and from the biweekly juvenile seine survey in the Merrymeeting Bay complex. The seine survey supplied the majority of the study fish, which were evenly spread out through the sample season. Lab personnel removed the otoliths, cleaned them in distilled water, and mounted them in a thermoplastic resin. The otoliths were ground using 9, 3, and 1 micro lapping film. Otoliths were ground to the mid-sagittal plane on one side, flipped over, and ground to mid-sagittal plane on the opposite side. A drop of Type FF (low fluorescing) immersion oil was placed on each otolith, and it was covered with a glass cover slip. A compound microscope was equipped with fluorescent light and a FITC filter set to illuminate the OTC ring if it was present. Any OTC marked otoliths exhibited a glowing ring representing the day that the fry were marked. The percent of marked fish indicate the percent contribution of hatchery fish to the sample.

Results from annual analyses of stocked versus wild juveniles indicated that 5.3 to 62.5 percent of the juveniles emigrating from the Androscoggin River systems were hatchery reared (Table 2.5). Percentages for the Kennebec River ranged from 2.4 to 22.2. Those in Merrymeeting Bay range from 2 to 10 percent. The State of Maine releases an average of approximately four million fry each year. The results from this study would indicate that a substantial population of wild adult shad is present in the Kennebec River below Waterville.

2.8 AGE

Currently, Maine uses Cating's methods of examining and counting the annuli present on American shad scales to determine age (Cating 1954). Subsequent workshops conducted by the ASMFC Shad and River Herring Technical Committee, have determined that these methods may need to be refined to obtain accurate age data. Maine reads the actual scales collected from shad unlike several other states that use the scale impression method to determine scale age.

The American shad is an anadromous fish species that grows to maturity in the ocean and returns to fresh water to spawn. Returning adults range from two to five years old with males usually maturing one year earlier than females. Four and five year old shad dominate the shad runs in the Northeast and Canadian Maritimes. (Flagg *et al*. 1976)

The State of Maine collects limited age data. Typically, only those shad trapped at the Saco River fishways and the Brunswick fishway on the Androscoggin River are available for ageing. Data are obtained only from mortalities on the Saco River, but are taken from most fish passed at Brunswick on the Androscoggin River. Field staff measured and recorded fork and total length to the nearest mm; during periods of high water temperature or large numbers of fish, shad are passed directly upstream without sampling. The State does not routinely sample smaller coastal rivers and streams. The Kennebec and Sebasticook rivers do not have upstream passage facilities. Shad in these rivers are difficult to catch and sample. Samples from the Saco and Androscoggin rivers were from fish between three and nine years of age (Table 2.6). Most males were four to six years old; most females were four to seven years old. Mean ages on the Saco River were 4.8 to 5.6. Mean ages on the Androscoggin River were 4.7 to 6.0. Occasionally older shad, typically repeat spawners, are collected. Some repeat spawners may live as long as 10 or 11 years (Flagg *et al*. 1976). The oldest American shad recorded from Maine rivers in recent years was 11 years old. The equation: $TL = 1.0258FL + 42.332$ was used to convert fork lengths in mm to total lengths in mm where total lengths were missing.

2.9 FISHERY DESCRIPTION

2.9.1 Commercial Fisheries

Historically, shad were abundant and harvested from all the major rivers along the entire coast of Maine. Reported commercial landings are available, but it is likely that these landings do not reflect the true magnitude of the resource. For at least 60 years prior to the systematic recording of commercial landings, dams excluded spawning adults from spawning habitat in the upper regions of major shad rivers. In addition, commercial catches recorded along the coast and outside the major river systems, were not definitively identified as fish of Maine origin. In effect, many fish taken in the commercial shad fishery of the late 1940s may have originated in the rivers to the south and possibly north of Maine. Most of the reported commercial harvest of American shad in Maine since 1950 occurred in gill nets.

Taylor (1951) listed 18 coastal rivers in Maine that historically supported runs of American shad (Table 2.1). Of the 18 rivers that Taylor listed as having shad runs, seven contained very large shad runs that either supported major commercial fisheries or had the potential to support major fisheries. Most of the shad runs in smaller rivers sharply declined during the very early colonization of Maine because early settlers had the ability to construct dams on small rivers to provide waterpower for mills. As technology advanced, it became possible to construct dams on the larger rivers and the large shad runs declined dramatically. In subsequent years, increased pollution took its toll on the river fisheries that persisted below the dams.

In the years 1903 to 1904, the shad fishery employed 285 to 373 people, 250 to 308 boats, and 153 to161 weirs (Flagg *et al*. 1976). The value of the fish, boats, and gear was $52,480 in 1903 and $71,603 in 1904. Available data from the period 1898 through 1906 show that the average annual number of commercial shad fishermen for the period was 297, ranging from a low of 168 to a high of 472. In 1904, two percent of the 18,175 commercial fishermen in Maine engaged in the shad fishery. In that year, the shad fishery ranked seventh in importance of the 11 major commercial fisheries listed. Lincoln and Sagadahoc counties accounted for 84.3 percent of all participants in the fishery during the period 1898 through 1906. These counties encompass fisheries of the Merrymeeting Bay complex.

Commercially exploitable populations of American shad no longer exist in Maine and directed commercial harvest is prohibited. All reported harvest since 1995 results from bycatch. Most occurs in commercial fishing operations for groundfish or Atlantic herring in the Exclusive Economic Zone (EEZ). The National Marine Fisheries Service compiles ocean bycatch in EEZ waters. American shad landings from offshore—southwestern Maine and Jeffrey's Ledge—occur mainly as a bycatch resulting from the groundfish gill net fishery. Several fisheries that target other species in near shore Maine waters, such as gill nets and trawls, catch American shad. These catches are minimal, especially since Maine closed state waters to the commercial harvest of all groundfish species annually during the months of April, May, and June. Maine does not collect discard data on American shad caught in the EEZ or Maine waters. Data are not available on biological characteristics of the catch in the historical Maine commercial harvest or the recent bycatch.

2.9.2 Recreational Fisheries

Maine has extremely limited recreational fisheries for American shad. Recreational fisheries occur in the Saco River and several small coastal rivers. Effective in 1998, possession was limited to two fish per day taken from the coastal and inland waters of Maine. Recreational shad fishermen may only take shad with hook and line. The Marine Recreational Fisheries Statistics Survey (MRFSS) sampled recreational catch and effort statistics for the State of Maine through 1994. The MDMR has been conducting the MRFSS survey since 1995. It is likely the MRFSS survey misses the small number of shad caught and retained by recreational anglers, especially in rivers.

2.10 FISHERY-INDEPENDENT SURVEYS

Maine uses annual fish passage counts, near-shore ocean trawl surveys, and estuarine juvenile index surveys to assess American shad stock condition.

2.10.1 Adult Fish

Saco River

Construction of the Cataract Projects, the first two dams on the Saco River, takes advantage of an island located in the middle section of this river. The dams incorporate the island into their structure, creating a channel on the east and west sides. Fish pass the Cataract Projects via a Denil style fishway on the west channel and a fish-lift on the east channel. Biologists have sampled fish at the Saco River fishways during the shad spawning run since the fishways became operational in 1993.

Biologists count all fish in the trap at the upriver end of the Denil fishway and in the fish-lift. The MDMR instructs biologists working for Florida Power and Light Energy (FPLE), a hydropower operation on the Saco River, to pass shad upstream or truck them around the next two upstream barriers. FPLE only collects biological data from fishway mortalities. Fishway personnel tend the trap and lift daily during the upstream spawning migration. Efficiency of the Denil fishway in the west channel at the Cataract Dam is suspected to be as low as it is at the Brunswick Dam (see below). We do not believe that the number passed at this facility reflects the number of shad below the dam on the west channel. The fish-lift at the east channel dam does a much better job of passing American shad. This lift is an automated lift system designed to trap and lift shad based on shad numbers in the tailrace. A technician needs to be present and manually operate the lift from daylight to dusk. When shad enter the trap, the trap gate is closed, and the lift passes the shad into the bypass channel. Typically, the fishway shuts down at 1700 hours and reopens at 0600 hours. Upstream passage is not available when the trap is not operating. We suspect that shad wait below the dam at night and are passed the next day when the lift opens and that most of the shad that make it to the base of the dam are eventually lifted. Thus, numbers passed probably reflect the annual run size in the east channel. Although we do not know if the proportion of shad that use the east channel is constant among years, we use the east channel lift data as an annual index of run size for the river because fish essentially can not pass the dam on the west channel. Most adult and juvenile American shad moving downriver on the Saco River pass through the turbines of the hydro facilities on the lowermost dam (the Cataract Dams).

Androscoggin River

Passage over the Brunswick Dam on the Androscoggin River occurs via a vertical slot fishway constructed in 1982. Since 1983, MDMR biologists have collected daily fish counts from the fish trap situated at the upriver end of the fishway. Field staff sample all shad ascending the fishway to the trap located at the top if the fishway. Fishway staff collect length data as well as scale and tissue samples from each shad collected in the fish trap. Fishway staff collects otoliths from any incidental fishway or transport mortalities. The trap operates daily during the period that shad are in the river. Shad are trapped, lifted, and sampled when they ascend the fishway to the trap. Department personnel staff the fishway between the hours of 0700 to 1700 hours daily.

For the past six years the Maine Department of Marine Resources conducted an underwater video camera study at the Brunswick fishway. The fishway design is not efficient at passing American shad upstream.

Fisheries staff use the cameras to identify problems at the fishway by observing behavior at several strategic points in the fishway and outside the fishway in the river. The six underwater cameras in the fishway record daily from 0600 through 1800 hours during the shad migrations. Fisheries staff review the tapes and classify shad behavior according to location. Underwater video and telemetry data collected below the dam indicate that the number of shad in the river is higher than the number of shad caught in the trap at the top of the fishway (Brown and Sleeper 2003). Video observations within the fishway suggest that although some shad enter the fishway and are present in lower pools, very few shad make it all of the way to the top of the fishway.

Telemetry studies of shad tagged below the dam indicate that shad make many attempts to enter the fishway, but very few are successful. The vertical slot fishway formerly prescribed by the USFWS at Brunswick is a notoriously poor design for passing American shad. Another vertical slot fishway on the Farmington River in Connecticut has similar problems. For these reasons, we do not feel that annual passage at this dam reflects annual abundance of American shad in the Androscoggin River. Biologists suspect spawning occurs in the 9.6 km of habitat below the Brunswick fishway. In June 2005, the field staff of Bowdoin College captured a small number of shad eggs in the river below Brunswick.

Downstream passage facilities are available at the three dams located on the main stem Androscoggin, but the downstream passage facility at the Brunswick Dam is between two turbine units—a poor location. Downstream attraction flows guide migrating adults and juveniles to the turbine units and the upstream passage. During years of high river flows, water may spill over the dam.

Kennebec River

The first barrier to upstream fish passage on the Kennebec River occurs at Waterville. Upstream fish passage will become available in May 2006, with the completion of a fish-lift at the Lockwood Hydropower site. Although a significant amount of free flowing river lies below Waterville, there is no easy location to capture fish and collect biological samples or to conduct an assessment. A tag and recapture study was conducted in 2004 with limited success.

Most adult and juvenile American shad moving downriver from above the first main stem dam at Waterville pass through the turbines at the Lockwood Hydropower facility. Fish produced below Waterville have free access to the ocean.

2.10.2 Juvenile Fish

Juvenile Abundance Indices

MDMR initiated sampling of age-0 American shad in 1979 at 14 sites in the Merrymeeting Bay estuary (Figure 2.2). There were four sites on the lower or tidal Kennebec River, three on the lower Androscoggin River, four on Merrymeeting Bay, and one each on the Eastern, Cathance, and Abbagadasett rivers. Eight sites were added to the Kennebec River above the former Edwards Dam in 2000 (Figure 2.3). Site 8A was abandoned because a recent bridge construction project altered the river at that sampling site.

Field crews sample sites once every two weeks between July 1 and October 1 each year. Collections are made with a beach seine within three hours of low water. From 1979 through 1982, the net was 9 m long, 1.8 m deep, and constructed with 3.2 mm stretched nylon mesh. Starting in 1983, the seine was constructed of 6.4 mm stretch mesh nylon and measured 17 m long, and 1.8 m deep with a 1.8 m x 1.8 m bag at its center. Although a bag was added and the method of seining was modified, the area sampled remained essentially the same.

During sampling, field staff holds one end of the seine stationary at the land-water interface and the boat operator tows the other end perpendicular to shore. When the net is fully extended, the distal end is towed in an arc upriver and pulled ashore. The net samples an area of approximately 220 square meters. Field personnel sort and process all samples at the sample location. Field staff count and measure all alosines. Fifty individuals of each species, other than alosines, are measured. Dividing the number of individuals caught by the number of seine hauls gives the catch-per-unit-effort (CPUE) index. The State does not collect juvenile index data from other river systems where shad spawning exists.

MDMR staff believes that age-0 shad move freely among sites in the lower Kennebec, Androscoggin, Eastern, Cathance, and Abbagadasett rivers, and Merrymeeting Bay. For this reason, data from these sites were combined and single arithmetic and geometric mean calculated each year. Separate means were calculated for the sites above the site of the former Edwards Dam on the upper Kennebec River.

Older Juvenile Fish

In 2000, MDMR initiated a near-shore trawl survey to assess groundfish abundance. Survey staff sample 120 stations stratified among five sections along the Maine coast each spring and fall (Figure 2.4). The survey counts and weighs all shad caught at each of the 120 sample stations. The survey sub-samples the shad catch and measures individual fork length to the nearest centimeter.

2.11 ASSESSMENT APPROACHES AND RESULTS

2.11.1 Statewide Landings

Early commercial landings remained relatively stable at around 445,000 kg from 1887 to 1911 (Table 2.7; Figure 2.5). They rose to a peak of 1,495,066 kg in 1912, dropped to mean of 51,400 kg in 1928 through 1933, and essentially became commercially extinct through 1940. Landings then increased to a high of 502,044 kg in 1945 and remained at a relatively low level from 1948 through 1976. Since 1978, landings have ranged from a high of 41,096 kg in 1981 to a low of 8.1 kg in 2002. From 1978 to 1990, landings averaged 14,369 kg. Since the directed fishery closed in 1995, annual landings have been less than 200 kg. In the past five years, ocean bycatch has decreased due to increases in the minimum gill-net mesh size allowed in the groundfish gill-net fishery (16.5 cm stretch mesh). Since 1950, commercial catches in gill nets generally exceeded those in other gears (Table 2.8). However, there is now no directed commercial fishery for shad in Maine waters

Flagg *et al*. (1976) estimated that the annual recreational harvest of American shad in Maine waters was 100 to 600 adults. Since 1999, the estimated recreational catch of American shad in Maine ranged from 438 fish in 2002 and 2003 to 2,191 fish in 2004 (Table 2.9). No trend in catch was apparent among years. The estimated harvest was zero, because all fish were released alive (MRFSS Database) and release mortality has been documented to be very low (Millard *et al*. 2003).

2.11.3 Saco River

We examined operating characteristics of the lowermost Saco River fish passage facilities at the Cataract Dams between 1993 and 2005. Timing of shad passage varied between channels within season and among seasons (Table 2.10). Run start times varied without trend from May 2 to June 17 in the east channel and May 10 to June 26 in the west channel. Start dates differed without trend between channels. Length of the run and number of fish passed were consistently greater on the east channel.

The number of fish passed over the Cataract Dams on the Saco River increased from 1993 to 1999, decreased in 2000, and has remained relatively stable through the present (Table 2.11). Passage levels to date have been much lower than the target of 208,997 shad for the Saco River.

To gain insight on the influence of adult fish passage on the future return of adults at the Cataract Dam, we evaluated the relationship between annual passage from 1993 through 1998 with passage five and six years later (Figure 2.6). No relationship was apparent for either time lag indicating that high passage in a given year does not predict good returns from progeny of passed fish five or six years later when they mature. Relationships were poor even if we removed the extreme data point for fish first passed in 1999. These results suggest that: (1) the passage facility does not pass a consistent proportion of returning adults; (2) there is annual variation in ocean losses at some life stage prior to maturity; or (3) there is annual variation in losses of juveniles migrating downriver at dams and hydropower facilities.

We estimated instantaneous rates of total mortality (Z) of adult shad passed over the lowermost dam on the Saco River as the slope of a linear regression of the natural log of number at age on age, within year, and sexes combined. Number-at-age was combined in pairs of successive years to increase sample size and reduce the influence of recruitment variation (Ricker 1975). Estimates of Z ranged from 0.94 in 1994 and 1995 to 1.63 in 1995 and 1996 (Table 2.12). All estimates were higher than that for natural mortality (M=0.36) and all exceeded F_{30} (F_{30}= FROM INTRO SECTION), both developed for New England in Section 2. Estimates also exceeded the F_{msy} developed by ASMFC (1998) of F_{msy}=0.51. Results suggest some loss of mature fish to fishing, spawning, or from mortality during downriver passage of adults over dams following spawning.

Status Summary

Current status of American shad in the Saco River is unknown. However, current abundance is likely to be low relative to historic potential because fewer than 2,000 adults are moved annually to spawning habitat above current barriers to migration. Moreover, downriver passage for post-spawning adults and juveniles remains nonexistent or poor. Natural reproduction is limited or nonexistent below the first barrier. High estimates of total mortality rates are of concern for this stock since directed harvest is banned. Population levels warrant continued monitoring of age structure and mortality rates.

2.11.4 Androscoggin River

Fewer than 100 fish have been passed over the Brunswick Dam annually since monitoring began in 1983 (Table 2.11). Given the low numbers and documented inefficiency of the fish passage facility, we did not use passage numbers as an index of stock abundance. Observations per hour in video monitoring of American shad below the Brunswick Dam suggest that abundance increased between 1999 and 2003 (Table 2.13). Annual passage levels to date have been well under the target of 235,000 fish.

Status Summary

American shad of the Androscoggin River are at very low levels compared to the potential for this stock. There is a suggestion that abundance below the Brunswick Dam has increased somewhat since 1999. However, fish passage over that dam has been meager and American shad have been denied access to most of their spawning habitat since the dam was constructed in 1809. Androscoggin River American shad are currently maintained by natural reproduction in limited habitat below the first dam and by stockings of shad larvae and adults above the first three dams on the system. Stock improvements are not likely until upriver and downriver passage at the three lowermost dams improves.

2.11.5 Kennebec River and the Merrymeeting Bay Complex

The annual geometric means for collections of age-0 American shad in the Merrymeeting Bay complex were relatively high in the 1980s, low during the1990s and have generally increased since 2000 (Table 2.14; Figure 2.7). The geometric mean catch per haul at the upper Kennebec sites fluctuated without trend from 2001 through 2005 (Table 2.15; Figure 2.8).

The highest catch rates of older juvenile American shad in coastal ocean waters generally occurred in Regions 1 and 2 along the westernmost coast of Maine (Tables 2.16 and 2.17). These regions bracket the mouths of the Saco and Kennebec River systems. The annual geometric mean catch per trawl tended to be higher in the spring than the fall although variation among years was similar (Figure 2.9). A very general trend of increase was apparent among years. Captured American shad were 9 –to 31 cm FL (Table 2.18). Mean lengths tended to be 15 to 20 cm. Age-length curves developed for American shad of the Hudson River suggest that these fish were one and two years old.

We evaluated trends in juvenile (age-0) abundance indices, the relationship between larvae stocked and age-0 abundance, and larvae stocked verses percent of stocked fish in juvenile collections.

To gain insight on the influence of age-0 abundance on future production of young, we evaluated the relationship between JAIs from 1984 to 2000 and 2001 and indices lagged five and six years later (Figure 2.10). No relationship was apparent for either time lag suggesting that good production in a given year does not predict good production from that year class five or six years later when they mature. Results suggest that: (1) the index is not a consistent measure of abundance; (2) that there is annual variation in losses during downriver movement of age-0 fish; or (3) there is annual variation in losses in the ocean prior to maturity.

We evaluated the influence of stocking on production of juveniles in the Merrymeeting Bay complex in 1984 through 2005 by: (1) a linear regression between the total number of fry stocked in the Kennebec, Androscoggin, and Sebasticook rivers and the JAI for the Merrymeeting Bay complex in the same year; and (2) a linear regression between number of adults stocked and the JAI. Results indicated that the number of larvae stocked in tributaries of Merrymeeting Bay positively influenced the abundance of age-0 American shad in the Bay complex ($P<0.03$; Figure 2.11). The relationship between the number of adults stocked and age-0 abundance was significant, but negative ($P<0.03$; Figure 2.12). We also compared the number of larvae stocked in the Kennebec River to the percent hatchery fish in age-0 collections for the Kennebec River (Figure 2.13). A weak positive relationship was apparent.

Finally, we evaluated the effects of removing the Edwards Dam in 1999 on juvenile production. Relative abundance of age-0 American shad in the Merrymeeting Bay complex appeared to increase following removal of the Edwards Dam at Augusta. However, the number of larvae stocked to the system also increased after dam removal. To evaluate changes in juvenile abundance, we compared age zero abundance indices in the Merrymeeting Bay complex before and after the removal of the Edwards Dam with a covariance analysis using number of stocked larvae and adults as covariates. Juvenile abundance indices were significantly higher following the removal of the dam ($P<0.004$), but they were not significantly different when the index was adjusted by the covariates. We do not know if survival of post dam larval stocking to the juvenile stage increased due to expanded nursery habitat.

Status Summary

Access to historical spawning and nursery habitat for American shad has been reduced in most tributaries of the Merrymeeting Bay complex and thus production of juvenile American shad is likely to be low relative to the historical potential of the Bay and tributary river systems. Limited natural reproduction and the stocking of shad larvae maintain current shad populations. Stock condition is likely to improve with the removal of the Edwards Dam, but will not reach full potential until upstream and downstream passage are provided at all barriers below and within in historic spawning reaches.

2.12 BENCHMARKS

A benchmark value of Z_{30}= 0.64 was calculated for New England American shad stocks (See Section 1.1.5).

2.13 CONCLUSIONS AND RECOMMENDATIONS

The current status of American shad in Maine river systems remains unknown, but current levels of abundance appear well below the potential for these stocks. The recent increase in the juvenile abundance index in the Merrymeeting Bay complex is a positive sign, but several stocks are maintained by larval and adult stocking. High mortality in the Saco River stock is a cause of concern because directed harvest is banned. Stock conditions are likely to improve in the Kennebec system following the removal of the Edwards Dam. However, it is not likely that American shad stocks in Maine will reach their full potential until effective upstream and downstream passage are provided at all barriers below and within historic spawning reaches.

Creel Survey

1. Conduct creel surveys in rivers with notable recreational fisheries

Fish Passage

1. Develop species-specific estimates of upstream and downstream passage efficiency at all fish passage facilities.
2. Improve upstream and downstream passage at all barriers below and in historic spawning habitat.
3. Take length, sex, and scale samples from at least 300 fish from each river for fish passed at fish passage facilities at the Cataract Dam on the Saco River, the Brunswick Dam on the Androscoggin River, and the Lockwood Dam on the Kennebec River.

Juvenile Abundance Indices

1. Continue abundance sampling of age-0 American shad in the Merrymeeting Bay complex and the Kennebec River.
2. Explore the presence of age-0 American shad below the first dam on the Saco river

Adult Monitoring

1. Develop a method to sample relative abundance of adult shad in the main stem Kennebec below the first dam.

Fishery Restrictions

1. Given the uncertainty about current stock status and limited access to historic spawning and nursery habitat, we recommend that current fishery restrictions in state and federal waters be maintained.

Stocking Activities

1. The stocking of larvae is apparently beneficial and should be maintained until access to spawning habitat has been obtained.

LITERATURE CITED

ASFMC (Atlantic States Marine Fisheries Commission). 1998. Stock assessment of American shad from selected Atlantic coast rivers. ASMFC, Special Report, Washington, D.C.

Atkins, C.G. 1868. First Report of the Commissioners of Fish and Game of the State of Maine for the year 1867. Augusta, Maine.

Atkins, C.G. 1887. The river fisheries of Maine. *In* Fisheries and Fisheries Industries of the United States, 1887, V/1.

Bigelow, H.B. and W.C. Schroeder 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service. Fishery Bull. 74(53): 577.

Brown, M.E. and H.E. Ryder. 2001. Anadromous alosine restoration in the Androscoggin River Watershed. Maine Department of Marine Resources, Completion Report, Hallowell.

Brown, M.E. and B. Sleeper. 2003. Anadromous alosine restoration in the Androscoggin River Watershed. Maine Department of Marine Resources, Completion Report, Hallowell.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

Flagg, L., T.S. Squires and L. Austin. 1976. American Shad Management Plan. Maine Department of Marine Resources, Completion Report, 5/ AFSC-13/FWAC-2-22 & 24. Augusta.

Ford, H.A. 1882. History of Penobscot County, Maine. Cleveland, Ohio.

Gibson, M.R., V.A. Crecco, and D.L. Stang. 1988. Stock assessment of American shad from selected Atlantic coastal rivers. Atlantic States Marine Fisheries Commission, Special Report 15, Washington, D.C.

Lary, S.J. 1999. State of Maine recovery plan for American shad (*Alosa sapidissima*) and river herring (*Alosa pseudoharengus* and *Alosa aestivalis*). Maine Department of Marine Resources, Augusta,.

Liem, A.H. and W.B. Scott. 1966. Fishes of the Atlantic Coast of Canada. Fisheries Research Board, Canada Bull. 155, Ottawa, Canada.

Millard, M.J., J. Mohler, A. Kahnle, K. Hattala, W. Keller, and A. Cosman. 2003. Mortality associated with catch and release angling of striped bass and American shad in the Hudson River. Report to the New York State Department of Environmental Conservation, New Paltz, New York.

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

Squiers, T.S., K.F. Beland, and J.D. McNeish. 1986. Lower Kennebec River Anadromous fish restoration plan and inland fisheries management overview. Maine Department of Marine Resources, Hallowell.

State of Maine. 1949. Sea and Shore Fisheries Laws and Regulations, revised September 1, 1949. Augusta, Maine.

Stira, R.J. and Smith, B.A. 1976. The distribution of early life stages of American shad (*Alosa sapidissima*) in the Hudson River estuary Pages 179-189 i*n* Proceedings of a workshop on American shad. Washington, D.C.: U.S. Fish Wildlife Service/National Marine Fisheries Service.

Stevenson, C.H. 1898. The restricted inland range of shad due to artificial obstructions and its effect upon natural reproduction. Bulletin of the U.S. Fish Commission, Washington, D.C.

Taylor, C.E. 1951. A survey of former shad streams in Maine. U.S. Fish and Wildlife Service, Special Scientific Report: Fisheries 66.

Walker, C.L. 1930. Survey and Report of River and Stream Conditions in the State of Maine. Augusta.

Table 2.1 Maine rivers containing populations of American shad. Historical information from Taylor 1951.

River	Shad Population Size	Commercial Fishery[a]	Period of Rapid Decline	Reasons for Decline	Management[c]	Management Target Numbers[c]
Mousam	Unknown	Incidental	1675	Dams	Passive	
Saco	Scarce	Minor	1860s	Pollution	Active	209,000
Nonesuch	Abundant	None	Late 1950s	Pollution	Passive	
Presumpscot	Abundant	Incidental	Not stated	Pollution	Passive	
Kennebec	Very abundant	Major	late 1830s, early 1920s	Dams and pollution	Active	725,000
Androscoggin	Very abundant	Major	late 1830s, early 1920s	Dams and pollution	Active	235,000
Cathance	Abundant	Major	late 1830s, early 1920s	Pollution	Passive	
Abbagadassett	Abundant	Major	late 1830s, early 1920s	Pollution	Passive	
Eastern	Very abundant	Major	late 1830s, early 1920s	Pollution	Passive	
Sheepscot	Abundant	Minor	Not stated	Dams	Passive	
St. George	Scarce	Incidental	Not stated	Dams	Passive	
Penobscot	Very Abundant	Major	late 1830s	Dams	Passive	
Chandler	Abundant	Incidental	Not stated	Dams	Passive	
Pleasant	Abundant	Incidental	Not stated	Dams	Passive	
Harrington	Abundant[b]	Incidental	Not stated	Dams	Passive	
East Machias	Scarce	Incidental	Not stated	Dams	Passive	
Denny's	Abundant	Incidental	1846	Dams	Passive	
St Croix	Very Abundant	Major	1825	Dams	Passive	

[a]Incidental: shad taken in association with salmon or alewife fisheries. No directed shad fishery.
Minor: directed shad fishery with small numbers harvested.
Major: directed shad fishery with large numbers harvested.
[b]Stocks probably originated from neighboring systems.
[c]From Maine Department of Marine Resources.

Table 2.2 Tag and recapture dates and recapture locations for American shad tagged in the Narraguagus River, Maine.

Date Tagged	Date Recaptured	Location Recaptured	Sex	Weight (Kg)	Total Length (mm)
6/5/1971	7/21/1971	5 miles SW Saint John Harbor, NB	male	1.04	499
6/21/1972	3/19/1973	Stumpy Point Bay, NC		1.50	513
5/16/1969	4/1/1970	Elizabeth City, NC		1.81	597
5/20/1969	5/20/1969	Cherryfield, ME		1.81	541
5/22/1969	4/1/1970	Poquoson, VA		1.70	569
6/5/1970	7/10/1970	Petitcodiac, NB	male	0.91	513
5/17/1968	5/30/1968	Cherryfield, ME		0.79	476
5/10/1968	4/8/1969	Manns Harbor, NC	female		
	1969	Albemarle Sound, NC			
5/13/1968	9/30/1968	Saint John Harbor, NB	female	1.81	626
5/1/1968	5/1/1969	Tunk River, ME			

Table 2.3 Number of American shad larvae raised at the Waldoboro Hatchery and stocked in Maine rivers, 1992-2005.

Year	Saco River	Medomak River	Androscoggin River	Main Stem Kennebac River	Sebasticook River	Kennebec River System[a]	Merry Meeting Bay Complex[b]
1992	0	230000	0	0	0	0	0
1993	0	61000	0	194400	0	194400	194400
1994	0	30460	0	58800	0	58800	58800
1995	0	318290	0	479612	0	479612	479612
1996	0	327495	0	339319	320000	659319	659319
1997	414201	208240	0	1615603	474313	2089916	2089916
1998	408575	269043	0	1381723	744163	2125886	2125886
1999	151774	17626	316967	1944712	839500	2784212	3101179
2000	259090	145900	522000	3374325	500004	3874329	4396329
2001	313560	213	308556	1496454	618879	2115333	2423889
2002	0	11143	295725	1571856	1013852	2585708	2881433
2003	0	0	1269842	5989358	1857184	7846542	9116384
2004	0	0	538613	4548947	382217	4931164	5469777
2005	0	0	96551	1105343	0	1105343	1201894
Total	**1547200**	**1619410**	**3348254**	**24100452**	**6750112**	**30850564**	**34198818**

[a]Sebasticook and main stem Kennebec rivers.
[b]Adroscoggin, Sebasticook, and main stem Kennebec rivers.

Table 2.4 Number of adult American shad transferred to Maine rivers for restoration, 1984-2005.

Year of Transfer	Receiving River	Androscoggin				Kennebec			
	Source River	**Cathance**	**Connecticut**	**Merrimack**	**Native Returns**	**Total**	**Connecticut**	**Narraguagus**	**Sagadahoc Bay**	**Total**
1984		52				**52**				**0**
1985		6				**6**				**0**
1986						**0**				**0**
1987						**0**		183	16	**199**
1988			513			**513**	616			**616**
1989			498			**498**	444	174		**618**
1990			353			**353**	568	36		**604**
1991			357			**357**	639			**639**
1992			566			**566**	994			**994**
1993			579			**579**	880			**880**
1994			706			**706**	879			**879**
1995			1087			**1087**	1518			**1518**
1996			310			**310**	462			**462**
1997			217			**217**	420			**420**
1998						**0**				**0**
1999			270			**270**				**0**
2000				0	88	**88**				**0**
2001				0	26	**26**				**0**
2002				267	11	**278**				**0**
2003				418	8	**426**				**0**
2004				917	12	**929**				**0**
2005				0	0	**0**				**0**
Total		**58**	**5456**	**1602**	**145**	**7261**	**7420**	**393**	**16**	**7829**

Table 2.5 Percent of hatchery fish in samples of age-0 American shad from the Kennebec and Androscoggin rivers and Merrymeeting Bay, Maine.

Year	Kennebec		Androscoggin		Merrymeeting Bay	
	Sample Size	Percent Marked	Sample Size	Percent Marked	Sample Size	Percent Marked
2000	9	22.2	5	20	-	-
2001	199	8.0	-	-	-	-
2002	68	13.2	19	5.3	-	-
2003	42	16.7	8	62.5	100	10
2004	97	7.2	71	25.4	100	6
2005	451	2.4	-	-	150	2

Table 2.6 American shad number-at-age and length data for (a) the Saco River and (b) the Androscoggin River in Maine.

(a)

Sex	Age	Number-at-Age						Mean Total Length (mm)					
		1994	1995	1996	1997	1998	1999	1994	1995	1996	1997	1998	1999
Males	4	1	1	10		1	3	405	407	393		420	388
	5	3	1	7		5	10	476	407	430		452	412
	6	1	2	3	1	1	6	452	499	443	488	510	448
Females	4			7	1	1	2			425	505	420	401
	5	3	4	12	9	14	35	491	494	447	501	496	437
	6	4	5	5	4	9	13	535	538	473	516	513	465
	7	2		1	1	2	2	587		510	572	559	506
All	4	1	1	17	1	2	5						
	5	6	7	19	9	19	45						
	6	5	9	8	5	10	19						
	7	2	0	1	1	2	2						
Mean Age All		**5.6**	**5.5**	**4.8**	**5.4**	**5.4**	**5.3**						

Table 2.6 (cont.) American shad number-at-age and length data for (a) the Saco River and (b) the Androscoggin River in Maine.

(b)

Sex	Age	Number-at-Age					Length														
							2000			2001			2002			2003			2004*		
		2000	2001	2002	2003	2004	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Males	3	1					490														
	4	6		2		3	471	439	494				427	420	433				455	452	460
	5	5	1	2	4	5	482	441	520	462			488	463	512	451	400	461	459	438	475
	6	2	3	1	1		489	483	495	474	430	510	502	502	502	495	495	495			
Females	4	10				1													463	463	463
	5	14		1		2							495	495	495				488	480	495
	6	2	2			1				535	514	555							560	560	560
	7	1	2							534	509	558									
	8																				
	9			1									527	527	527						
Unknown	4			1						502			445	445	445						
	5		1	1	2								505	505	505	470	470	470			
	6		1	1						482			527	527	527						
All	3	1	0	0	0	0															
	4	16	0	3	0	4															
	5	19	2	4	6	7															
	6	4	6	2	1	1															
	7	1	2	0	0	0															
	8																				
	9	0	0	1	0	0															
Mean Age All		**4.7**	**6.0**	**5.3**	**5.1**	**4.8**															

*No shad were captured in 2005

Table 2.7 Reported commercial landings of American shad from Maine state and federal waters.

Year	Pounds	Kg	Year	Pounds	Kg	Year	Pounds	Kg
1887	1,095,720	497,019	1935	13,000	5,897	1971		
1888	839,256	380,687	1936			1972		
1889			1937	9,300	4,218	1973		
1890			1938	11,900	5,398	1974	588	267
1891			1939	9,266	4,203	1975	34,669	15,726
1892			1940	32,164	14,590	1976	14,855	6,738
1893			1941	47,800	21,682	1977	22,100	10,025
1894			1942	160,374	72,746	1978	24,500	11,113
1895			1943	360,923	163,715	1979	18,600	8,437
1896	366,738	166,352	1944	452,549	205,276	1980	27,958	12,682
1897			1945	637,620	289,224	1981	90,600	41,096
1898	1,152,000	522,547	1946	1,106,800	502,044	1982	25,883	11,741
1899			1947	304,395	138,074	1983	38,700	17,554
1900	820,400	372,133	1948	2,552	1,158	1984	33,414	15,157
1901	731,000	331,582	1949	4,908	2,226	1985	16,000	7,258
1902	773,400	350,814	1950	2,427	1,101	1986	23,012	10,438
1903	1,143,600	518,737	1951	76,164	34,548	1987	26,400	11,975
1904	1,259,400	571,264	1952	50,450	22,884	1988	31,881	14,461
1905	1,087,200	493,154	1953	27,294	12,381	1989	46,498	21,091
1906	470,200	213,283	1954	1,981	899	1990	11,804	5,354
1907	873,400	396,174	1955	6,570	2,980	1991	1,991	903
1908	1,881,800	853,584	1956	2,011	912	1992	1,450	658
1909	980,350	444,687	1957	7,613	3,453	1993		
1910	847,200	384,290	1958	10,098	4,580	1994	1,051	477
1911	1,386,400	628,871	1959	1,635	742	1995		
1912	3,296,000	1,495,066	1960	311	141	1996		
1913	2,088,400	947,298	1961	154	70	1997		
1914	2,086,200	946,300	1962	65	29	1998		
1915			1963			1999	169	77
1928	110,149	49,964	1964			2000	291	132
1929	36,123	16,385	1965			2001	476	216
1930	88,635	40,205	1966	2,072	940	2002	18	8
1931	157,763	71,561	1967	125	57	2003	54	24
1932	107,891	48,939	1968	2,311	1,048	2004	55	25
1933	178,901	81,149	1969			2005	53	24
1934			1970					

Table 2.8 Reported commercial landings (kg) of American shad in Maine by gear.

Year	Gill Net	Trawl	Other	Total	Year	Gill Net	Trawl	Other	Total
1950	1043.28	0	45.36	**1088.64**	1978	11022.48	90.72	0	**11113.2**
1951	21500.64	45.36	13018.32	**34564.3**	1979	8210.16	136.08	90.72	**8436.96**
1952	22770.72	0	136.08	**22906.8**	1980	12474	226.8	0	**12700.8**
1953	12247.2	45.36	0	**12292.6**	1981	40325.04	771.12	0	**41096.2**
1954	816.48	90.72	0	**907.2**	1982	11385.36	181.44	136.08	**11702.9**
1955	2948.4	45.36	0	**2993.76**	1983	16556.4	997.92	0	**17554.3**
1956	861.84	45.36	0	**907.2**	1984	14061.6	997.92	45.36	**15104.9**
1957	3084.48	317.52	45.36	**3447.36**	1985	6078.24	1179.36	0	**7257.6**
1958	4536	45.36	0	**4581.36**	1986	9752.4	725.76	0	**10478.2**
1959	725.76	0	0	**725.76**	1987	9570.96	2449.44	0	**12020.4**
1960	136.08	0	0	**136.08**	1988	13154.4	1179.36	0	**14333.8**
1961	0	0	0	**0**	1989	20457.36	680.4	0	**21137.8**
1962	45.36	0	0	**45.36**	1990	5010.4656	343.8288	0	**5354.29**
1963	0	0	0	**0**	1991	783.3672	119.7504	0	**903.118**
1964	0	0	0	**0**	1992	492.156	164.2032	0	**656.359**
1965	0	0	0	**0**	1993	311.6232	52.164	0	**363.787**
1966	0	952.56	0	**952.56**	1994	440.8992	35.8344	0	**476.734**
1967	0	45.36	0	**45.36**	1995	165.564	7.7112	0	**173.275**
1968	0	0	1043.28	**1043.28**	1996	442.7136	42.6384	0	**485.352**
1969	0	0	0	**0**	1997	49.896	38.1024	0	**87.9984**
1970	0	0	0	**0**	1998	43.5456	148.7808	0	**192.326**
1971	0	0	0	**0**	1999	59.8752	14.9688	1.8144	**76.6584**
1972	0	0	0	**0**	2000	97.0704	34.9272	0	**131.998**
1973	0	0	0	**0**	2001	192.78	23.1336	0	**215.914**
1974	181.44	45.36	0	**226.8**	2002	2.7216	5.4432	0	**8.1648**
1975	15513.12	90.72	90.72	**15694.6**	2003	0	1.8144	0	**1.8144**
1976	6486.48	181.44	0	**6667.92**	2004	3.6288	0	0	**3.6288**
1977	9752.4	272.16	0	**10024.6**	2005				

Table 2.9 Estimated recreational catch of American shad in Maine water based on the MRFSS.

Year	Number Caught	CV	Harvest
1998	0	0	0
1999	1,065	0.74	0
2000	1,078	0.7	0
2001	1,661	0.59	0
2002	438	0.99	0
2003	438	0.99	0
2004	2,191	0.77	0
2005	1,244	0.99	0

Table 2.10 Characteristics of American shad passage up the east and west channel fishways at the lowest dams on the Saco River, Maine.

Year	Start Date	End Date	Run Length (days)	Date of Modal Passage	Number of Days Shad Present	Modal Number	Total Passage
East Channel							
1993	4-Jun	5-Aug	62	19-Jun	30	159	876
1994	6-Jun	15-Jul	39	12-Jun	31	66	395
1995	15-May	30-Jul	76	17-Jun	34	55	571
1996	22-May	20-Aug	90	19-Jun	29	95	810
1997	3-Jun	17-Aug	75	23-Jun	30	166	1069
1998	26-May	20-Jul	55	2-Jun	14	295	1370
1999	21-May	30-Jul	70	4-Jun	37	440	4534
2000	1-Jun	25-Aug	85	9-Jun	41	103	1052
2001	12-May	29-Jul	78	28-May	40	277	1976
2002	24-May	22-Jul	59	3-Jul	37	139	807
2003	17-Jun	3-Jul	16	24-Jun	14	307	1099
West Channel							
1993	26-Jun	6-Jul	10		6	1	6
1994	24-Jun	8-Jul	14	8-Jul	3	2	4
1995	28-May	21-Jun	24	16-Jun	6	3	9
1996	7-Jun	3-Jul	26	12-Jun	9	15	27
1997	7-Jun	31-Jul	54	9-Jun	14	7	35
1998	24-May	9-Jun	16		2	2	4
1999	16-May	25-Jun	40	23-May	23	130	460
2000	1-Jun	5-Jul	34	10-Jun	21	48	274
2001	10-May	18-Jul	69	30-May	33	86	594
2002	28-May	3-Jul	36	1-Jun	17	107	207
2003	31-May	21-Jun	21	11-Jun	15	30	128

Table 2.11 Passage of fish over the lower most dams on the Saco and Androscoggin rivers in Maine, 1983-2005.

Year	Saco	Androscoggin
1983	0	2
1984	0	1
1985	0	0
1986	0	0
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	0
1992	0	0
1993	877	0
1994	399	1
1995	587	3
1996	837	2
1997	1,104	2
1998	1,374	5
1999	4,994	88
2000	1,323	88
2001	2,570	26
2002	1,014	11
2003	1,227	7
2004	1,668	12
2005	744	0

Table 2.12 Estimates of instantaneous mortality (Z) for American shad of the Saco River, Maine. Sexes combined and data summed between succeeding pairs of years.

1994+1995	1995+1996	1996+1997	1997+1998	1998+1999
0.94	1.63	1.31	1.12	1.37

Table 2.13 Video observations of American shad in and near the Brunswick Dam fishway on the Androscoggin River, Maine.

Year	Number of Days Taped	Total Hours Observed	Observation Dates	Number of Observations	Observations by Camera Location			Survey Index[a]	Obs/Hr
					River	Pool # 6	Pool 23 Exit		
1999	58	832	6/6 - 7/28	4,377	4,377			4,377	5
2000	42	1,548	6/12 - 7/24	52,836	41,497	10,937	402	52,836	34
2001	37	2,376	6/1 - 7/7	126,033	86,232	8,325	237	94,794	53
2002	61	4,392	6/1 - 7/31	318,250	297,570	1,850	100	299,520	68
2003	52	3,672	6/18 - 8/8	under review					

[a]Sum of river, pool #6, and pool 23 exit.

Table 2.14 Mean catch-per-unit-effort of age-0 American shad from the Merrymeeting Bay complex in Maine. The complex includes Merrymeeting Bay and the lower Kennebec, Androscoggin, Eastern, Cathance, and Abbagadasett rivers.

Year	Sample Size	Total Catch	Arithmetic		Geometric		
			Mean	SE	Mean	LCI	UCI
1979	45	10	0.22	0.13	0.10	-0.01	0.23
1980	57	9	0.16				
1981	58	29	0.50				
1982	59	9	0.15				
1983	53	42	0.79				
1984	45	32	0.71	0.33	0.29	0.08	0.54
1985	42	77	1.83	0.68	0.68	0.30	1.17
1986	62	32	0.52	0.21	0.22	0.07	0.39
1987	60	136	2.27	0.87	0.63	0.29	1.06
1988	100	1377	13.77	8.88	0.52	0.22	0.89
1989	92	72	0.78	0.32	0.23	0.08	0.40
1990	98	211	2.15	0.69	0.51	0.26	0.81
1991	88	64	0.73	0.28	0.25	0.10	0.42
1992	80	62	0.78	0.31	0.26	0.10	0.44
1993	106	80	0.75	0.63	0.10	0.00	0.21
1994	114	24	0.21	0.11	0.09	0.02	0.16
1995	117	55	0.47	0.20	0.16	0.06	0.27
1996	93	111	1.19	0.90	0.21	0.07	0.36
1997	112	37	0.33	0.19	0.09	0.01	0.18
1998	112	40	0.36	0.28	0.06	-0.01	0.14
1999	114	1059	9.29	4.33	0.51	0.14	0.99
2000	120	398	3.32	2.16	0.29	0.11	0.49
2001	138	234	1.70	0.67	0.20	0.08	0.33
2002	137	316	2.31	1.18	0.45	0.26	0.67
2003	120	680	5.67	7.44	0.95	0.54	1.47
2004	111	1356	12.22	6.90	1.02	0.58	1.58
2005	120	879	7.33	2.69	1.07	0.66	1.59

Table 2.15 Mean catch-per-unit-effort of age-0 American shad from the Kennebec River above the former site of Edwards Dam.

Year	Sample Size	Total Catch	Arithmetic		Geometric		
			Mean	SD	Mean	LCI	UCI
2000	76	437	5.75	4.68	0.32	0.08	0.62
2001	63	1379	21.89	10.10	1.01	0.35	1.98
2002	64	1974	30.84	26.28	0.64	0.18	1.28
2003	46	702	15.26	8.14	0.73	0.12	1.66
2004	42	648	15.43	8.45	1.43	0.51	2.92
2005	41	3701	90.27	53.30	1.06	0.13	2.75

Table 2.16 Arithmetic mean and variation of number of American shad taken per trawl in the near-shore ocean waters of Maine.

Year	Statistic	Region 1	2	3	4	5	Total
		September - November					
2000	N	14	16	14	17	17	**78**
	Mean	0.36	2.25	0.14	0.12	0.00	**0.58**
	SD	0.84	3.53	0.36	0.33	0.00	**1.83**
2001	N	18	18	15	18	6	**75**
	Mean	0.78	0.72	0.00	0.00	0.00	**0.36**
	SD	1.80	2.59	0.00	0.00	0.00	**1.56**
2002	N	15	17	17	14	18	**81**
	Mean	0.13	4.82	0.35	0.00	0.00	**1.11**
	SD	0.35	9.19	0.79	0.00	0.00	**4.56**
2003	N	16	15	12	18	17	**78**
	Mean	3.94	18.87	0.33	0.06	0.06	**4.51**
	SD	12.15	63.24	0.65	0.24	0.24	**28.42**
2004	N	18	20	16	17	16	**87**
	Mean	2.28	2.17	0.19	0.30	0.06	**1.07**
	SD	3.97	6.08	0.75	0.60	0.25	**3.53**
		April - June					
2001	N	21	23	22	22	23	**111**
	Mean	0.24	1.09	0.55	1.14	2.13	**1.05**
	SD	0.54	3.36	1.34	3.20	4.16	**2.91**
2002	N	19	20	18	18	19	**94**
	Mean	7.32	1.85	0.39	2.61	2.00	**2.85**
	SD	12.73	3.73	0.70	5.61	4.53	**7.05**
2003	N	20	21	20	20	20	**101**
	Mean	1.85	1.00	2.30	1.35	1.10	**1.51**
	SD	3.70	2.21	3.25	2.70	1.59	**2.77**
2004	N	22	23	19	20	19	**103**
	Mean	1.03	0.45	0.43	0.10	0.47	**0.51**
	SD	1.78	0.94	0.85	0.31	1.22	**1.16**
2005	N	20	22	20	21	21	**104**
	Mean	1.82	6.00	2.40	0.86	1.53	**2.56**
	SD	2.38	16.88	2.04	1.19	2.50	**8.05**

Table 2.17 Geometric mean and variation of number of American shad taken per trawl in the near-shore ocean waters of Maine.

Year	Statistic	Region 1	2	3	4	5	Total
September - November							
2000	N	14	16	14	17	17	78
	Mean	0.22	1.06	0.10	0.08	0.00	0.25
	SD	0.53	1.55	0.29	0.26	0.00	0.72
2001	N	18	18	15	18	6	75
	Mean	0.37	0.24	0.00	0.00	0.00	0.14
	SD	0.89	0.84	0.00	0.00	0.00	0.56
2002	N	15	17	17	14	18	81
	Mean	0.10	1.82	0.23	0.00	0.00	0.32
	SD	0.28	2.11	0.50	0.00	0.00	0.97
2003	N	16	15	12	18	17	78
	Mean	0.90	1.77	0.23	0.04	0.04	0.46
	SD	1.89	3.97	0.47	0.18	0.18	1.54
2004	N	18	20	16	17	16	87
	Mean	1.19	0.72	0.09	0.21	0.04	0.42
	SD	1.31	1.42	0.41	0.44	0.19	0.95
April - June							
2001	N	21	23	22	22	23	111
	Mean	0.16	0.40	0.30	0.49	0.81	0.42
	SD	0.39	1.01	0.66	0.98	1.61	0.97
2002	N	19	20	18	18	19	94
	Mean	2.12	0.80	0.27	0.94	0.92	0.93
	SD	2.97	1.37	0.50	1.66	1.26	1.63
2003	N	20	21	20	20	20	101
	Mean	0.79	0.45	1.11	0.68	0.71	0.73
	SD	1.37	1.01	1.57	1.07	0.86	1.17
2004	N	22	23	19	20	19	103
	Mean	0.59	0.29	0.28	0.07	0.25	0.29
	SD	0.92	0.54	0.56	0.24	0.64	0.62
2005	N	20	22	20	21	21	104
	Mean	1.05	1.68	1.77	0.60	0.81	1.13
	SD	1.24	2.24	1.01	0.69	1.16	1.32

Table 2.18 Fork length (cm) of American shad collected by bottom trawl in near-shore ocean waters of Maine.

Year	Season	Min	Max	Mean	SD
2000	Fall	9	29	18.0	5.9
2001	Spring	12	26	15.5	2.4
	Fall	19	28	22.7	2.4
2002	Spring	12	28	17.0	2.6
	Fall	8	22	13.5	3.2
2003	Spring	10	19	14.9	1.6
	Fall	10	31	19.4	5.0
2004	Spring	11	24	14.7	2.4

Figure 2.1 Map of Maine rivers containing populations of American shad.

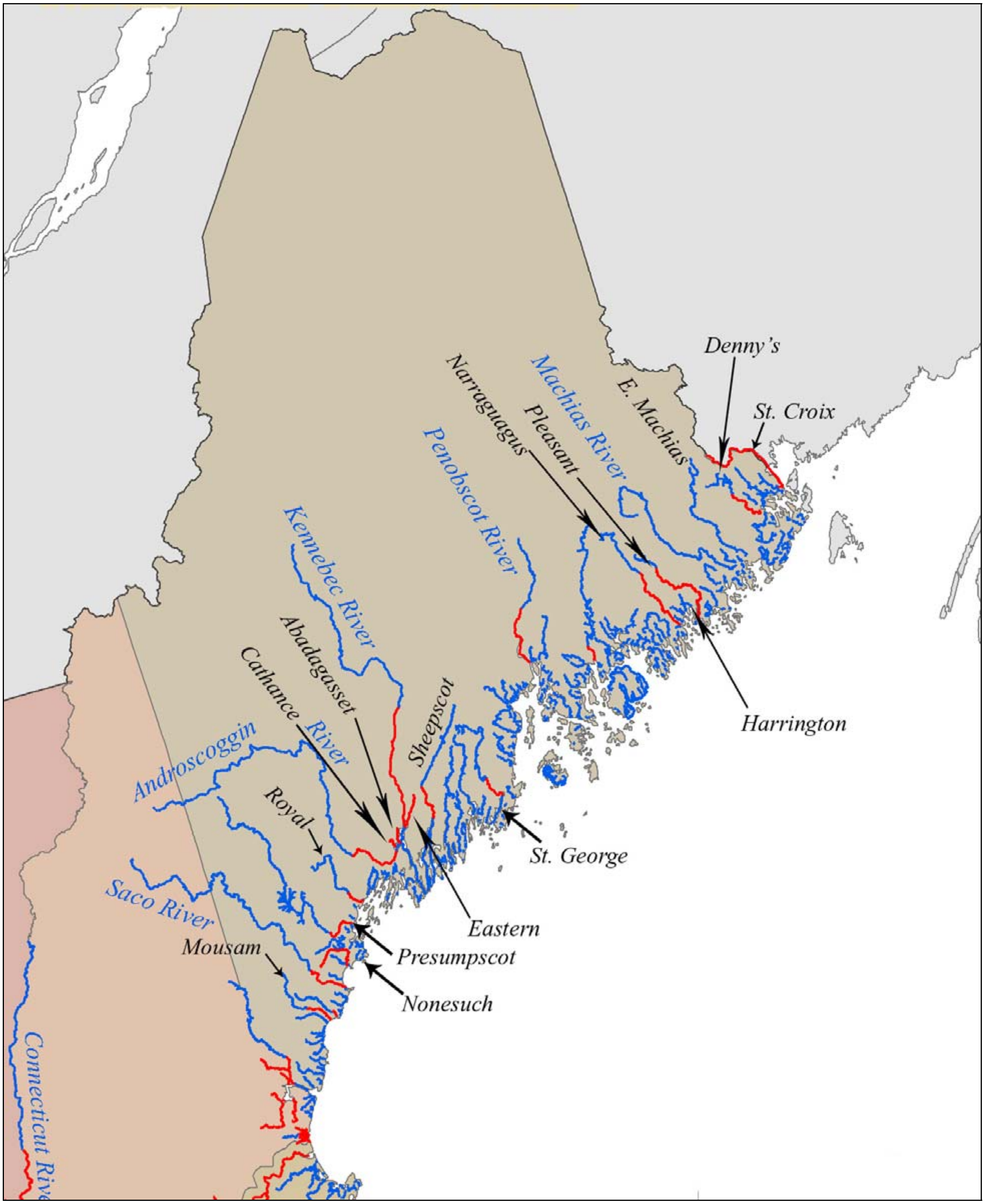


Figure 2.2 Juvenile alosine surveys sites in the Kennebec and Androscoggin estuary complex.

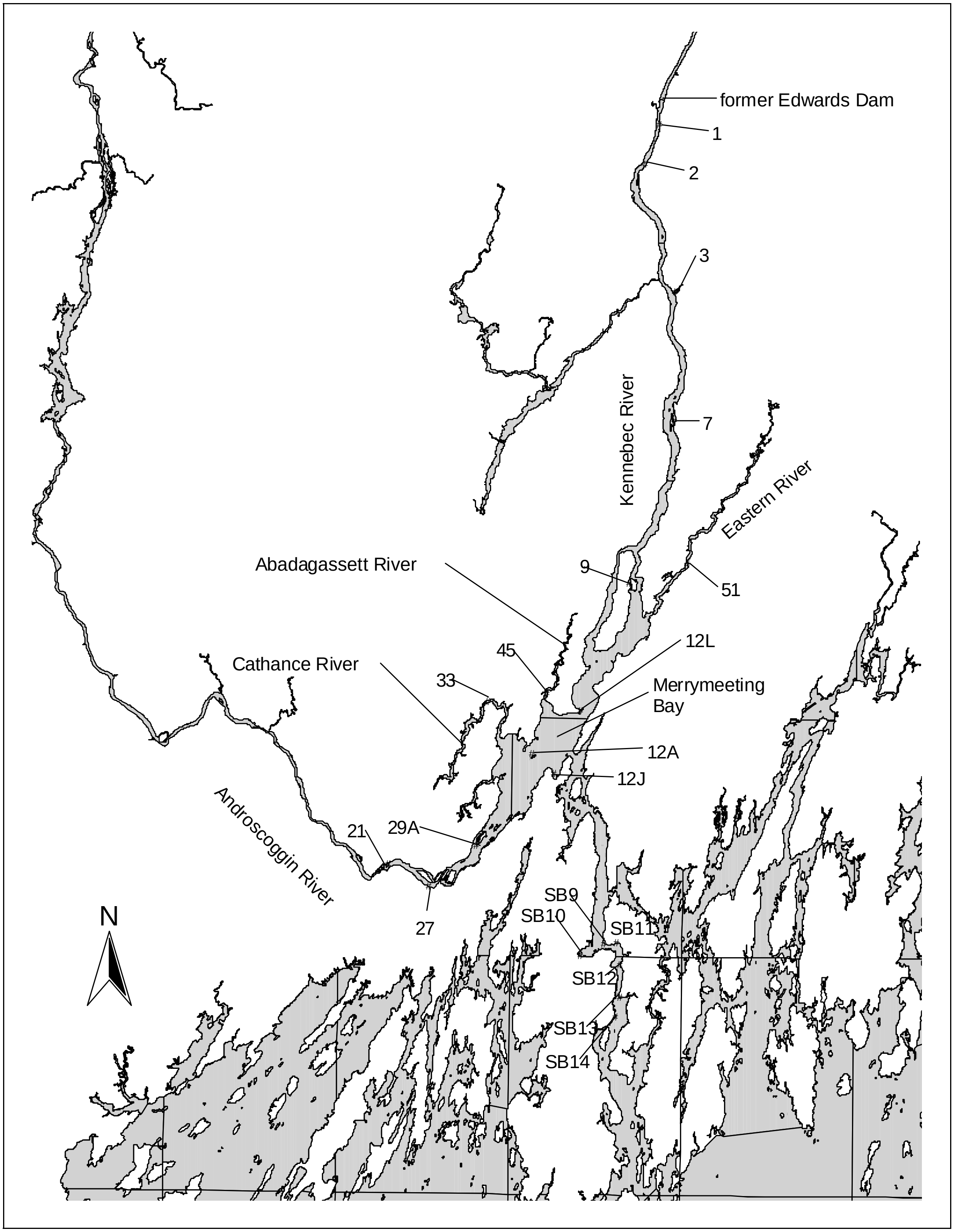


Figure 2.3 Beach seine sites in the Kennebec River above the former Edwards Dam.

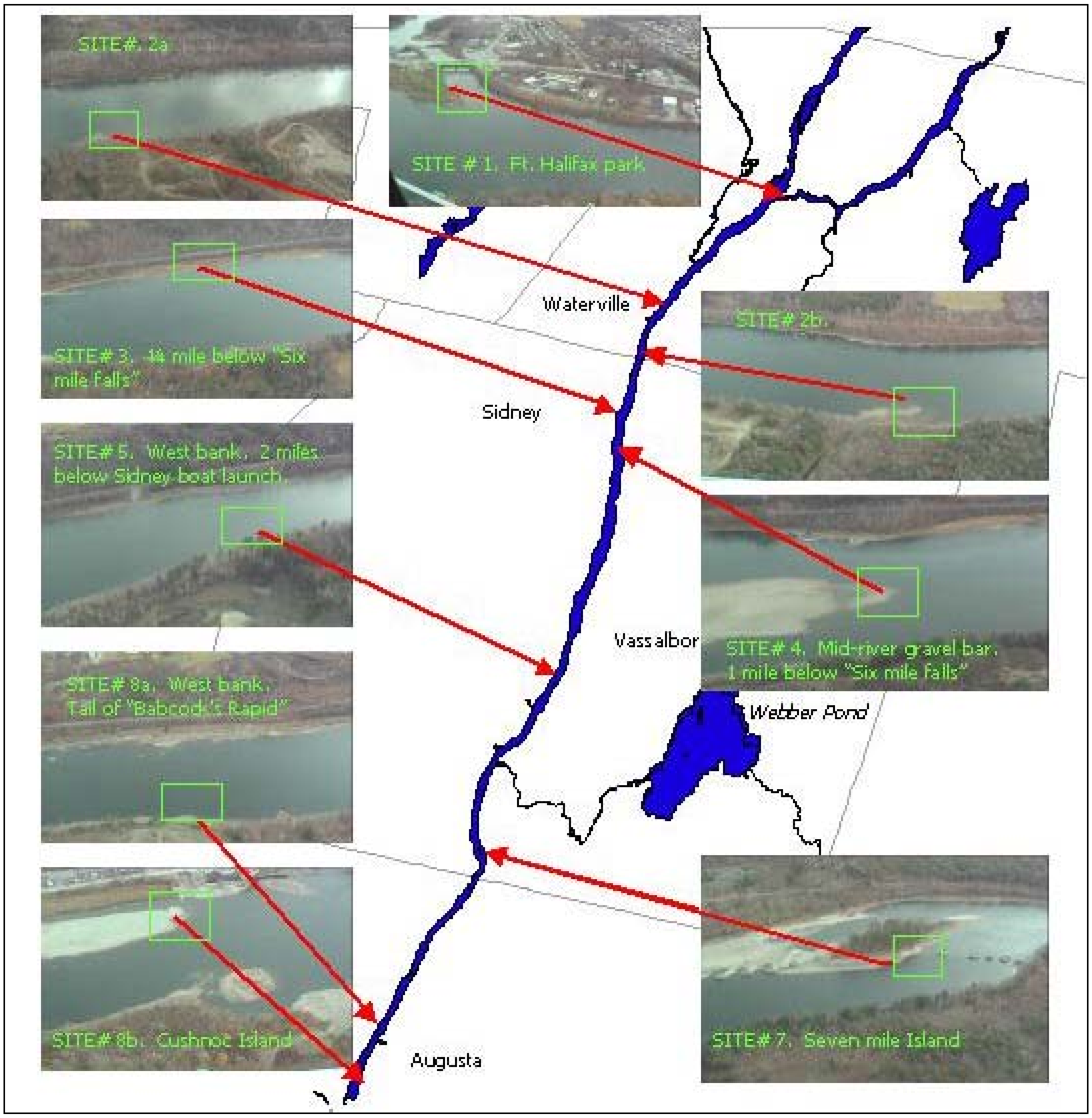


Figure 2.4 Ocean trawl sampling regions on the coast of Maine and New Hampshire.

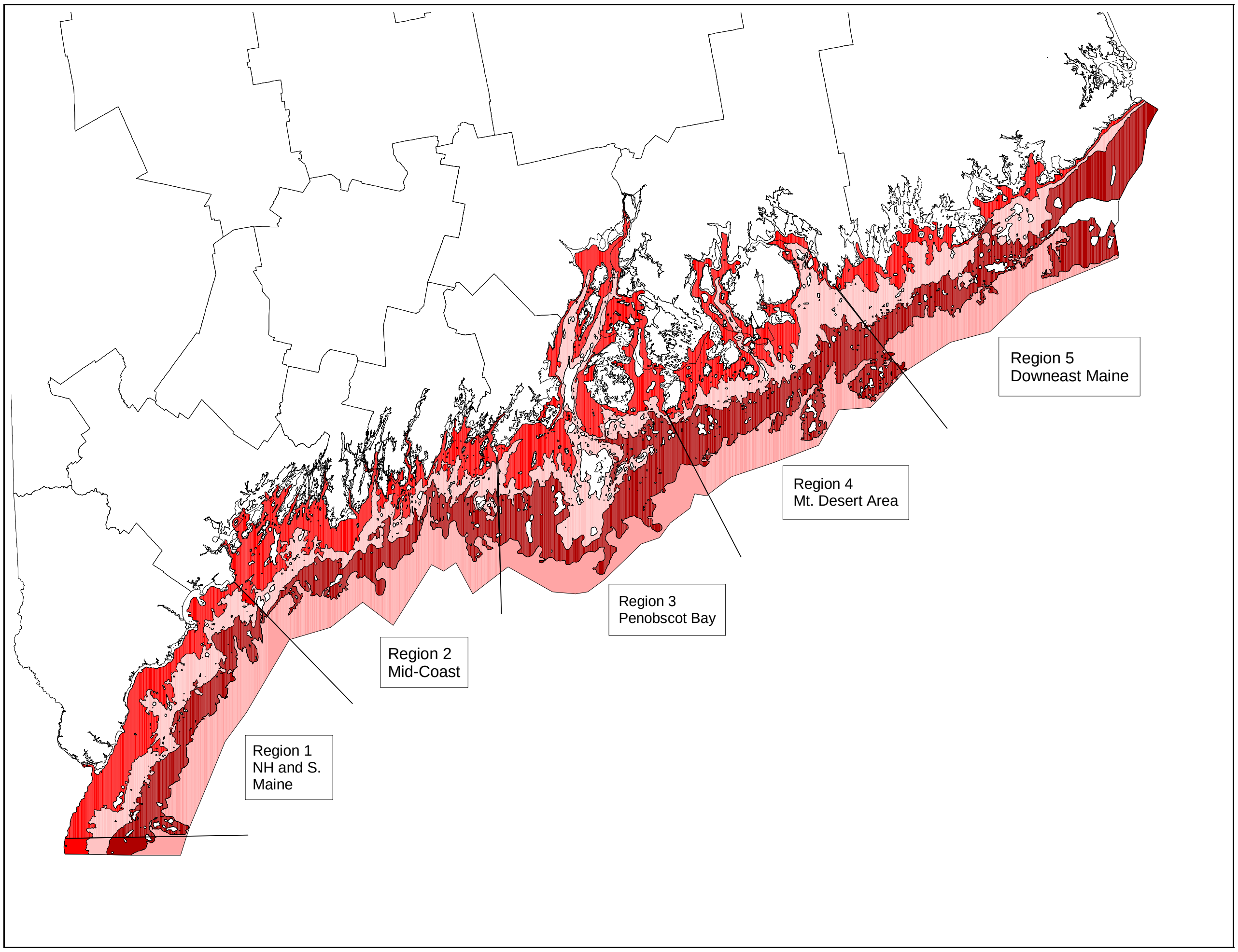


Figure 2.5 Commercial American shad landings for the State of Maine, 1887-2005.

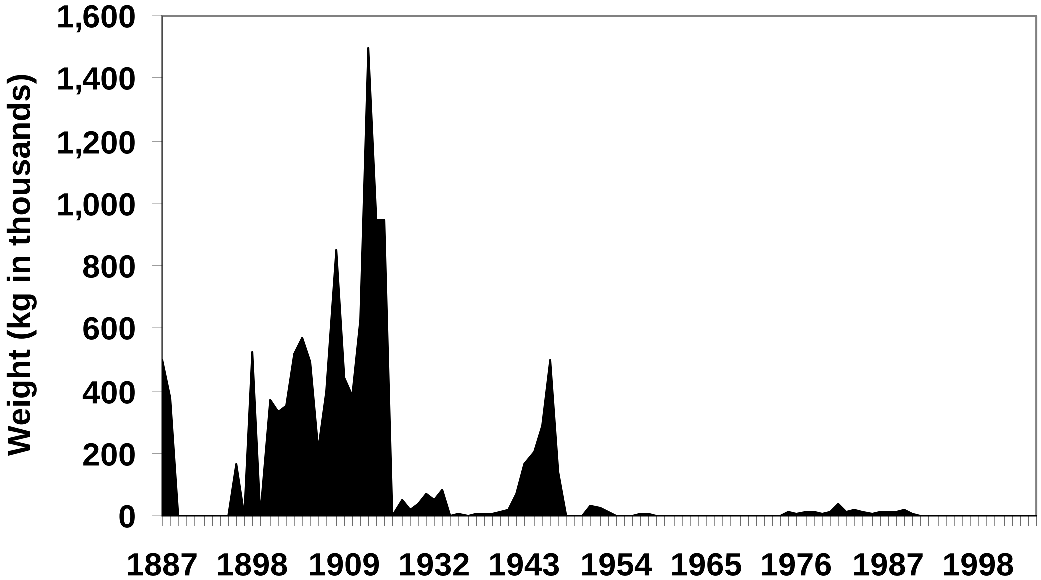
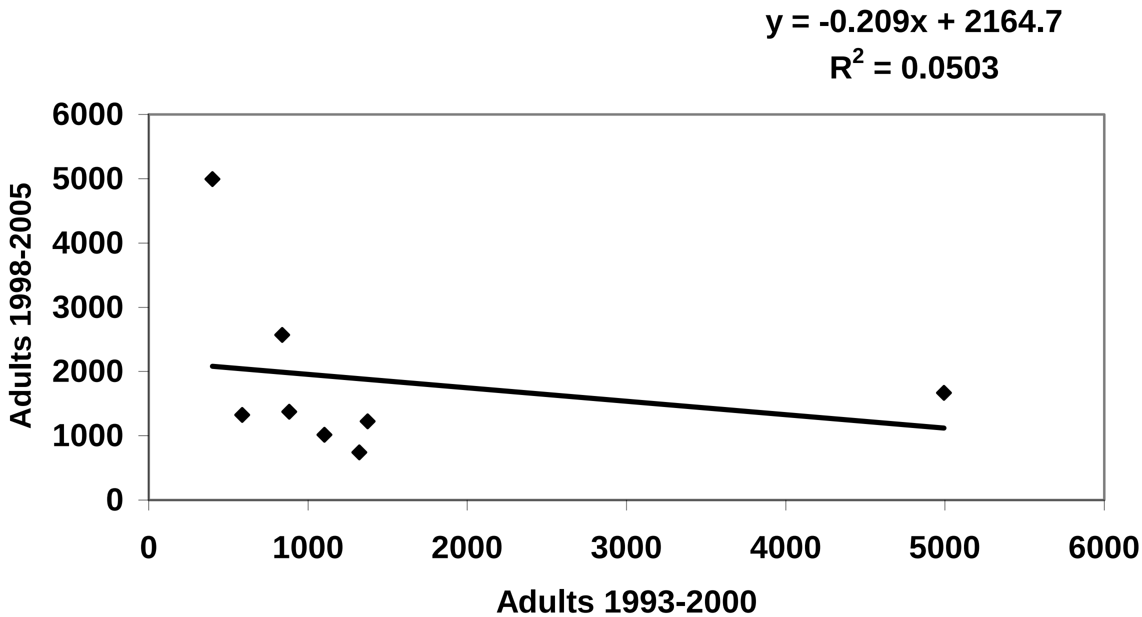


Figure 2.6 Relationship between annual fish passage in 1993-1998 and passage (a) five and (b) six years later at the lowermost dam on the Saco River.

(a)



(b)

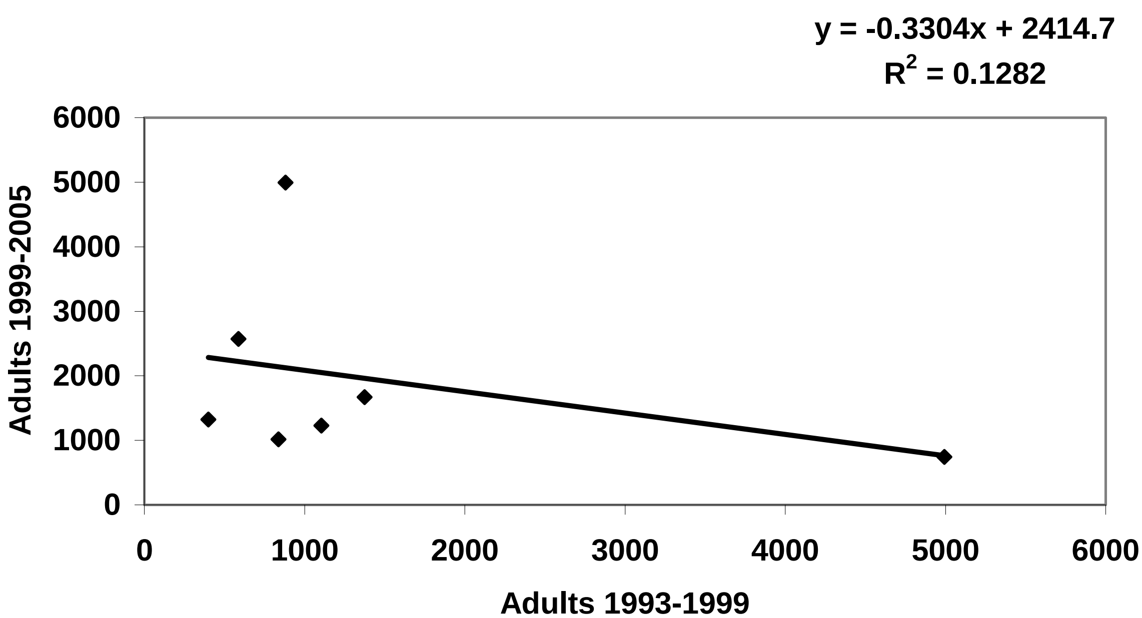


Figure 2.7 Geometric mean catch-per-seine-haul of age-0 American shad at sites in Merrymeeting Bay and the lower Kennebec, Androscoggin, Eastern, Cathance, and Abbagadasett Rivers.

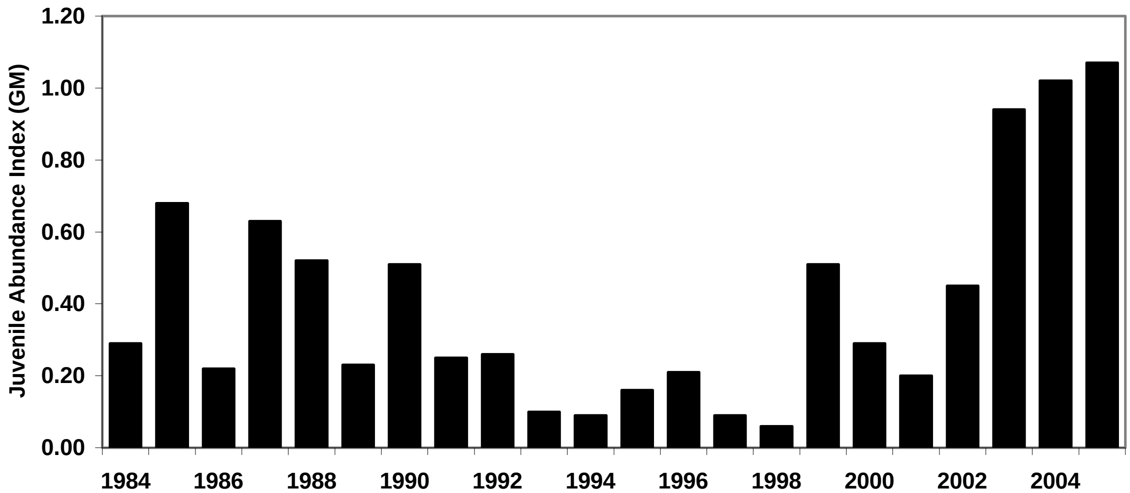


Figure 2.8 Geometric mean catch-per-seine-haul of age-0 American shad sites in the upper Kennebec River, Maine.

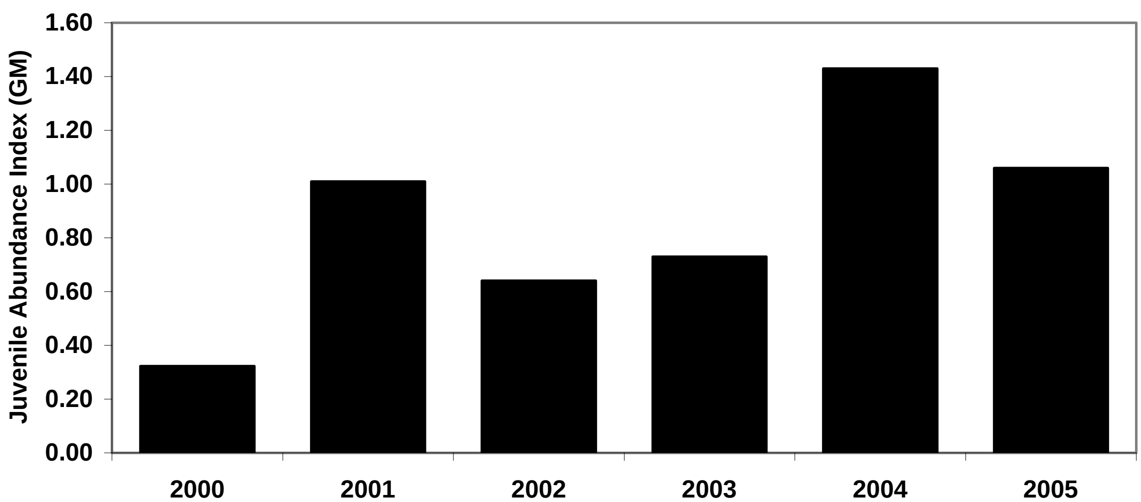


Figure 2.9 Catch-per-trawl of juvenile American shad.

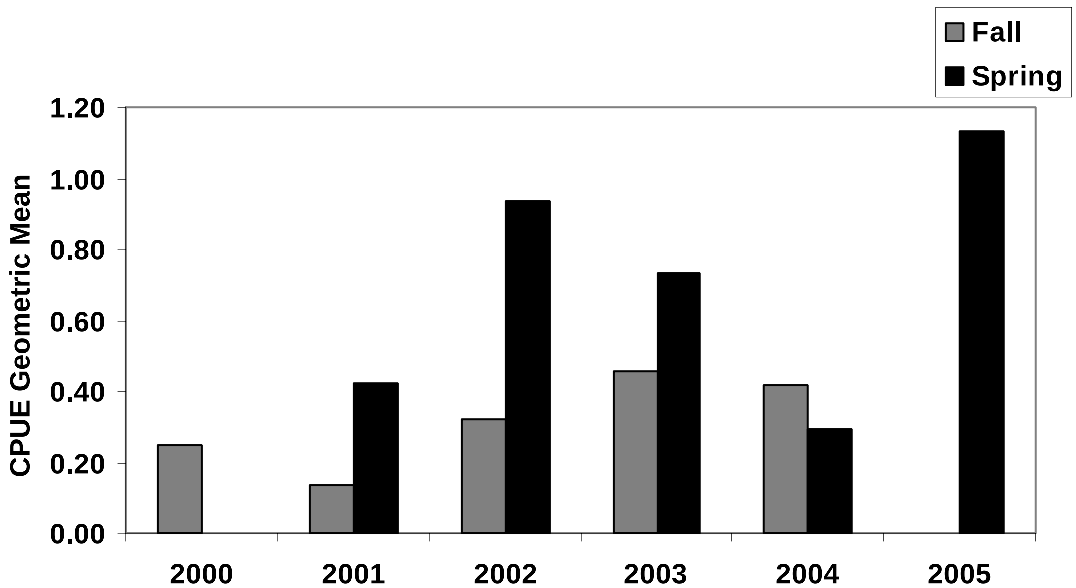
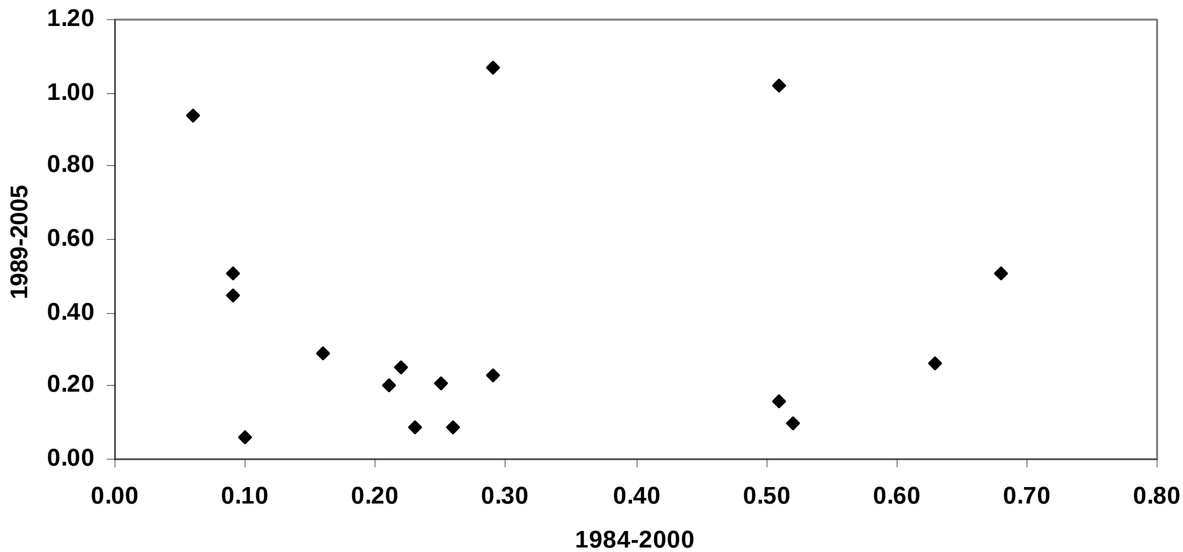


Figure 2.10 Relationship between relative abundance of age-0 American shad in the Merrymeeting Bay complex and relative abundance of age-0 American shad lagged (a) five and (b) six years.

(a)



(b)

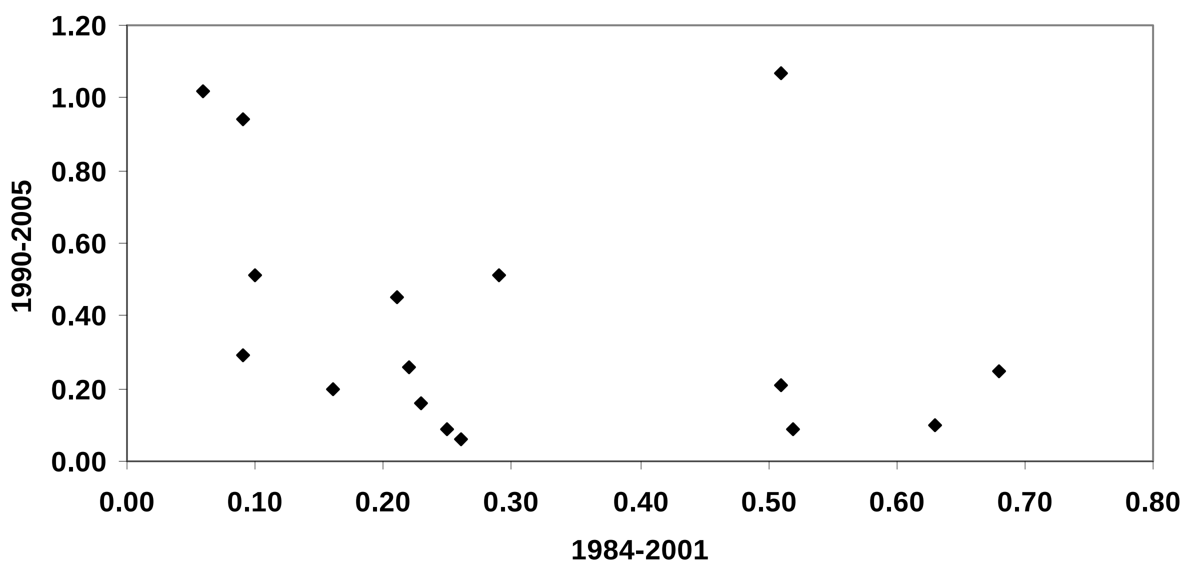


Figure 2.11 Relationship between number of American shad larvae stocked to rivers of the Merrymeeting Bay complex and relative abundance of age-0 American shad from the same waters in the same year.

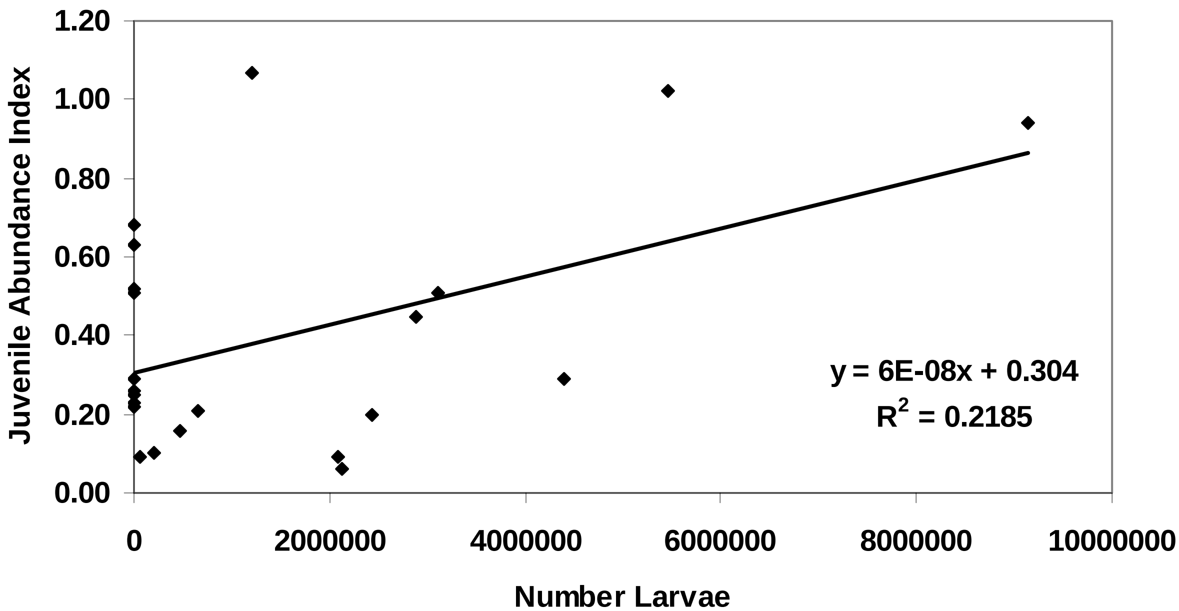


Figure 2.12 Relationship between number of American shad adults stocked to rivers of the Merrymeeting Bay complex and relative abundance of age-0 American shad from the same waters in the same year.

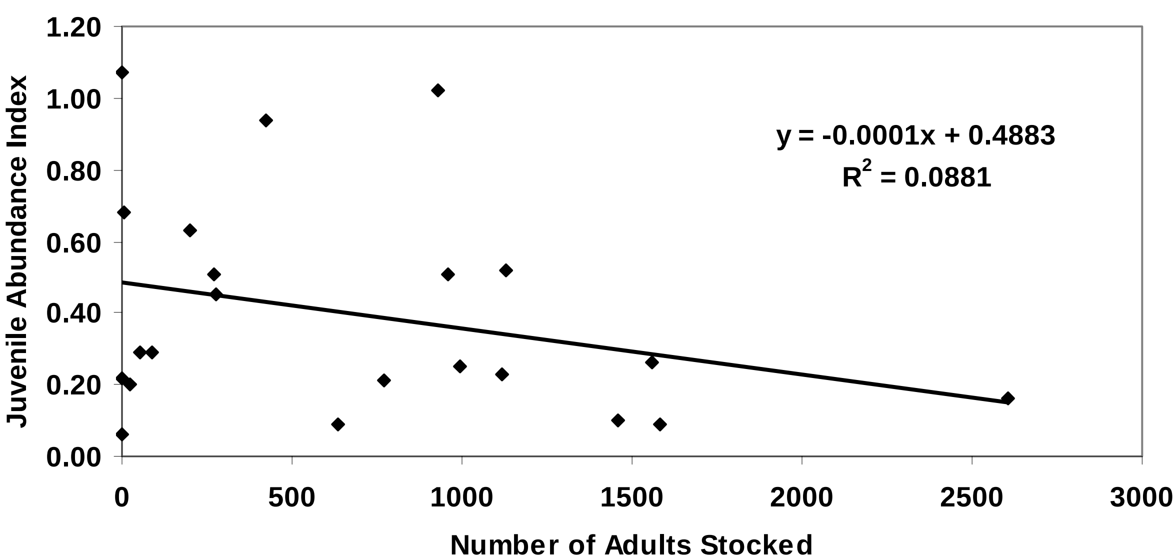
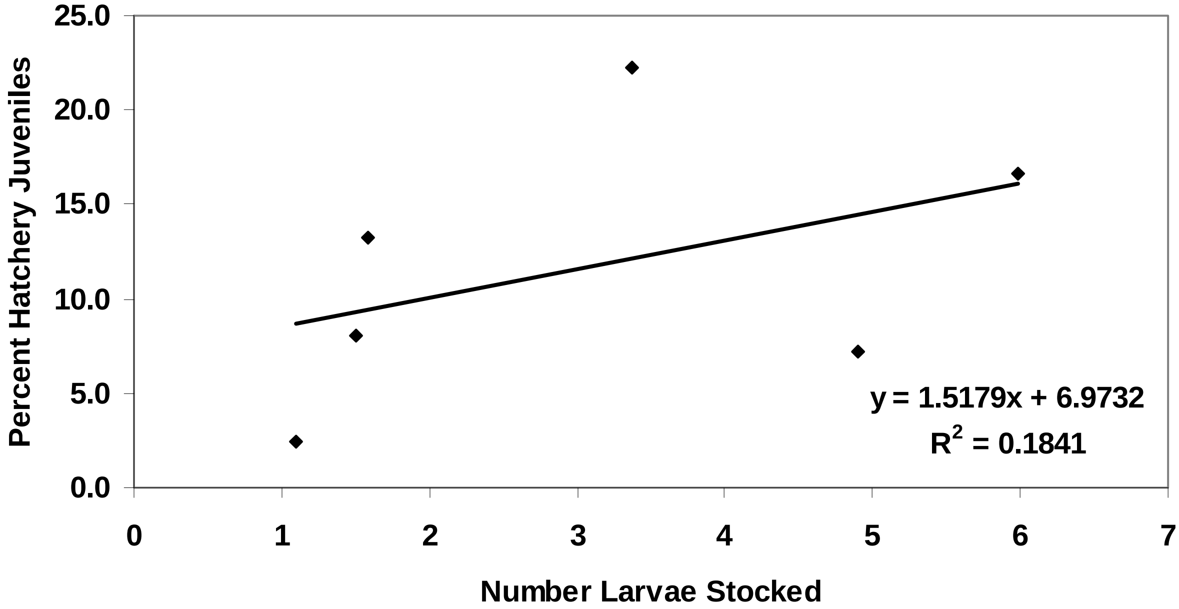


Figure 2.13 Relationship between number of shad larvae stocked and percent hatchery juveniles in the Kennebec River, Maine.



Section 3
Status of American Shad Stocks in New Hampshire Rivers

Contributors:

Cheri Patterson
New Hampshire Fish and Game Department
225 Main Street, Durham, New Hampshire 03824

Andrew Kahnle and Kathy Hattala
Hudson River Fisheries Unit, New York State Department of Environmental Conservation
21 S. Putt Corners Road, New Paltz, New York 12561

3.1 INTRODUCTION

New Hampshire's coastal rivers once supported abundant runs of anadromous fish including American shad, river herring (alewife and blueback herring), and Atlantic salmon (Jackson 1944). These and other 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 in most New Hampshire coastal rivers. Barriers eliminated American shad and Atlantic salmon populations, but river herring only declined in numbers because they utilized the small area of freshwater at the base of dams during spring runoffs for spawning.

Restoration of diadromous fish populations in New Hampshire began with construction of fishways in the late 1950s and continued through the early 1970s by the New Hampshire Fish and Game Department (NHFGD) in the Cocheco, Exeter, Oyster, Lamprey, and Winnicut rivers in the Great Bay estuary (Figure 3.1), and the Taylor River in the Hampton-Seabrook estuary. These fishways re-opened acres of freshwater spawning and nursery habitat for American shad, river herring, and other diadromous fish.

3.2 MANAGEMENT UNIT DEFINITION

The American shad stocks in the Exeter, Lamprey, and Cocheco rivers were evaluated in this assessment and are considered to be an individual management unit.

3.2.1 Exeter River

The Exeter River drains an area of 326 square km in southern New Hampshire (Figure 3.2). The River flows east and north from the Town of Chester to the Town of Exeter. It empties into Great Bay northeast of Exeter. The head-of-tide occurs at the Town of Exeter (www.des.state.nh.us) and the saltwater portion of the river is called the Squamscott River.

The two lowermost dams on the main stem Exeter River (Figure 3.3) are the Great Dam in Exeter at river kilometer (rkm) 13.5 and the Pickpocket Dam at rkm 26.9 (each 4.6 m high). The next barrier above Pickpocket Dam is a set of natural falls at rkm 38.1. NHFGD constructed upstream fish passage facilities (Denil fishways) on both dams from 1969 to 1971 for anadromous fish, funded in part by the U.S. Fish and Wildlife Service (USFWS). Fish ladder improvements occurred in 1994 and 1999 including placing a fish trap at the upriver end of the fish ladder. There are no downstream fish passage facilities on either dam so emigrating adults and juveniles pass over the spillway when river flows allow. There are approximately one hundred meters of fresh water that occurs between head-of-tide and the Great Dam caused by an elevated ledge that prevents saltwater incursion. American shad have been observed below the Great Dam and have the ability to spawn in this area. Most spawning and rearing habitat occurs above the dam. Periodic water quality monitoring has recorded declines in dissolved oxygen (DO) between the two dams for some years since 1995 (Smith *et al*. 2005; Langan 1995). Restoration is focused on this river as upstream fish passage is available and provides access to the greatest amount of habitat within New Hampshire coastal rivers.

3.2.2 Lamprey River

The Lamprey River flows 97 km through southern New Hampshire to the Town of Newmarket where it becomes tidal and enters the Great Bay estuary just north of the mouth of the Exeter River. The Lamprey River watershed is shown in Figure 3.4. The Macallen Dam, located at rkm 3.8 in Newmarket, is the lowermost head-of-tide dam (8.2 m high) on the Lamprey River (Figure 3.5). Fish passage on this river is a Denil fish ladder constructed from 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. The Wiswall Dam is located 4.8 km above the Macallen Dam and currently does not have fish passage. It has a 3.4 m spillway and is an effective barrier to upstream movement of American shad. A fish passage system is being designed and construction is anticipated to occur within the next five years. There are no downstream passage facilities at the Macallen Dam and emigrating juveniles and adults must pass over the spillway. Fish kills have not been observed below the first dam suggesting that adults emigrate with limited mortality.

3.2.3 Cocheco River

The Cocheco River flows 48 km southeast through southern New Hampshire to Dover where it joins the Salmon Falls River to form the Piscataqua River. The Cocheco River watershed is shown in Figure 3.4. The lowermost dam (4.6m high, built on a natural ledge for a total height of 8-10 m) on the Cocheco River is within the City of Dover, at rkm 6.1 (Figure 3.6). A Denil fish ladder was constructed at the dam in 1969 to 1970 for anadromous fish by NHFGD, funded in part by the USFWS. The next barrier is a set of natural falls located at rkm 10.6. Brackish water extends upriver to the lowermost dam on the Cocheco River.

The City of Dover currently owns the dam and leases the attached hydroelectric facility to Southern New Hampshire Hydroelectric Development Corporation (SNHHDC). The Federal Energy Regulatory Commission (FERC) requires SNHHDC to provide downstream fish passage and utilize a grating system to prevent small fish from passing through the turbines. The downstream passage system is a PVC tube emptying in a plunge pool below the dam. This system successfully passes emigrating diadromous species when operating efficiently. Emigrating juvenile and adult American shad must either pass over the dam if flows allow, travel through the downstream migration tube, or move through the turbines at the hydroelectric facility if they can pass through the grating system.

3.3 REGULATORY HISTORY

The regulatory history of American shad in New Hampshire state waters (inland and 0-3 miles) started in 1968 with the prohibition of the take of saltwater shad or "true shad." If shad were accidentally taken, they were to be immediately released. In 1976, the rule changed to allow a two fish limit (no size limit) of American or sea-run shad to be taken via angling only by a licensed angler. The shad could only be taken from salt and brackish water upstream or north of the Memorial Bridge in Portsmouth. If shad were taken by any other method, they were to be immediately released. In 1998, the language was amended to allow the take of two shad (no size limit) from New Hampshire waters, instead of limiting the take from waters north of the Memorial Bridge in Portsmouth.

Shad taken using commercial gear in the Exclusive Economic Zone (EEZ, ocean waters 3-200 miles) outside of the State's territorial waters (0-3 miles) can be landed in the state. In 2005, an addition to the regulation that allowed shad to be landed from the EEZ stated that no person shall transport, possess, or land shad from outside the jurisdiction of the state that exceeds more than five percent of the total landing by weight per commercial trip.

3.4 ASSESSMENT HISTORY

New Hampshire American shad stocks have not been included in past American shad stock assessments. American shad restoration is still in its early stages in New Hampshire.

3.5 STOCK-SPECIFIC LIFE HISTORY

The oldest American shad in New Hampshire, observed during the period 1999 to 2005, was age-10 for females and age-9 for males.

3.5.1 Growth

New Hampshire collects adult length and age data during the fishery-independent surveys for American shad caught on each river. A von Bertalanffy growth curve was calculated using the length data. Length and age data from other systems were used to "anchor" the curve for the youngest ages. Additional length data for age-0 were included from the Hudson; age-1 and 2 data were obtained from the Maine-New Hampshire near shore bottom trawl survey conducted along the New England coast. Data are presented in Table 3.1 and Figure 3.7

3.5.2 Fecundity

Fecundity for female American shad has not been estimated for New Hampshire rivers.

3.6 HABITAT DESCRIPTIONS

As stated in Atlantic States Marine Fisheries Commission's Amendment 1 of the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 1999), habitats used by all American shad and other alosines include spawning sites in coastal rivers and nursery areas, which are primarily freshwater portions of rivers and their associated bays and estuaries. In addition to spawning and nursery areas, adult habitats also consist of the near shore ocean. Adult American shad have also been found to migrate up to 60 miles off the coast. These habitats are distributed along the East Coast from the Bay of Fundy, Canada to Florida. Use of these habitats by migratory alosines may increase or diminish as the size of the population changes.

Dams and natural barriers restrict potential available spawning and nursery habitat in New Hampshire coastal rivers for American shad. Anthropogenic changes to these river systems can further affect habitat (e.g., increased development, increased impervious surfaces, increased water withdrawals). These may have affected all three river systems, but their effects are the most dramatic in the Exeter River. Currently, several New Hampshire state agencies are working with the Town of Exeter on dam water release and water withdrawal for water resources. These factors have affected the downstream emigration ability of both adult and juvenile shad with both barrier concerns and water quality issues. These issues came to New Hampshire's attention when low DO levels were found in 1995 by water quality data collection by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) that indicated low levels of dissolved oxygen between two and five mg per liter in impoundment reaches of the Exeter River (Rich Langan, unpublished data).

Poor water quality can have potential growth impacts on emigrating young-of-year (YOY) American Shad (Smith *et al*. 2005). In this study, YOY shad were captured in the freshwater impoundments of the

Exeter River during early to mid-September in 2005. Dissolved oxygen data collected during this period indicate daily minimum values of at or near 40 percent saturation in early September. This level was shown to significantly impact growth in laboratory trials.

3.7 RESTORATION PROGRAMS

Restoration activities for both American shad and river herring in New Hampshire river systems have included constructing and improving upstream passage facilities at dams; stocking of eggs, larvae, and adult fish into historic and viable spawning reaches; removing dams; and improving water quality in spawning and rearing reaches (NHFGD 2005).

American shad restoration in New Hampshire began in 1972 with egg stocking that continued under Federal Project F-36-R from 1973 to 1978; however no eggs were available in 1977. Adult shad were captured by floating gill nets in the Connecticut River below Holyoke Dam in Massachusetts. Eggs were artificially stripped, fertilized, transported, and broadcast into the Lamprey River. A sample of eggs from each stocking was placed in an egg box for observation of survival to hatch. This technique produced returns of fewer than a dozen shad per year.

The purchase of circular transport tanks in the 1980s allowed the opportunity to transport live, gravid adults to naturally spawn in New Hampshire's coastal river systems. From 1980 to 1988, between 600 and 1,300 gravid adult shad were transported annually from the Connecticut River and distributed into the Exeter, Lamprey, and Cocheco rivers (Table 3.2). In 1989, the decision was made to concentrate restoration efforts to one river at a time. The Exeter River was chosen for the American shad restoration program due to the presence of two fish ladders providing access to the greatest amount of habitat. This river continues to be the focus of the American shad restoration program with primarily adult shad transfers from either the Connecticut or Merrimack rivers. This lack of supplemental stocking into other New Hampshire rivers has been evident in return numbers in recent years; however, residual American shad spawning runs still remain in the Lamprey and Cocheco rivers.

Harvesters have reported shad present in other rivers within the Great Bay and Hampton-Seabrook estuaries. American shad have been caught in the Bellamy River weir fishery for river herring in the late 1970s, in the Salmon Falls River by anglers, and in the Taylor River gill net fishery for river herring.

3.7.1 Restoration Objective

The restoration target for New Hampshire's American shad rivers is to have spawning adults at abundance levels that sustain natural reproduction without supplemental stocking from other river systems or hatchery augmentation (NHFGD 1999). The focus will be to restore one river at a time. Since 1989, all efforts have been focused on the Exeter River.

3.7.2 Hatchery Evaluations

During the spring of 2004, 250,000 hatchery-reared, oxytetracycline (OTC) marked American shad fry were released at locations separated by passage impediments in the Exeter River, New Hampshire. The purpose of the study was to examine the effects of environmental conditions, including low DO levels, on survival, growth, and out-migration of juvenile American shad. Evaluation methods included beach seining, incline plane trapping, and cage trapping in fish ladders. Forty-four YOY American shad were captured over three successive seining efforts in early fall with 19 being OTC marked. No American shad YOY were captured by the two other trapping methods. The low number of shad captured may have been influenced by abnormally high water levels that increased the number of locations available for YOY shad to seek refuge and many of these areas were inaccessible to the boat and seine because of vegetation and debris.

3.7.3 Fish Passage Efficiency

New Hampshire has not conducted specific fish passage efficiency studies on the seven fish ladders on coastal rivers.

3.8 AGE

New Hampshire annually collects adult shad at fishways on the Exeter, Lamprey, and Cocheco rivers each spring. Biological samples taken include length measurements, sex determination, and scale samples for age determination. All American shad encountered are sampled unless the fish shows signs of stress due to elevated water temperatures. All shad scale samples are cleaned, mounted between glass slides, and aged using an overhead scale projector via methods described by Cating (1953) for American shad. Spawning marks are also counted while ageing to determine the number of times a fish may have returned to spawn. Two or more readers independently age all scales.

3.9 FISHERY DESCRIPTIONS

There is a very limited recreational fishery for American shad at head-of-tide in the Salmon Falls River. The recreational fishery for American shad within New Hampshire is very limited due to the low abundance of this species during restoration efforts.

Limited American shad harvest has been reported as bycatch from EEZ commercial gill net and otter trawl fisheries. Also, shad bycatch can occur within the coastal river herring net fishery; however, shad cannot be kept if harvested with gear other than hook and line within state waters.

3.9.1 Commercial Fisheries

Most of New Hampshire's commercial landings of American shad are from vessels fishing in the EEZ. Landings peaked in 1988 at roughly 21,000 kg followed by a second smaller peak in 1996 (Table 3.3; Figure 3.8). Landings during the last three years have been virtually non-existent. The primary gear used was gill nets (Table 3.3). Since shad were caught in ocean waters, they were most likely of mixed stock origin.

New Hampshire has been granted *de minimis* status since 1998 and therefore is not required to conduct sampling of commercially harvested American shad.

3.9.2 Bycatch

During spring river herring runs, there is a small in-river net fishery that may produce a bycatch of American shad in New Hampshire waters. Since nets must be actively tended, bycatch mortality of shad should be minimal.

The commercial fisheries that occur in the EEZ and land in New Hampshire are restricted to landing a 5 percent bycatch of shad per trip. Bycatch landings of shad, as stated above, have been minimal since 2001 (Table 3.3).

New Hampshire American shad are assumed to follow the migration pattern described in Section 1. They are most likely caught as bycatch in other fisheries operating along their Atlantic coast migration route.

3.9.3 Recreational Fisheries

New Hampshire conducts the Marine Recreational Fisheries Statistic Survey (MRFSS) to evaluate all saltwater and estuarine recreational fisheries including the very limited American shad fishery. New Hampshire conducts sampling three times above the MRFSS baseline of surveys assigned to the state. This covers the New Hampshire coast into the brackish areas of estuaries. The low abundance of American shad in New Hampshire and the “pulse” characteristic of this particular fishery result in low levels of precision for the catch estimates of American shad.

As there have been no recorded recreational landings in New Hampshire since 1997, there have been no biological samples taken.

3.10 FISHERY-INDEPENDENT SURVEYS

Two fishery-independent surveys are conducted in New Hampshire to monitor American shad. Each spring or early summer (April through June) NHFGD operates seven fish ladders along coastal rivers to enumerate and monitor migrating diadromous species, described below. In addition to monitoring adult migration of American shad, NHFGD conducts a seine survey in the Great Bay and Hampton-Seabrook estuaries for juvenile finfish utilizing available nursery habitat or those emigrating to the ocean.

3.10.1 Adult Catch Data

Seven fish ladders on six coastal New Hampshire rivers (Cocheco, Exeter, Lamprey, Oyster, Winnicut, and Taylor rivers) are operated from early April to mid-July, to allow for the passage of American shad, river herring, and other diadromous fish to historical spawning and nursery areas. The number of fish passing through the fishways is either enumerated by hand passing or estimated by the use of Smith-Root Model 1100 electronic fish counters. Counts recorded by the electronic fish counters are adjusted by the results of daily calibration counts consisting of a minimum of ten one-minute counts. During daily visits, fish ladders and electronic counting devices are examined to assure they are functioning properly.

The restoration effort for American shad is currently concentrated within the Exeter River. The fish ladder on the Exeter can be set up as a trap, limiting passage for all species, or as a grate structure to allow river herring to pass through a counting tube but not American shad, allowing for the enumeration and biological monitoring of all shad returning to this river on a daily basis.

The Cocheco and Lamprey rivers have very small residual shad spawning runs and are monitored similarly. The Lamprey ladder is operated as a swim through operation with a counting tube until the majority of the river herring (alewife) run passes. The ladder is then set as a trap to allow for enumeration and biological sampling of American shad that arrive after the river herring spawning run. The Cocheco River fish ladder is operated as a trap therefore any American shad encountered are monitored as described above.

Although the numbers are small, the runs in the Lamprey and Cocheco rivers still persist without any supplemental stocking. Returns in the Lamprey increased slightly in 2003 and 2004 only to drop in 2005 (Table 3.2). The Cocheco has consistent returns at between one and twenty-four fish. While all rivers declined, none did so to the extent of the Exeter River, which dropped from 22 fish in 2004 to three fish in 2005. Furthermore, numbers of returns in the Exeter River have been decreasing each year since 2000 when a peak of 163 shad returned. This is a confounding occurrence given that restoration efforts using trap and transport operations have focused exclusively on the Exeter River since 1989.

Several factors may be effecting the continued reduction in shad returns. Despite American shad's strong philopatry, there have been studies indicating straying occurs to nearby river system (Waters *et al*. 1999). Considering the close proximity of the confluence of the Lamprey and Exeter River into Great Bay, straying of these two shad populations may be occurring between the two river systems.

High flows before and during the runs may also be influencing the decline in returns in monitored rivers. The efficiency of the fishways can be reduced if water flows are too high to allow the migrating diadromous fish to find the entrance of the fishway.

In the Exeter River, supplemental stocking between 1995 and 1997 ceased due to constraints on American shad transfers from the Connecticut River. However, the decline in return numbers since 2004 has occurred across all year classes, suggesting that other factors are affecting returns other than the three-year cessation of shad transfers. Potential factors affecting returns on the Exeter include low DO during summer months (affecting YOY survival), downstream passage problems, water withdrawals by the local town, and drought conditions in some years. Changes in fish passage and trap efficiency have also occurred over the years. Upriver passage was hampered for the first 10 years of operation by an abundance of sea lamprey that inundated the ladder during anadromous runs. Fish trap design was improved in 1994 and again in 1999. Finally, droughts hampered downstream passage in 2000 and perhaps in 1999.

Although the smallest decline in return numbers is seen in returning shad in the Cocheco River, these numbers are still low, reflecting the termination of adult shad stocking in 1988. It appears that wild returns from previous stockings may be insufficient to sustain a spawning population in this river.

Biological Characteristics

New Hampshire collects biological data from American shad only at the Exeter, Lamprey, and Cocheco fish ladders as they have not been observed in any other fish passage system monitored by NHFGD.

Length for males ranges from 310 mm to 579 mm (Table 3.4). The majority of males fall within the range of 459 mm to 519 mm (data from all rivers combined). Mean lengths of males varied annually (Table 3.5; Figure 3.9), increasing slightly from 1991 to 2005 on the Exeter and Cocheco rivers. Females range from 319 mm to 619 mm and most occur between 519 mm to 579 mm (Table 3.4). Mean length of females increased in a similar trend (Table 3.5; Figure 3.9). Further inferences are difficult due to the small number of fish in the annual returns.

Age Composition

The American shad returning to the Exeter River fish ladder ranged in age from three to ten years old (Table 3.6). Most male shad ranged in age from five to seven whereas the majority of female shad ranged from age six to eight. Mean age of males varied between 4.9 and 6.2 (Table 3.6); the oldest mean age occurred in 1999 and 2000, which may have been a consequence of returns from previous years of high stocking levels (1990 through 1994) in the Exeter. A similar increase in mean age of females also occurred in 2000 to 7.2 (Table 3.6). In most years mean age was variable ranging from 5.0 to 8.3. This was likely influenced by the small numbers of female shad retuning to the Exeter.

The age distribution of American shad returning to the Exeter River included a wider range of ages than other New England rivers. Since shad stocks from all New England rivers probably face the same mortality factors at sea, the difference is likely caused by factors within rivers. Characteristics of New Hampshire rivers that might explain the difference include small watersheds and short migrations to the spawning reaches and low head dams that might facilitate downriver emigration of adults in the spring over spillways.

For most years between 1998 and 2005, the returning shad to all three rivers averaged at least one spawning event prior to fish ladder capture (Table 3.7). During the most productive years of returns, 1999 and 2000, the average numbers of repeat spawning events for male shad was highest at 1.2 and 1.5, respectively. The mean repeat female spawners also were highest during those years at 1.6 spawning events.

Mean length-at-age, for both sexes, varied without trend over the entire times series (Table 3.8).

3.10.3 Juvenile Catch Data

A beach seine survey is conducted annually to monitor the relative abundance of juvenile finfish utilizing New Hampshire estuaries for nursery habitat. However, there is no concentrated effort within the Exeter River with the exception of 2004 (see Section 3.7.2). Although the survey is designed to be a general-finfish survey, it is conducted in salt and brackish waters of Great Bay Estuary, focusing on the primary species of interest: winter flounder, rainbow smelt, river herring, American shad, and Atlantic silverside. All fish captured are identified to the lowest possible taxon and enumerated. For each haul seine sample, up to 25 fish from each species are measured (total length in mm); if there are less than 25 fish of a species, each individual is measured. An annual index of relative abundance is determined using the geometric mean catch-per-seine-haul.

The highest relative abundance for American shad in the juvenile seine survey occurred in 1999, coincident with the year of highest adult return (Table 3.9). The indices, in general, are very low for juvenile American shad. There has been no American shad captured in the juvenile seine survey since 2002. However, in 2004, 44 YOY American shad were captured in the Exeter, indicating that in most years, the juvenile finfish survey that focuses on estuarine locations may miss YOY shad.

3.11 ASSESSMENT APPROACHES AND RESULTS

3.11.1 Total Mortality

Catch curve analysis was used to calculate total instantaneous mortality rates (Z) on spawning American shad returning to the fishway on the Exeter River. Too few fish returned to the Lamprey and Cocheco rivers to calculate any estimate. Several methods were evaluated, including within-year and combinations of two years of successive data. The latter is suggested by Ricker (1975) to smooth yearly fluctuations due to differences in annual recruitment. Effects of environmental conditions (i.e., inconsistent water flows contributing to low DO levels or water temperatures) may also influence adult recruitment.

For males, Z-estimates fluctuated, but generally increased until 1999 followed by a decline through 2002 and then a dramatic increase until 2005 (Table 3.10; Figure 3.10). Z-estimates for females were extremely variable. Low sample size contributes a high level of uncertainty to these estimates. Z-estimates for males generally exceeded Z_{30} (0.64), especially in 2005 (Section 1); however, the low sample size results in a high level of uncertainty to these estimates.

3.11.2 Cohort Return

Returns of spawning adult shad to New Hampshire coastal rivers continue to be low despite more than 30 years of restoration efforts. Even in the Exeter River, where restoration efforts have been focused for the past 15 years, returns have been low with the exception of 1999 and 2000.

Gross analysis of the relationship of returns versus adult stock levels (wild and stocked) six years earlier was weakly positive (Figure 3.11). Table 3.11 shows the total returns segregated into cohort for each year of return. Abundance of returning cohorts again showed a weak, positive relationship to the adult stock levels that produced the cohorts (Figure 3.12).

Table 3.12 shows an expected maximum age of the returns based on date of cohort initiation and return date. No consistent pattern was apparent between observed and expected maximum age through the time period (Tables 3.11 and 3.12).

3.12 BENCHMARKS

A benchmark value of Z_{30}= 0.64 was calculated for New England American shad stocks (See Section 1.1.5).

3.13 CONCLUSIONS AND RECOMMENDATIONS

New Hampshire rivers were severely impacted over the past several centuries, negatively affecting anadromous species. Dams, fishing, and poor water quality are among the many obstacles that American shad have faced. Restoration efforts should continue with focus on the following strategies for New Hampshire coastal rivers targeted for restoration:

1. Continue efforts to monitor and, where needed, improve water quality.
2. Expand efforts to obtain large numbers of American shad fry for stocking.
3. Continue transporting spawning adult American shad from donor rivers until a consistent long-term source of cultured shad fry is secured.
4. Continue work to install upstream and downstream fish passage or remove dams in coastal rivers.
5. Continue to monitor returns of spawning adult American shad to fish ladders.
6. Re-evaluate the beach seine survey relative to American shad; include sites in the freshwater portions of spawning rivers to monitor the relative abundance of YOY American shad.
7. Efforts should be made to identify and reduce all sources of mortality whether during ocean residency or in-river.

LITERATURE CITED

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring, ASMFC, 76, Washington, D.C.

Cating, J.P. 1953. Determining age of Atlantic shad from their scales. U.S. Fish and Wildlife Service Bull. 85: 187-199, Washington D.C.

Jackson, C.F. 1944. A Biological Survey of Great Bay New Hampshire: No. 1 Physical and Biological Features of Great Bay and the Present Status of its Marine Resources. 61. Marine Fisheries Commission, Durham, New Hampshire.

Lagan, R. 1995. Cooperative Institute for Coastal and Estuarine Environmental Technology. Unpublished data.

Langan, R. 2004. Cooperative Institute for Coastal and Estuarine Environmental Technology. Unpublished data.

NHFGD (New Hampshire Fish and Game Department). 1999. New Hampshire's Anadromous Fish Investigations and Marine Recreational Fishery Evaluation. New Hampshire Fish and Game Department, Final Report. Federal Aid Project F-50-R., Durham, New Hampshire.

NHFGD (New Hampshire Fish and Game Department). 2005. New Hampshire's Anadromous Fish Investigations and Marine Recreational Fishery Evaluation. New Hampshire Fish and Game Department, Final Report Federal Aid Project F-61-R- Project 1, Job 1, Durham, New Hampshire. 34 p.

Smith, B., K. Weaver and D. Berlinsky. 2005. The Effects of Passage Impediments and Environmental Conditions on Out-Migrating Juvenile American Shad. NMFS Federal Aid Project Final Report no. NA03NMF4050199. Washington, D.C. 20 p.

Waters, J.M., J.M. Epifanio, T. Gunter and B.L. Brown. 1999. Homing behaviour facilitates subtle genetic differentiation among river populations of *Alosa sapidissima*: microsatellites and mtDNA. Journal of Fish Biology (2000). 56: 622-636.

Table 3.1 Von Bertalanffy growth curve parameters for American shad from New Hampshire rivers.

		Female	SE	Male	SE
	L_{inf}	**641.100**	**4.760**	**593.600**	**4.552**
	K	**0.243**	**0.004**	**0.281**	**0.014**
Age	t_0	**-0.025**	**0.006**	**-0.213**	**0.034**
0		52.9		84.1	
1		141.2		171.6	
2		249.0		275.1	
3		333.5		353.2	
4		399.8		412.1	
5		451.8		456.6	
6		492.6		490.2	
7		524.6		515.6	
8		549.7		534.7	
9		569.4		549.1	
10		584.9		560.0	

Table 3.2 The number of American shad stocked and the number of American shad returning to the first dam on the Exeter, Lamprey, and Cocheco rivers, New Hampshire, 1980-2004. "a" indicates that there were no counts, the ladder was operated as a swim-through. "b" indicates minimum counts, the ladder was operated as a swim-through until the last day of May.

Year	Exeter			Lamprey		Cocheco	
	Stocked	Returns	Stocked and Returned	Stocked	Returns	Stocked	Returns
1980	283		283	286		212	
1981	212		212	192		183	
1982	185		185	218		120	
1983	265		265	206		135	3
1984	517		517	453		241	
1985	418		418	409	2	90	1
1986	680		680	437	39	205	1
1987	420		420	420		230	
1988	375		375	372	a	190	4
1989	779		779		a		8
1990	1275		1275		a		3
1991	1386	12	1398		2		6
1992	1384	22	1406		5		24
1993	979	21	1000		200b		17
1994	1462		1462		13b		9
1995	0	18	18		14b		8
1996	0	58	58		2b		5
1997	0	30	30		4b		11
1998	1164	33	1197		3b		6
1999	954	129	1083		3b		2
2000	987	163	1150		7b		14
2001	1168	42	1210		6b		6
2002	1173	41	1214		4b		4
2003	1142	33	1175		26b		6
2004	1332	22	1354		33b		12
2005	0	3	3		12b		8

Table 3.3 Reported ocean commercial landings (kg) of American shad in New Hampshire from the NMFS, 1975-2005.

Year	By Gear			Total
	Gill Nets	Trawl	Other	
1975	227	0	0	227
1976	816	0	0	816
1977	1814	91	0	1905
1978	3357	181	0	3538
1979	2404	907	0	3311
1980	3130	0	0	3130
1981	2495	45	0	2540
1982	1225	0	0	1225
1983	1542	0	0	1542
1984	2313	0	0	2313
1985	3311	0	0	3311
1986	7620	45	0	7666
1987	15150	181	3402	18734
1988	20457	363	0	20837
1989	13699	181	0	13882
1990	17087	243	0	17330
1991	8295	288	0	8584
1992	4063	429	0	4492
1993	2908	62	0	2971
1994	12712	92	0	9862
1995	13807	56	0	13862
1996	16002	116	0	16130
1997	11513	25	0	11538
1998	6797	83	0	6881
1999	1642	24	0	1667
2000	1791	7	897	2695
2001	350	18	0	569
2002	0	0	0	0
2003	0	0	0	1
2004	0	0	0	49
2005	11	0	0	11

Table 3.4 Length frequency of (a) male and (b) female American shad returning to New Hampshire rivers, 1991-2005.

(a)

							Males								
TL-mm	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300-319							1								
320-339															
340-359															
360-379							1				1				
380-399							2		1						
400-419		1	1	1	1	1	0	3	3		2				
420-439	1	6			1		1	11	10	2	1	5	1		1
440-459	3	7	8		4	8	2	14	38	2	1	12	5	3	
460-479	2	11	26	1	5	10	7	8	31	11	1	12	13	5	1
480-499	3	6	25	2	1	11	3	3	17	32	7	2	18	8	6
500-519	1	5	18		3	7	3	1	5	32	7	3	6	6	1
520-539	1		5		1	5	4	1		9	1		3	2	2
540-559			2		2				1	1		3	3	3	
560-579			1	2	1					2	2				
580-599															
600-619															
620-639															
Total	**11**	**36**	**86**	**6**	**19**	**42**	**24**	**41**	**106**	**91**	**23**	**37**	**49**	**27**	**11**

Table 3.4 cont. Length frequency of (a) male and (b) female American shad returning to New Hampshire rivers, 1991-2005.

(b)

	Females														
TL-mm	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300-319	1														
320-339															
340-359															
360-379															
380-399					1										
400-419							1								
420-439							1						1		
440-459						1			3				1		
460-479		1	4			1			4	1			3	1	
480-499	1	1	5	1	1		1		8	3	2	1	1	1	1
500-519		5	14	1	1	4	4		11	13	1	4	2	3	4
520-539		4	31	5	1	7	4		2	34	5		4	9	1
540-559	2	1	18	1	3	3	4	1	1	29	12	1	1	7	2
560-579	1	2	13	1		2	3			11	7	2	2	6	
580-599	1	1	2		2	1	1				2			2	
600-619	1											1			
620-639															
Total	**7**	**15**	**87**	**9**	**9**	**19**	**19**	**1**	**29**	**91**	**29**	**9**	**15**	**29**	**8**

Table 3.5 Mean total length (mm) of American shad returning to the first dam on the Cocheco, Exeter, and Lamprey rivers, New Hampshire, 1991-2005.

Year	Cocheco						Exeter						Lamprey					
	Male		Female		All		Male		Female		All		Male		Female		All	
	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
1991	3	475.0	3	444.3	24	459.7	8	478.9	4	576.0	12	511.3						
1992	17	466.1	7	531.9	16	485.3	18	467.8	4	520.0	22	477.3	1	469.0	4	528.3	5	516.4
1993	6	469.0	10	519.7	2	500.7	12	480.1	8	455.8	20	470.4	68	490.7	70	536.1	139	513.7
1994			2	525.5	6	525.5							6	501.0	7	533.3	13	518.4
1995	6	471.3			4	471.3	9	479.8	5	515.2	14	492.4	4	511.0	4	546.5	8	528.8
1996	2	470.0	2	463.0	10	466.5	39	481.8	16	535.1	55	497.3	1	512.0	1	575.0	2	543.5
1997	2	490.5	8	526.8	6	519.5	20	456.1	10	522.7	30	478.3	2	524.5	1	550.0	3	533.0
1998	6	470.5			2	470.5	32	448.8	1	540.0	33	451.6	3	455.0			3	455.0
1999	1	477.0	1	455.0	14	466.0	103	462.5	27	496.6	130	469.6	2	456.0	1	512.0	3	474.7
2000	9	484.0	5	537.2	5	503.0	78	499.0	84	536.2	162	518.3	4	508.8	2	537.5	6	518.3
2001	4	483.3	1	540.0	2	494.6	16	479.4	26	546.8	42	521.1	3	510.0	2	545.5	5	524.2
2002			2	528.0	6	528.0	33	470.8	7	536.6	41	484.5	4	456.8			4	456.8
2003	3	474.7	3	507.0	9	490.8	27	486.6	6	535.3	33	495.4	19	491.1	6	531.3	25	500.8
2004	7	499.4	2	549.0	8	510.4	11	493.1	10	540.5	21	515.7	9	489.3	17	541.2	27	523.5
2005	4	479.8	4	511.5	112	495.6	1	493.0	2	542.0	3	525.7	6	495.5	2	519.5	8	501.5

Table 3.6 Number-at-age of American shad collected from the Exeter River, New Hampshire, 1991-2005.

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Male															
3							2	1				1	1		
4	1	7	1			11	3	16		1	5	10	4	1	
5	3	6	5		5	10	7	7	17	10	2	9	13	5	2
6	3	4	3		1	11	4	4	51	28	5	4	9	4	8
7	1	1	2		3	3	1	3	27	29	2	5		1	1
8			1			1		1	3	4		3			
9									1	2	1				
Total	**8**	**18**	**12**	**0**	**9**	**36**	**17**	**32**	**99**	**74**	**15**	**32**	**27**	**11**	**11**
Mean Age	**5.5**	**4.9**	**5.8**		**5.8**	**5.3**	**4.9**	**4.8**	**6.1**	**6.2**	**5.1**	**5.3**	**5.1**	**5.5**	**5.9**
Female															
3					1		1								
4						1							1		
5		2	1		1	2	1		1	1		1	1	3	1
6			1		2	4			9	16	6	1	2	5	2
7		1	6			4	3		9	33	12	2	2	2	5
8	3	1				3	3	1	8	20	4	1			
9	1					1				7	1	2			
10							1			1					
Total	**4**	**4**	**8**	**0**	**4**	**15**	**9**	**1**	**27**	**78**	**23**	**7**	**6**	**10**	**8**
Mean Age	**8.3**	**6.3**	**6.6**		**5.0**	**6.6**	**7.0**	**8.0**	**6.9**	**7.2**	**7.0**	**7.3**	**5.8**	**5.9**	**6.5**

Table 3.7 Number of spawn marks at age for American shad collected from the Exeter River, New Hampshire, 1991-2005.

Spawning Marks	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Males															
0								12	27	7	7	13	9	4	4
1								11	33	27	4	14	12	6	6
2								7	28	36	3	3	5	1	1
3								2	10	2	1	1	1		
4									1	2		1			
Total								**32**	**99**	**74**	**15**	**32**	**27**	**11**	**11**
Mean Repeat								**1.0**	**1.2**	**1.5**	**0.9**	**0.8**	**0.9**	**0.7**	**0.7**
Females															
0									3	7	2	2	2	8	8
1								1	10	33	10	3	1	1	1
2									9	23	7	1	3	1	1
3									5	12	3	1			
4										3	1				
Total								**1**	**27**	**78**	**23**	**7**	**6**	**10**	**10**
Mean Repeat								**1.0**	**1.6**	**1.6**	**1.6**	**1.1**	**1.2**	**0.3**	**0.3**

Table 3.8 Mean total length-at-age (TL, mm) of American shad returning to New Hampshire rivers, 1991-2005.

Year / Age	Male							Female							
	3	4	5	6	7	8	9	3	4	5	6	7	8	9	10
	Length-at-Age														
1991		455.0	462.0	477.5	509.0	534.0			281.0		490.0		583.0	558.5	
1992	412.0	445.0	477.5	484.6	508.7				471.0	508.5	522.0	530.0	565.8		
1993		460.7	484.6	499.9	516.0	555.0			500.5	513.6	535.8	544.6	584.3	569.0	
1994			409.0	479.5	534.0		570.0				510.0	525.5	533.3		579.0
1995	409.0		456.6	480.0	519.3		540.0	395.0		504.0	560.0	496.0	559.0	550.0	581.0
1996		454.0	474.9	494.6	514.5	521.0			486.5	517.5	530.0	529.3	571.5	565.0	
1997	382.0	391.0	480.3	489.6	522.5			409.0	513.0	515.0	517.0	532.6	555.0	570.0	566.5
1998	441.5	441.1	449.9	462.8	490.5	483.0							540.0		
1999			450.2	463.5	463.5	476.0	556.0			464.0	491.9	494.7	505.5		
2000		444.0	488.1	499.5	500.1	517.0	547.5			493.0	521.9	533.6	548.0	556.7	558.0
2001		424.4	483.0	497.0	502.0		566.0				530.6	555.6	555.3	550.0	
2002	428.0	449.4	464.5	463.0	482.6	545.3				504.0	516.3	515.5	562.0	583.0	
2003	452.0	458.7	487.4	501.3	528.7				474.0	490.5	535.4	562.5	591.0		
2004		446.0	482.6	503.5	535.0	552.0				520.8	535.6	565.8	584.0		
2005			449.5	493.5	538.0					488.0	509.5	532.4			

Table 3.9 Annual juvenile abundance index of American shad seined in New Hampshire estuaries, 1997-2005.

Year	N Caught	Arithmetic		Geometric		Special Study
		Mean	STD	Mean	STD	N
1997	2	0.02	*	0.02	0.11	
1998	0	0	0	0.00	0.00	
1999	261	2.9	25.44	0.12	0.95	
2000	14	0.16	1.2	0.04	0.35	
2001	4	0.04	0.3	0.02	0.18	
2002	2	0.02	0.21	0.01	0.12	
2003	0	0	0	0.00	0.00	
2004	0	0	0	0.00	0.00	44
2005	0	0	0	0.00	0.00	

* No STD calculated in 1997

Table 3.10 Estimates of instantaneous mortality (Z) for American shad in the Exeter River, New Hampshire based on within year, spawning marks (SM), and two year combined catch curves, 1991-2005.

Year	Males			Females		
	Within Year	SM	2 Year	Within Year	SM	2 Year
1991	1.10			1.10		
1992	0.62	0.75		0.25	1.39	
1993	0.52	0.80			1.95	
1994		0.52				
1995	0.26	0.26				
1996	1.20	0.88		0.69	0.57	
1997	0.97	0.98		0.55	0.76	
1998	0.64	0.71	0.85		0.69	
1999	1.40	1.40	1.15	0.12		0.35
2000	1.34	1.19	1.07	1.15	1.26	0.78
2001	0.51	0.92	0.69	1.24	1.25	0.78
2002	0.30	0.51	0.90		0.77	0.55
2003	0.37	0.69	1.24		0.35	
2004	0.80	1.45	1.79	0.92	0.56	
2005	2.08	0.80	0.41		0.22	

Table 3.11 Total returns by cohort of American shad, sexes combined, at the lowermost dam on the Exeter River, New Hampshire.

Cohort	Collection Year														
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
2000													1	1	
1999												1	5	8	
1998												10	14	9	
1997											6	10	11	3	
1996										1	2	5	2		
1995								1		12	12	7			
1994							3	16	19	47	15	5			
1993							3	7	62	66	4	2			
1992					1	13	9	4	37	26	2				
1991						14	5	3	11	10					
1990					8	17	5	2	1	1					
1989			1		4	8	3								
1988		7	7		4	5									
1987	1	8	4			1	1								
1986	3	4	8												
1985	3	2	1												
1984	1	1													
1983	3														
1982	1														

Table 3.12 Returns by cohort, maximum age, and number of age classes observed, of American shad at the lowermost dam on the Exeter River, New Hampshire.

Cohort	Age								Observed Maximum Age of Cohort	Number of Age Classes	Max Age that Should be Present
	3	4	5	6	7	8	9	10			
2000	1	1							4	2	5
1999	1	5	8						5	3	6
1998		10	14	9					6	3	7
1997		6	10	11	3				7	4	8
1996		1	2	5	2				7	4	9
1995	1		12	12	7				7	4	10
1994	3	16	19	47	15	5			8	6	10
1993		3	7	62	66	4	2		9	6	10
1992	1	13	9	4	37	26	2		9	7	10
1991			14	5	3	11	10		9	5	10
1990			8	17	5	2	1	1	10	6	10
1989				4	8	3			8	3	10
1988		7	7		4	5			8	4	10
1987	1	8	4				1	1	10	5	10

Figure 3.1 Great Bay Estuary rivers with fish passage and available anadromous spawning and rearing habitat.

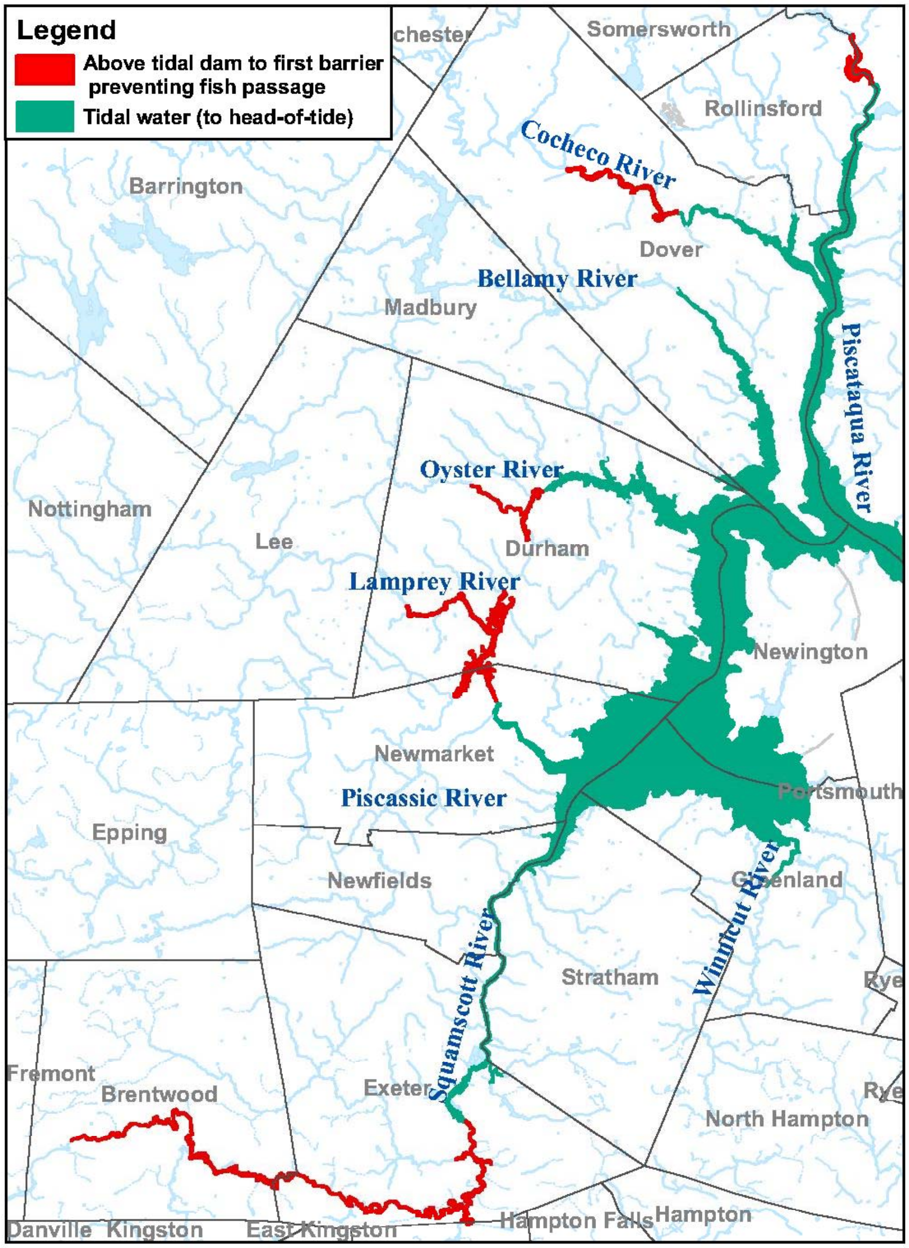


Figure 3.2 Exeter River watershed, New Hampshire.

Figure 3.3 Exeter River watershed dams and fish passage, New Hampshire.

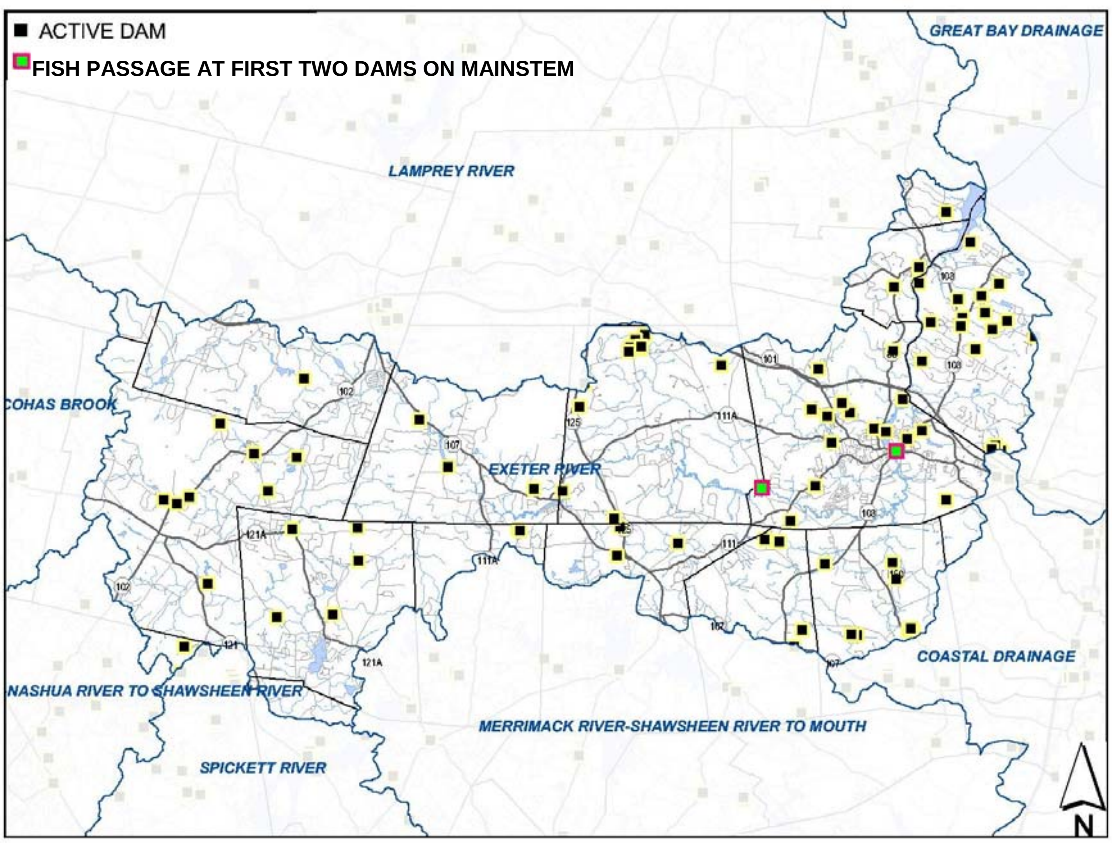


Figure 3.4 Great Bay watershed with Lamprey and Cocheco rivers, New Hampshire.

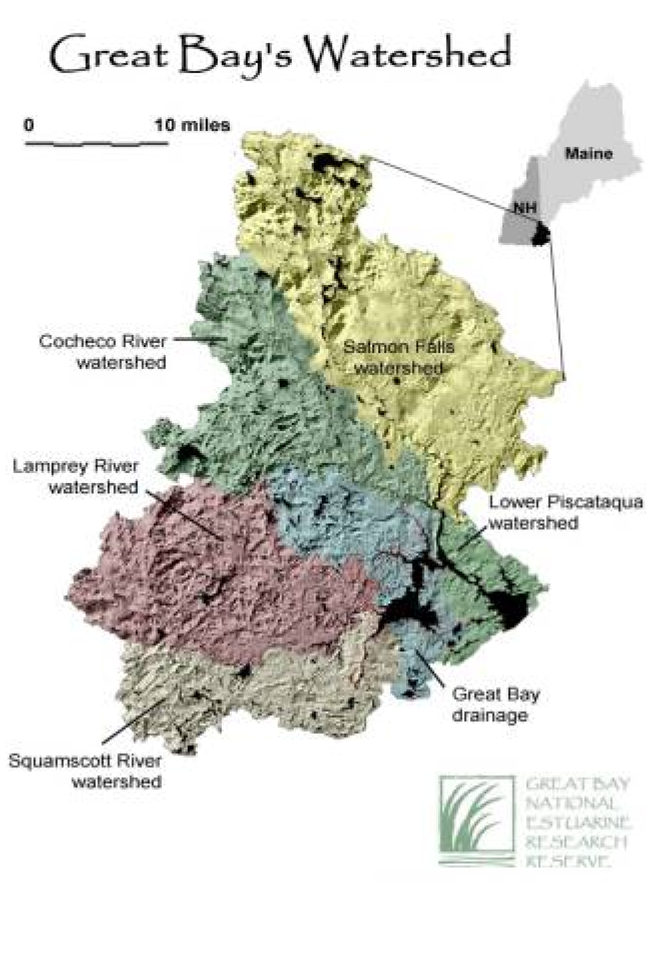


Figure 3.5 Lanprey River watershed dams and fish passage, New Hampshire.

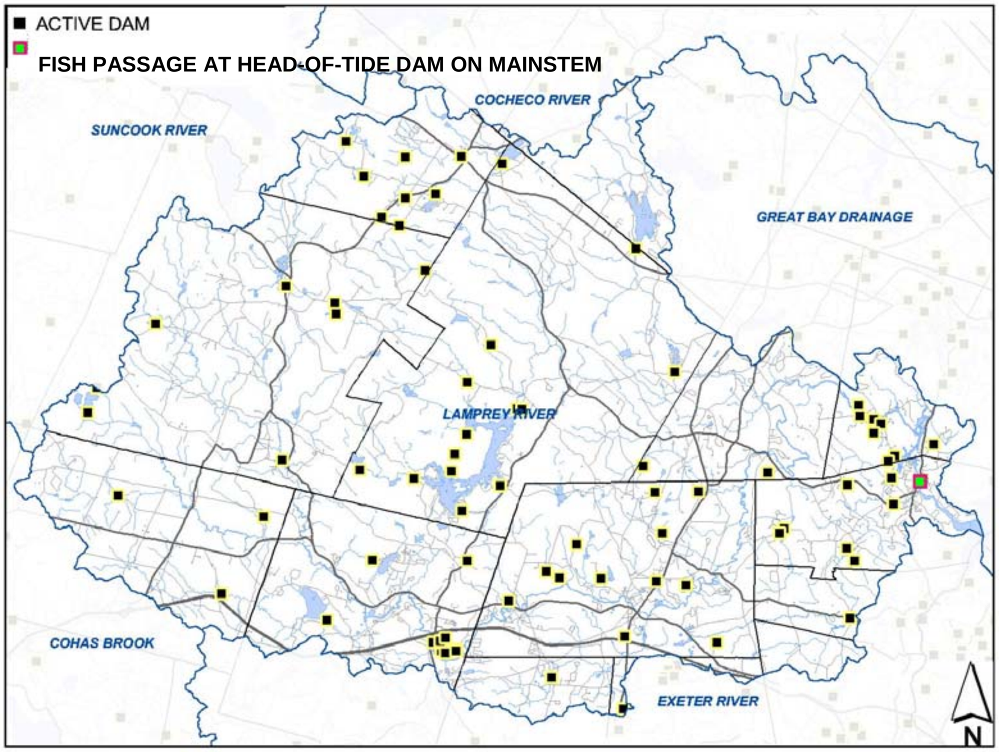


Figure 3.6 Cocheco River watershed dams and fish passage, New Hampshire.

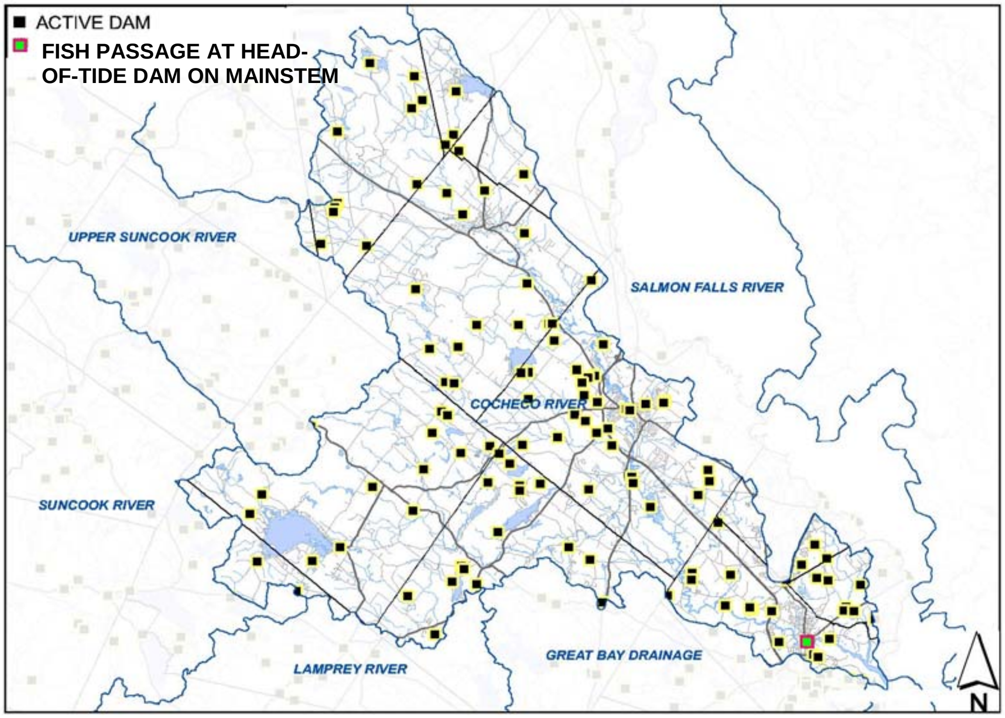
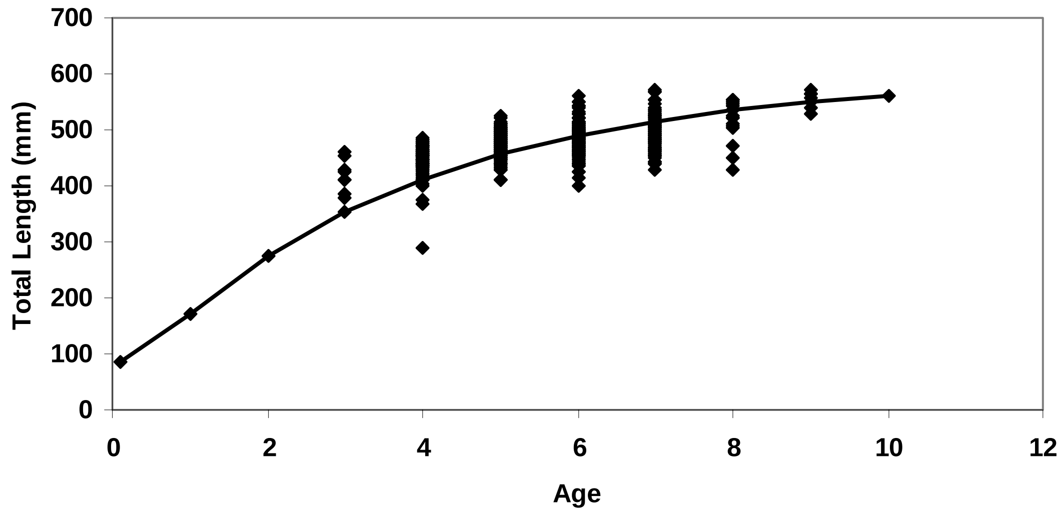


Figure 3.7 Von Bertalanffy growth curves for (a) male and (b) female American shad from New Hampshire rivers.

(a)



(b)

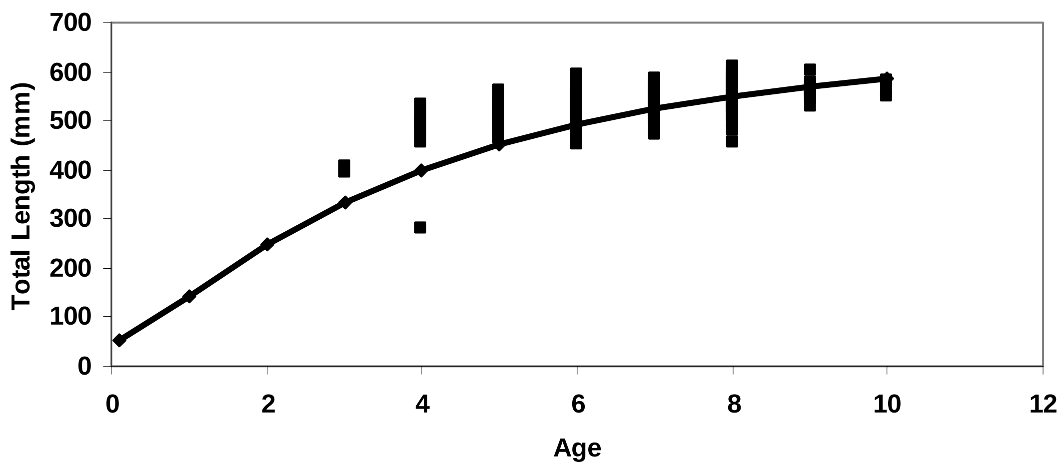


Figure 3.8 New Hampshire American shad commercial landings (kg), 1975-2005.

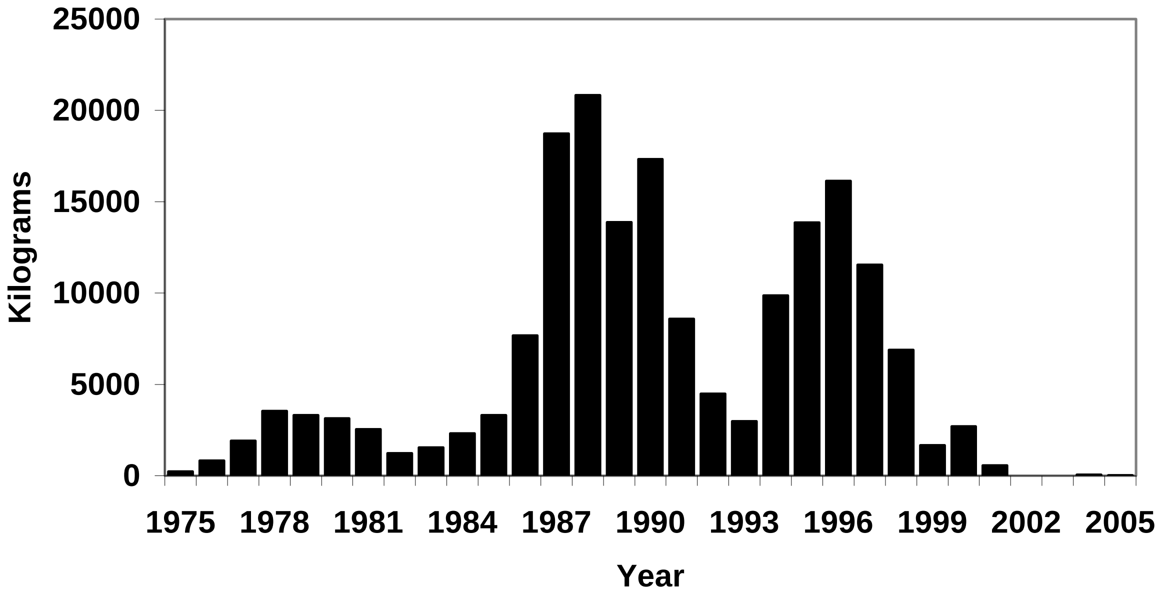
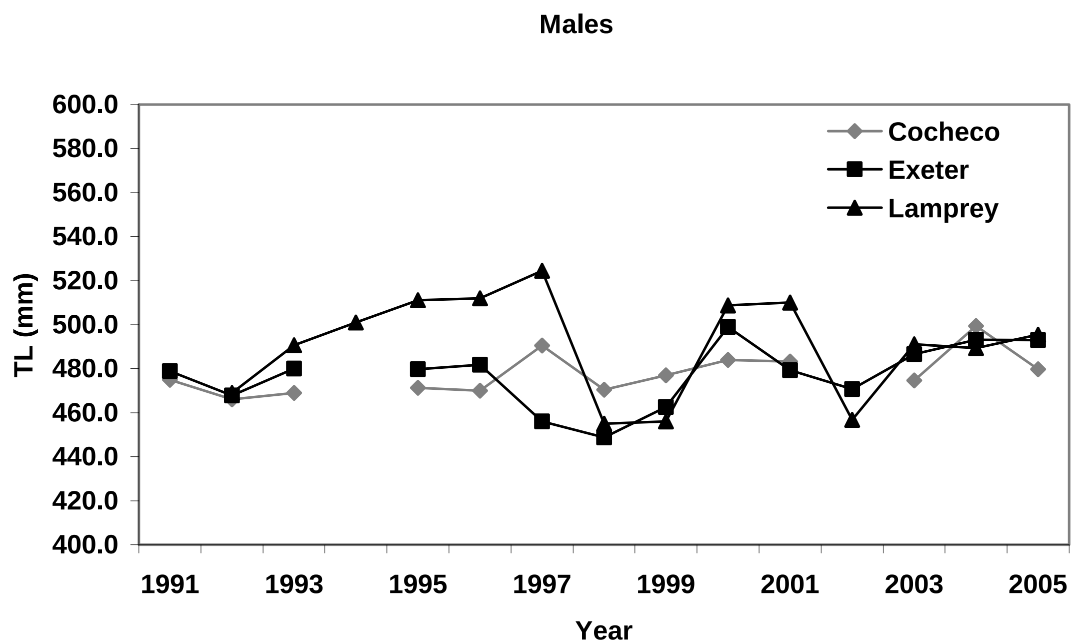


Figure 3.9 Mean total length (mm) of American shad returning to the first dam on the Cocheco, Exeter, and Lamprey rivers, New Hampshire, 1991-2005.



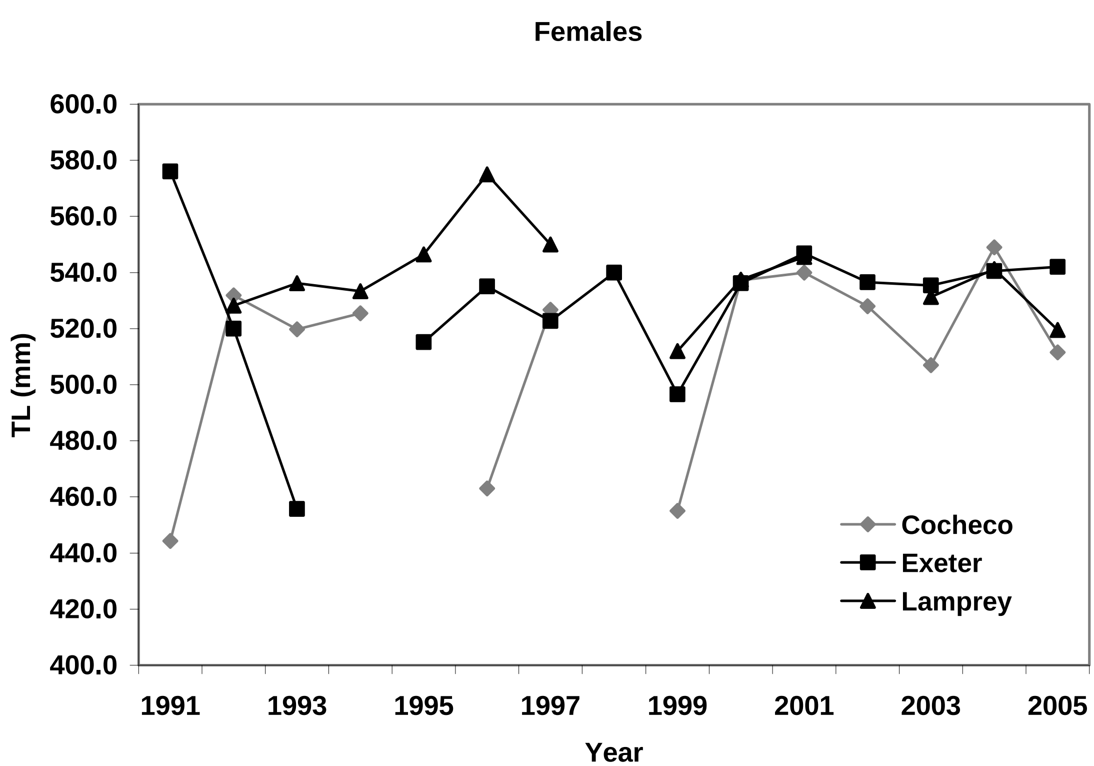
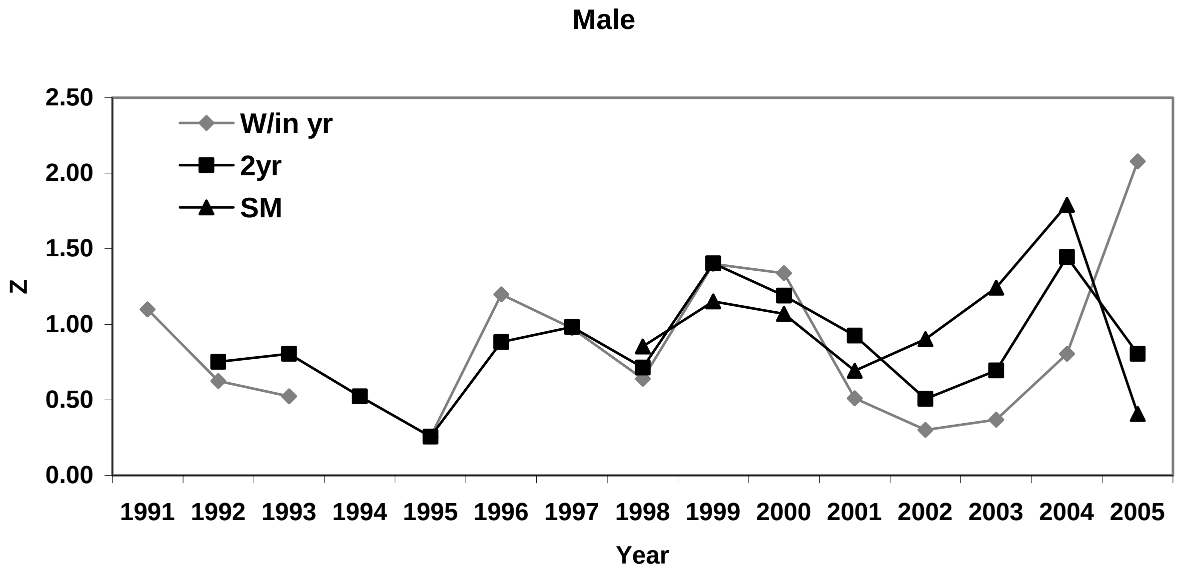


Figure 3.10 Estimates of total instantaneous mortality (Z) for American shad in the Exeter River, New Hampshire, based on catch curves using within year number-at-age (w/in yr), two year combined (2yr), and spawning marks (SM), 1991-2005.



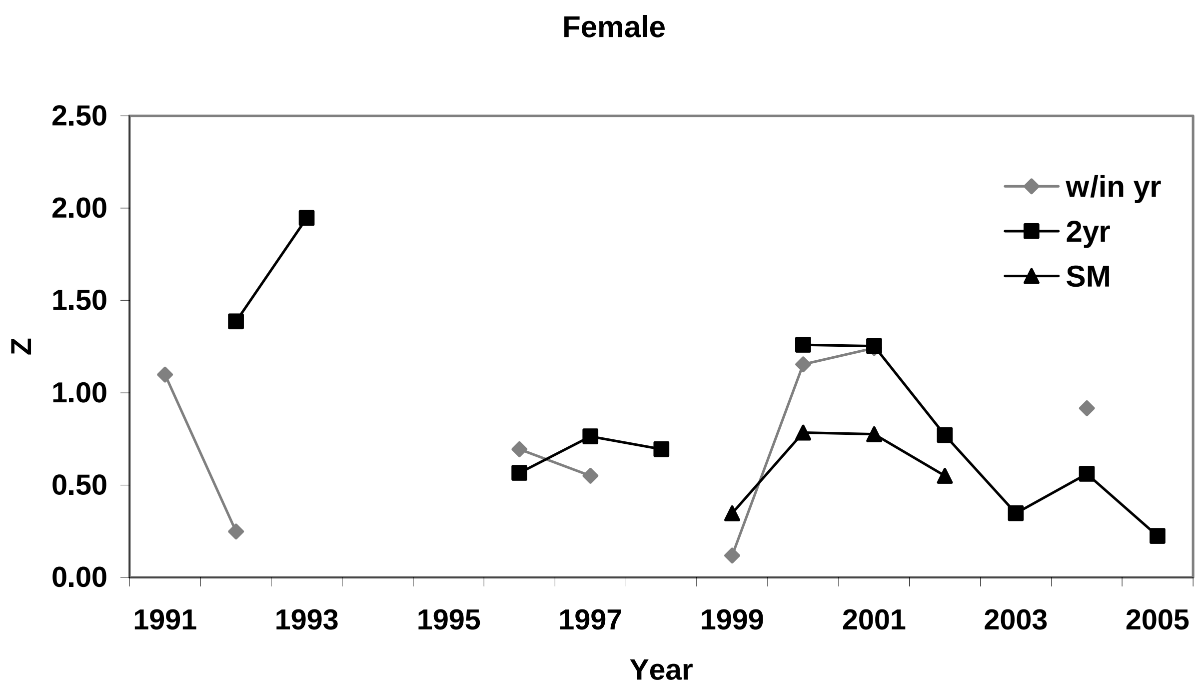


Figure 3.11 Relationship between the numbers of American shad stocked and passed over the first dam on the Exeter River, New Hampshire and the number of returning adults six years later.

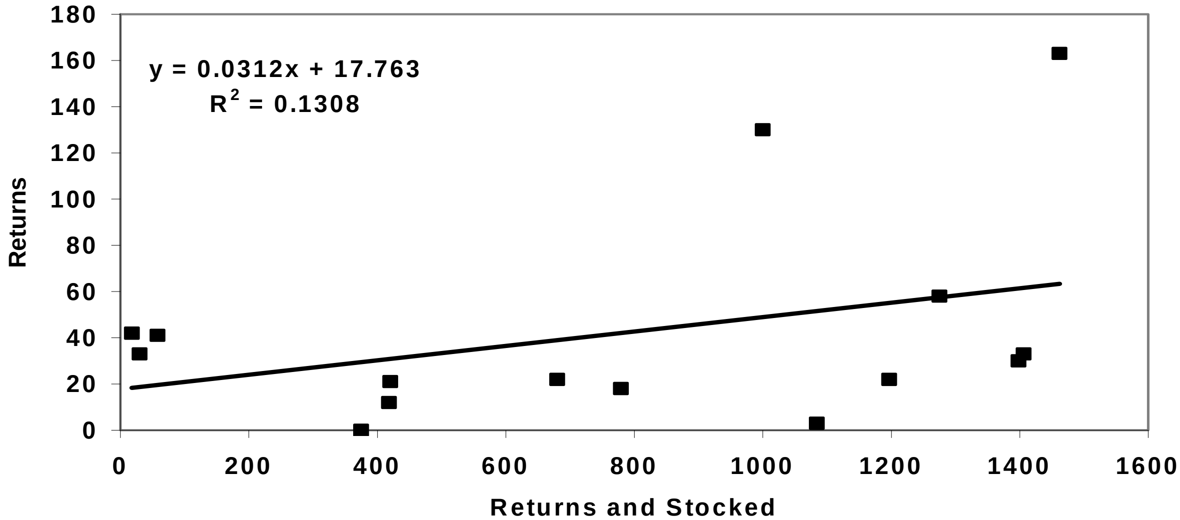
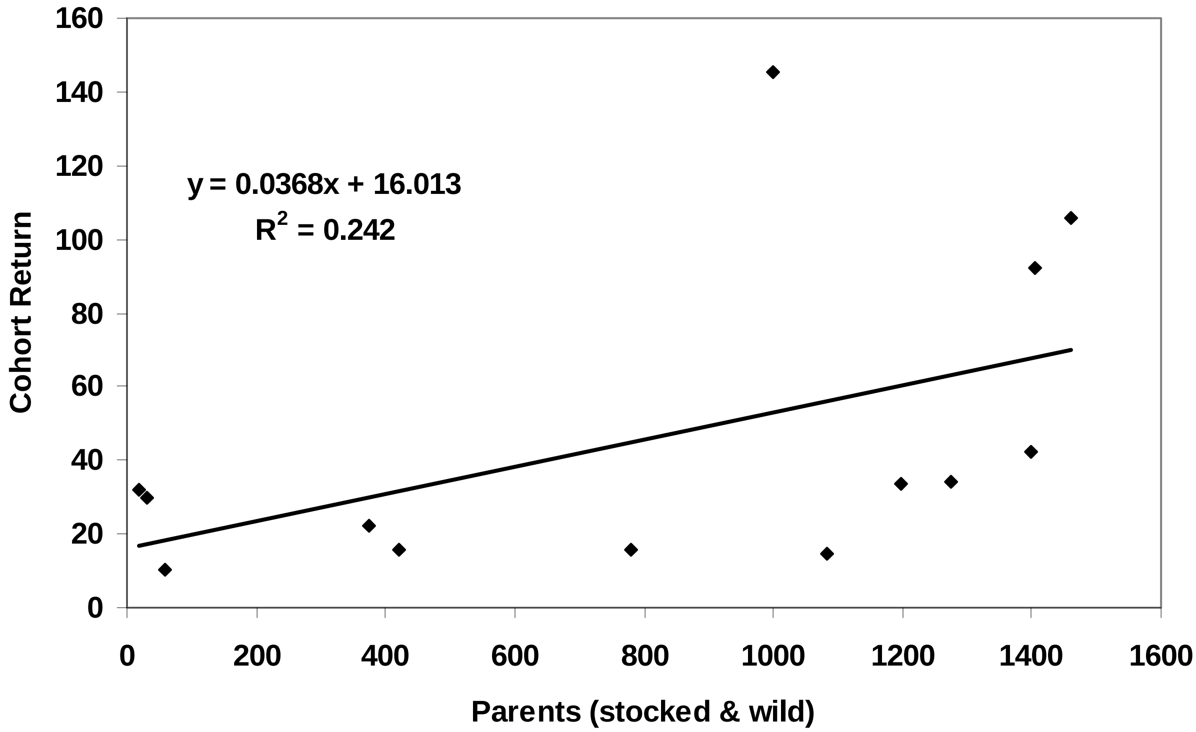


Figure 3.12 Cohort returns of American shad to the parent stock that produced them in the Exeter River, New Hampshire.



Section 4
Status of the Merrimack River American Shad Stock

Contributors:

Phillips Brady and Kristen Ferry
Massachusetts Division of Marine Fisheries
123 Purchase Street, New Bedford, Massachusetts 02744

Kathryn Hattala and Andrew Kahnle
Hudson River Fisheries Unit, New York State Department of Environmental Conservation
21 S. Putt Corners Road, New Paltz, New York 12561

4.1 INTRODUCTION

American shad were formerly an important component of the anadromous fish fauna 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. Over the last century, they were extirpated or reduced to extremely small unsustainable populations in all the rivers where they occurred by the construction of dams, water pollution at the spawning grounds, and overfishing.

In times of abundance, American shad supported both commercial and recreational fisheries. At present, commercial fishing for shad is prohibited in Massachusetts; however, small recreational fisheries exist in a few systems, including the Merrimack River. Populations in the other rivers remain very low or non-existent.

4.1.1 Early History

The earliest recorded history of the Merrimack River valley dates back to the early 1700s. The Pennacook Indian Confederacy was this area's first recorded inhabitants. Each spring, tribes met at Pawtucket Falls on the banks of the Merrimack to fish during the day and conduct business at night. American shad, Atlantic salmon, and river herring provided a stable spring food source. After the end of the fish runs tribes moved upriver to plant and harvest crops. By 1725 the way of life changed inextricably as English settlers made their mark on the land (NPS 2006). They too recognized the importance of the river for fishing. During the period 1735 through 1795, a series of Acts of the Commonwealth were enacted to regulate the "catching of salmon, shad and alewives" along with providing protection to maintain a free flowing river (ASHP 2006).

In spite of legislative acts in Massachusetts and New Hampshire that placed restrictions on the river, dam construction began on the Merrimack in the early 1800s. Although these dams were required to build in fish passage, the designs were often poor and ineffective. In 1836, the Amoskeag Dam was built near Manchester, New Hampshire, named with a Native American word meaning "great fishing place." Amoskeag Dam was constructed with a fish passage facility, the first structure of its kind on the main stem Merrimack (Tech. Comm. Anad. Fish Mgmt. 1997). Unfortunately, the fish ladder was ineffective and the construction of Amoskeag was the beginning of the end for the anadromous fish runs in the Merrimack. In 1823, a group from Boston began textile operations in East Chelmsford, Massachusetts, using the 32-foot Pawtucket Falls (NPS 2006). They founded ten textile companies in this town that they renamed Lowell. For the next 30 years, the city led the nation in cotton textile production. Dam construction helped mill owners obtain a steady hydropower supply. The Pawtucket Dam was built in Lowell, Massachusetts in 1847 followed quickly by the Essex Dam in Lawrence, Massachusetts in 1848 (the lowest dam on the Merrimack at river km 46). These two dams were the death knell for anadromous resources in the Merrimack as they were constructed without fish passage facilities. Ladders were later installed, but the ladder at Essex Dam was destroyed during a flood in 1896 and not replaced until 1898 (Tech. Comm. Anad. Fish Mgmt. 1997). Merrimack River anadromous fish populations were considered collapsed by 1850 and dam building continued through the late 1800s (ConNe – UMB 2006).

Although the construction of dams provided the final blow to anadromous fish in the Merrimack by preventing them from reaching their traditional spawning grounds, a number of issues likely influenced their decline. For example, a New Hampshire Fish and Game report from 1857 cited a number of problems for American shad including unregulated harvest, harvest on the spawning grounds, pollution, water diversions, construction of dams, and high juvenile mortality due to millwheels (Tech. Comm. Anad. Fish Mgmt. 1997).

4.1.2 Fish Passage

Historically, American shad once ran the full length (204 km) of the Merrimack River. At the junction of the Pemigewasset and the Winnipesaukee rivers where the Merrimack is formed, shad were known to move east into the warmer Winnipesaukee River (Figure 4.1). News articles dating to 1760 reported large catches of shad in the Winnipesaukee River. Some of the Merrimack's nine tributaries also supported shad. Presently, the main stem Merrimack has five hydroelectric dams. Fish passage is provided on the lower three facilities and ends at the Hooksett Dam in Hooksett, New Hampshire (Tech. Comm. Anad. Fish Mgmt. 1997).

Although "fishways" were built at the Essex (km 46) and Pawtucket (km 65) dams in the mid 1800s, the most recent upgrades for current fishway facilities occurred only within the past 25 years. With the completion of the modern-day fish passage facility at the Essex Dam the summer of 1982, adult shad were able to ascend the river beyond Lawrence, Massachusetts. In 1986, adult shad were able to ascend the river upstream from the Pawtucket Dam with the installation of a fish-lift and a modified Ice Harbor ladder, which is opened during high flow events. For the first time in nearly a century, adult American shad were able to reach Amoskeag Dam (km 120) in Manchester, New Hampshire. In 1989, Public Service of New Hampshire, in cooperation with the New Hampshire Fish and Game Department, and the U.S. Fish and Wildlife Service, constructed the current fish ladder at the Amoskeag Dam. This fishway allows shad access to the Hooksett Dam (km 135; Tech. Comm. Anad. Fish Mgmt. 1997).

Fish passage counts may not be indicative of the size of the American shad population that enters the river annually. The number of shad counted at the Essex Dam fish-lift varies from year to year. The variation may be related to environmental conditions, fish passage effectiveness, and the size of the population entering the river and reaching Essex Dam. Adult American shad are known to spawn in the river downstream from the Essex Dam. High river flows can retard upstream movement of the adults and reduce fish passage effectiveness because of the competitive flows. Low river temperatures, often associated with high river flows, can also retard upstream movement of the adults and may increase the incidence of downriver spawning (Tech. Comm. Anad. Fish Mgmt. 1997).

Major changes in the entrance to the fish-lift at Essex Dam occurred in 1995 and studies suggested that the changes increased the effectiveness of the facility. Work is ongoing to evaluate the passage efficiency of these facilities. In 1993, a new downstream bypass facility became operable at Essex Dam and a plan was instituted to seasonally close the South Canal that diverts flow from the river at this location. The downstream bypass has been shown to be reasonably effective for passing clupeids. A downstream bypass sluice also exists at the Lowell Hydroelectric Project (Pawtucket Dam) and was modified in 1993 to increase its effectiveness. Tests of this bypass structure in 1994 and 1995 indicate reasonable downstream passage for clupeids, but poor passage for Atlantic salmon smolts. Downstream fish passage evaluations are ongoing at both dams (Tech. Comm. Anad. Fish Mgmt. 1997).

4.2 MANAGEMENT UNIT DEFINITION

The Massachusetts in-river management area for American shad is the Merrimack River.

4.3 REGULATORY HISTORY

Currently there is a moratorium on commercial harvest of American shad in Massachusetts waters.

Under Massachusetts Marine Fisheries Laws, MGL Chapter 130: and Title 322: CMR, American shad may be taken by hook and line only. Section 4.12 of the CMR prohibits the landing of net caught shad, even when taken outside of Massachusetts waters in the EEZ or in the territorial seas of another state (Brady 2006).

> 322 CMR: (1987)
>
> 4.12: <u>Use of Nets for Taking Striped Bass (*Morone saxatalis*) or Shad (*Alosa sapidissima*).</u>
>
> (1) It is unlawful to off-load onto any vessel within waters under the jurisdiction of Massachusetts or to off-load onto any pier, wharf or other structure within Massachusetts any striped bass or shad which was harvested, caught or taken by any net.
>
> (2) It is unlawful for any vessel registered under the laws of the state as that term is defined in M.G.L.c.130, § 1 to harvest, catch or take any striped bass or shad by any net in any waters under the jurisdiction of Massachusetts or in those waters within the United States 200 miles exclusive economic zone bounded in such a way that the inner boundary is a line drawn in such a manner that each point on it is 200 nautical miles from the baseline from which the territorial sea is measured, as depicted on nautical charts of the National Oceanic and Atmospheric Administration.

Recreationally, anglers may possess six American shad per day caught by hook and line. There is a small catch and release recreational fishery in the lower Merrimack River (Brady 2006).

4.4 ASSESSMENT HISTORY

The Merrimack River was included in the 1998 ASMFC coastwide stock assessment (ASMFC 1998). Analysis was limited to a simple discussion of the trend in relative abundance of fish-lifted at the Essex Dam. The assessment stated that the fishway counts for the period of 1985 through 1995 varied without trend and there was no evidence of decline.

4.5 STOCK-SPECIFIC LIFE HISTORY

4.5.1 Growth

Length-at-age and weight-at-age were calculated for Merrimack River American shad using adult data collected in 1999, 2000, 2004, and 2005. Data for 2001 to 2003 should be added once scale samples are aged and data entry into an electronic database is complete. Since only adult data are available from the Merrimack, length and weight data from other systems were used to "anchor" the curve for the youngest ages. Additional length and weight data for age-0 fish from the Hudson were included; age-1 and 2 data were obtained from the Maine-New Hampshire near shore bottom trawl survey run along the New England coast. Weight-at-age and length-at-age curves are shown in Figure 4.2; growth curve parameters are in Table 4.1.

4.5.2 Reproduction

Merrimack American shad are iteroparous. Males returning to spawn are predominately age four through six; females are age five through seven. The percent of repeat spawning increased in recent years (see Section 4.8). The shad run in the Merrimack River begins in May and ends mid-July (Figure 4.3, Table 4.2).

4.6 HABITAT DESCRIPTION

The Merrimack River is formed by the junction of the Pemigewasset and Winnipesaukee rivers in Franklin, New Hampshire where it flows 185 km to the Atlantic Ocean in Newburyport, Massachusetts (MRWC 2006). It is the fourth largest river in New England and has nine major tributaries (Tech. Comm. Anad. Fish Mgmt. 1997). The average annual flow of the Merrimack is 8,000 cubic feet per second (cfs), measured at the mouth; however, extreme fluctuations often occur among seasons and even within a given month. The highest discharge ever recorded for the Merrimack (Lowell, Massachusetts) was 173,000 cfs in March of 1936. A historic low discharge of 199 cfs was recorded in 1923 (Tech. Comm. Anad. Fish Mgmt. 1997). In 2006, a near historic flood event occurred on May 15, when the river peaked near 103,000 cfs after multiple severe rain events struck the Merrimack Valley.

Three quarters of the Merrimack watershed is located in New Hampshire, covering 5,010 square miles. Nearly 80 percent of the land within 0.75 miles of the upper Merrimack River is currently undeveloped and consists of forest, farm, or wetland. Due in part to its undeveloped nature, the upper portion of the watershed has high water quality. The water quality becomes compromised as the river flows through the large industrial cities of Manchester, New Hampshire, and Lowell and Lawrence, Massachusetts. Recently problems with water quality are a direct result of development and an increase in impervious surfaces combined with sewer overflows and industrial pollution (MRWC 2006; USACE 2004).

4.7 RESTORATION PROGRAMS

In 1969 the Merrimack River Anadromous Fish Restoration Program was established to formalize restoration efforts. Cooperating agencies include the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), the U.S. Forest Service, the Massachusetts Division of Marine Fisheries, the Massachusetts Division of Fisheries and Wildlife, and the New Hampshire Fish and Game Department. The program is administered through the cooperating agencies and through a Policy Committee and a Technical Committee. The Restoration Program goals are (1) to strive for the realization of the full potential of the anadromous and resident fishery resources of the river in order to provide the public with high quality sport fishing opportunities and (2) to assist in providing for the long-term needs of the human population for food through development and management of the commercial fishery resources (Brady 2002; Tech. Comm. Anad. Fish Mgmt. 1997).

4.7.1 Restoration Objectives and Target

The Merrimack River Anadromous Fish Restoration Program developed a shad restoration plan for the Merrimack in 1997. The restoration target is directed at developing and maintaining a self-sustaining population of American shad in their historical habitat. Although the full restoration level for American shad in the Merrimack is unknown because of insufficient life history and habitat data, an interim objective has been set at an annual average of 35,000 adult American shad passing the Essex fish-lift in Lawrence, Massachusetts (Tech. Comm. Anad. Fish Mgmt. 1997).

The 1997 Strategic Plan lists the following key restoration components for American shad and river herring:

> Section 1.B.3. Assess the American shad and river herring populations in the Merrimack River and develop plans for their restoration.
>
> - Evaluate the shad and herring populations in the river.
> - Identify, quantify and map shad and herring spawning and rearing habitat throughout the basin.
> - Determine the need for and evaluate the effectiveness of intra-basin as well as inter-basin transfers of adult shad and river herring and continue and/or modify program as appropriate.
> - Evaluate and pursue opportunities for providing fish passage to facilitate restoration of river herring into currently blocked habitat.
> - Identify and quantify exploitation of adult shad and river herring within the Merrimack River Basin.
> - Evaluate the feasibility of implementing fish culture operations for American shad.

An updated version of the Strategic Plan for shad will be completed in 2007 (Brown 2006). Although subject to change, the current draft plan builds upon the previous plan and includes several new restoration targets. These include:

- Implementation of a fry culture and stocking program using Merrimack origin broodstock. Fry would be released upstream of Garvins Falls Dam, the fifth main stem obstruction. Monitoring and evaluation for this effort will be led by the USFWS.
- Establishment of trigger numbers for the 3rd-5th main stem obstructions (Amoskeag Dam, Hooksett Dam, and Garvins Falls Dam, all in New Hampshire). Trigger numbers would require initiation of fish passage construction at Hooksett and Garvins Falls.
- Restoration and annual migration of a self-sustaining population of American shad upstream of Garvins Falls Dam (Brown 2006).

4.7.2 Hatchery Evaluations

The first culture effort on the Merrimack occurred during the mid to late 1800s, and included fry stocking of Connecticut River origin American shad. A separate shad hatchery operated for approximately 10 years in Andover, Massachusetts during the late 1800s. Historic culture efforts were abandoned due to unregulated commercial harvest (Tech. Comm. Anad. Fish Mgmt. 1997).

More recent restoration efforts began with the stocking of Connecticut River origin eggs in the Merrimack over the period 1969 through 1978 (Table 4.3). Eggs were released in the Sewalls Falls area downriver to Lowell and Lawrence, Massachusetts.

4.7.3 Charles River American Shad Restoration Project

In 2005, the Massachusetts Division of Marine Fisheries initiated a program to restore a viable population of American shad to the Charles River, Massachusetts. This project is a long-term collaborative effort between the Division of Marine Fisheries and the USFWS, and includes a fry-stocking program modeled after successful programs implemented for the Chesapeake Bay (Hendricks 1995). The Charles River is the primary target for restoration due to (a) the availability of spawning and rearing habitat, (b) the availability of functioning fishways suitable for American shad passage, and (c) the historical significance of shad in this system. The Charles project is relevant to the Merrimack, because adult broodstock shad will be obtained from the Merrimack at the Essex Dam fish-lift in Lawrence, Massachusetts and spawned at regional federal hatcheries for stocking into the Charles River. Limited pilot production was conducted in 2005 to evaluate newly constructed hatchery infrastructure and to test rearing techniques; however, no fry were released (Brady *et al*. 2006; Ferry 2006)

In June and July 2006, 703 adult broodstock from the Merrimack River were injected with a luteinizing-releasing hormone analogue and salmon gonadotropin releasing hormone and were successfully spawned at the Nashua National Fish Hatchery, Nashua, New Hampshire. Broodstock were obtained via electrofishing below Essex Dam following a historic flood in the Merrimack River in May, which closed the fish-lift for the majority of the fish passage season. Initially, 4.3 million eggs were produced, and average egg viability was 50.7%. Fry survival from hatch to stock was 86.9%. All 1,785,622 stocked fry were immersed in an oxytetracycline bath to mark their otoliths prior to release. Following stocking in July, continuous water quality data were recorded by a YSI 6920 Sonde downriver of the stocking site (river km 22). In September, potential hatchery origin juveniles were detected during an electrofishing monitoring survey. Confirmation of marks will occur as soon resources are available. Returning adults will be sampled and examined for marked otoliths beginning in 2009.

4.7.4 Fish Passage Efficiency

The assessment of fish passage efficiency is ongoing for Essex and Pawtucket Dams by the Merrimack River Anadromous Fish Restoration Program. On average, between 1989 and 2001, only 17 percent of the shad that passed Essex Dam also passed through the fish-lift at Pawtucket Dam. In 2002 the USFWS conducted a radiotelemetry study to (a) determine the number of tagged American shad that pass Essex Dam and reach the tailrace for Pawtucket Dam and (b) to monitor American shad movements between the two dams. Telemetry study results indicated that American shad passage efficiency at Pawtucket requires improvement and unfavorable conditions in the tailrace are potentially preventing shad from advancing upriver through the fish-lift (Sprankle 2005). As a follow-up to the telemetry study, the Restoration Program has conducted multiple dye tests to examine both the general flow patterns in the Pawtucket tailrace and the attraction flow for the Pawtucket fish-lift. SCUBA divers also examined the tailrace for underwater structures that might repel shad from the Pawtucket fish-lift. No unusual structures were observed and dye test results are pending.

During high flood events, fish passage can be adversely affected (e.g., 2005; Table 4.2).

4.7.5 Trap and Transport

The transfer of adult shad from the Connecticut River to the Merrimack River took place from 1979 to 1985 and again from 1990 to 1996, and replaced the egg stocking effort. Transferred shad were released above major barriers on the river (Table 4.3). Intra-basin transfers have also occurred periodically, with the Essex Dam fish-lift and trapping facility as the source location. Since 1996, the stock relies solely on wild reproduction.

4.8 AGE

The maximum age reported for the Merrimack River is 10. Scale samples are aged using the method described by Cating (1953). Scales are mounted with clear tape to a glass slides and examined. Ageing is performed by two individuals, one of which has consistently aged shad in Massachusetts for most all years reported.

4.9 FISHERY DESCRIPTIONS

4.9.1 Commercial Fisheries

The historical record for commercial landings of American shad in Massachusetts begins in the late 1880s. Landings were reported annually beginning in about 1928. It is unknown if landings of American shad prior to 1945 are from inland or ocean waters (Tables 4.4 and 4.5). Since 1950, all landings were from ocean waters. Total kilograms of fish varied between several thousand kilograms to nearly 133,000 kg until the mid 1950s (Table 4.4; Figure 4.4). The highest catch, 957,000 kg, occurred in 1957 and was landed by purse seine. This fishery was short lived as gill nets and pound nets became the primary gear (Table 4.5; Figure 4.5). After 1967, catches became more sporadic; one exception was a period of increased landings from 1981 to 1989.

Currently, there is a moratorium on commercial shad harvest in all waters of the Commonwealth of Massachusetts. This moratorium has been in place since 1987 (see Section 4.3). Massachusetts has been granted *de minimis* status.

4.9.2 Bycatch Losses

The only landings reported for Massachusetts are those compiled by the NMFS. These shad, if landed, are considered illegal harvest due to the moratorium on commercial shad harvest in Massachusetts. Less than 1,000 kg have been landed annually since 1990.

4.9.3 Recreational Fisheries

The Commonwealth has five river systems supporting American shad sport fisheries. These are the Merrimack River on the north shore, the North and South rivers or Indianhead River of Pembroke and Marshfield, the Palmer River of Rehoboth, and the Connecticut River. Coastal runs of American shad in the state are relatively small compared to those of other New England systems and the mid and south Atlantic regions. Fisheries are predominantly catch and release. Systems with the largest potential for support of natal American shad, the Connecticut and Merrimack rivers, are undergoing restoration. Both systems have governmental, multi-state, and multi-agency anadromous fish restoration and management plans in effect (Brady 2005).

During the period of 1984 through 1988, the Massachusetts Division of Fisheries and Wildlife obtained sport fishery data for American shad in the Merrimack River (Table 4.6). The creel census was conducted downriver of the Essex Dam and only in the Lawrence area. This river reach is known to have a relatively strong recreational American shad fishery. In years of good fish passage, anglers in the Lowell area of the river's main stem also seek American shad. More recently anglers have shifted their efforts to the large influx of striped bass (Tech. Comm. Anad. Fish Mgmt. 1997).

4.10 FISHERY-INDEPENDENT SURVEYS

4.10.1 Adult Catch Data

Efforts for the restoration of the Merrimack River American shad population have been ongoing since 1969. Each year a sub-sample of fish are collected at the Essex Dam fishway and examined for biological data (length and weight measured, and scales taken for age analysis).

The Essex Dam fish-lift generally operates between May 1 and July 15; however, start and end dates may vary slightly by year, due to fluctuations in water level and discharge, and the presence of anadromous fish (i.e., the lift will remain open as long as reasonable numbers of fish are attempting to pass). The May to July timeframe encompasses the period that American shad are present in the lower portion of the Merrimack at or below Essex Dam. The fish-lift operates seven days per week, generally from 0800 to 1600 hours throughout the spring fish passage season (Slater 2005).

The total number of shad lifted at the Essex Dam slowly increased from about 5,000 fish in 1983 to a peak of 76,000 in 2001 (Table 4.7; Figure 4.6). Since then, the lift numbers decreased about 40 percent to 45,000 in 2004. In 2005, the Merrimack experienced significant high water events that resulted in a closure of the fish-lift for the majority of the season, which severely impacted the passage of American shad. Less than 6,500 shad were passed in 2005. Not all returning adult shad move above the dam. Some shad are known to spawn below the dam in the lower Merrimack. The percent of adults above the Essex dam that were stocked ranged from zero to 100 (Table 4.8). Because of the variables affecting passage at the Essex Dam and the unknown proportion of adults that spawn below the dam, we have not used passage numbers as an index of adult abundance.

Length and weight data were collected infrequently for American shad in the Merrimack. The most consistent data collection effort occurred after 1999 resulting from implementation of the Atlantic States Marine Fisheries Commission's Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring. Length frequency data, by sex, are summarized for the period 1999 to 2005 (Table 4.9). No trend was apparent among years in mean length or weight-at-age (Table 4.10). Males are generally smaller than females. An interesting trend of increasing size was noted for both sexes. In 1999, most males fell between 439-499mm TL, but by 2004 and 2005 most were 479-559 mm TL (Table 4.9). The same trend is noted for females: most were 479-519 in 1999, and by 2003 through 2005 this shifted to 519-579 mm TL. Annual mean length indicates that the fish caught in the most recent years (2003-2005) are similar in size to those caught back in the mid-1980s (Table 4.11).

4.10.2 Age Composition

Ages for 2001 and 2003 were estimated using a length-at-age key developed from existing Merrimack River American shad data from 1999, 2000, 2004, and 2005. Age frequency was not available prior to 1999. A noticeable change in age structure occurred in recent years for both sexes. In 1999 and 2000, males ranged in age from three to seven, but most were age-4 and 5 (Table 4.12). In 2003 and2004, a much broader age structure was present, with fish up to age ten. The same expansion in age structure from 1999 to 2004 was observed for females. The change in age structure for both sexes is supported by the increase in the size range of fish as indicated in Table 4.9.

Mean age increased over the short time periods when shad were collected. Mean age of males was low in the early 1980s (4.27) and increased to 5.8 in 2003 and 2004, then declined to 4.9 in 2005. For females, mean age followed the same increase from the 1980s, to a high of 7.2 in 2003, then declined to 6.1 in 2005. The percent of repeat spawning increased from 31% in 1999 to 57% in 2005. Females had the highest percent repeat spawners in 2004 at 50%, which decline to 36% in 2005 (Table 4.13).

An evaluation of annual mean length and annual mean age suggested that ageing techniques might have differed between the periods 1983-1985 and 1999-2005. Mean age at a given mean length was much lower for the earlier period than those in the later period. Moreover, mean age did not perceptively increase with mean length in the earlier period. These discrepancies suggest ageing techniques differed between the two time periods and ages in the earlier time period are suspect.

4.10.3 Juvenile Catch Data

No juvenile survey has been conducted on the Merrimack River; however, juvenile sampling is expected upon implementation of the updated strategic plan for restoration of American shad to the Merrimack River (Brown 2006).

4.11 ASSESSMENT APPROACHES AND RESULTS

4.11.1 Adult Passage

We evaluated the relationship between the annual number of stocked fish and fish passage numbers of returning fish five and six years later at the Essex Dam. No relationship was evident (Figure 4.7). This is reasonable given the variable stocking effort and the small percentage of adults that were stocked above the Essex Dam in most years. We also evaluated the relationship between number of adults above the dam (stocked and wild) in a given year with number of adults passed at the dam five and six years later. Again, no relationship was evident (Figure 4.7). This lack of relationships suggests that the percent of the population passed above the dam, the in-river mortality from emigration from the system, the at sea mortality for juvenile or adult fish, or a combination of the three varies among years.

During high flood events, fish passage can be adversely affected (e.g., 2005; Table 4.2; Figure 4.6).

4.11.2 Total Mortality Estimates

Total mortality (Z) estimates were made by calculating within-year catch curves (natural log of age on age and natural log of number of repeat spawners on spawning marks; Crecco and Gibson 1988). Based on apparent problems with age estimates prior to 1999 (Section 1), we confined our analyses of total mortality to 1999 to 2005. For males, Z was 1.28 in 1999 and declined until 2003 to 0.36, and then it increased to 0.99 in 2005 (Table 4.12; Figure 4.8). Z-estimates from repeat spawn marks were similar, except in 2000. For females, Z was highest in 2000 (1.95) and 2003 (2.37) and declined to 0.79 in 2005. Z-estimates developed from repeat spawn data were similar in pattern to the Z-estimates developed from age data (Table 4.12; Figure 4.8). In all cases but one, the estimates of Z exceeded levels of Z_{30} developed in Section 1. Results suggest some level of adult mortality either in-river from downriver passage or at sea from bycatch or predation.

4.11.3 Status Summary

Current status of American shad in the Merrimack River remains unknown. Although lift counts at the lowermost dam exceeded the target for several years in the late 1990s and early 2000s, we do not know how the target number compares to the potential for this stock. Passage numbers at the lowermost dam have declined since 2001 and this is a cause for concern. We suggest that there is a need to identify if this decline is related to relative stock size or to changes in passage efficiency. Total mortality rates have been high, but are now declining. With the decline in mortality, mean age and size have increased. Mortality rates however, remain well above our estimate of natural mortality suggesting that mortality from downstream passage or bycatch and predation at sea is occurring. Habitat access and loss are a major concern on this river. Continued efforts to improve passage efficiency and to identify sources of adult mortality are warranted.

4.12 BENCHMARKS

A benchmark value of Z_{30}= 0.64 was calculated for New England American shad stocks (See Section 1.1.5).

4.13 CONCLUSIONS AND RECOMMENDATIONS

Current status of American shad in the Merrimack River remains unknown. The decrease in fish passage counts at Essex Dam since 2001 warrants further investigation. Work should identify the factor(s) contributing to this decline (i.e., has relative stock size decreased, has passage efficiency changed, how have environmental conditions affected run size and passage?). Total mortality estimates generally exceed estimates of Z_{30}, but mean age and size has increased in recent years. The high mortality rates suggest that mortality from downstream passage or bycatch and predation at sea is occurring. Habitat access and loss are a major concern on this river. Continued efforts to improve passage efficiency and to identify sources of adult mortality are needed.

We suggest that the following be completed:

1. Update and implement the strategic plan for the restoration of American shad to the Merrimack River by the Anadromous Fish Restoration Program (Brown 2006) to address fish passage problems, restoration strategies, and improved monitoring.
2. Make efforts to identify and reduce all sources of mortality whether during ocean residency or in-river.
3. Develop an index of age-0 abundance for the Merrimack stock downriver of the lowermost dam.
4. Develop an index of adult abundance for shad below the lowermost dam to aid in evaluating passage efficiency.
5. Evaluate the effects of river conditions such as flow and temperature on fish passage numbers.
6. Collect at least 300 adult American shad by time stratified samples from the fish-lift at the lowermost dam for annual data on sex, size, and age composition.
7. Document and develop an estimate of recreational harvest of American shad on the Merrimack River.
8. Improve fish passage throughout the system.

LITERATURE CITED

ASHP (Atlantic Salmon History Project). 2006. Available: home.gwi.net.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. American Shad Stock Assessment, Peer Review Report. Washington, D.C.

Brady, P. 2002. Report to the Atlantic States Marine Fisheries Commission on Massachusetts' Restoration plan for the Merrimack River. Massachusetts Division on Marine Fisheries. Washington, D.C.

Brady, P. 2005. Commonwealth of Massachusetts Shad and River Herring Annual Report to the Atlantic States Marine Fisheries Commission, for 2004. Washington, D.C.

Brady, P. 2006. Commonwealth of Massachusetts Shad and River Herring Annual Report to the Atlantic States Marine Fisheries Commission, for 2005. Washington, D.C.

Brady, P., B. Chase and K. Ferry. 2006. Anadromous fish restoration. Available: www.mass.gov.

Brown, J. 2006. *Draft,* A strategic plan for the restoration of American shad to the Merrimack River watershed. Prepared for the Technical Committee for Anadromous Fishery Management of the Merrimack River Basin.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

ConNe-UMB (Conservation Biology of New England – University of Massachusetts at Boston). 2006. Mills and dams. Available: www.umb.edu.

Crecco, V. and M. Gibson. 1988. Methods of estimating fishing mortality rates on American shad stocks. Atlantic States Marine Fisheries Commission, Special report, Washington, D.C.

Ferry, K.H. 2006. Anadromous fish restoration in Massachusetts Bay, American shad propagation. Massachusetts Division of Marine Fisheries, Hubline Progress Report. Gloucester, Massachusetts.

Hendricks, M.L. 1995. The contribution of hatchery fish to the restoration of American shad in the Susquehanna River. Pages 329-336 *in* H. L. Schram and R. G. Piper, eds. Uses and effects of cultured fish in Aquatic ecosystems. American Fisheries Society, Symposium 15, Bethesda, Maryland.

History of the fishways. Amoskeag Fishways 2006. Available: www.amoskeagfishways.org.

MRWC (Merrimack River Watershed Council, Inc.) 2006. Geographical introduction to the Merrimack River watershed. MRWC, Available: www.merrimack.org.

NPS (National Park Service). 2006. The Merrimack River. NPS. Available: www.nps.gov.

Slater, C. 2005.Merrimack River Anadromous Fish Investigations Massachusetts Federal Aid Report,.F-45-R-23, Boston.

Sprankle, K. 2005. Interdam movements and passage attraction of American shad in the lower Merrimack River main stem. North American Journal of Fisheries Management. 25: 1456-1466.

Technical Committee for the Anadromous Fishery Management of the Merrimack River Basin and Advisors to the technical committee. 1997. Strategic Plan and Status review, Anadromous Fish Restoration Program, Merrimack River. Boston.

USACE (U.S. Army Corps of Engineers). 2004. Merrimack River Watershed Assessment Study. U.S. Army Corps of Engineers. Available: www.nae.usace.army.mil.

Table 4.1 Weight-at-age and length-at-age growth curve parameters for American shad in the Merrimack River, Massachusetts. Data 1999, 2000, 2004, and 2005.

Gompertz Growth Model (Weight)	**Female**		**Male**	
	Estimate	**SE**	**Estimate**	**SE**
W_o	0.321	0.179	1.104	0.455
G	8.670	0.558	7.168	0.397
sg	0.620	0.027	0.590	0.023
von Bertalanffy Growth Model (Length)	**Female**		**Male**	
	Estimate	**SE**	**Estimate**	**SE**
L_∞	724.200	5.928	641.100	4.760
K	0.203	0.003	0.243	0.004
t_0	-0.277	0.006	-0.249	0.006

Table 4.2 American shad counted in (a) May, (b) June, (c) July, and (d) May-July by year at Essex Dam on the Merrimack River, Lowell, Massachusetts. (*) Indicates ladder not used. (**) Indicates a ladder estimate.

(a)

Day	1989	1990	1991	1992	1993*	1994**	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1	1	0**	8	0	0	0	0	0	0								
2	0	2**	0	0	0	0	0	0	0								
3	0	0**	3	0	0	0	0	0	0		21						
4	0	1**	0	0	0	0	0	0	0	3		17					
5	0	0**	3	0	0	0	0	0	0	1		17				37	
6	0	0**	17	0	0	0	0	0	0		5			1		3	
7	0	1**	15	0	0	0	0	0	0		13			15		49	
8	0	1**	7	0	0	0	0	0	0		18	228	231	523		34	
9	0	1**	20	1	0	0	12	0	0		3	373	383	809		130	
10	0	7**	12	2	3	0	27	0	0		71	89	1,221	375		230	
11	0	11**	13	22	1	0	11	0	0		202	53	2,307	1,203	31	305	
12	0	3**	115	7	0	0	11	0	0		566	8		552	3	891	0
13	0	0**	753	29	11	0	2	0	0		654	7		384	5	1,402	
14	0	0	1,577	118	0	0	3	0	2	4	943	7	3,560	55		1,640	0
15	0	2**	1,910	282	0	0	1	0	4	1	968	164	2,475			1,404	0
16	0	8**	1,364	227	17	2	2	0	10	19	1,326	1,109	3,527		15	69	0
17	0	5**	364	627	10	1	26	0	1	25	2,266	2,552	4,503				28
18	5	1**	110	706	32	0	3	0	1	348	3,498	2,113	3,264		614		17
19	12	2**	107	314	7	0	2	0	2	918	5,007	1,512	3,449		909		31
20	2	7**	328	490	13	0	22	0	4	373	2,527	2,041	4,318		165	292	425
21	4	3**	352	903	67	0	73	0	2	1,589	627	1,263	4,109		332	2,478	189
22	15	0**	731	323	101	1	346	4	7	1,414	1,707	1,013	4,281	288	1,140	1,933	26
23	53	1**	297	795	108	4	308	2	10	1,596	1,448	1,758	4,245	404	1,437	1,511	2
24	10	1**	325	816	388	17	873	0	118	1,467	1,913	932	2,649	1,376	692	1,688	2
25	60	0**	492	324	358	12	708	0	391	2,504	2,298	1,436	3,595	1,585	1,012	37	0
26	64	1**	512	263	701	72	761	16	0	882	1,916	622	3,946	2,984	1,765		
27	116	6**	533	290	591	222	776	26	636	1,535	1,365	2,113	2,218	3,336	113		
28	48	1**	372	717	158	25	442	18	612	2,292	1,211	1,514	2,128	778	7		
29	19	15**	465	272	146	26	0	204	1,049	1,205	1,216	145	133	3,601			
30	38	40**	532	363	415	0	1,142	0	1,280	1,908	2,254	5,029	364	5,449			
31	138	26	450	1,045	0	21	195	12	989	1,157	2,081	3,762	325	3,620			
Total	**585**	**26**	**11,787**	**8,936**	**3,127**	**403**	**5,746**	**282**	**5,118**	**19,241**	**36,124**	**29,877**	**57,231**	**27,338**	**8,240**	**14,133**	**720**

Table 4.2 cont. American shad counted in (a) May, (b) June, (c) July, and (d) May-July by year at Essex Dam on the Merrimack River, Lowell, Massachusetts. (*) Indicates ladder not used. (**) Indicates a ladder estimate.

(b)

Day	1989	1990	1991	1992	1993*	1994**	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1	62	8**	262	395	305	55	164	20	499	1,095	2,949	4,044	1,539	1,465			5
2	123	19**	272	440	213	43	948	91	91	874	3,593	6,732	554	3,029	2,515	939	2
3	230	113**	247	345	250	368	552	515	351	475	2,085	6,204	391	1,292	4,510	3,260	48
4	808	186	330	689	117	270	749	929	497	430	1,779	3,767	178	145	3,153	3,113	747
5	104	364	350	595	156	138	140	1,141	1,183	293	1,304	1,519		820	4,317	1,985	737
6	426	255	261	550	552	307	372	602	1,416	606	1,171	371		1,659	4,279	2,930	273
7	21	94	75	511	150	126**	222	335	1,379	308	988	180	100	611	6,445	2,138	878
8	4	98	295	66	109	119**	274	139	771	257	1,128	264	2,138		3,181	2,469	374
9	314	247	184	121	170	356	509	71	986	395	790	223	2,752	2,808	3,307	1,224	135
10	19	102	270	323	186	417**	686	49	1,637	1,099	384	1,260	922	2,662	1,993		201
11	8	27	200	1,282	166	207	343	472	1,451	495	256	3,357	1,744	2,494	1,566	393	271
12	0	66	152	682	119	264	335	722	1,291	429	372	1,217	1,259	421	941	686	84
13	9	253	124	601	520	174	528	443	968	304	511	619	1,247	955	1,146	1,049	8
14	20	189	101	556	309	12**	342	556	785		568	1,393	800	249	643	1,981	8
15	277	60	78	1,016	285	43	227	312	783		315	778	834	386		2,063	0
16	140	55	73	662	503	47	156	387	446		154	632	627	516	116	2,118	254
17	56	289	72	673	478	287	106	658	516		187	858	309	833		1,296	4
18	532	52	66	277	140	111	36	1,814	256		239	908	775	715	229	781	0
19	341	315	39	297	119	154	287	465	386		241	461	515	721	1,343	697	0
20	169	157	91	130	120	46	356	616	305		206	1,221	169	321	289	91	0
21	59	136	90	254	53	29	213	108	116		115	830	366	339	1,345	117	32
22	365	545	120	330	18	40	176	45	147		139	1,557	226	336	979	145	
23	438	239	77	46	101	21	112	29	223		161	1,612	359		309	77	790
24	431	409	50	128	42	12	52	9	177		157	818	245	109	136	175	8
25	575	365	43	152	44	39	23	0	126		194	425	121	789	81	267	41
26	32	218	99	103	23	23	61	0	162		85	246	30	275	149	364	40
27	2	72	32	94	29	33	43	52	12		70	213	100	178	361	144	2
28	0	76	35	112	34	41	13	32	98		56	167	123	1,652	823	86	200
29	69	46	25	49	40	11	49	88	26		64	222	56	388	401	101	24
30	39	55	7	56	13	32	9	41	71		40	115	64	201	81	92	9
Total	**5,673**	**4,970**	**4,120**	**11,535**	**5,364**	**3,151**	**8,083**	**10,741**	**17,155**	**7,060**	**20,301**	**42,213**	**18,543**	**26,369**	**44,638**	**30,781**	**5,175**

Table 4.2 cont. American shad counted in (a) May, (b) June, (c) July, and (d) May-July by year at Essex Dam on the Merrimack River, Lowell, Massachusetts. (*) Indicates ladder not used. (**) Indicates a ladder estimate.

(c)

Day	1989	1990	1991	1992	1993*	1994**	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1	493	103	23	86	29	32	0	83	75		10	180	62	98	45	86	0
2	274	39	20	23	2	0	0	104	21		26	110	61	182	9	34	0
3	206	37	22	10	8	0	0	76	2			192	59	271	7		55
4	0	43	10	6	0	0	0	10	0								0
5	39	121	8	15	0	54	19	13	30			103	137	73			38
6	240	82	4	20	47	1	2	6	85			51	87	67		81	155
7	190	43	12	6	0	26	3	7		132		74	0	54			
8	55	37	25	13	11	1	4			290			0	49			
9	21	45	3	12	5	7	4			285			0	20			26
10	8	15	6	9	0					184			0	24			7
11	14	26	18	9	0				20	107			135	18			2
12	5	46	18	6	0				40	48			116	23			1
13	7	10	10	9	3					158			41				7
14	29	22	12	25	0					72							108
15	8	16	0	9	3					68							73
16	0	21	0	1						109			77				29
17	3	3	0	10					16	3			42				
18	0	14	0	0					54	84			50				42
19	6	1	0	0					5	19			45				19
20	0	5	0	23					40	14			31				
21	16	0	0	1						5							
22	0	0	0	10						12							
23	0	0	0	5													
24	1	0	0	2													
25	0	1	0	0													
26	1	3	0	0													
27	0	7	0	9													
28	1	0	0	1													
29	0	0	0	2													
30	0	0	0	1													
31	0	2	0	2													
Total	**1,617**	**742**	**191**	**325**	**108**	**121**	**32**	**299**	**388**	**1,590**	**36**	**710**	**943**	**879**	**61**	**201**	**562**

Table 4.2 cont. American shad counted in (a) May, (b) June, (c) July, and (d) May-July by year at Essex Dam on the Merrimack River, Lowell, Massachusetts. (*) Indicates ladder not used. (**) Indicates a ladder estimate.

(d)

Day	**1989**	**1990**	**1991**	**1992**	**1993***	**1994****	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Total	**7,875**	**5,738**	**16,098**	**20,796**	**8,599**	**3,675**	**13,861**	**11,322**	**22,661**	**27,891**	**56,461**	**72,800**	**76,717**	**54,586**	**52,939**	**45,115**	**6,457**

Table 4.3 Stocking history of American shad eggs and adult transfers in the Merrimack River, Massachusetts.

Release Year	Number	River of Origin	Release Location
		American Shad Eggs	
1969	940,000	Connecticut	Above Hooksett Dam
	1,420,000	Connecticut	Above Pawtucket Dam
1970	450,000	Connecticut	Above Sewalls Falls Dam
	540,000	Connecticut	Above Pawtucket Dam
1971	1,330,000	Connecticut	Above Sewalls Falls Dam
	568,000	Connecticut	Above Pawtucket Dam
1972	3,200,000	Connecticut	Above Sewalls Falls Dam
1973	1,900,000	Connecticut	Above Sewalls Falls Dam
1974	4,300,000	Connecticut	Above Sewalls Falls Dam
1975	3,970,000	Connecticut	Above Essex Dam
1976	4,430,000	Connecticut	Above Hooksett Dam
1977	1,700,000	Connecticut	Above Pawtucket Dam
1978	780,000	Connecticut	Above Garvins Falls Dam
		Adult American Shad Releases	
1979	690	Connecticut	Above Hooksett Dam
	370	Connecticut	Above Pawtucket Dam
1980	1,231	Connecticut	Above Pawtucket Dam
1981	400	Connecticut	Above Garvins Falls Dam
	700	Connecticut	Above Pawtucket Dam
1982	770	Connecticut	Above Garvins Falls Dam
1983	1,079	Connecticut	Above Garvins Falls Dam
1984	98	Connecticut	Above Garvins Falls Dam
	77	Merrimack	Above Garvins Falls Dam
	1,433	Connecticut	Above Sewalls Falls
1985	110	Merrimack	Nashua River in Hollis
	979	Connecticut	Above Garvins Falls Dam
1986	214	Merrimack	Concord River
	127	Merrimack	Nashua River in Pepperell
	673	Merrimack	Above Garvins Falls Dam
1990	750	Connecticut	Above Garvins Falls Dam
	250	Connecticut	Above Sewalls Falls
1991	251	Connecticut	Above Sewalls Falls
	754	Connecticut	Above Garvins Falls Dam
1992	2,082	Connecticut	Above Garvins Falls Dam
	180	Connecticut	Nashua River above Mines Falls
1993	1,282	Connecticut	Above Garvins Falls Dam
1994	1,173	Connecticut	Above Garvins Falls Dam
1995	250	Connecticut	Manchester Reach
	292	Merrimack	Manchester Reach
1996	640	Connecticut	Manchester Reach
	40	Merrimack	Manchester Reach

Table 4.4 Commercial landings (kg) of American shad in Massachusetts, 1885-2005 (data from NMFS).

Year	Landings	Year	Landings	Year	Landings
1885		1926		1967	221546
1886		1927		1968	958
1887	57935	1928	13504	1969	2222
1888	113256	1929	40075	1970	610
1889	101930	1930	23522	1971	174
1890		1931	65340	1972	218
1891		1932	24394	1973	523
1892		1933	27443	1974	1437
1893		1934		1975	479
1894		1935	133294	1976	0
1895		1936		1977	87
1896	49658	1937	20909	1978	348
1897		1938	23522	1979	1350
1898	12632	1939	37026	1980	3659
1899		1940	41382	1981	7275
1900		1941		1982	12807
1901		1942	14375	1983	5881
1902	9148	1943	49658	1984	12937
1903		1944	8712	1985	9714
1904		1945	12720	1986	26180
1905	39640	1946	4530	1987	17772
1906		1947	22782	1988	22055
1907		1948	14985	1989	5933
1908	169448	1949	4835	1990	2439
1909		1950	12066	1991	278
1910		1951	31407	1992	134
1911		1952	21127	1993	184
1912		1953	17337	1994	125
1913		1954	3877	1995	198
1914		1955	16291	1996	58
1915		1956	315244	1997	328
1916		1957	964506	1998	769
1917		1958	184999	1999	97
1918		1959	602478	2000	117
1919	27007	1960	12458	2001	458
1920		1961	34804	2002	185
1921		1962	2875	2003	483
1922		1963	9365	2004	11
1923		1964	17119	2005	227
1924	74923	1965	10542		
1925		1966	5053		

Table 4.5 Losses of American shad in Massachusetts waters: commercial landings by gear, recreational harvest, and scientific losses, 1950-2005. There were no records of removals recorded for recreational harvest, scientific studies, and stocking prior to 1998. PS = purse seine; GN = gill net; PN = pound net.

Year	Commercial Landings by Gear (kg)				
	PS	GN	Trawl	PN	Other
1950	3311	7362	566	828	
1951		28532	610	2265	
1952		15943	3093	2091	
1953	7405	6229		3703	
1954		174	1002	2701	
1955	6360	6403	305	3223	
1956	302306	261	87	12502	
1957	957405	3485	392	3223	
1958	175416	2483	436	6665	
1959	589846	1263	1525	9845	
1960		348	1263	10846	
1961	25265	392	87	9060	
1962			44	2831	
1963			218	9148	
1964	392		2483	14244	
1965			2483	8059	
1966			218	4835	
1967	215753		44	5663	
1968				871	
1969			305	1917	
1970			392	218	
1971				174	
1972		131		87	
1973		305	44	174	
1974		479	44	915	
1975		436	44		
1976					
1977			87		

Year	Commercial Landings by Gear (kg)					Recreational Harvest (kg) (MRFSS A+B1)	Scientific Studies (number)	Stocking (number)
	PS	GN	Trawl	PN	Other			
1978		305		44				
1979		218		1133				
1980		2222		784	653			
1981		4400	131	2657	87			
1982		7579	218	5009				
1983		5271	131	479				
1984		12894		44				
1985		9583	44		87			
1986		25613	392		174			
1987		17598	44		87			
1988		21911	87	70	87			
1989		4138	1394	174	174			
1990		1908	534					
1991		236	42					
1992	1	109	22		2			
1993	11	171	2					
1994		125						
1995		193			4			
1996		54			4			
1997		276	51					
1998		457	312			1495	≤ 100	≤ 1,000
1999		85	12				≤ 250	≤ 1,000
2000		51	66			4868	≤ 250	≤ 2,000
2001		361	28		68	1733	≤ 250	≤ 3,000
2002		185					≤ 225	≤3,500
2003		434	13	36				
2004		11						
2005		227						

Table 4.6 Creel survey data for the recreational fishery for American shad in the lower Merrimack, Massachusetts, 1984-1988.

Category	**1984**	**1985**	**1986**	**1987**	**1988**
Expanded Total Hours	9934	7516	4190	8947	6324
Average Angling Day (hours)	2.46	3.27	2.33	1.79	2.7
Expanded Total Anglers	4020	2239	1747	5011	2330
No. Shad Creeled	1642	870	148	0	474
No. Shad Released	4525	3763	1383	3668	3162
Total Shad Caught	6167	4633	1531	3668	3162
No. Shad Caught / Hour	0.62	0.62	0.37	0.41	0.5
No. Shad Caught / Angler	1.53	2.07	0.82	0.73	1.35

Table 4.7 Number of American shad at fish passage facilities on the Merrimack River, Massachusetts, 1983-2005.

Year	**Essex Dam**	**Pawtucket Dam Fish Passage Complex**	**Amoskeag Dam Fish Ladder**
1983	5,629	Not in operation	Not in operation
1984	5,497	Not in operation	Not in operation
1985	12,793	Not in operation	Not in operation
1986	18,173	1,630	Not in operation
1987	16,909	3,926	Not in operation
1988	12,359	1,289	Not in operation
1989	7,875	940	4
1990	6,013	443	0
1991	16,098	428	12
1992	20,796	6,491	7
1993	8,599	1,679	0
1994	4,349	383	No counts made
1995	13,857	5,255	1
1996	11,322	400 (incomplete)	0
1997	22,586		
1998	27,891		
1999	56,465		
2000	72,781		
2001	76,717		
2002	54,586		
2003	52,939		
2004	45,115		
2005	6,457	716	

Table 4.8 Number of American shad adults stocked and wild returns collected at Essex Dam in the Merrimack River, Massachusetts.

Year	Adults Stocked	Wild Adult Returns at Lift	Stocked + Returned Fish	% Stocked
1978				
1979	1,060		1,060	100.0%
1980	1,231		1,231	100.0%
1981	1,100		1,100	100.0%
1983	1,079	5,629	6,708	16.1%
1984	1,608	5,497	7,105	22.6%
1985	1,089	12,793	13,882	7.8%
1987	0	16,909	16,909	0.0%
1988	0	12,359	12,359	0.0%
1989	0	7,875	7,875	0.0%
1990	1,000	6,013	7,013	14.3%
1991	1,005	16,098	17,103	5.9%
1992	2,262	20,796	23,058	9.8%
1993	1,282	8,599	9,881	13.0%
1994	1,173	4,349	5,522	21.2%
1995	542	13,857	14,399	3.8%
1996	680	11,322	12,002	5.7%
1997		22,586	22,586	0.0%
1998		27,891	27,891	0.0%
1999		56,465	56,465	0.0%
2000		72,781	72,781	0.0%
2001		76,717	76,717	0.0%
2002		54,586	54,586	0.0%
2003		52,939	52,939	0.0%
2004		45,115	45,115	0.0%
2005		6,457	6,457	0.0%

Table 4.9 Length-frequency of American shad collected at the Essex Dam, Merrimack River, Massachusetts.

TL (mm)	**Males**							**Females**						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
319														
339														
359										1				
379	2					1								
399	2	3					3							
419	7	4	6			4	1							
439	30	7	6		3	12	4	1	2					
459	41	23	16		4	12	10	1	0	1				1
479	34	32	24		5	34	20	11	5	1			1	7
499	13	18	29		8	29	22	23	11	6			7	12
519	3	13	25		9	21	11	16	46	21		7	16	10
539		2	7		7	17	11	4	33	24		7	34	18
559	1		2		2	13	16	4	14	20		20	26	22
579					1	6	4	3	3	13		25	19	15
599						3	3	1		1		13	7	5
619										1		2	8	3
639												2	1	1
														1
Total	**133**	**102**	**115**	**0**	**39**	**152**	**105**	**64**	**114**	**89**	**0**	**76**	**119**	**94**

Table 4.10 Annual mean total length (mm) and weight (g)-at-age for American shad in the Merrimack River, Massachusetts.

Age	Mean TL-at-Age					Mean Weight-at-Age				
	1999	2000	2004	2005	All Years	1999	2000	2004	2005	All Years
Males										
3	407.0	404.4	415.5		407.4	575.0	670.0	600.0		633.3
4	437.2	450.7	438.8	450.5	442.7	781.3	931.3	769.4	780.0	819.7
5	453.2	468.6	472.3	466.9	464.1	887.0	1062.2	990.0	925.3	958.3
6	475.3	489.2	495.2	497.1	491.4	982.4	1182.9	1098.9	1124.4	1102.7
7		505.0	527.4	540.9	533.6		1180.0	1335.3	1384.7	1354.9
8			546.1	523.6	538.1			1494.4	1320.0	1432.1
9			548.8	569.0	554.6			1490.0	1640.0	1532.9
10			562.5		562.5			1500.0		1500.0
Females										
3										
4		464.7	470.0	489.0	468.4		1250.0	850.0	1230.0	1197.5
5	484.0	502.5	515.1	517.0	503.5	1170.8	1408.6	1398.0	1407.9	1334.9
6	500.1	522.2	529.4	526.5	521.6	1358.3	1525.6	1439.2	1415.0	1448.0
7	539.0	531.9	553.8	547.9	546.8	1450.0	1612.4	1686.4	1683.5	1661.7
8	550.0	574.0	581.8	592.8	582.5	1825.0	2250.0	1877.3	1901.3	1898.2
9			571.7		571.7			2083.3		2083.3
10			610.0		610.0			2350.0		2350.0

Table 4.11 Annual mean total length and weight for American shad in the Merrimack River, Massachusetts.

Year	Males					Females				
	N	Mean TL (mm)	SD	Mean Weight (g)	SD	N	Mean TL (mm)	SD	Mean Weight (g)	SD
1983	29	480.3		1000.0		14	545.0		1700.0	
1984	19	503.9				29	568.6			
1985	41	500.9				34	548.1			
1986						0				
1987						0				
1988						0				
1989	17	509.1		1200.0		22	555.2		1800.0	
1990										
1991	61	487.5		1100.0		46	529.6		1600.0	
1992	22					26				
1993	6					26				
1994										
1995	101	456.8		900.0		59	519.3		1500.0	
1996										
1997										
1998										
1999	133	452.1	26.2	874.8	158.9	64	500.2	29.3	1322.6	251.8
2000	102	466.8	27.9	1043.3	221.6	114	516.5	23.8	1512.5	255.6
2001	115	480.2	30.9	1043.1	204.4	89	530.5	32.8	1470.9	276.9
2002										
2003	39	494.9	34.2	1159.5	269.5	76	561.2	26.0	1924.2	327.3
2004	152	489.1	41.0	1081.6	290.6	119	542.4	32.2	1589.6	345.8
2005	105	497.5	42.3	1114.0	328.3	95	535.0	38.0	1518.0	358.2

Table 4.12 (a) Age structure and (b) repeat spawn data for American shad in the Merrimack River, Massachusetts.

(a)

Age	Males												
	1983	**1984**	**1985**	**1991**	**1992**	**1993**	**1999**	**2000**	**2001***	**2002**	**2003***	**2004**	**2005**
3							2	5	4		1	1	8
4							35	23	14		4	18	30
5							68	41	19		5	50	35
6							19	21	23		7	37	18
7								1	9		5	18	5
8									8		5	9	2
9									3		3	5	
10									1		2	2	
Total	**29**	**19**	**41**	**61**	**22**	**6**	**124**	**91**	**82**		**30**	**140**	**98**
Mean Age	**4.27**	**4.53**	**4.37**	**4.7**	**4.4**	**4.5**	**4.8**	**4.9**	**5.6**		**5.8**	**5.8**	**4.9**

Age	Females												
	1983	**1984**	**1985**	**1991**	**1992**	**1993**	**1999**	**2000**	**2001***	**2002**	**2003***	**2004**	**2005**
3													
4								6	3		0	1	1
5							26	22	14		4	20	19
6							24	49	18		8	37	39
7							2	21	17		15	44	17
8							2	1	8		16	11	8
9									11		4	3	
10									1		0	1	
Total	**14**	**29**	**34**	**46**	**26**	**26**	**54**	**99**	**73**		**48**	**117**	**84**
Mean Age	**5.1**	**5.1**	**4.9**	**5.3**	**5.2**	**5.0**	**5.6**	**5.9**	**6.4**		**7.2**	**6.5**	**6.1**

* Estimated from MA length at age key, see text for discussion on males in 2001 and 2003.

Table 4.12 cont. (a) Age structure and (b) repeat spawn data for American shad in the Merrimack River, Massachusetts.

(b)

Repeat	**Males**												
	1983	**1984**	**1985**	**1991**	**1992**	**1993**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
0							86	66				64	42
1							30	23				40	27
2							8	2				19	16
3												8	10
4												6	3
5												2	
6												1	
Total							**124**	**91**				**140**	**98**
Mean Repeat							**0.37**	**0.30**				**1.01**	**1.03**
% Repeat							**0.31**	**0.27**				**0.54**	**0.57**

Repeat	**Females**												
	1983	**1984**	**1985**	**1991**	**1992**	**1993**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
0							35	63				59	54
1							10	26				34	18
2							8	8				13	8
3							1	2				7	4
4												3	
5												1	
6													
Total							**54**	**99**				**117**	**84**
Mean Repeat							**0.54**	**0.48**				**0.84**	**0.55**
% Repeat							**0.35**	**0.36**				**0.50**	**0.36**

Table 4.13 Merrimack River American shad total instantaneous (Z) mortality and survival (S) rates.

Year	Males					Females				
	Age		%Repeat	Repeat Spawn Marks		Age		%Repeat	Repeat Spawn Marks	
	Z	S		Z	S	Z	S		Z	S
1999	1.28	0.28	31%	1.32	0.27	1.24	0.29	35%	1.15	0.32
2000	0.67	0.51	27%	2.44	0.09	1.95	0.14	36%	1.28	0.28
2001*	0.74	0.48				0.62	0.54			
2002										
2003*	0.36	0.70				2.37	0.09			
2004	0.65	0.52	54%	0.73	0.48	1.27	0.28	50%	0.85	0.43
2005	0.99	0.37	57%	0.71	0.49	0.79	0.45	36%	0.75	0.47

* Age estimated

Figure 4.1 Merrimack River Watershed, Massachusetts and New Hampshire with dams shown (map from USACOE 2004).

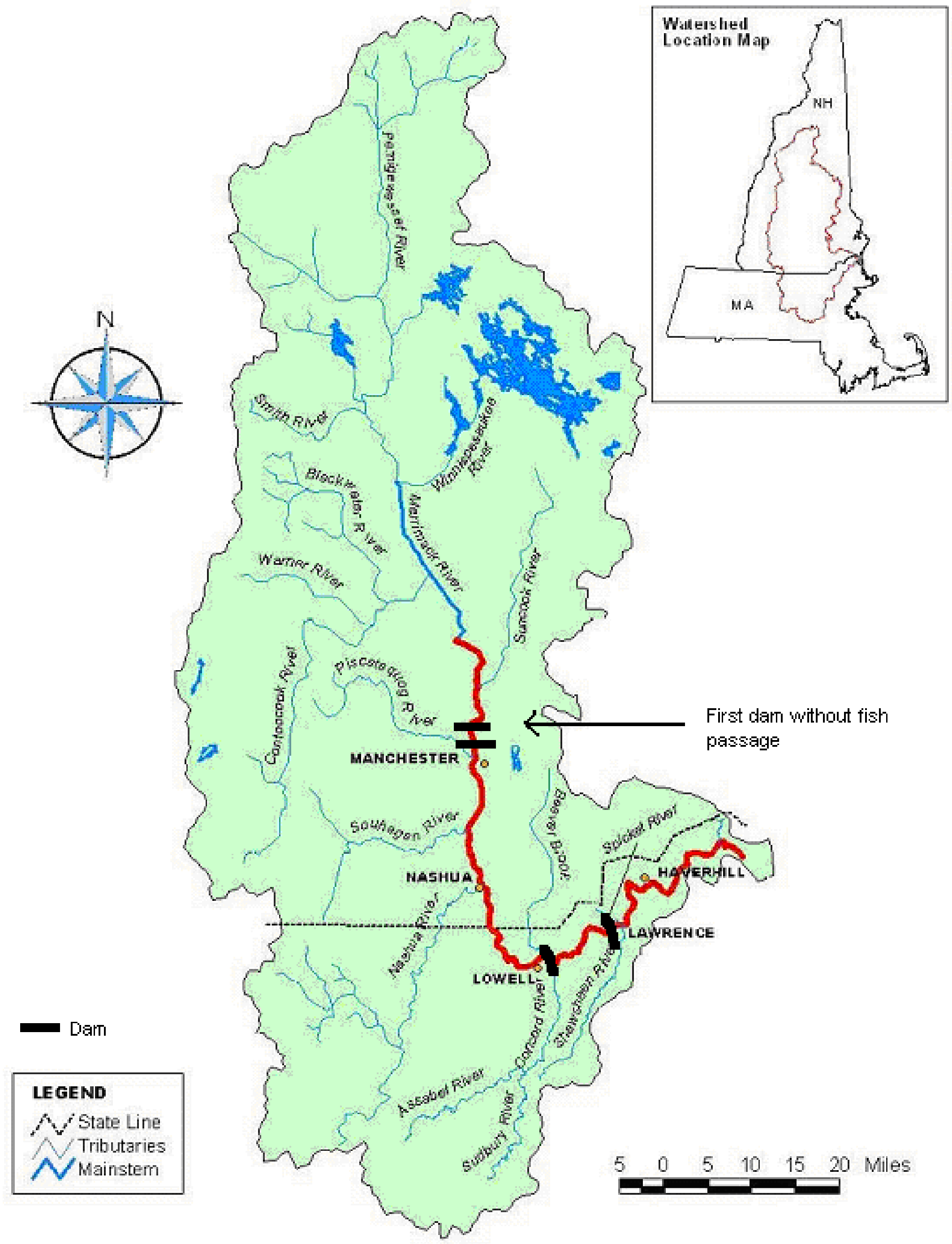
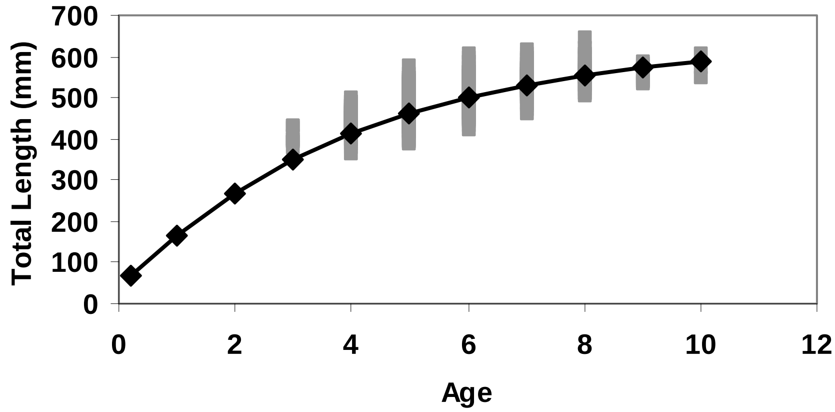


Figure 4.2 Weight-at-age (Gompertz) and length-at-age (von Bertalanffy) growth curves for (a) male and (b) female American shad in the Merrimack River, Massachusetts.

(a) Male



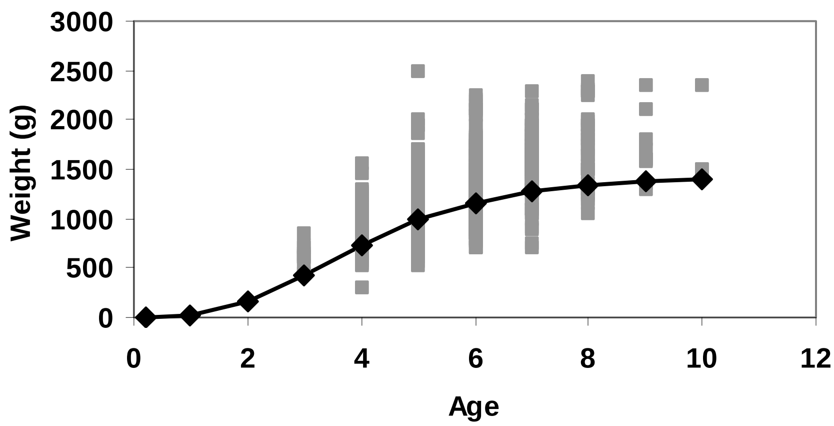
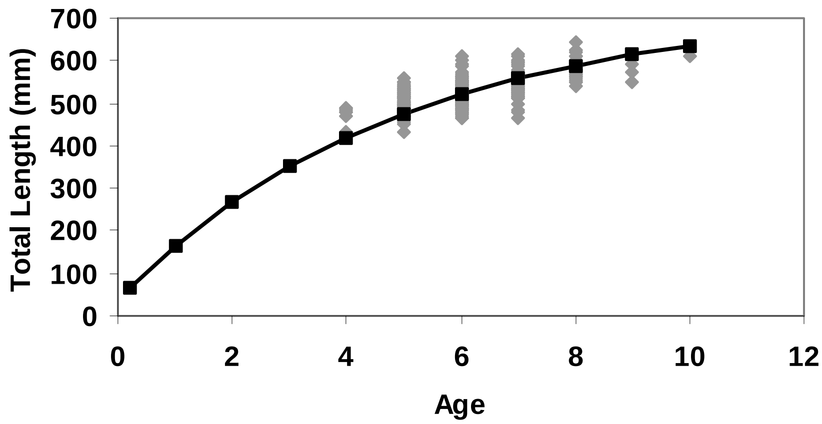


Figure 4.2 cont. Weight-at-age (Gompertz) and length-at-age (von Bertalanffy) growth curves for (a) male and (b) female American shad in the Merrimack River, Massachusetts.

(b) Female



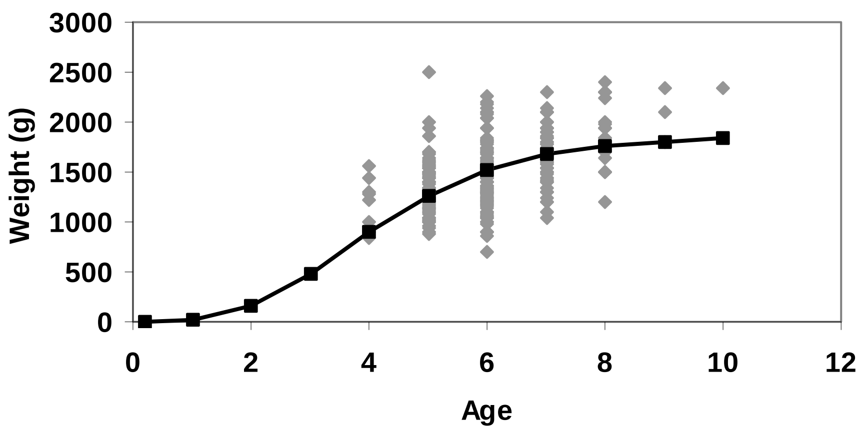
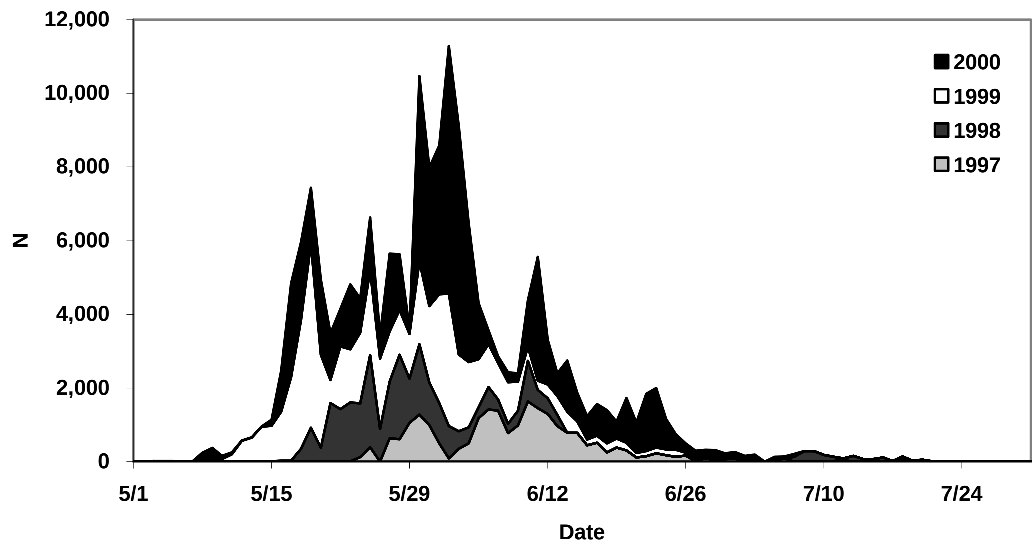


Figure 4.3 Daily fish lift counts of American shad at the Essex Dam fish-lift, Merrimack River, Massachusetts, 1997-2005.



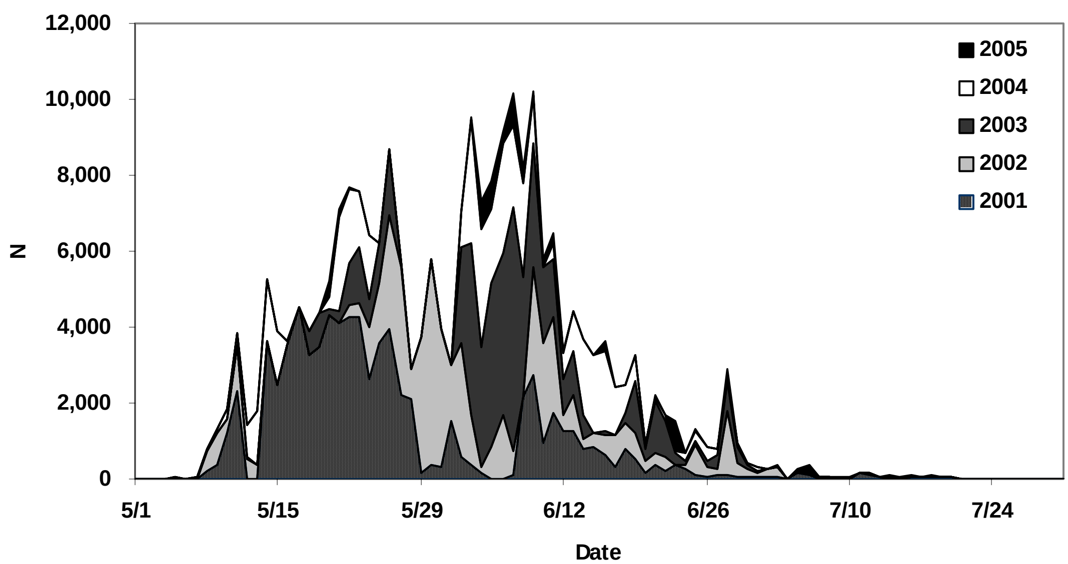


Figure 4.4 Commercial landings of American shad in Massachusetts.

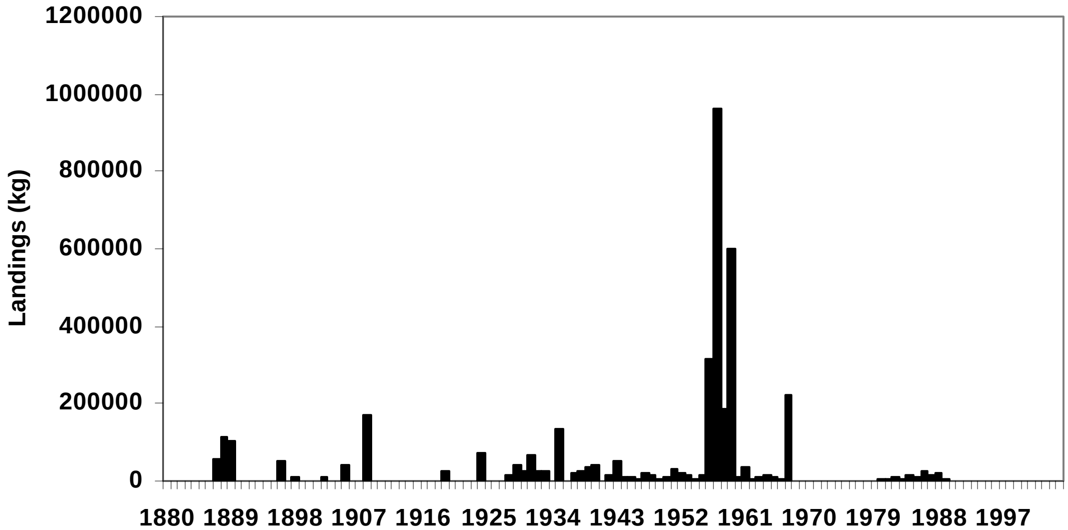
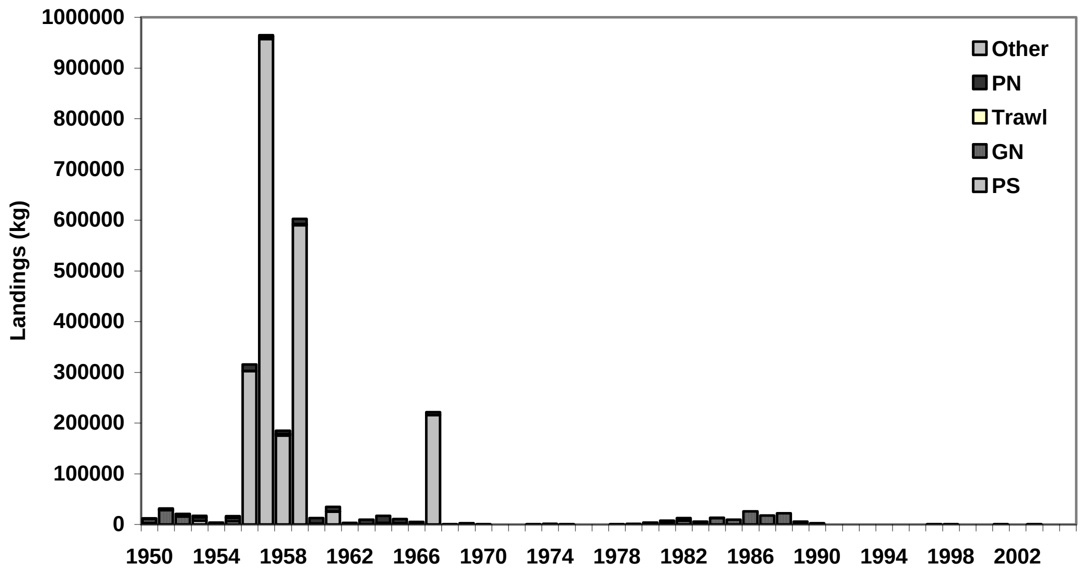


Figure 4.5 Commercial landings of American shad in Massachusetts waters by gear (a) 1950-2005 and (b) 1980-2005.

(a)



(b)

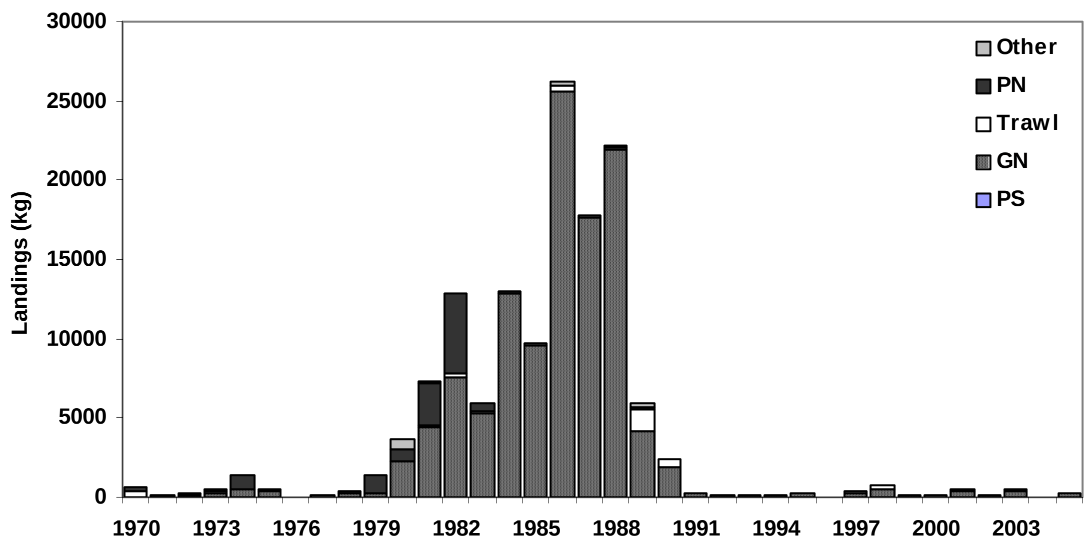


Figure 4.6 Number of American shad lifted at the Essex Dam, Merrimack River, Massachusetts, 1983-2005.

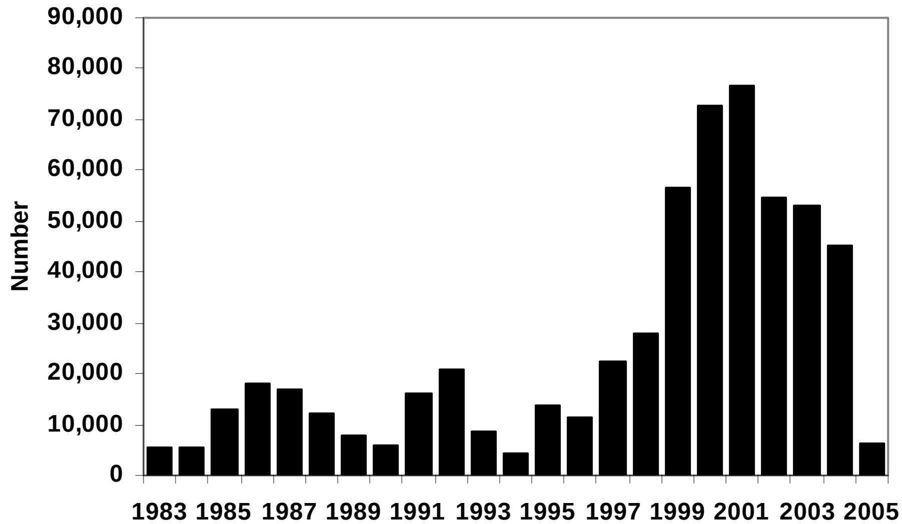
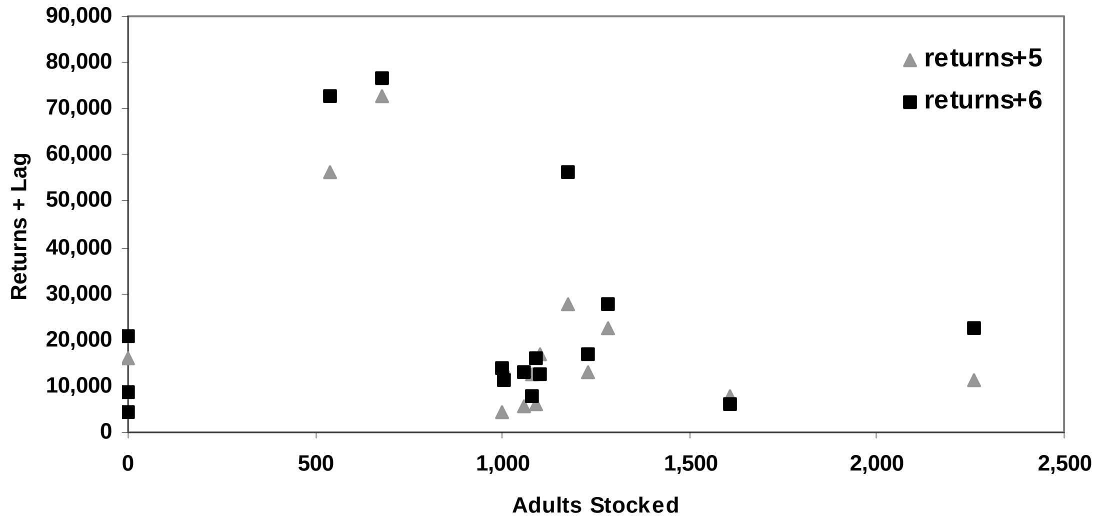


Figure 4.7 Relationship between returning American shad adults, both (a)stocked and (b) stocked and wild fish, and adult returns five and six years later in the Merrimack River, Massachusetts.

(a)



(b)

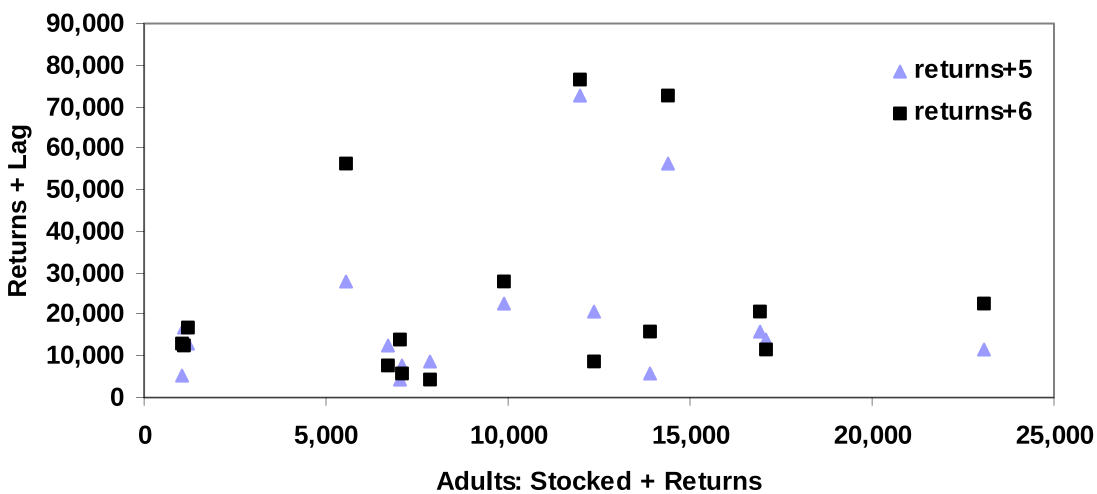
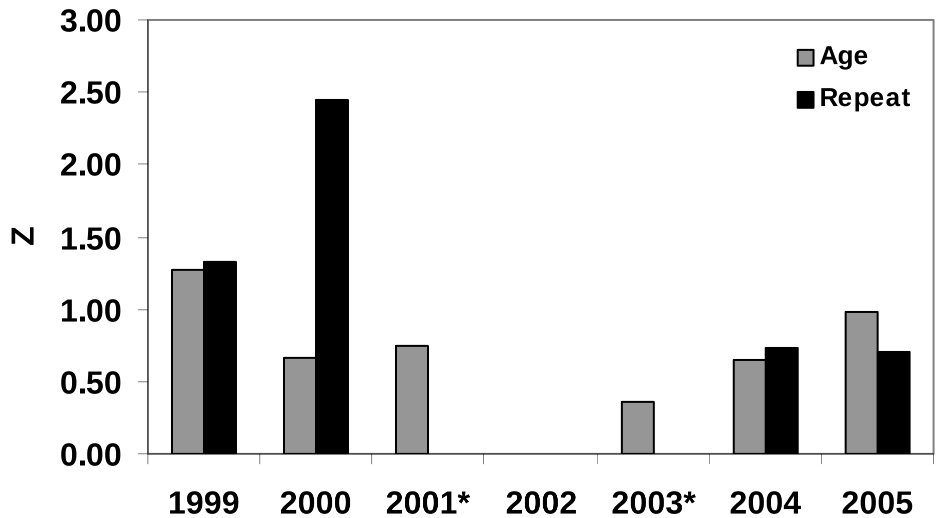
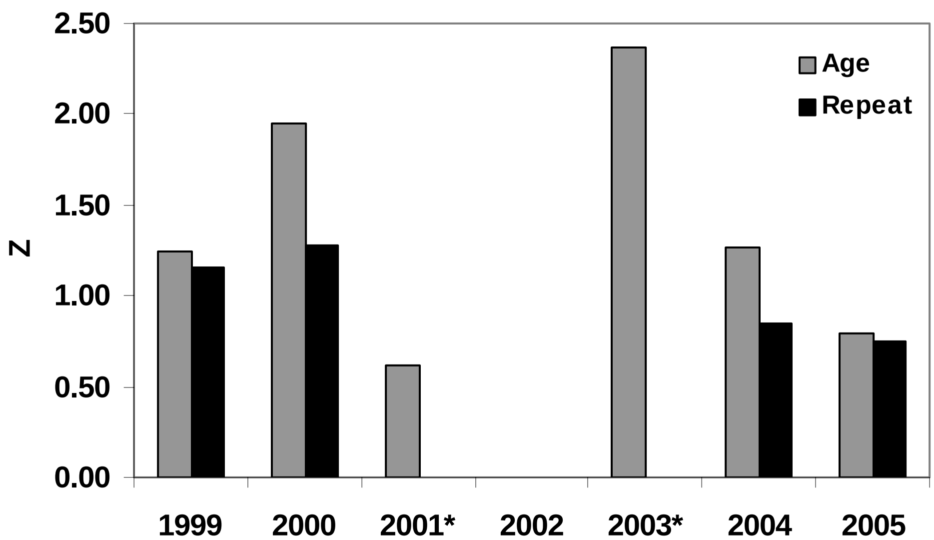


Figure 4.8 Merrimack River American shad total instantaneous (Z) mortality rates for (a) males and (b) females

(a)



(b)



Section 5
Status of the Pawcatuck River, Rhode Island American Shad Stock

Contributors:

Phillip Edwards and Laura M. Lee
Rhode Island Department of Environmental Management, Fish and Wildlife
277 Greatneck Road, West Kingston, Rhode Island 02892

Kathryn Hattala and Andrew Kahnle
Hudson River Fisheries Unit, New York State Department of Environmental Conservation
21 S. Putt Corners Road, New Paltz, New York 12561

5.1 INTRODUCTION

The Pawcatuck River stock of American shad originates from Connecticut River broodstock and is the only self-sustaining population of American shad currently known to exist within Rhode Island (D. Erkan, pers. comm.; P. Edwards, pers. comm.). The only other run of American shad in Rhode Island known to exist is a remnant population in the Runnins River (Erkan 2002), but there is no monitoring program in place for this stock. This report evaluates the status of American shad in the Pawcatuck River.

5.2 MANAGEMENT UNIT DEFINITION

The Rhode Island Department of Environmental Management (RIDEM) has management authority over American shad occurring in the state's fresh and marine waters [RI Gen. Laws § 20-1-2].

5.3 REGULATORY HISTORY

Currently there is a moratorium on harvest of American shad in Rhode Island's fresh and marine waters [RIDFW Reg. Part 2.3 2006; RIMF Reg. Part 7.17 2006a]. Prior to 2003, there were no regulations governing catches of American shad in marine waters. In 2003, Rhode Island enacted a time-period closure to achieve the 40 percent effort reduction in the American shad commercial ocean-intercept fishery mandated by the Atlantic States Marine Fisheries Commission (ASMFC) (ASMFC 1999) [RIMF Reg. Part 7.17 2002]. A closure of the commercial fishery in marine waters went into effect January 1, 2005 in compliance with Amendment 1 of the ASMFC's Shad and River Herring Management Plan (ASMFC 1999) [RIMF Reg. Part 7.17 2006a].

5.4 ASSESSMENT HISTORY

The first formal assessment of the Pawcatuck River stock was performed in 1988 as part of an ASMFC assessment of multiple American shad stocks from selected rivers along the Atlantic Coast (Gibson *et al*. 1988). A generalized Shepherd stock-recruitment (S-R) model was used to estimate maximum sustainable yield (MSY) and the fishing mortality rate that produces MSY (F_{msy}). The fit of the model was poor (R^2 =0.35), which may be due to limited inputs (nine data points). The results of the 1988 assessment suggested that the Pawcatuck River stock was depleted, but not experiencing overfishing at that time. The resulting F_{msy} values would only be considered usable for a stock that was "restored." No restoration goals were stated in this assessment.

Gibson (1993) also modeled the relationship of spawning adult females and recruitment for the 1974 through 1987 year-classes using a Ricker-type curve. The model incorporated June flow events during the spawning period and was parameterized to account for both transplanted and native spawning adult females. The results suggested no compensation in the transplanted females and so the transplant component was removed from the final model. The fitted model explained 69.5 percent of the variation in recruitment. Gibson (1993) concluded that recruitment of American shad in the Pawcatuck River was a linear function of female spawners and June flow rates.

The Pawcatuck River stock underwent a second formal assessment and evaluation in 1998 as part of a peer-reviewed assessment of stocks from selected rivers along the Atlantic Coast (ASMFC 1998a). The evaluation of the Pawcatuck River stock was limited to an analysis of general trends, due to data limitations. As such, the status of the stock could not be quantitatively determined, but the review of trends led the assessment committee to conclude that the stock was probably not overfished (ASMFC 1998a, 1998b).

Rhode Island's American shad recovery plan indicates that the stock is in recovery (Edwards 1999b).

5.5 STOCK-SPECIFIC LIFE HISTORY

The American shad stock in the Pawcatuck River is iteroparous. The population was regenerated by stocking efforts in the 1970s and 1980s (see Section 5.7.3). In 2001, juvenile American shad were collected from Pawcatuck River for microchemistry analysis of otolith isotope ratios. The results of this analysis will serve as a baseline for stock identification.

5.6 HABITAT DESCRIPTION

The Pawcatuck Watershed, also known as the Wood-Pawcatuck Watershed, encompasses a 308-square mile (197,000 acres) area across southwestern Rhode Island and southeastern Connecticut (Desbonnet 1999; Erkan 2002; Figure 5.1). Approximately 80 percent of the watershed is located in Rhode Island (Erkan 2002). One of the major rivers within the watershed is the Pawcatuck River, which originates in southern Rhode Island and generally flows southeast and south where it serves as a natural border between southern Connecticut and Rhode Island before emptying into Little Narragansett Bay (Figure 5.2). The Pawcatuck River is approximately 48 km long. The lower 2.5 km are tidal, with a small, breached dam located at river kilometer (rkm) 2 of the Pawcatuck River (measuring from its confluence with the Pawcatuck River Estuary; Erkan 2002).

The Pawcatuck River supports spawning runs of several anadromous fish species, including American shad. The annual runs once supported lucrative in-river fisheries on which Native Americans and colonists relied (URI EDC 2006). The importance of these fisheries to residents was reflected in historic legislation aimed at protecting fish passage (Clark 1984; Buckley and Nixon 2001). For example, laws passed in 1735 and 1767 prohibited the construction of obstacles on the Pawcatuck River that would hinder the passage of fish (Clark 1984). The favor shown towards the river fisheries eventually waned as people placed more value on rivers as a source of waterpower for the growing textile industry (Buckley and Nixon 2001). By 1896, upstream shad passage along the Pawcatuck River was completely blocked by dams (Mansueti and Kolb 1953). The construction of the dams was accompanied by decreased water quality (O'Brien and Stolgitis 1977). As the number of textile factories increased, more wastewater was discharged into the river. The growing number of mills also drew more people into the area, which led to an increase in the municipal waste discharged into the river. Anadromous fish runs disappeared from most rivers and the small populations that remained were heavily fished. A few remnant runs of American shad persisted and one still exists in the Runnins River (Erkan 2002). The Pawcatuck River's native population of American shad was extirpated for about one hundred years (O'Brien 1979).

There are currently 24 dams throughout the Pawcatuck watershed, many of which were built over a hundred years ago and are no longer functional (Desbonnet 1999). Eight dams are on the main stem of the

Pawcatuck River (Figure 5.2). Currently, it is thought that American shad returning to the Pawcatuck River spawn in the 11-kilometer river section between Potter Hill and Bradford dams (Edwards, pers. comm.; D. Erkan, pers. comm.). These are the only dams on the Pawcatuck River that are equipped with fishways and the one at Bradford has not been suitable for passage of American shad (see Section 5.7.4; Edwards, pers. comm.; Edwards 2004-2006). It is not known if American shad spawn in the 11-km stretch below the Potter Hill Dam.

5.7 RESTORATION PROGRAMS

5.7.1 Recovery Target

The state of Rhode Island has informally adopted a recovery target of 5,000 spawning adults—the restoration level recommended by Richard St. Pierre from the U.S. Fish and Wildlife Service (R. St. Pierre, meeting of the ASMFC American Shad and River Herring Technical Committee, January 1999). This target was based on the numbers of spawning adults observed in past returns and river size. The target level is greater than the maximum number of American shad that have been observed at the Potter Hill Dam fishway on the Pawcatuck River in any year. For this reason, achieving the target is not an ASMFC compliance requirement for the state.

5.7.2 Restoration Objectives

An anadromous fish restoration plan for Rhode Island was published in 2002 (Erkan 2002). The plan is intended to serve as a tool for identifying and prioritizing activities that will facilitate the restoration of anadromous fish species to the state's coastal streams. Central to the plan is the identification of sites within the state's watersheds capable of providing passage for migrating adults and juveniles into unutilized and underutilized habitats. Recommendations for improving existing fishways or constructing new fishways aim to minimize passage-induced mortality in a cost-effective manner. The plan also considers reintroduction of spawning broodstock to be another critical component of restoration efforts.

Recent and upcoming initiatives for anadromous fish habitat restoration in other systems are summarized by Edwards (2004-2006).

5.7.3 Stocking Efforts

Initial efforts to restore American shad to the Pawcatuck River began in 1972 (Phillips 1972; Guthrie 1973, 1974; Table 5.1). Eggs were collected from ripe females taken from the Connecticut River, fertilized, and then transplanted into the Pawcatuck River (Phillips 1972; Guthrie 1973, 1974). The stocking of fertilized eggs was deemed unsuccessful and so the RIDFW began stocking fingerlings and spawning adults in 1975 (Guthrie 1975; O'Brien 1977–1981). Stocking of fingerlings ended in 1980 and stocking of adults ended in 1985 (Guthrie 1975; O'Brien 1977–1986). Since 1986, the Pawcatuck River stock has solely relied on wild reproduction and is considered a self-sustaining run.

5.7.4 Fish Passage

The Denil fishway at the Potter Hill Dam (km 11) on the Pawcatuck River is the primary survey site for monitoring returning adult American shad (Figure 5.2). The Potter Hill Dam, completed in 1903, is approximately eight feet in height and is the first intact dam on the Pawcatuck River (Erkan 2002; URI EDC 2006). There has been an ongoing concern regarding the passage efficiency of the fishway (Edwards, pers. comm.; D. Erkan, pers. comm.). RIDFW biologists observed that during periods of high flow, the ladder is completely submerged, hindering the passage of migrating American shad. In 1995, the RIDFW sought assistance from Dick Quinn, a hydraulic engineer with the U.S. Fish and Wildlife Service

(USFWS), to evaluate the condition and function of various fishways in Rhode Island, including the fish ladder at Potter Hill Dam (Powell 1996, 1997). Quinn concluded that the bottom of the fishway was approximately one foot lower than designed. This resulted in increased current velocity in the fishway during periods of high flow, limiting or precluding shad from passing during those periods. The recommendation was to install 12-inch spacer boards in the slot below each baffle in order to reduce water velocity in the fishway and enable American shad to ascend the ladder earlier and more easily. The spacer boards have since been used during the course of the fish run.

Another factor affecting the efficiency of passage at the Potter Hill Dam is the attraction flow created by broken gates on the opposite side of the dam (D. Erkan, pers. comm.). While most fish have no difficulty ascending the fishway, the attraction flow draws migrating fish away from the entrance to the fish ladder. The RIDFW is taking steps to correct this problem.

The next dam beyond Potter Hill on the Pawcatuck River is the Bradford Pond Dam (km 22; Erkan 2002; Figure 5.2). A Denil fishway exists at the Bradford Dam, but an erosion problem has negatively affected operation of the fish ladder (Edwards, pers. comm.). American shad are unable to pass the fishway in its current state. Plans to repair the fishway are underway (Edwards 2004-2006). The necessary modifications should be completed by the fall of 2007.

The RIDFW is working with outside partners to address passage issues associated with the Shannock Mill Pond, Horseshoe Falls, and Kenyon Mill Pond dams (Edwards, pers. comm.; Edwards 2004-2006; Figure 5.2). Currently, a feasibility study is being developed to determine the best approach for facilitating passage at these sites. The options include construction of fishways and partial or total removal of the dams. Projects to improve passage efficiency are intended to provide anadromous fish access to upstream nursery and spawning areas in the Pawcatuck River that were previously inaccessible to these species.

There are a number of projects aimed at restoring and improving fish passage in other waterways throughout Rhode Island. These include restoring runs on the Pawtuxet, Ten Mile, and Blackstone rivers; and installing fish ladders at dams on the Three Mile River.

5.8 AGE

Scale samples collected from RIDFW's sampling programs were pressed between glass slides and aged using the approach described by Cating (1953). The age of each fish and number of spawning marks were recorded. Regenerated scales are not considered reliable for ageing. Two groups have carried out most of the ageing work for American scales since the re-establishment of the spawning run in the Pawcatuck River in the late 1970s. The first group processed the majority of scales from 1979–1992 and the second group aged archived scales collected from 1993–1997 and scales sampled from 2000 to the present. Biologists from both groups have worked together to ensure consistency of methodology in the collection, processing, and age determination of scale samples.

In considering the Pawcatuck system, the short length of the river (44 km at most) reduces residency time—freshwater marks are much smaller than marks on fish from larger rivers of several hundred (or more) km. Spawning marks may also not always be obvious, given the short length of river.

Due to concerns with ageing, the age data were used in this report as a trend indicator only.

5.9 FISHERY DESCRIPTION

5.9.1 Brief Overview of Fisheries

Currently there is a moratorium on American shad harvest in Rhode Island fresh and marine waters. A small non-directed recreational catch-and-release fishery exists in the freshwater portions of the Pawcatuck River. A complete closure of the commercial fishery in Rhode Island marine waters was enacted in 2005 [RIMF Reg. Part 7.17 2006a].

5.9.2 Commercial Fishery

American shad have been landed in Rhode Island since at least the late 1800s (Figures 5.3). It is unknown if the early reported harvest in the late 1800s occurred from a combination of inland and ocean waters. After 1950, all commercial landings were from ocean waters on fish of mixed stock origin (Figure 5.4).

Prior to 1942, commercial landings were fairly low, with the exception of two peaks, one in the early 1940s and the other just prior to the turn of the 19th century (Table 5.2; Figure 5.3). In these early years, floating fish traps and occasionally pound nets landed the majority of American shad. Landings were relatively low in most years from 1942 to 1980, yielding an annual average of 2,387 kg (Figures 5.3 and 5.4). During this period, pound nets were no longer landing American shad, though the floating fish traps continued to harvest shad (Table 5.3). In 1963, commercial trawling began and outperformed the fish traps in eight of the next fourteen years. American shad landings demonstrated a marked increase beginning in the early 1980s and peaked in 1988 at over 55,000 kg. The commercial landings of American shad taken during the 1980s were among the highest on record, averaging 26,500 kg for the time period. The 1980s was also the most active time period for the commercial gill-net fishery, though rarely landing more American shad than the floating fish traps or trawls during the time period. The proportion of landings attributed to the gill-net fishery substantially decreased in the early 1990s and has been fairly low since. Reporting of commercial American shad landings by miscellaneous gears increased in the 1990s and 2000s. Between 2000 and 2005, an average of 17,114 kg of American shad were landed in Rhode Island per year.

The first step in closing the mixed stock fishery, as per Amendment 1 of ASMFC (1999), occurred in 2003 calling for a 40 percent decrease in effort. Rhode Island instituted a time-period closure of the commercial fishery that resulted in a large decrease in landings; the total weight landed in 2003 was 17,548 kg, which is 56 percent less than the 2002 estimate of 39,552 kg [RIMF Reg. Part 7.17 2002]. In 2004, annual commercial landings were just over 6,600 kg—an estimated 62 percent less than the 2003 landings. The final closure of the commercial ocean-intercept fishery in the beginning of 2005 had a significant impact on the landings for that year; the 2005 landings estimate of 304 kg was the lowest recorded for Rhode Island [RIMF Reg. Part 7.17 2006a]. A change in the gear types dominating the commercial fishery for American shad is also evident following the implementation of these management measures. Prior to the regulations, American shad were primarily exploited by floating fish traps since the mid-1970s, accounting for nearly 70 percent of commercial landings from 1975 to 2003. However, the fish traps were responsible for less than one percent of the American shad landed in Rhode Island in 2004 and 2005. Almost all the commercial landings for 2004 and 2005 are attributed to miscellaneous gears. The trawl fishery landed 26% of the American shad catch in 2004 and 32% of the landings estimated for 2005. Commercial landings of American shad were reported in Rhode Island throughout the year, but the majority of landings occur from May through August, based on recent data from 1990 through 2005 (Table 5.4; Figure 5.5).

Commercial harvest is reported through Interactive Voice Recording (IVR) and the Standard Atlantic Fisheries Information System (SAFIS). The IVR is a phone-in system designed to monitor quotamanaged species, though other landings are reported. The implementation of the SAFIS reporting was in response to federal [50 CFR Part 648] and state [RIMF Reg. Part 19.14 2006b] regulations. The SAFIS requires seafood dealers to collect detailed information on commercial catches landed and purchased in Rhode Island. The reports are submitted electronically over the web. Dealers that successfully demonstrate utilization of the SAFIS are relieved of the state requirement of calling in landings via the computerized IVR system. In addition to SAFIS all commercial harvesters are required to fill out a logbook detailing all of their catch and effort directed in commercial fisheries. The SAFIS collects trip level information including vessel name, vessel identification (state registration or U.S. Coast Guard Documentation Number), Rhode Island commercial license number, port landed, species caught, reported quantity, unit of measure, date landed, and price. As of March 2006, all Rhode Island-licensed seafood dealers are required to submit electronic reports to the SAFIS [RIMF Reg. Part 19.14 2006b]. In addition to the data collected via SAFIS, the Rhode Island Harvester Logbook collects trip level catch and effort information including gear type, gear hauls, and area fished. The commercial harvest reported for Rhode Island via SAFIS is considered a complete census.

Both SAFIS and the RI Harvester Logbook were developed in accordance with data standards developed by the Atlantic Coastal Cooperative Statistics Survey Program (ACCSP). Commercial landings data are reported to NMFS and ACCSP, who may further process data to ensure compatibility with other states that may employ different survey methods.

Biases

Only non-confidential data are available from the NMFS on-line query, so landings reported by species may be misleading due to data confidentiality. Other caveats associated with these data are discussed at the following website: http://www.st.nmfs.gov/.

Rhode Island staff expressed concern that commercial landings of hickory shad have been reported as American shad. The biologist responsible for Rhode Island's port sampling (see below) noted that hickory shad were sometimes misidentified as American shad (N. Calabrese, pers. comm.; P. Edwards, pers. comm.). This suggests that estimates of American shad landed in Rhode Island by commercial vessels are biased high; however, the amount of commercial landings that have been misidentified is unknown.

Biological Sampling

In 1999 and 2000, NMFS port samplers collected length measurements of American shad landed in Rhode Island commercial fisheries. The RIDFW initiated a dockside-sampling program of commercial floating fish trap and rod and reel fisheries in 2000. The floating fish traps had dominated the ocean-intercept fishery for American shad in Rhode Island waters. Port sampling for American shad was attempted in various landing points in Rhode Island where fish traps land their catch. Sampling of American shad was based on availability of fish, as well as staff time. Samples are collected from May through October. The timing of visits to fish houses is random and depends on the fish company. American shad samples were collected from Rhode Island commercial fisheries in 2000, 2001, and 2004 (N. Calabrese, pers. comm.). The fork length (FL) was recorded for each individual sampled. In 2001 and 2004, scales were collected for age determination and spawning mark counts. A small number of individual weights were recorded in 2004. Collection of samples for American shad ended in 2005 with the closure of the ocean-intercept fishery.

5.9.3 Recreational Fishery

There is a moratorium on the take of American shad in Rhode Island [RIDFW Reg. Part 2.3 2006; RIMF Reg. Part 7.17 2006a]. However, a small non-directed catch-and-release fishery occurs in the spring on the Pawcatuck River. The number of American shad caught in this fishery is not known.

5.10 FISHERY-INDEPENDENT SURVEYS

Data collected from RIDFW's fishery-independent surveys were not available in electronic format for years prior to 1998. Most of the original data records are no longer available either. Data observed in these earlier years were obtained from performance reports that are submitted to the USFWS on an annual basis as cited throughout this report. The degree of detail available varies among years (Table 5.5). All fishery-independent survey data are being moved into an electronic database to facilitate its access and use in the future.

5.10.1 Adult Returns

The RIDFW began monitoring adult returns of American shad to the Pawcatuck River in 1973 (Guthrie 1973). The survey is conducted at a modified fishway at the Potter Hill Dam—the first intact dam on the Pawcatuck River (Erkan 2002; Figure 5.2). A trap is set at the upper end of the fishway, which is intended to retain larger fish such as shad and salmon species while allowing smaller species such as alewife to pass through (O'Brien 1986). The trap is set in early April and by mid-April, the trap is checked daily. In years with high returns the trap is checked twice daily. Sampling is intended to encompass the entire spring migration, which usually ends by July 1, but can extend into late July. This is a sample of fish that varies to an unknown degree annually due to problems associated with passage and flow issues at the dam (see Section 5.4). All American shad in the trap are enumerated. Sub-samples of fish are taken to collect data on FL, sex, and reproductive condition. Scales are removed for age determination. No weights have been taken for the period 2000 through 2005. All American shad are released upstream after processing. Water level and water temperature are recorded.

5.10.2 Juvenile Monitoring

In 1986, the RIDFW initiated a beach seine survey to monitor the annual abundance of juvenile American shad in the tidal portion of the Pawcatuck River (O'Brien 1986). Five stations are sampled weekly from August to November (Figure 5.6). The sampling gear is a 150-foot center bag beach seine with an 8-foot drop and one-quarter inch square delta mesh. At each station the seine is set from a 16-foot skiff powered by an outboard motor. The net is pulled ashore and the contents of the bag are examined. All American shad are enumerated. In some years, length measurements were taken. Water temperature, salinity, and dissolved oxygen are also recorded. Weekly count and environmental data are not available for 1992. In 1992, station 3 was temporarily moved 100 yards downriver to avoid debris.

5.11 ASSESSMENT APPROACHES AND RESULTS

5.11.1 Harvest

Few American shad were sampled from the commercial fishery. Length measurements were recorded for samples collected from the floating fish traps in 2000, 2001, and 2004 (Table 5.6). Age and counts of repeat spawning marks were also available for 2001 and 2004 (Table 5.7). Most of the American shad samples were taken in June; four of the 2004 samples were collected in July. Though the sample sizes were less than 30 fish each year, the length-frequencies show that the fish traps can catch fish of varying size (Table 5.6; Figure 5.7). American shad sampled from the commercial landings ranged from 330 to

610 mm FL. The age samples indicate that the commercial floating fish traps caught American shad ranging in age from 4 to 7 years, including repeat spawners (Table 5.7). Sample sizes are too small to reliably characterize the entire catch. Comparison of the samples collected in all years (2000, 2001 and 2004) suggests that catches vary annually. In 2000, all of the American shad sampled were less than 430 mm FL (Figure 5.7). In contrast, the lengths of fish sampled in 2001 were 430 mm FL or greater. Also, the youngest age observed in the 2001 samples was 4 (Table 5.7). These age-4 American shad ranged in length from 450 to 490 mm FL. Given that samples were collected in June during both 2000 and 2001, it is not unlikely that the smaller fish observed in 2000 are younger than age 4. Additionally, individual weights were recorded for eleven of the fish sampled in 2004. The weights ranged from 2.6 to 4.8 pounds and produced an average of 4.0 pounds.

5.11.2 Adults

The type and detail of data available for the adult monitoring survey among survey years was not consistent prior to 2000. Observations of daily counts and individual biological samples from 1991 were lost, though total number observed and frequency of males and females in the sub-samples were available (Gibson 1992). Daily count data collected in 1984 and 1985 were missing. Table 5.2 summarizes the availability of data, most of which were compiled from annual performance reports submitted to the USFWS.

The median date of return for each year was estimated as the date when at least fifty percent of the spawning adults had passed through the fishway. It is not known if all returning adults below the fishway pass the Potter Hill Dam. Because of this, age composition may not be representative of the entire spawning population. The sex ratio of the Pawcatuck River stock was calculated for each survey year by dividing the estimated total number of males by the estimated total number of females. A chi-square test (α=0.05) was applied to examine whether the sex composition significantly deviated from a 1:1 ratio. The proportion of repeat spawners, the average age of all adults and repeat spawners only, and annual average fork lengths were calculated.

The relationship of returning adult American shad to water level, water temperature, and discharge was explored. Water level and water temperature were recorded as part of the survey program. Daily discharge rates were obtained from the National Water Information System for all dates sampled since the inception of the survey (USGS 2001). The distribution of the numbers of fish counted over the observed range of each environmental variable was summarized using histograms.

Adult Returns

Following several years of stocking efforts (Table 5.1), adult American shad were observed in 1979 in the Pawcatuck River for the first time in over a century (Table 5.8; Figure 5.8). Only five spawning adults were counted in 1979, but returning adults were observed in every year since, ranging in number from a high of 4,219 in 1985 to the recent low of 151 in 2005. The average number of spawning adults observed from 1979 through 2005 was 1,065 fish. Annual counts have been less than 1,000 from 2000 to 2005, with an average of 474 per year. A general decline has occurred since 1999; returning adults in 2003, 2004, and 2005 were among the lowest on record. In 2006, only 92 American shad were observed in the spawning run (P. Edwards, pers. comm.).

Environmental Factors Affecting Returns

The median date of return for spawning adults was estimated for years where daily count data were available. The median return date was fairly consistent among years, occurring most often in mid-May (Figure 5.9). The latest median return date occurred in 1983, on June 13. This estimate is later than expected likely due to a delayed start to the survey—sampling did not begin until May 7—and the sampling season in 1983 was the second shortest on record. The data suggest a trend of increasingly later median return dates in the last three years of the time series, 2003 to 2005.

The total number of adult American shad captured in the Potter Hill fish trap over the time series was plotted against discharge rates, water temperature, and water level. The discharge rates ranged from 91 to 6,220 cubic feet per second (cfs) during the survey time period (Table 5.9). Almost 50 percent of returning American shad was observed when the discharge was 300 to 400 cfs (Figure 5.10). Less than five percent of the total number of adults occurred when the flow exceeded 1,000 cfs. No returning adults were observed at flow rates greater than 1,700 cfs. Water temperatures ranged from 9 to 27°C at the Potter Hill fishway (Table 5.9). American shad were observed at water temperatures ranging from 9 to 25°C (Figure 5.11). Most were observed when the temperature was between 13 and 21°C (96%). The recorded water level ranged from 0.40 to 3.4 feet at the Potter Hill fishway (Table 5.9). Half of the American shad that passed over the dam were observed when the water level was 1.2 to 1.4 feet (Figure 5.12). Fewer than 10 percent of spawning adults were observed when the water level was 2.2 feet or greater.

Biological Characteristics of Adults

Female American shad are larger in length than males (Tables 5.10 and 5,11; Figure 5.13). Females ranging in length from 340 to 588 mm FL have been observed at Potter Hill. The mean size of females collected in the mid-1990s is smaller than those collected in the earlier period from 1981 to 1985 and smaller than those collected since 2000 (Tables 5.10 and 5.11). The lengths of males have ranged from 306 to 540 mm FL (Tables 5.10 and 5.11). The same trend in mean size occurred for males, smaller fish were present in the mid 1990s than were collected in the 1980s and since 2000. American shad length distributions observed in the Pawcatuck River spawning run overlapped those in Rhode Island's ocean-intercept fishery (Figure 5.7). In 2000, most American shad sampled from the fishery landings were smaller in length than those sampled from river. In 2001 the length distributions were similar and in 2004 most of the fish from the commercial fishery were larger in length than those sampled from the spawning run. Although sample size from the ocean-intercept landings were fairly small ($n<30$ for each year), it indicates that in some years there is potential of the commercial fishery impacting the Pawcatuck stock, as well as others.

The ratio of males to females in the adult population has varied over time (Table 5.10; Figure 5.14). The population was dominated by males in most years prior to 1999 and has been predominantly females since. The annual sex ratios showed a significant ($\alpha=0.05$) departure from the expected 1:1 ratio in all years except 1982 and 1992. A possible explanation for the change in sex composition could be an increase in the abundance of predators. Male American shad are smaller than females and so may be more vulnerable to predation, resulting in a higher mortality rate for males.

Adult American shad returning to spawn in the Pawcatuck River have ranged in age from 3 to 8 years old, though age-8 fish were only observed between 1986 and 1992 (Table 5.12). Females tend to achieve older ages than males, ranging in age from 4 to 8. Males generally ranged in age from 3 to 6, but age-7 males were observed in 1981 and 1985. Between 1980 and 1988, the mean age of females varied between 5.1 and 5.4; mean age of males was 4.2 to 5.0 (Table 5.12). From 2000 to 2005, the average age of both sexes were younger than those observed in the 1980s.

The percent of repeat spawners has been variable throughout the survey time period (Table 5.12; Figure 5.15). The fraction of repeat spawners increased from the beginning of the time series to a peak in 1992 when an estimated 31 percent of the spawning adults had spawned previously. Since 2002, percent of repeat spawning has declined.

The numbers of repeat spawnings by age group for the American shad samples were available for 1981-1983 and 2000-2005 (Table 5.13). Repeat spawners ranged in age from 4 to 7 years. The average age of female repeat spawners was 6 years and the average age of male repeat spawners was 5 years. Based on spawning mark counts, only one adult American shad sample showed evidence of having previously spawned more than once. However, the number of spawning marks observed in samples taken from 1981–1983 was not specified though the number or proportion of sampled fish that had spawning marks was reported (O'Brien 1987–1986; Gibson 1988–1991, 1993). The data records for those years are no longer available and so it is not clear if more than one spawning mark was observed on those scale samples.

5.11.3 Juvenile Abundance Indices

Indices of relative abundance were computed on an annual basis for the time series. Arithmetic and geometric means were estimated for each year as the number of juvenile American shad caught divided by the number of seine hauls. Estimates of the variation about each mean were also computed. The normal and lognormal distributions were fit to the observed numbers to assess the appropriateness of using the arithmetic and geometric means, respectively, to characterize the data.

Length measurements of juveniles were taken in 1985, 1992 to 1996, and 2000 to 2006. Individual lengths were available for 1992 and 2000 to 2006. The available length data were summarized using 5-mm length bins and the sample size for each length-frequency was noted.

Trends in juvenile abundance varied over time (Table 5.14). Relative indices based on the arithmetic average number caught per haul were relatively low through much of the survey time series (Figure 5.16). The largest arithmetic-based index occurred in 1985, the first year of the survey. Another peak was observed in 1995, though the precision of that estimate is relatively low. The geometric indices were also fairly low in most years with progressively smaller peaks observed in 1985, 1994, 2000, and 2004.

The lengths of juvenile American shad sampled during the seine survey in the lower Pawcatuck River varied widely, between 30 and 100 mm FL in most years based on available samples (Table 5.15). In 1993, the observed size mode was larger than seen in other years, with lengths ranging from 80 to 140 mm FL. The average length in 1993 was about 121 mm FL, whereas the average length ranged from 57 to 80 mm FL in the other years. In the six other years where length data are available, length distributions vary, with the mode varying between 50 and 80 mm. These fish are most likely YOY; however, annual differences may result from varying summer flow affecting residence time in freshwater. To ensure juveniles sampled are YOY, scales should be collected from American shad with lengths greater than 100 mm.

5.11.4 Growth

Several functions were used to model growth in FL (mm) with age (years). The von Bertalanffy, Gompertz, Richard's, and logistic (Richard's growth function with p=1) models were applied to the individual length and age data collected from spawning adult American shad sampled from the Potter Hill Dam in the Pawcatuck River. Data were available by sex and year for 2000 to 2005. Data from scales that were identified as regenerated were not used. The growth models were also applied to various subsets of the data in order to compare the fitted curves as described below. The configurations included: all observations, females only for all years combined, and males only for all years combined. Attempts to fit the models to more detailed subsets of the data (e.g., individual years, individual years by sex) often failed to converge or resulted in nonsensical parameter estimates. This is likely partly attributable to the reduced number of observations. Too few data configurations successfully converged to allow for comparisons between models or among subsets at this level of detail.

The four growth models that were considered successfully converged when applied to all observations and to the female only dataset. The Richard's function failed to converge when applied to the male only data. Estimates of L_∞ and K and the associated standard errors were similar among the von Bertalanffy, Gompertz, and logistic models (Table 5.16). The various growth models predicted values of L_∞ ranging from 503 to 571 mm FL based on all observations, ranging from 502 to 521 mm FL based on the female only data, and ranging from 461 to 464 based on the male only data. The Richard's growth model yielded the smallest predicted values for L_∞.

The fits of the different growth models were compared using Akaike's Information Criterion (AIC) for use with sum of squares (Hongzhi 1989; Hilborn and Mangel 1997). The AIC is a simple method for determining which of a competing set of models is the most likely given the data. In order to assess how much more likely, Akaike weights were calculated to quantify the relative probability that each model is correct (Burnham and Anderson 2002).

The AIC values for each dataset configuration that successfully converged were marginally different among the four growth functions, as is evident in the calculated Akaike weights. The Akaike weights were equal among the four growth models when fit to all observations and to the female only data. For these dataset configurations, the Akaike weights suggested that each of the models had an estimated 25 percent probability of providing the best description of the data among the models compared. The three models that successfully converged on the male only data also yielded equivalent Akaike weights, each with an estimated 33 percent probability of being the best among the three growth functions. These results suggest that for each dataset configuration, the models that successfully converged are equally likely in predicting growth in length with age.

The analysis of the residual sum of squares (ARSS) method was applied to test whether growth curves fit to the different datasets are statistically different (Chen *et al*. 1992; Haddon 2001). The approach requires that the same model be fit to each dataset. Here, the ARSS could only be used to test for differences between the sex-specific growth curves.

The ARSS method was used to test whether the best-fit growth curves are coincident between the male and female only data. The analysis was applied to compare predicted male and female curves for each growth function, with the exception of the Richard's model, which failed to converge on the male only data. The results suggested that the growth curves fit to the sex-specific datasets are statistically significantly different (P<0.001), regardless of the model applied.

5.11.5 Mortality Rates

Life-History Approach

Total mortality (Z) can be estimated using Hoenig's (1983) geometric mean regression model. This is a simplistic method that only requires maximum age as an input. For the Pawcatuck River stock, maximum ages of 6 through and 8 were considered.

The instantaneous total mortality of American shad in the Pawcatuck River was estimated using several methods. Based on Hoenig's (1983) geometric mean regression model, the Z-estimate was 0.58 assuming a maximum age of 8, 0.67 assuming a maximum age of 7, and 0.79 assuming a maximum age of 6. This method works well for lightly exploited or unexploited stocks. Applying this technique to an exploited stock would under-estimate Z. The values 0.58 to 0.79 can only be presumed to be a lower bound, knowing that ocean mixed stock fishery had the opportunity to take fish from the Pawcatuck River stock.

Catch Curve Analysis

Total mortality rates were estimated using linearized catch curves (slope of the log of the catch-at-age against age). Age of full recruitment varied among years.

The catch curve analysis was applied to all age classes within each year and by cohort. Within year catch curves represent multiple year-classes observed in a single year. This approach assumes recruitment is constant across years, fishing and natural mortality rates are constant, and vulnerability to the sampling gear is constant for fully recruited age-classes. The assumption of constant recruitment can be avoided by applying the catch curves to individual year-classes over time (i.e., cohorts). Catch curves were developed for cohorts based on assumptions of constant mortality and equal vulnerability to the sampling gear above a certain age.

Catch curve estimates of Z based on cohorts exhibited more variability than estimates based on within year catch curves (Table 5.17; Figure 5.17). Total mortality estimates ranged from 0.61 to 1.55 for within year catch curves and ranged from 0.08 to 2.6 for cohorts (Table 5.17).

Total mortality rates for cohorts were estimated for those year classes that have passed completely through the survey. The variances, coefficients of variation (CV), and lower and upper 95% confidence limits of the instantaneous mortality rate estimates were also computed. These dispersion estimates could only be computed for catch curves that had observations for a minimum of three fully recruited age-classes.

Survival rates were also estimated as e^{-Z}, where Z is the total mortality rate estimated from the catch curve analyses. Annual survival was also estimated using Heincke's method (1913, cited in Ricker 1975) for comparison. In Heincke's method, successive ages are weighted by their abundance. This method can be useful if the ages of older fish are unreliable; as older fish tend to be less common in a sample, their numbers would be given less weight.

Estimates of survival based on cohorts exhibited much more variability among years than estimates based on catch curves (Figure 5.18). For both approaches, annual variability was greater prior to 1993. Catch curve survival estimates ranged from 0.21 to 0.54 while cohort estimates ranging from 0.07 to 0.92. The survival estimates based suggest a general increasing trend since the late 1990s. However, sample size in recent years has been small, and issues with ageing were identified, all mortality and survival estimates should be interpreted with caution.

5.11.6 Parent-Progeny Relationship

The spawner-recruit (S-R) models applied by Gibson (1993 and 1988) were not updated. This modeling included parent (spawner) data back to 1975. No spawning occurred in the Pawcatuck prior to 1979, it is unclear where the earliest five years of data originated. S-R models generally require a long times series of data to properly characterize how a stock behaves over various stock sizes. The short time series currently available occurs at depressed stock size and did not warrant further analysis of this detail.

We did further examine the relationship first concluded by Gibson—that of a linear relationship of adult spawners to subsequent YOY production. Gibson (1993) examined the relationship between adults and year classes produced in the same year. For the 1985 to 1992 year-classes, there appeared to be a strong relationship (Figure 5.19a) even without the flow data that Gibson suggested was essential. We expanded his relationship to include number of stocked adults and the relationship improved slightly (Figure 5.19b). Prior to adding additional years, we removed the 1993 juvenile data point, as in this year age-1+ fish comprised most of the catch, rather than YOY. When we added data through 2005 the relationship weakened greatly (Figure 5.19c). Only one year, the point of the highest returns (1985: adult return of 4,219 fish), produced young in the same proportion. However, this one point drives the relationship. If removed, the slope of all lines degrades to values close to or less than zero (0.00005 to -0.0001). These results suggest one of the following: passage numbers do not reflect the size of the spawning stock, we do not have a good measure of juvenile abundance, or factors such as flow and water temperature are more important than stock size in determining year class success.

We also examined the relationship between the JAI and returning adults from the same year class four, five, and six years later. Here we used annual fish passage numbers at the Potter Hill dam as a measure of adult abundance. We observed a weak negative relationship for the four-year lag and weak positive relationships for the five and six year lags (Figure 5.20). These results suggest that strong year classes return in relatively high numbers as mature fish.

5.12 BENCHMARK

Given the uncertainty for some of the data above, we determined that most of the data could be only used as trend indicators. The best data available, with the least amount of uncertainty, were the adult lift numbers. It is not known whether all adults ascend the fishway. For the benchmark we chose to use the simple long-term mean of 1,100 fish. Current adult run estimates are clearly well below that mean and are declining. A benchmark value of Z_{30}= 0.64 was calculated for New England American shad stocks (See Section 1.1.5).

5.13 CONCLUSIONS

1. The number of American shad returning to the trap at Potter Hill Dam in the Pawcatuck River has decreased dramatically in the past seven years. Current estimates are well below the benchmark of 1,100 fish. The potential for recovery is uncertain.
2. The average age of both adult males and females decreased from 1993 through 2005 relative to 1980 through 1988. Since 1993, the maximum age achieved by males and females has been 6 and 7, respectively, but the numbers observed at these ages has been declining. Observed decline in the repeat spawning rate and mean age of the Pawcatuck River stock provide some evidence of a declining population. Older fish are not present and reduced repeat spawners will negatively impact the stock's recovery potential
3. Mean size of fish has increased slightly in the past six years. This is unexpected compared to the decline in mean age and percent repeat spawn. However, if smaller, mostly male, fish are missing (evidenced by the now female-skewed sex ratio) size could increase due to the lack of smaller fish in the sample. Small sample size could also be an issue here, as well as concerns regarding ageing and identification of spawning marks.
4. No relationship occurred between adults passed and subsequent young produced in the same year. The relationship between juvenile American shad and subsequent returning year classes was only weakly positive. This suggests one or more of the following: adults caught at the trap may only characterize an unknown proportion, young may not be measured well, or there are other factors influencing production of fish. Further evaluation of juvenile-adult relationship can be explored if the juvenile data can be segregated to a single year class and the true proportion of adult population at the dam can be determined.

5. The extent to which the Pawcatuck River population is, and was, exploited by commercial fisheries is unknown. The contribution of the Pawcatuck River population to landings in other states is also unknown. Because there is currently no estimate of the proportion of commercial landings attributable to the Pawcatuck River stock, the uncertainty of mortality estimates considerably increases.
6. Catch curve estimates of total mortality have decreased since 2002. However, small sample size and ageing concerns lends uncertainty to these estimates.
7. A number of projects are underway that are intended to improve fish passage along the Pawcatuck River and provide anadromous species access to habitat that was previously inaccessible. Boreman and Friedland (2003) concluded that including activities such as fish passage improvement and habitat quality enhancement in a management program may prove more beneficial to restoration of American shad stocks than reduction of fishing mortality alone.
8. The fishery moratorium and projects to improve passage efficiency are likely among the best options for management; however, the implementation of these initiatives does not ensure that the Pawcatuck River population will recover.

LITERATURE CITED

ASMFC (Atlantic States Marine Fisheries Commission). 1998. American shad stock assessment—peer review report. Prepared by the ASMFC Shad and River Herring Stock Assessment Subcommittee, March 1998. ASMFC Report, Washington, D.C. 234 p.

ASMFC (Atlantic States Marine Fisheries Commission). 1998. American shad and Atlantic sturgeon stock assessment peer review—terms of reference and advisory report. Summary of the external peer review held March 17–19, 1998. ASMFC Report, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the interstate fishery management plan for shad and river herring. ASMFC, Fishery Management Report 35, Washington, D.C.

Boreman, J, and K.D. Friedland. 2003. Sensitivity of American shad to changes in fishing mortality. Pages 267–273 *in* K.E. Limburg and J.R. Waldman (editors), Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35-375.Washington, D.C.

Buckley, B., and S.W. Nixon. 2001. An historical assessment of anadromous fish in the Blackstone River. Final Report to the Narragansett Bay Estuary Program, the Blackstone River Valley National Heritage Corridor Commission, and Trout Unlimited. University of Rhode Island, Narragansett,

Burnham, K.P., and D.R. Anderson. 2002. "Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach". 2nd Edition. Springer-Verlag, New York, NY.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

Chen, Y., D.A. Jackson, and H.H. Harvey. 1992. A comparison for von Bertalanffy and polynomial functions in modeling fish growth data. Canadian Journal of Fisheries and Aquatic Sciences 49: 1228–1235.

Clark, H.A. 1984. Historical references to the fisheries of New England. Section II Appendix, Pages 675-737 *In*: Goode, The fisheries and fishery industries of the United States.

Desbonnet, A. 1999. Pawcatuck watershed water resources: a management issues profile. University of Rhode Island, Sea Grant Institute, Narragansett.

Edwards, P.A. 1998–2005. Annual report on Rhode Island's American shad fisheries and management. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. 8 reports. Annual Compliance Reports to the Atlantic States Marine Fisheries Commission. Washington, D.C.

Edwards, P.A. 1999. State of RI American shad recovery plan 2000–2005. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Report to the Atlantic States Marine Fisheries Commission, Washington, D.C.

Edwards, P.A. 1999–2006. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/33–40, Washington, D.C.

Erkan, D. 2002. Strategic plan for the restoration of anadromous fishes to Rhode Island coastal streams. Rhode Island Department of Environmental Management. Completion Report for Federal Aid Sportfish Restoration, Project F-55-R/83, Washington, D.C.

Gibson, M.R. 1988–1993. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/22–27, Washington, D.C.

Gibson, M.R., V.A. Crecco, and D.L. Stang. 1988. Stock assessment of American shad from selected Atlantic coastal rivers. Atlantic States Marine Fisheries Commission, Special Report 15, Washington, D.C.

Guthrie, R.C. 1973–1975. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/8–10.

Haddon, M. 2001. "Modeling and Quantitative Methods in Fisheries". Chapman and Hall/CRC, Boca Raton, Florida.

Heincke, F. 1913. Investigations on the plaice. General report I. Plaice fishery and protective measures. Preliminary brief summary of the most important points on the report. Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer 17:1-153.

Hilborn, R., and M. Mangel. 1997. "The Ecological Detective: Confronting Models with Data". Princeton University Press, Princeton, New Jersey.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 81(4):898–903.

Hongzhi, A. 1989. Fast stepwise procedures of selection of variables by using AIC and BIC criteria. Acta Mathematicae Applicatae Sinica 5: 60–67.

Mansueti, R.J., and H. Kolb. 1953. An historical review of the shad fisheries of North America. Chesapeake Biological Laboratory, 97.

O'Brien, J.F., and J.A. Stolgitis. 1977. A successful system for the transportation of adult American shad. Pages 252–260 *in* R. St. Pierre (editor), Proceedings of a workshop on American shad. December 14–16, 1976, Amherst, Massachusetts.

O'Brien, J.F. 1977–1987. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Project years 1976–1986, 10 reports. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/12–21, Washington, D.C>

Phillips, C.L. 1971–1972. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/6–7, Washington, D.C.

Powell, J.C. 1994–1998. Restoration and establishment of sea run fisheries. Rhode Island Division of Fish and Wildlife, Freshwater and Anadromous Fisheries Section. Annual Performance Reports to the U.S. Fish and Wildlife Service, Project F-26-R/28–32, Washington, D.C.

RIFDW (Rhode Island Division of Fish and Wildlife). 2006. Rhode Island Freshwater and Anadromous Fishing Regulations for the 2006–2007 Season. Adopted by the Rhode Island Department of Environmental Management, March 22, 2006, Providence, Rhode Island.

RIMF (Rhode Island Marine Fisheries). 2002. Rhode Island Marine Fisheries Statutes and Regulations—Part VII: Minimum Sizes of Fish/Shellfish. Adopted by the Rhode Island Department of Environmental Management, December 11, 2002, Providence, Rhode Island.

RIMF. (Rhode Island Marine Fisheries) 2006b. Rhode Island Marine Fisheries Statutes and Regulations—Part XIX: Fish/Shellfish Dealer Regulations. Adopted by the Rhode Island Department of Environmental Management, January 20, 2006, Providence, Rhode Island.

RIMF (Rhode Island Marine Fisheries). 2006a. Rhode Island Marine Fisheries Statutes and Regulations—Part VII: Minimum Sizes of Fish/Shellfish. Adopted by the Rhode Island Department of Environmental Management, May 12, 2006, Providence, Rhode Island.

Ricker, W.E. 1975. Computations and interpretation of biological statistics of fish populations. Fisheries Research Board, Bull. 191, Ottowa, Canada.

URI EDC (University of Rhode Island Environmental Data Center). 2006. Rhode Island's coastal habitats: anadromous fish habitats. Restoring coastal habitats for Rhode Island's future, Rhode Island Habitat Restoration. Available: http://www.edc.uri.edu/restoration/html/intro/fish.htm#restoration (November 2006).

USGS (U.S. Geological Survey). 2001. National Water Information System (NWISWeb) Available: http://waterdata.usgs.gov/nwis/ (November 22, 2006). Data retrieved for site: USGS 01118500 Pawcatuck River at Westerly, Rhode Island.

Table 5.1 Number of American shad stocked in the Pawcatuck River, Rhode Island, 1972-1985.

Year Class	Fertilized Eggs	Hatched Fry	Stocked Adults*
1972	57,000		
1973	147,500		
1974	64,000		
1975		12,000	374
1976		40,000	2,500
1977		75,000	2,000
1978		94,000	2,100
1979		97,000	3,500
1980		50,000	4,700
1981			3,281
1982			1,667
1983			2,953
1984			859
1985			500

* Source of adults: Connecticut River

Table 5.2 Commercial landings of American shad for Rhode Island, 1887-2005.

Year	Landings (kg)
1887	7711
1888	7711
1889	7711
1890	21818
1891	
1892	11045
1893	
1894	
1895	
1896	22428
1897	
1898	11340
1899	
1900	
1901	
1902	14062
1903	
1904	
1905	7711
1906	
1907	
1908	1814
1909	
1910	
1911	
1912	
1913	
1914	
1915	
1916	
1917	
1918	
1919	
1920	
1921	
1922	
1923	
1924	4990
1925	
1926	
1927	
1928	2722
1929	6804
1930	1814
1931	8165
1932	3629
1933	4990
1934	
1935	2722
1936	
1937	2268
1938	4536
1939	12565
1940	24630
1941	
1942	499
1943	1089
1944	1588
1945	1134
1946	1406
1947	816
1948	1043
1949	1678
1950	953
1951	2540
1952	2223
1953	1814
1954	771
1955	2404
1956	590
1957	2041
1958	953
1959	1361
1960	1406
1961	1996
1962	3221
1963	998
1964	1225
1965	2041
1966	10387
1967	2132
1968	907
1969	2586
1970	5352
1971	19142
1972	6260
1973	1134
1974	3130
1975	2540
1976	1225
1977	363
1978	544
1979	635
1980	953
1981	15150
1982	35970
1983	10660
1984	16602
1985	41187
1986	23769
1987	47129
1988	55339
1989	18869
1990	10337
1991	12617
1992	6029
1993	18394
1994	8137
1995	12678
1996	6452
1997	16674
1998	15236
1999	20072
2000	7854
2001	30777
2002	39553
2003	17548
2004	6647
2005	304

Table 5.3 Commercial landings by gear of American shad for Rhode Island, 1950-2005.

Year	**Landings (kg)**	**Landings by Gear**			
		Floating Trap	**Gill Net**	**Trawl**	**Other***
1950	953	862			91
1951	2540	2449			91
1952	2223	1769			454
1953	1814	1724			91
1954	771	726			45
1955	2404	2359			45
1956	590	454			136
1957	2041	1996			45
1958	953	953			
1959	1361	1361			
1960	1406	1406			
1961	1996	1996			
1962	3221	3221			
1963	998	862		136	
1964	1225	499		726	
1965	2041	1497		544	
1966	10387	8709		1678	
1967	2132	1860		272	
1968	907	408		499	
1969	2586	998		1588	
1970	5352	771		4581	
1971	19142	1225		17917	
1972	6260	227		4037	1996
1973	1134	227		907	
1974	3130	907		2223	
1975	2540	1406		1134	
1976	1225	1225			
1977	363	363			
1978	544	544			
1979	635	590	45		
1980	907	953			
1981	14243	15060	91		
1982	35970	34791	1043	136	
1983	10660	7439	2540	635	45
1984	16602	2495	9208	4899	
1985	41187	16420	11385	13245	136
1986	23769	16829	2586	4355	
1987	47129	27987	3311	15831	
1988	55339	48082	1724	5534	
1989	19038	7711	4581	6577	
1990	10337	2722	1055	6560	
1991	12617	5556	1489	5236	336
1992	6029	1461	575	3980	14
1993	18394	11476	356	6563	
1994	8137	3364	151	4546	76
1995	12683	10023	560	2095	
1996	6452	3655	538	2069	190
1997	16674	13325	25	3324	
1998	15236	10437	58	3861	881
1999	20076	17044	15	3001	14
2000	7854	6292	347	1083	132
2001	30777	20915	77	9710	76
2002	39553	38532	58	962	1
2003	17548	15898	75	797	778
2004	6652	35	33	1754	4830
2005	304	14	2	101	190

*Other:by hand, scallop dredge, hand line, long lines, mid water, or unspecified trawl, pots, traps, and pound nets.

Table 5.4 Monthly landings (kg) of American shad caught in the commercial fishery, Rhode Island, 1990-2005.

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1990	475	109	738	795	744	5901	1163	36	54	39	181	100
1991	168	259	1106	2249	1657	6261	226	16	12	8	198	458
1992	199	165	227	866	812	3275	45	189	66	0	63	123
1993	60	12	78	464	2595	14444	594	13	53	38	5	39
1994	17	13	62	335	1364	5250	886	29	27	95	24	36
1995	158	45	159	556	396	10624	62	44	226	234	96	79
1996	16	34	49	425	1863	1500	1326	394	59	463	111	212
1997	184	206	400	769	1150	8079	4191	880	347	269	15	184
1998	76	125	85	1074	1970	7005	1517	62	1931	106	300	987
1999	152	399	331	425	3778	12933	1887	44	81	15	12	15
2000	6	62	73	402	1007	1148	2483	1331	655	601	68	18
2001	280	67	49	108	562	10689	9453	5904	3541	48	43	32
2002	28	36	8	178	1255	9444	15522	12261	740	55	1	25
2003	17	4	18	77	338	1970	5985	5836	2035	1247	14	7
2004	5	8	5	37	289	3831	2229	124	73	0	5	53
2005	0		4	4	113	19	87	11	8	44	6	7
Average	**115**	**103**	**212**	**548**	**1243**	**6398**	**2979**	**1698**	**619**	**204**	**71**	**149**

Table 5.5 Summary of level of detail available for fishery-independent data for the Pawcatuck River, Rhode Island, 1979-2005. Data availability: bold "S" denoted by sex, "X" is unspecified data.

Year	Number		Length		Age		Repeat Spawning		
	Daily Samples	Total for Year	Individ. Samples	Total for Year	Individ. Samples	Total for Year	Individ. Samples	Total by Age	Total for Year
1979			**S**		**S**				
1980				**S**		**S**			
1981				**S**		**S**		**S**	
1982	**S**			**S**		**S**		X	
1983	**S**					**S**		**S**	
1984		**S**				**S**			X
1985	**S**				**S**				X
1986	**S**				**S**				X
1987	**S**				**S**				X
1988	**S**				**S**				X
1989	**S**				X				X
1990	**S**				X				X
1991		**S**							X
1992	**S**			**S**	X				X
1993	**S**			**S**		**S**			
1994	**S**			**S**		**S**			
1995		**S**		**S**		**S**			
1996	**S**			**S**		**S**			
1997	**S**		**S**			**S**			
1998	**S**		**S**			**S**			
1999	**S**		**S**			**S**			
2000	**S**		**S**		**S**		**S**		
2001	**S**		**S**		**S**		**S**		
2002	**S**		**S**		**S**		**S**		
2003	**S**		**S**		**S**		**S**		
2004	**S**		**S**		**S**		**S**		
2005	**S**		**S**		**S**		**S**		

Table 5.6 Length frequency of American shad caught in the ocean floating trap net fishery, Rhode Island.

Fork Length (mm)	Year 2000	2001	2002	2003	2004
330	1				
340	2				
350	3				
360	3				
370	4				
380	3				
390	3				
400	3				
410	3				
420	2				
430		1			
440		2			
450		3			
460		2			1
470		4			
480		4			2
490		4			1
500		4			
510		4			3
520					
530					1
540					
550		1			
560					1
570					
580					1
590					
600					
610					1
Total	**27**	**29**	**0**	**0**	**11**

Table 5.7 American shad caught and sampled from the ocean floating trap net fishery, Rhode Island.

Year	Sample size			Age			
	Total kg	Total N	Repeat	4	5	6	7
1999	17044						
2000	6292	0	-				
2001	20914	28	0	4	12	6	1
			1		1	4	
2002	38531	0	-				
2003	15898	0	-				
2004	35	11	0	1	4	5	
			1			1	

Table 5.8 Number of American shad counted at the Potter Hill Fishway, Pawcatuck River, Rhode Island.

Year	Total
1973-1978	
1979	5
1980	165
1981	882
1982	647
1983	491
1984	1265
1985	4219
1986	3031
1987	724
1988	580
1989	533
1990	894
1991	1900
1992	2119
1993	797
1994	270
1995	740
1996	1505
1997	2061
1998	936
1999	2149
2000	608
2001	774
2002	768
2003	243
2004	301
2005	151

Table 5.9 Observed range of physical environmental conditions during the spring spawning immigration of adult American shad in the Pawcatuck River, Rhode Island.

River Discharge	
cfs	N Caught
0	0
100	55
200	2502
300	4742
400	6502
500	2944
600	2313
700	1441
800	1022
900	918
1000	447
1100	160
1200	39
1300	676
1400	19
1500	10
1600	0
1700	11
1800	0
1900	0
2000	0
2100	0
2200	0
2300	0
2400	0
2500	0
2600	
2900	0
3000	
5600	0
6200	0

Water Temperature	
Temp (Celsius)	N caught
0	0
9	22
10	7
11	113
12	248
13	1192
14	1941
15	2785
16	4282
17	2607
18	3328
19	3026
20	2342
21	1368
22	310
23	149
24	36
25	4
26	0
27	0

Water Level	
Feet	N caught
0	0
0.4	1
0.6	13
0.8	440
1	3759
1.2	6068
1.4	5814
1.6	2802
1.8	1796
2	1365
2.2	773
2.4	226
2.6	692
2.8	44
3	0
3.2	5
3.4	0

Table 5.10 Mean total length-at-age, annual mean length, and sex ratio of adult American shad sampled in the Pawcatuck River, Rhode Island for (a) males, (b) females, and (c) sexes combined.

(a) Males

Year	Mean Total Length-at-Age						N	Annual Mean TL
	3	4	5	6	7	8		
1980	377	452	485				99	455.8
1981	356	429	485	508	560		245	477.7
1982	361	435	499	529			78	499.3
1983	354	448	490	540			89	458.8
1984	411	447	487	562			140	457.0
1985		466	491	518	500		135	484.3
1986	398	462	516	546			52	
1987	410	463	496	540			26	
1988	394	431	499	528			84	
1989	396	429	476	519	570		62	
1990	413	466	482	523			80	
1991								
1992	428	450	479	516	515		69	
1993								477.8
1994								452.0
1995								441.7
1996								448.9
1997								441.2
1998								463.0
1999								453.5
2000	449	453	484				14	458.5
2001	478	509	487				17	494.9
2002	433	491	511	533			29	488.2
2003	488	496		506			6	482.6
2004	463	481	496				34	482.2
2005		507	509				5	502.8

Table 5.10 cont. Mean total length-at-age, annual mean length, and sex ratio of adult American shad sampled in the Pawcatuck River, Rhode Island for (a) males, (b) females, and (c) sexes combined.

(b) Females

Year	Mean Total Length-at-Age						N	Annual Mean TL
	3	4	5	6	7	8		
1980								
1981	366	446	510	548	589		106	530.4
1982	371	445	517	562	578		77	561.8
1983	405	488	541	562	600		49	552.4
1984		477	538	571			48	535.5
1985		503	533	568	606		68	537.4
1986			565	585	597	645	125	
1987			571	590	603	630	52	
1988			530	574	609	600	40	
1989			482	558	576	590	42	
1990		498	572	579	620		26	
1991								
1992		478	515	536	565	580	68	
1993								522.7
1994								522.2
1995								508.1
1996								524.7
1997								499.4
1998								513.0
1999								509.5
2000		543	565	595			27	558.6
2001		513	534	559	564		25	536.0
2002		497	538	556	566		37	533.0
2003			553	597			9	548.7
2004		495	528	549	562		44	523.2
2005		494	530	562			31	532.9

Table 5.10 cont. Mean total length-at-age, annual mean length, and sex ratio of adult American shad sampled in the Pawcatuck River, Rhode Island for (a) males, (b) females, and (c) sexes combined.

(c) Sexes Combined

Year	Mean Total Length-at-Age						N	Annual Mean TL	Sex ratio M:F
	3	4	5	6	7	8			
1980	377	452	485				99	452.3	25.4
1981							351		2.31
1982							155		1.01
1983							138		1.82
1984							188		2.92
1985							203		1.99
1986							177		0.42
1987							78		0.50
1988	394	431	515	551	609	600	124	520.3	2.10
1989	396	429	479	538	573	590	104	506.1	1.46
1990	413	482	527	551	620		106	507.5	3.06
1991							0		1.75
1992							137		1.01
1993							0		0.57
1994							0		1.22
1995							0		1.25
1996							0		5.27
1997							0		1.23
1998							0		1.89
1999							0		0.65
2000							41		0.54
2001							42		0.70
2002							66		0.74
2003							15		0.83
2004							78		0.71
2005							36		0.15

Table 5.11 Length frequency of (a) male and (b) female adult American shad sampled in the Pawcatuck River, Rhode Island.

(a)

Fork Length (mm)	**Males**										
	1993	**1994**	**1995**	**1996**	**1997**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300											
310			1								
320											
330			1								
340			3								
350		2	3	1	2						
360		3	7	1	5						
370		1	2	5	3			1			
380		2	1	8	4	2	1	2			
390		2	1	13	6	2		1	1	1	
400		1	3	11	3	1		3			
410		3	8	8	2	6	1	3	1	4	
420	1	3	2	6	3	1	3	2	2	9	1
430			3	3	2	1	5	1		8	
440	1	4	2	1	1		1	2	4	6	6
450			1	1	2	1	1	4	1	5	
460	4		2			1	2	3		1	1
470	3							1		1	
480	3							2	1		
490	6						3	2			
500	4	1									1
510											
520	1							2			
530	1						1				
540											
550											
560											
570											
580											
590											
Total	**24**	**22**	**40**	**58**	**33**	**15**	**18**	**29**	**10**	**35**	**9**

Table 5.11 cont. Length frequency of (a) male and (b) female adult American shad sampled in the Pawcatuck River, Rhode Island.

(b)

Fork Length (mm)	Females										
	1993	**1994**	**1995**	**1996**	**1997**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300											
310											
320											
330											
340											
350			1								
360											
370			1								
380			1		1			1			
390			1								
400			2		1			1		2	1
410			1		2						
420			3		3						2
430			2	2	2			1	1	3	
440		4	3		5	1	2	2	1	5	8
450		1	5	1	4		3	4		8	
460	1	3	4	1	1	2	4	3		3	7
470		4	1	3	4					6	
480		1	4	2	2	3	4	6	1	9	16
490		3	3	1		6	4	1	2	4	
500	5	1		1		2	2	8	1	6	6
510	5	1			1	2	1	3		1	
520	8					1	4	5	1	2	2
530	7					3		1	1	1	
540	6					3			2		
550	2					3				1	
560	3					1		1			
570	1						1				
580											
590	1										
Total	**39**	**18**	**32**	**11**	**26**	**27**	**25**	**37**	**10**	**51**	**42**

Table 5.12 Age structure and percent repeat spawning of (a) males, (b) females, and (c) sexes combined for American shad from the Pawcatuck River, Rhode Island collected at the Potter Hill Fishway.

(a) Males

Year	Number-at-Age								Percent-at-Age						Percent Repeat Spawn
	3	4	5	6	7	8	Total	Mean Age	3	4	5	6	7	8	
1980															
1981	2	39	150	53	1		245	5.05	1%	16%	61%	22%	0%	0%	
1982	3	10	47	18			78	5.03	4%	13%	60%	23%	0%	0%	
1983	7	42	32	6			87	4.43	8%	48%	37%	7%	0%	0%	
1984	11	88	39	2			140	4.23	8%	63%	28%	1%	0%	0%	
1985		47	76	10	1		134	4.74	0%	35%	57%	7%	1%	0%	
1986	5	6	32	9	0		52	4.87	10%	12%	62%	17%	0%	0%	
1987	1	10	8	7	0		26	4.81	4%	38%	31%	27%	0%	0%	
1988															
1989															
1990															
1991															
1992															
1993															
1994															
1995															
1996															
1997															
1998															
1999															
2000	3	8	3	1			15	4.13	20%	53%	20%	7%	0%	0%	
2001	2	11	5				18	4.17	11%	61%	28%	0%	0%	0%	
2002	5	12	11	1			29	4.28	17%	41%	38%	3%	0%	0%	
2003	2	7		1			10	4.00	20%	70%	0%	10%	0%	0%	
2004	2	26	7				35	4.14	6%	74%	20%	0%	0%	0%	
2005		6	2				8	4.25							

Table 5.12 cont. Age structure and percent repeat spawning of (a) males, (b) females, and (c) sexes combined for American shad from the Pawcatuck River, Rhode Island collected at the Potter Hill Fishway.

(b) Females

Year	Number-at-Age								Percent-at-Age						Percent Repeat Spawn
	3	4	5	6	7	8	Total	Mean Age	3	4	5	6	7	8	
1980															
1981															
1982	1	1	50	47	8		107	5.56	1%	1%	47%	44%	7%	0%	
1983			28	40	9		77	5.75	0%	0%	36%	52%	12%	0%	
1984		7	22	14	3		46	5.28	0%	15%	48%	30%	7%	0%	
1985		9	26	13			48	5.08	0%	19%	54%	27%	0%	0%	
1986			3	39	22	5	69	6.42	0%	0%	4%	57%	32%	7%	
1987	0	0	53	58	13	1	125	5.70	0%	0%	42%	46%	10%	1%	
1988	0	0	8	33	10	1	52	6.08	0%	0%	15%	63%	19%	2%	
1989															
1990															
1991															
1992															
1993															
1994															
1995															
1996															
1997															
1998															
1999															
2000			7	15	5		27	4.93							
2001			5	9	9	2	25	5.32	0%	0%	20%	36%	36%	8%	
2002			6	19	10	2	37	5.22	0%	0%	16%	51%	27%	5%	
2003				8	2		10	5.20	0%	0%	0%	80%	20%	0%	
2004			13	18	15	5	51	5.24	0%	0%	25%	35%	29%	10%	
2005		1	2	22	13		38	5.24	0%	3%	5%	58%	34%	0%	

Table 5.12 cont. Age structure and percent repeat spawning of (a) males, (b) females, and (c) sexes combined for American shad from the Pawcatuck River, Rhode Island collected at the Potter Hill Fishway.

(c) Sexes Combined

Year	Number-at-Age								Percent-at-Age						Percent
	3	4	5	6	7	8	Total	Mean Age	3	4	5	6	7	8	Repeat Spawn
1980															
1981	8	77	18				103	4.10	8%	75%	17%	0%	0%	0%	1%
1982	3	40	200	100	9	0	352	5.20	1%	11%	57%	28%	3%	0%	6%
1983	3	10	75	58	9	0	155	5.39	2%	6%	48%	37%	6%	0%	12%
1984	7	49	54	20	3	0	133	4.72	5%	37%	41%	15%	2%	0%	11%
1985	11	97	65	15	0	0	188	4.45	6%	52%	35%	8%	0%	0%	6%
1986	0	47	79	49	23	5	203	5.31	0%	23%	39%	24%	11%	2%	9%
1987	5	6	85	67	13	1	177	5.45	3%	3%	48%	38%	7%	1%	15%
1988	1	10	16	40	10	1	78	5.65	1%	13%	21%	51%	13%	1%	12%
1989	8	9	75	30	11	4	137	5.28	6%	7%	55%	22%	8%	3%	15%
1990	5	24	22	21	26	7	105	5.57	5%	23%	21%	20%	25%	7%	25%
1991	2	53	36	14	2		107	4.64	2%	50%	34%	13%	2%	0%	28%
1992															31%
1993	3	27	57	29	12	2	130	5.20	2%	21%	44%	22%	9%	2%	
1994															
1995															
1996															
1997															
1998															
1999															
2000	3	15	18	6	0	0	42	4.64	7%	36%	43%	14%	0%	0%	24%
2001	2	16	14	9	2	0	43	4.84	5%	37%	33%	21%	5%	0%	20%
2002	5	18	30	11	2	0	66	4.80	8%	27%	45%	17%	3%	0%	28%
2003	2	7	8	3	0	0	20	4.60	10%	35%	40%	15%	0%	0%	24%
2004	2	39	25	15	5	0	86	4.79	2%	45%	29%	17%	6%	0%	11%
2005	1	8	24	13	0	0	46	5.07	2%	17%	52%	28%	0%	0%	9%

Table 5.13 Repeat spawning of American shad from the Pawcatuck River Rhode Island, collected at the Potter Hill Fishway. Data are not available by sex.

Year	Repeat Marks	Age					Total N	% Repeat Spawn
		3	4	5	6	7		
1981	0	2	40	199	99	9	349	
	1			1	1		3	1%
1982	0	3	10	69	54	9	145	
	1			6	4		11	7%
1983	0	7	49	44	15	2	117	
	1			10	5	1	17	13%
2000	0	3	15	10	5	1	34	
	1			8	2		11	24%
2001	0	2	17	11	4	1	35	
	1			4	3	1	9	20%
2002	0	6	17	19	6	2	50	
	1		1	12	5		19	28%
2003	0	2	7	7			16	
	1			1	3		5	24%
2004	0	2	39	24	10	4	79	
	1			1	5		7	
	2					1	3	11%
2005	0	1	8	23	11		43	
	1			1	2		4	9%

Table 5.14 Juvenile abundance indices for American shad collected in the Pawcatuck River, Rhode Island.

Year	Number of Hauls	n	Geometric Mean				Arithmetic Mean	
			Zero Hauls	Mean	L95% CL	95% CL	Mean	SE
1977							8.42	3.22
1978							5.30	2.57
1979								
1980								
1981								
1982								
1983								
1984								
1985	32	521	11	3.61	1.62	7.13	16.28	6.08
1986	33	60	19	0.84	0.37	1.48	1.82	0.62
1987	38	3	35	0.06	-0.01	0.12	0.08	0.04
1988	40	59	28	0.49	0.16	0.91	1.48	0.66
1989	45	3	43	0.04	-0.02	0.10	0.07	0.05
1990	45	11	40	0.13	0.01	0.26	0.24	0.12
1991	20	44	14	0.74	0.11	1.74	2.20	1.08
1992		242					7.81	
1993	33	474	27	0.55	0.01	1.39	14.36	13.47
1994	25	209	9	1.80	0.69	3.63	8.36	5.08
1995	30	62	19	0.84	0.31	1.59	2.07	0.71
1996	30	21	21	0.36	0.10	0.68	0.70	0.31
1997	38	11	33	0.16	0.01	0.32	0.29	0.14
1998	55	23	46	0.21	0.07	0.38	0.42	0.16
1999	45	56	28	0.63	0.32	1.02	1.24	0.37
2000	65	157	27	1.30	0.86	1.83	2.42	0.47
2001	65	14	60	0.09	0.00	0.19	0.22	0.13
2002	50	66	36	0.47	0.19	0.81	1.32	0.58
2003	54	38	42	0.33	0.13	0.56	0.70	0.25
2004	56	152	27	1.23	0.73	1.88	2.71	0.58
2005	57	33	41	0.32	0.16	0.52	0.58	0.18

* 1993 fish caught were age-1+

Table 5.15 Length frequency data of juvenile American shad collected by beach seine in the Pawcatuck River, Rhode Island.

FL (mm)	1985	1992	1993	1994	1995	1996	2000	2001	2002	2003	2004	2005	2006
30	1	3											1
35	3	7										2	
40	6	11				1			1	1	1		
45	6	30					4	1	1	2	5		1
50	32	51				3	3		4	13	6	12	
55	19	17				2	11	2		6	15	4	
60	36	10	1	1			17			5	8	7	2
65	35	4		3	1	5	24	7	2	3	17		1
70	27	8	3	23	13	5	22	1	6	2	14	1	1
75	22	4	6	26	13	1	20		3	1	10		1
80	15	5	4	40	19	1	16		9	4	7		1
85	3	6	5	24	6		12		8	1	11	2	
90	1	4	10	12	5		13		7	2	11	1	
95			8	4	5		7		9		11	3	
100			8	3			6		6		8		
105			17				2		6		12	1	
110			5				1				6		
115													
120											1		
125													
130											1		
135													
140			1										
Total	**206**	**160**	**68**	**136**	**62**	**18**	**158**	**11**	**62**	**40**	**144**	**33**	**8**

Table 5.16 Best-fit parameter estimates of age-length growth models for adult American shad in the Pawcatuck River, Rhode Island.

Sex	Model	L_{inf} (SE)		K (SE)		t_0 (SE)		*P*	RSS	DF
Both	von Bertalanffy	571.0	(48.8)	0.280	(0.13)	-1.227	(1.4)	-	265393	275
	Gompertz	558.6	(38.3)	0.351	(0.13)	-0.046	(0.72)	-	265227	275
	Richard's	502.7	(11.0)	4.058	(6.5)	4.849	(1.1)	0.02	263437	274
	Logistic	549.6	(31.5)	0.422	(0.13)	0.745	(0.41)	-	265072	275
								-		
Females	von Bertalanffy	520.6	(21.9)	0.566	(0.32)	0.436	(1.6)	-	141451	170
	Gompertz	519.4	(20.3)	0.611	(0.32)	0.787	(1.3)	-	141428	170
	Richard's	502.0	(9.84)	5.005	(16)	4.832	(2.1)	0.01	140774	169
	Logistic	518.3	(18.9)	0.657	(0.32)	1.093	(1.1)	-	141405	170
Males	von Bertalanffy	463.6	(27.6)	0.623	(0.49)	-0.199	(2.1)	-	80720.4	102
	Gompertz	462.4	(25.5)	0.674	(0.50)	0.124	(1.7)	-	80727.2	102
	Richard's					**Failed to converge**				
	Logistic	461.3	(23.7)	0.725	(0.50)	0.404	(1.4)	-	80734.1	102

Table 5.17 Pawcatuck River American shad total mortality and survival rates. Note: data are missing for some years.

Year	Sexes Combined		Males		Females		Year Class	Cohorts (Sexes Combined)			
	Z	S	Z	S	Z	S		Z	s2(Z)	CV(Z)	S
1979							1975				
1980	1.45	0.23					1976	1.91	0.46	0.36	0.15
1981	1.55	0.21	2.51	0.08	0.92	0.40	1977	1.44			0.24
1982	1.06	0.35	0.96	0.38	1.49	0.23	1978	0.72	0.09	0.42	0.49
1983	1.45	0.24	0.97	0.38	1.00	0.37	1979	1.26	0.33	0.45	0.28
1984	0.93	0.39	1.89	0.15	0.69	0.50	1980	1.62	0.26	0.32	0.20
1985	0.90	0.41	2.17	0.11	1.03	0.36	1981	1.36	0.12	0.25	0.26
1986	1.31	0.27			2.03	0.13	1982	0.08	0.01	0.92	0.92
1987	1.08	0.34			1.75	0.17	1983	1.88	0.03	0.09	0.15
1988	0.98	0.38					1984	0.43	0.00	0.15	0.65
1989	1.31	0.27					1985	0.25	0.08	1.16	0.78
1990	1.08	0.34					1986	2.01	0.66		0.13
1991							1987	2.61	0.18	0.16	0.07
1992	1.09	0.34					1988	2.00	0.10	0.16	0.14
1993							1989	0.65			0.52
1994							1990	0.91			0.40
1995							1991	1.35	0.02	0.11	0.26
1996							1992	1.60	0.06	0.15	0.20
1997							1993	0.83			0.44
1998							1994	1.54	0.16	0.26	0.21
1999							1995	1.21	0.19	0.36	0.30
2000	1.10	0.33	1.04	0.35	1.10	0.33	1996	0.70			0.50
2001	0.67	0.51	0.79	0.45	1.50	0.22	1997	1.50	0.08	0.18	0.22
2002	1.35	0.26	1.24	0.29	1.13	0.32	1998	0.77			0.46
2003	0.98	0.38	0.97	0.38	1.39	0.25	1999	0.64			0.53
2004	0.67	0.51	1.31	0.27	0.64	0.53					
2005	0.61	0.54	1.10	0.33	0.53	0.59					

Figure 5.1 The Pawcatuck River watershed in Rhode Island and Connecticut.

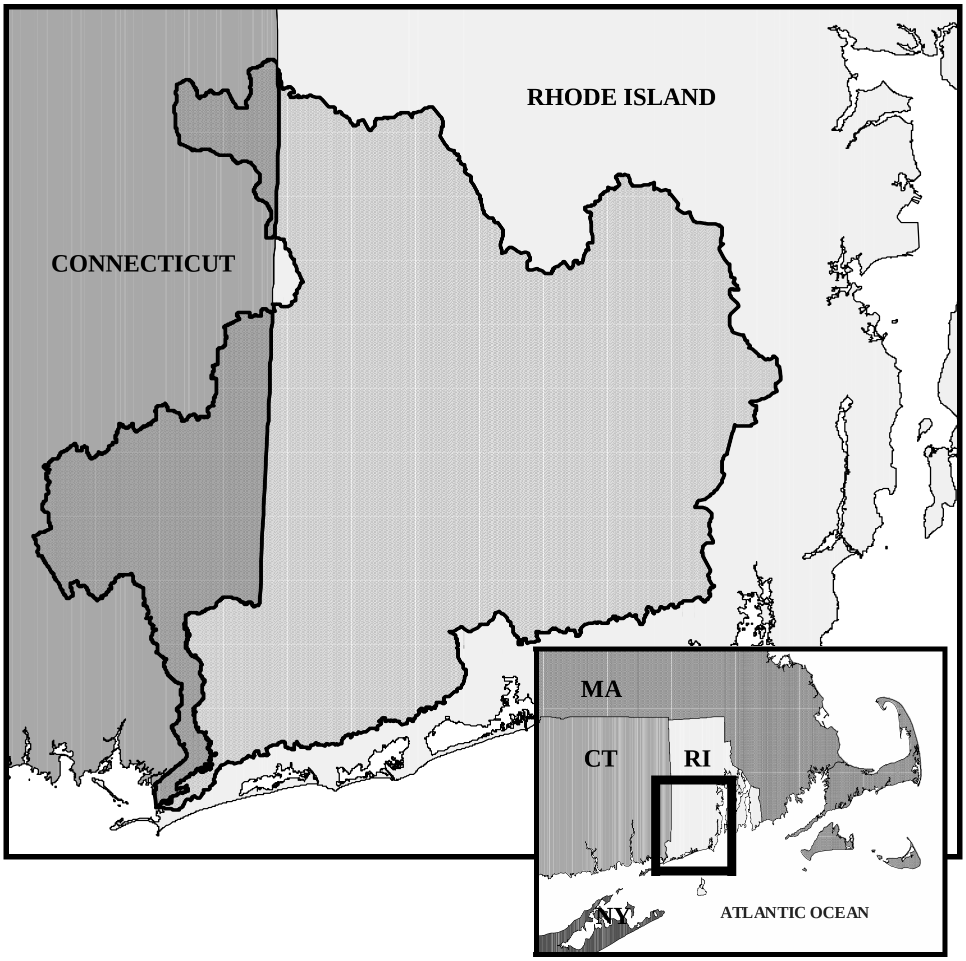


Figure 5.2 The Pawcatuck River, Rhode Island, with all dams and obstructions: 1. White Rock Dam, km 2.5 (passable to anadromous fish); 2. Potter Hill Dam, km 11(with fishway and trap), 3. Bradford Pond Dam, km 22 (impassable barrier for anadromous fish); 4. Route 91 Dam; 5. Carolina Pond Dam, 6. Shannock Mill Pond Dam , 7. Horseshoe Falls Dam, and 8. Kenyon Mill Pond Dam.

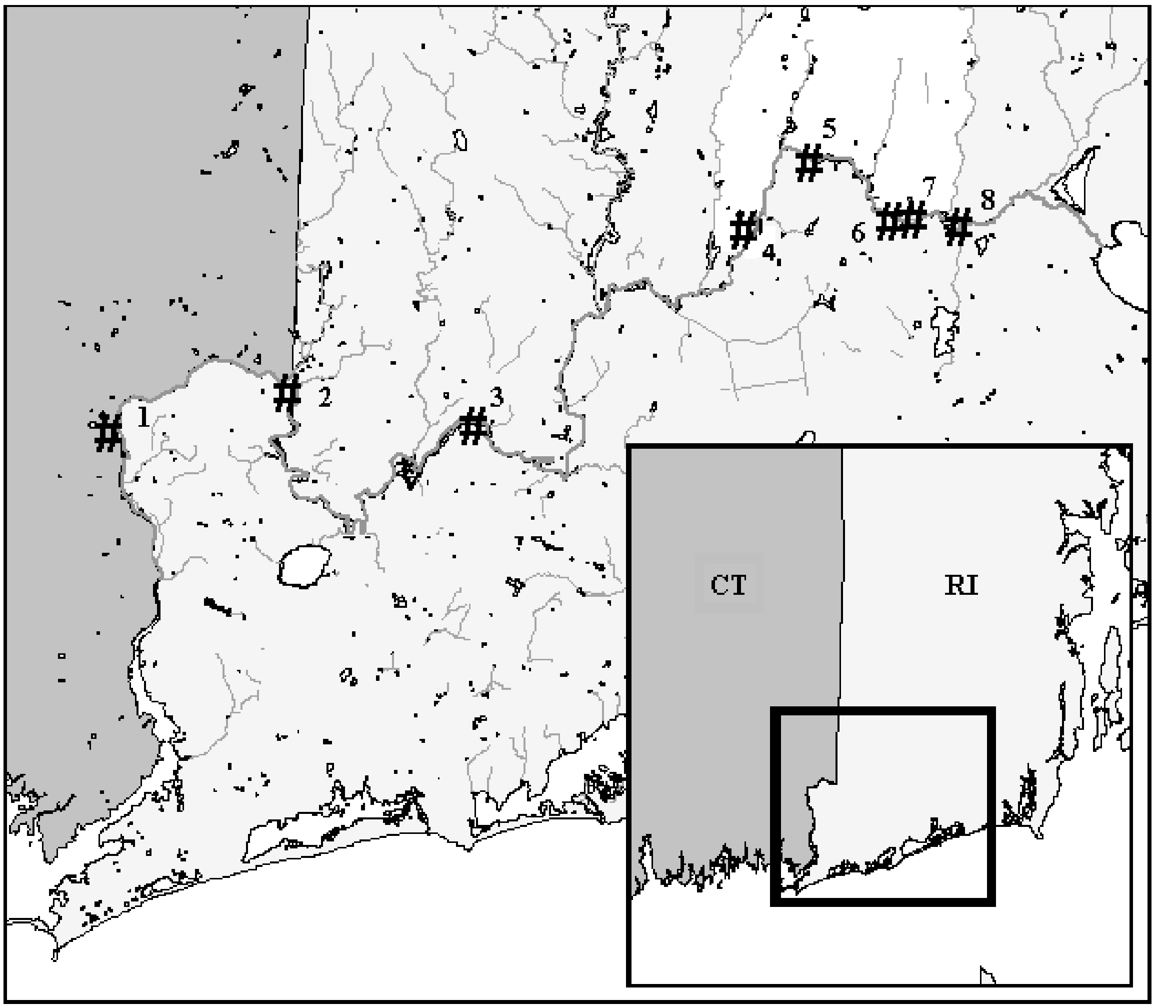


Figure 5.3 Rhode Island American shad commercial landings.

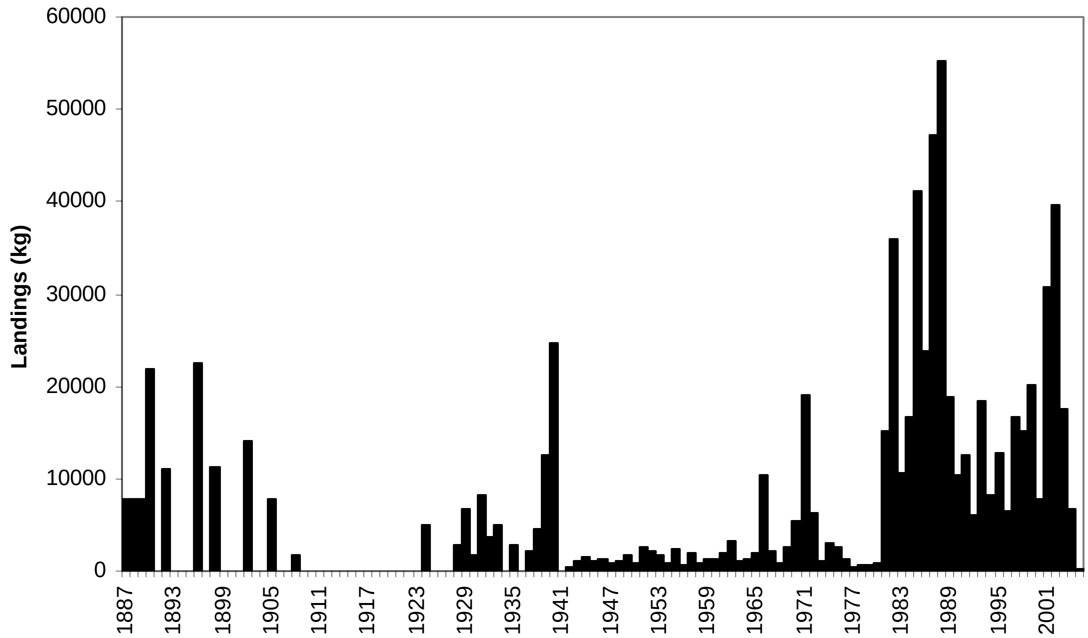
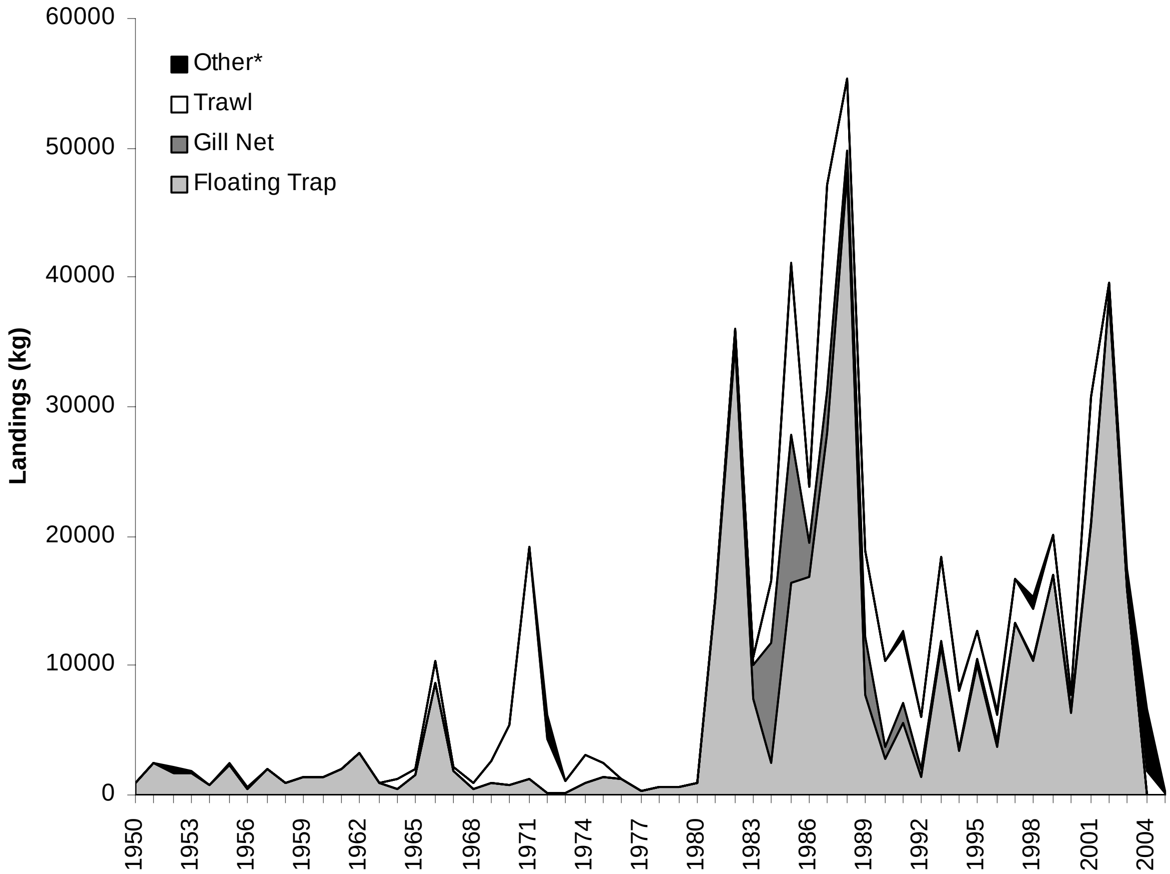


Figure 5.4 Rhode Island American shad commercial landings by gear.



*Other: by hand, scallop dredge, hand line, long lines, mid water, or unspecified trawl, pots, traps, and pound nets.

Figure 5.5 Average monthly commercial landings of American shad caught in Rhode Island, 1990-2005.

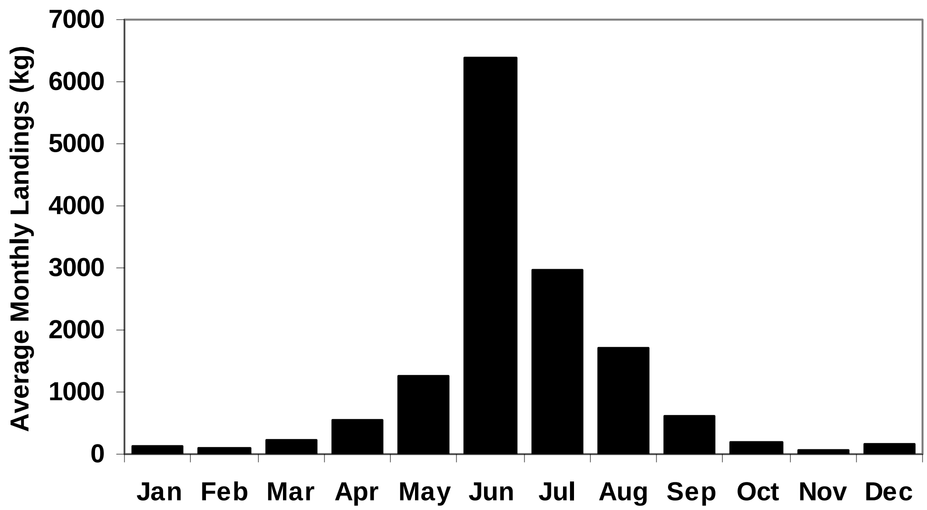


Figure 5.6 Sampling locations for the juvenile American shad beach seine survey in the Pawcatuck River, Rhode Island.

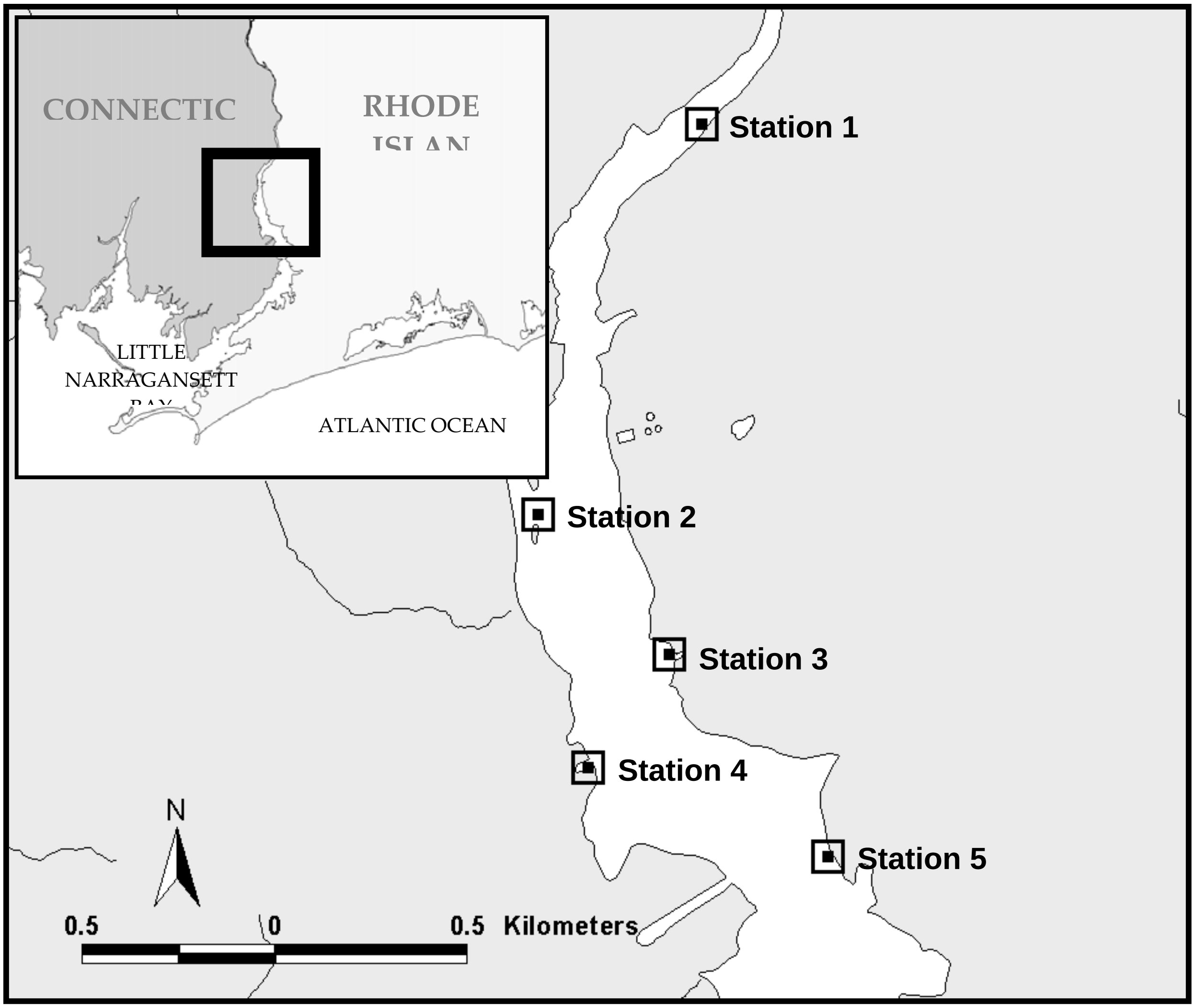


Figure 5.7 Comparison of American shad length-frequencies from sampling of the ocean-intercept fishery and the fishway at Potter Hill Dam, 2000, 2001, and 2004. All three figures share the same x-axis values.

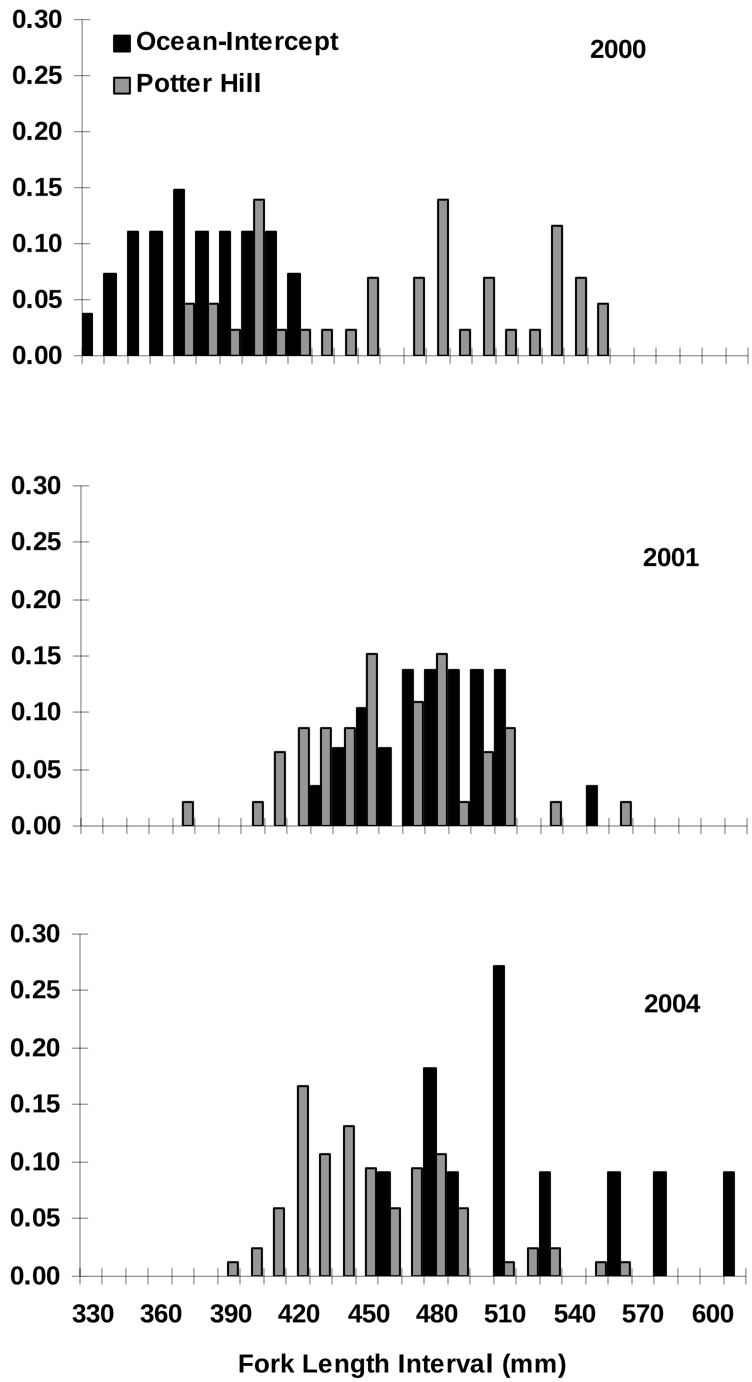


Figure 5.8 Number of American shad counted at the Potter Hill Fishway, Pawcatuck River Rhode Island.

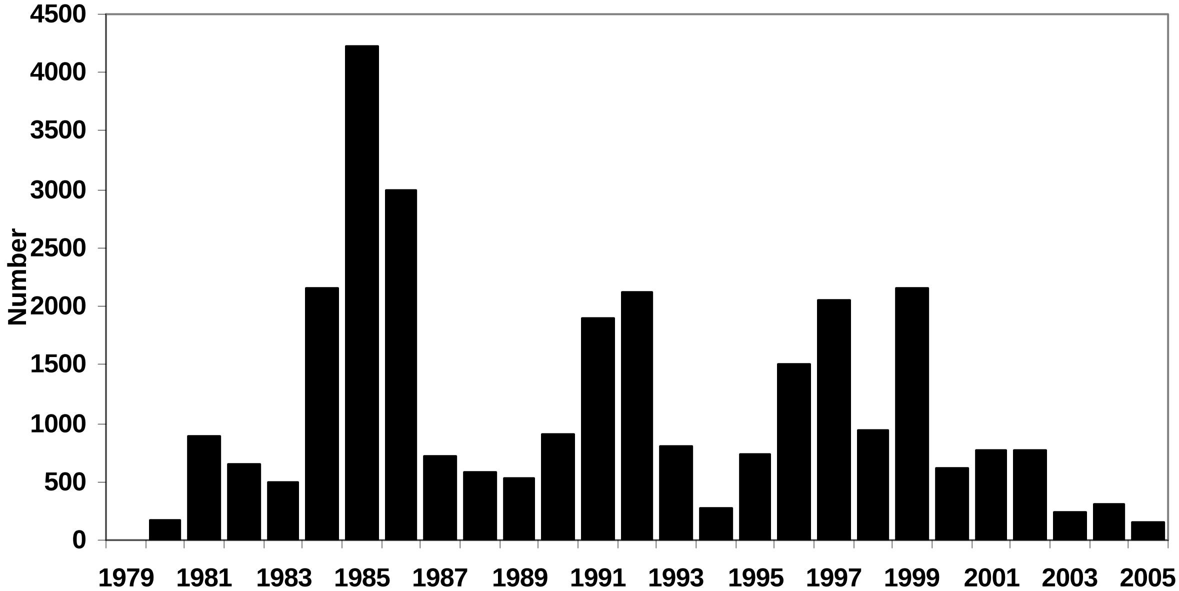


Figure 5.9 Median date of return for the American shad spawning run in the Pawcatuck River, Rhode Island, 1982-2005.

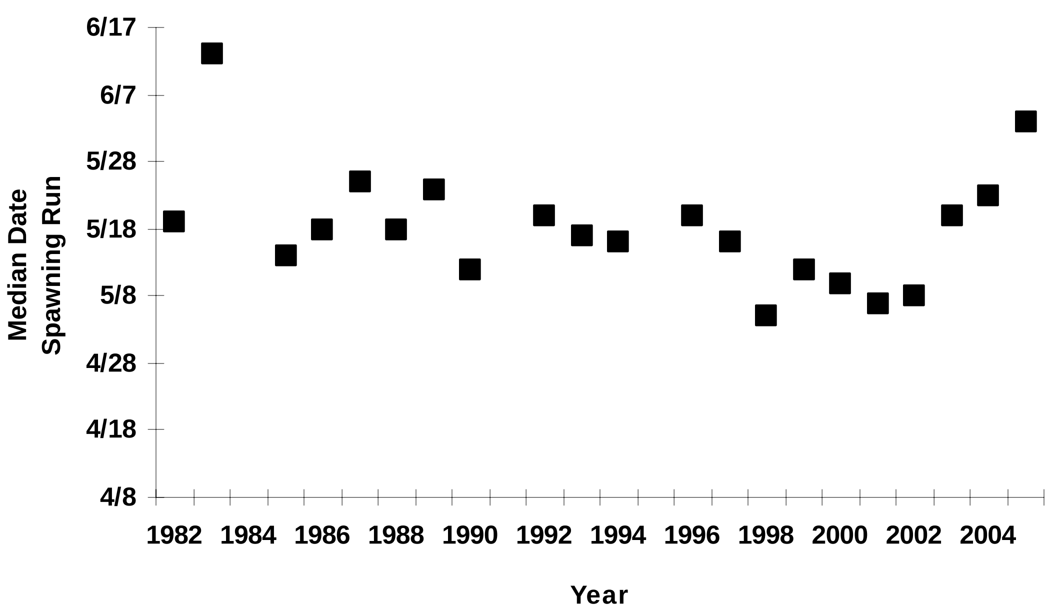


Figure 5.10 Distribution of the numbers of adult American shad over the observed range of discharge rates (cfs) at the Potter Hill Fishway, Pawcatuck River, Rhode Island.

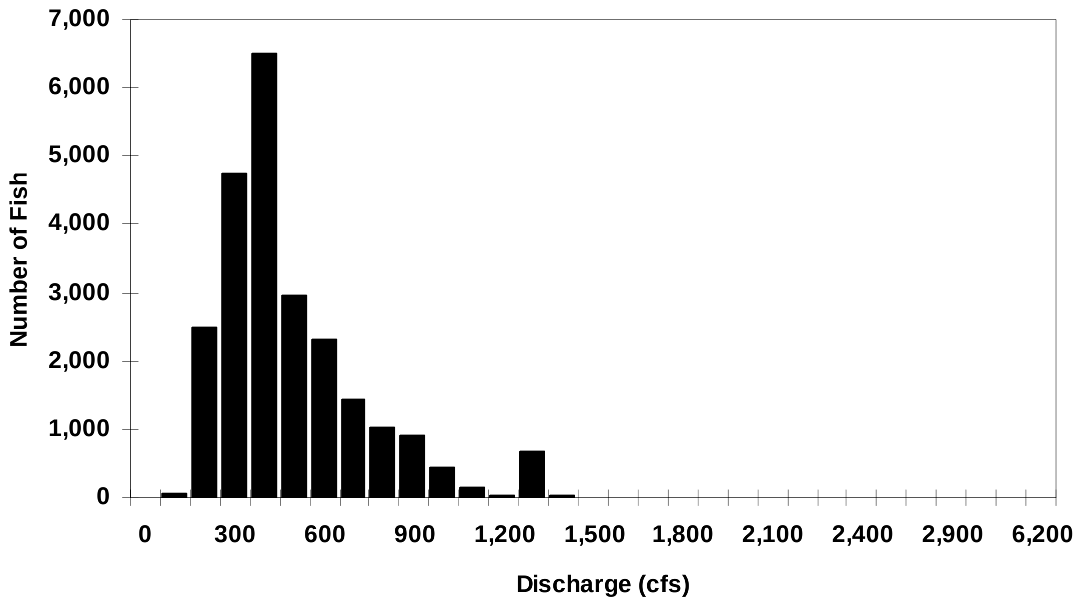


Figure 5.11 Distribution of the numbers of adult American shad over the observed range of water temperatures (ºC) at the Potter Hill Fishway, Pawcatuck River Rhode Island.

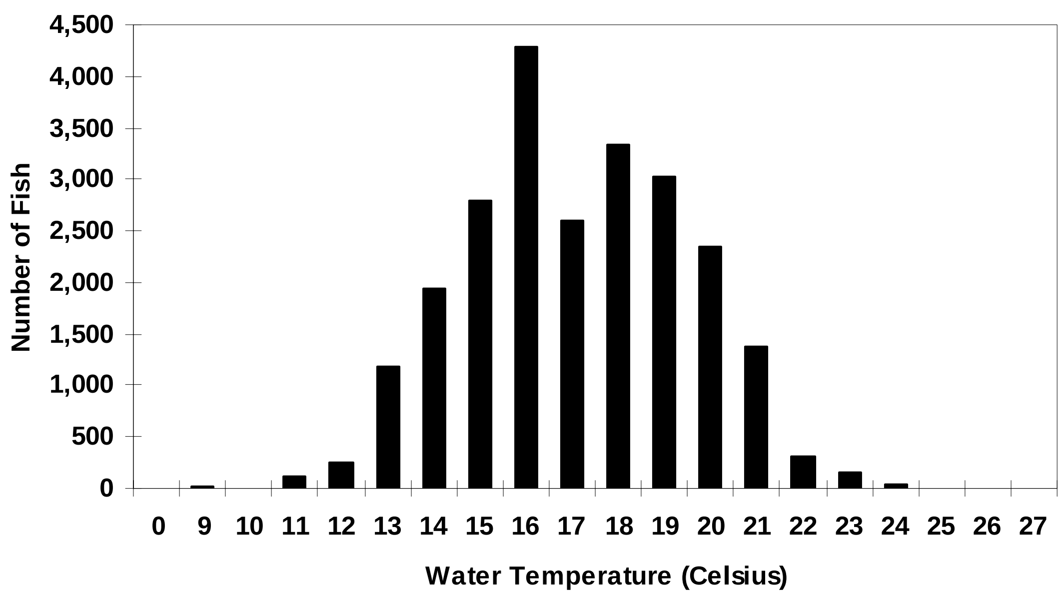


Figure 5.12 Distribution of the numbers of adult American shad over the observed range of water levels (ft) at the Potter Hill Fishway, Pawcatuck River, Rhode Island.

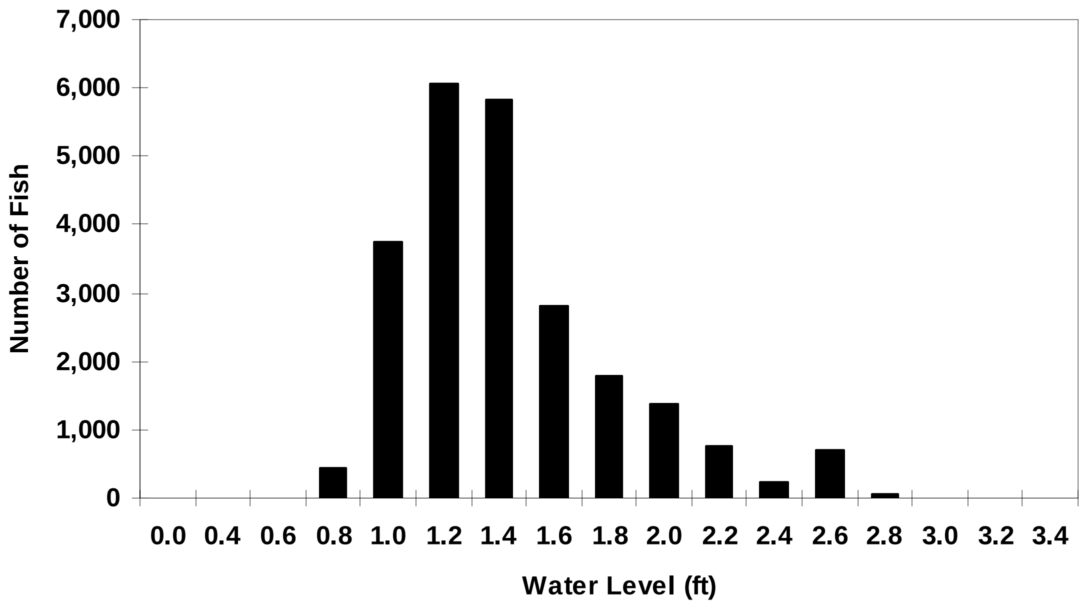


Figure 5.13 Annual mean total length (mm) of American shad in the Pawcatuck River, Rhode Island.

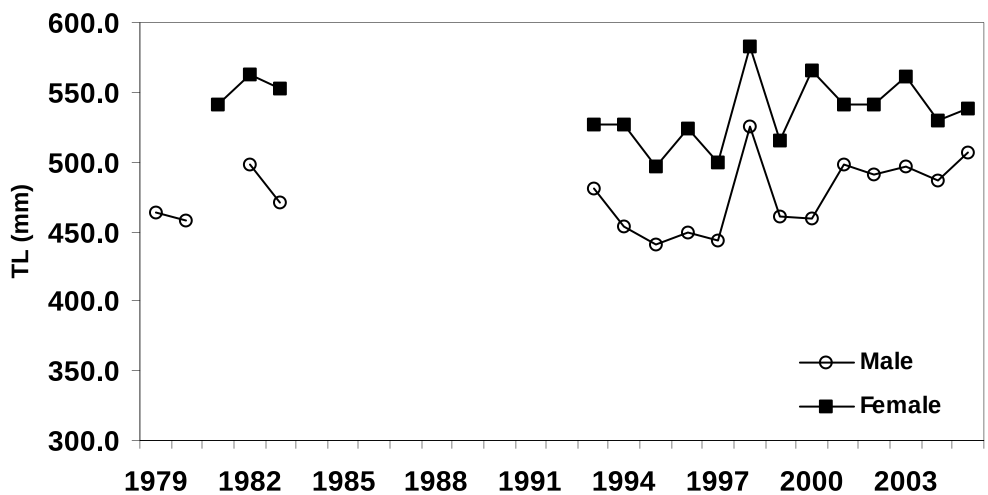


Figure 5.14 Ratio of male to female adult American shad in the Pawcatuck River, 1980–2005.

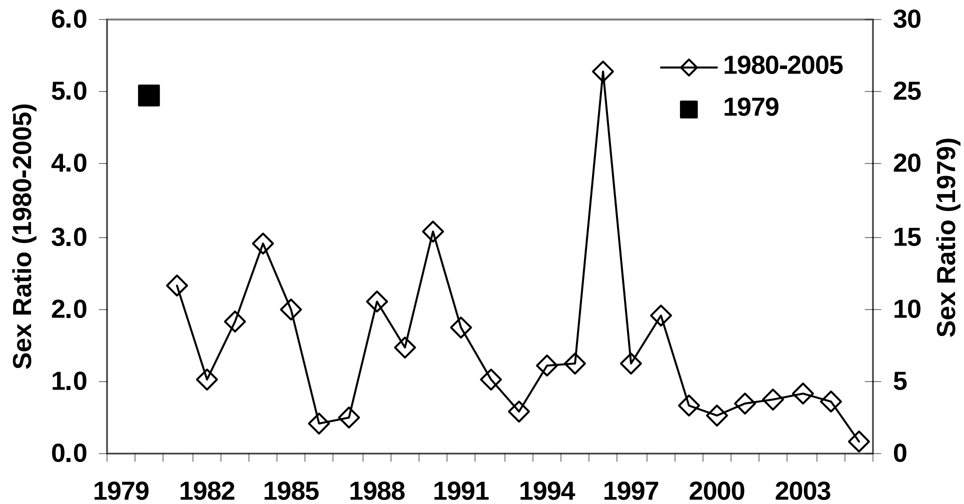


Figure 5.15 Proportion of American shad repeat spawners in the Pawcatuck River, Rhode Island, 1979–2005.

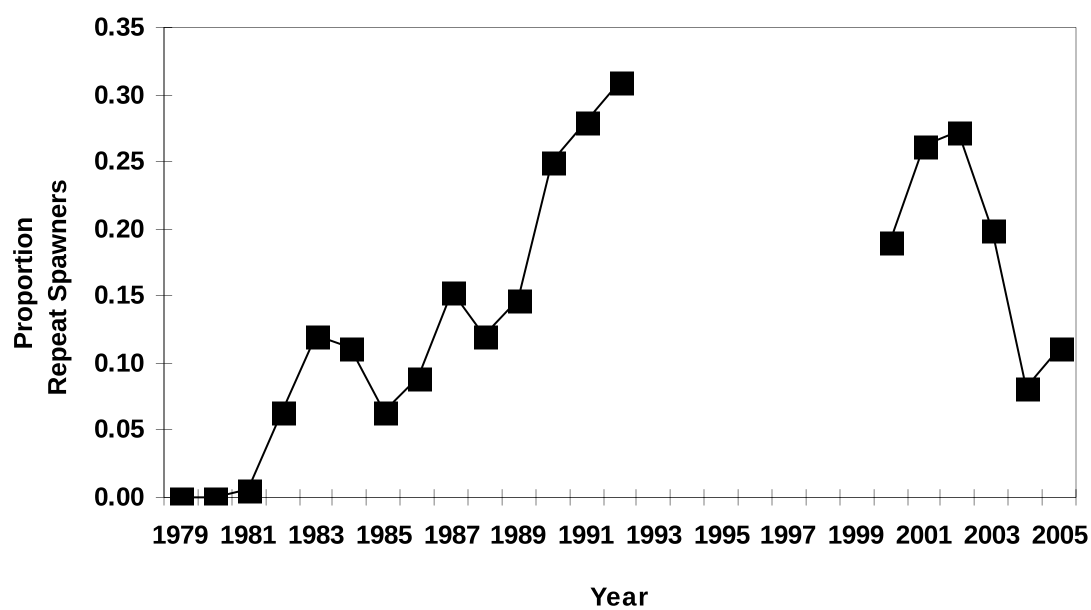


Figure 5.16 Juvenile abundance indices for American shad collected in the Pawcatuck River, RI. Arithmetic mean (AM) and geometric mean (GM).

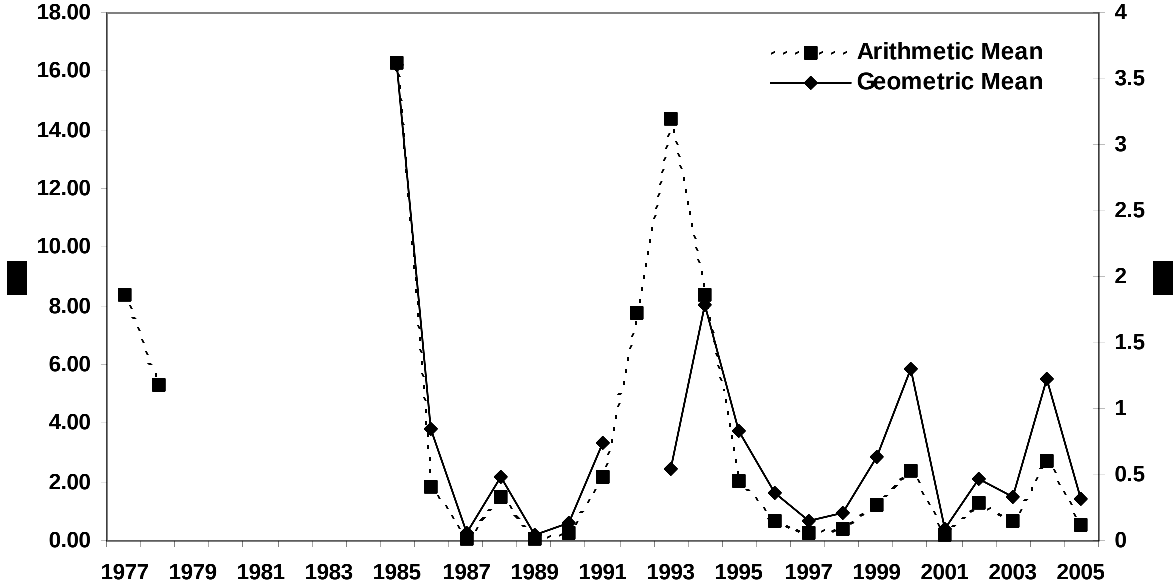


Figure 5.17 Total mortality rate (Z) of American shad in the Pawcatuck River, Rhode Island.

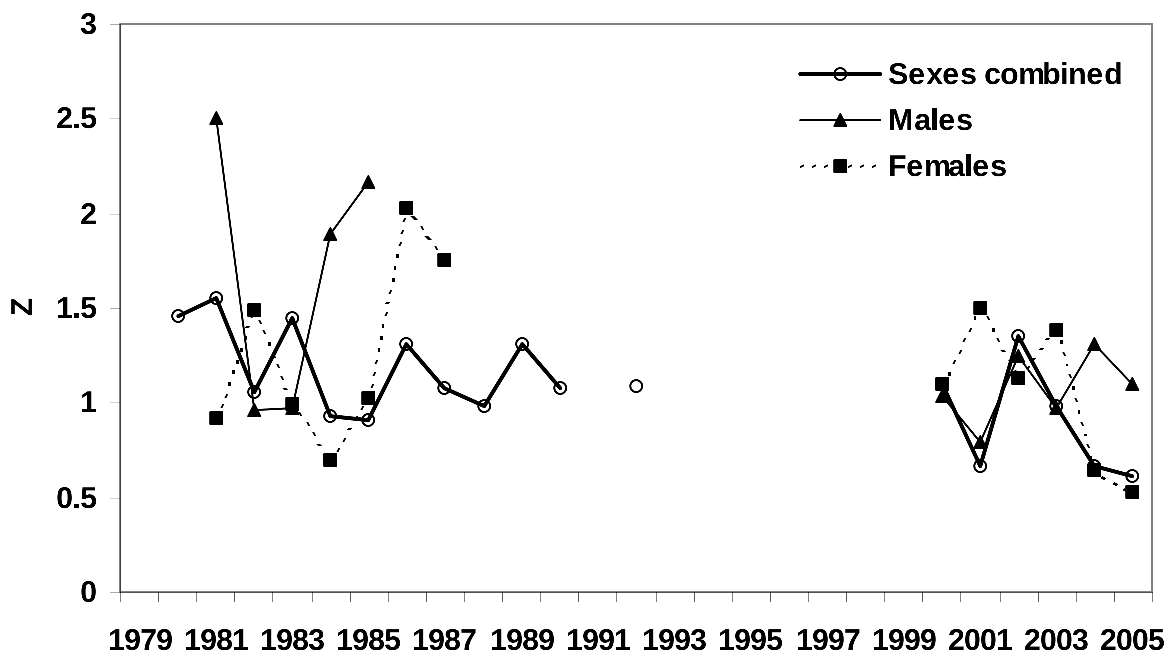


Figure 5.18 Survival rate (S), by catch curve and by cohort, of American shad in the Pawcatuck River.

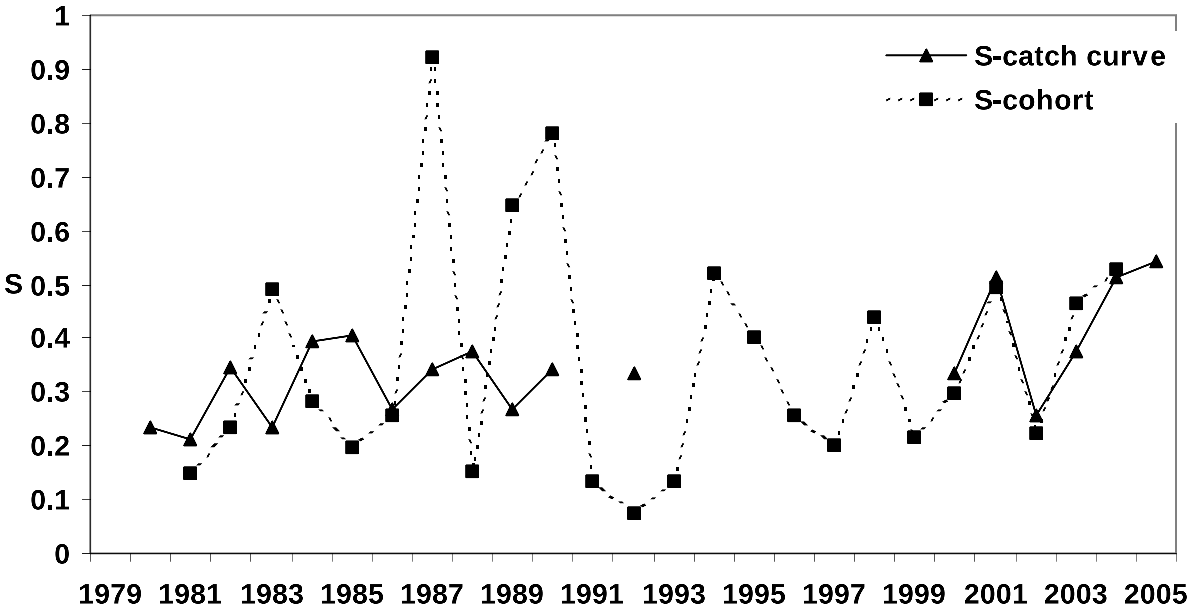
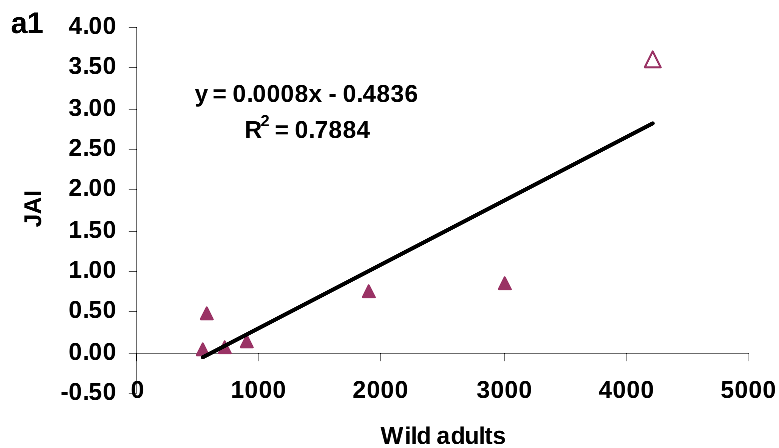


Figure 5.19 Relationship between adult returns and subsequent YOY production (geometric mean of the JAI) in the Pawcatuck River, Rhode Island. Open triangle is the highest year of return. (a1) Wild adult versus the same year YOY production, 1985-1992. (a2) Wild adult versus the same year YOY production, 1985-1992 with highest value removed. (b1) Wild and stocked adults versus the same year YOY production, 1985-1992. (b2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-1992. (c1) Wild and stocked adults versus the same year YOY production, 1985-2005. (c2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-2002.



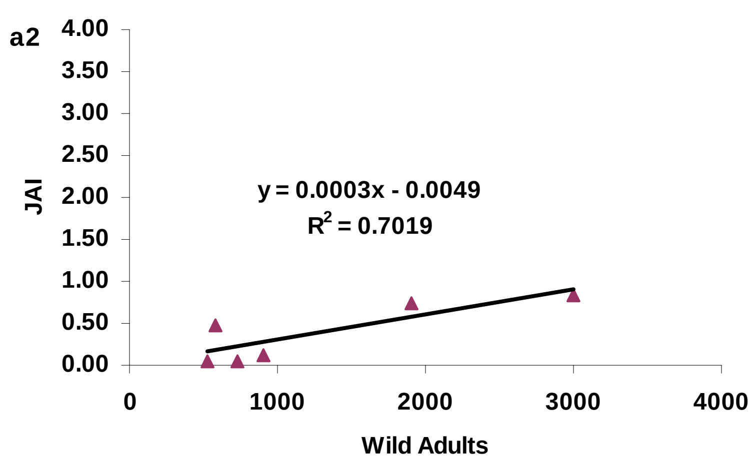
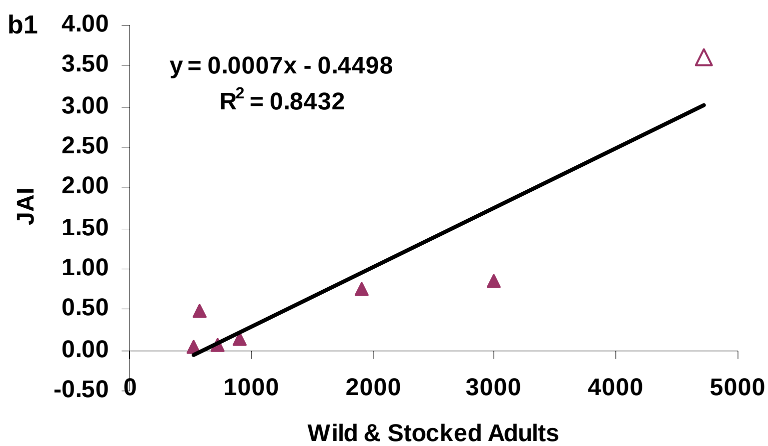


Figure 5.19 cont. Relationship between adult returns and subsequent YOY production (geometric mean of the JAI) in the Pawcatuck River, Rhode Island. Open triangle is the highest year of return. (a1) Wild adult versus the same year YOY production, 1985-1992. (a2) Wild adult versus the same year YOY production, 1985-1992 with highest value removed. (b1) Wild and stocked adults versus the same year YOY production, 1985-1992. (b2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-1992. (c1) Wild and stocked adults versus the same year YOY production, 1985-2005. (c2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-2002.



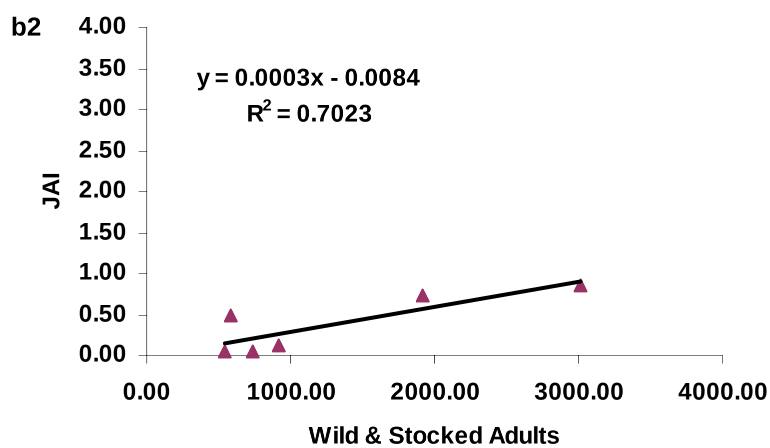
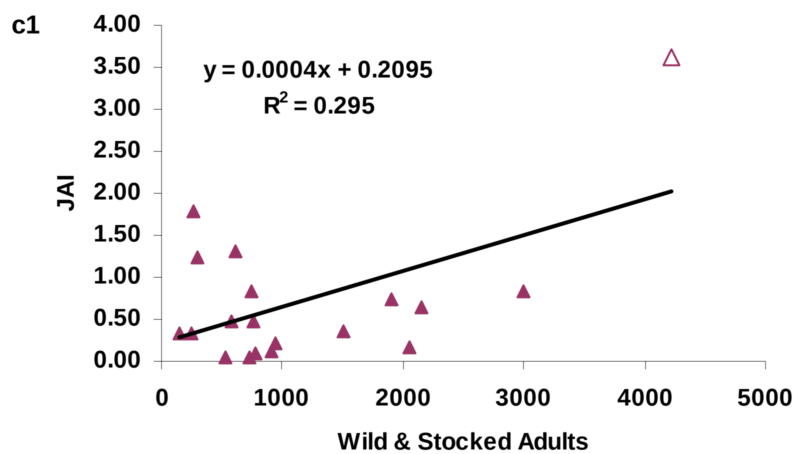


Figure 5.19 cont. Relationship between adult returns and subsequent YOY production (geometric mean of the JAI) in the Pawcatuck River, Rhode Island. Open triangle is the highest year of return. (a1) Wild adult versus the same year YOY production, 1985-1992. (a2) Wild adult versus the same year YOY production, 1985-1992 with highest value removed. (b1) Wild and stocked adults versus the same year YOY production, 1985-1992. (b2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-1992. (c1) Wild and stocked adults versus the same year YOY production, 1985-2005. (c2) Wild and stocked adults versus the same year YOY production with the highest year value removed, 1985-2002.



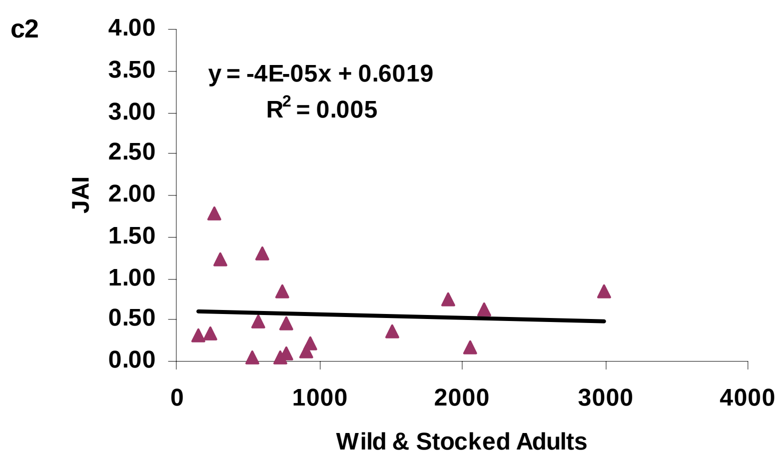
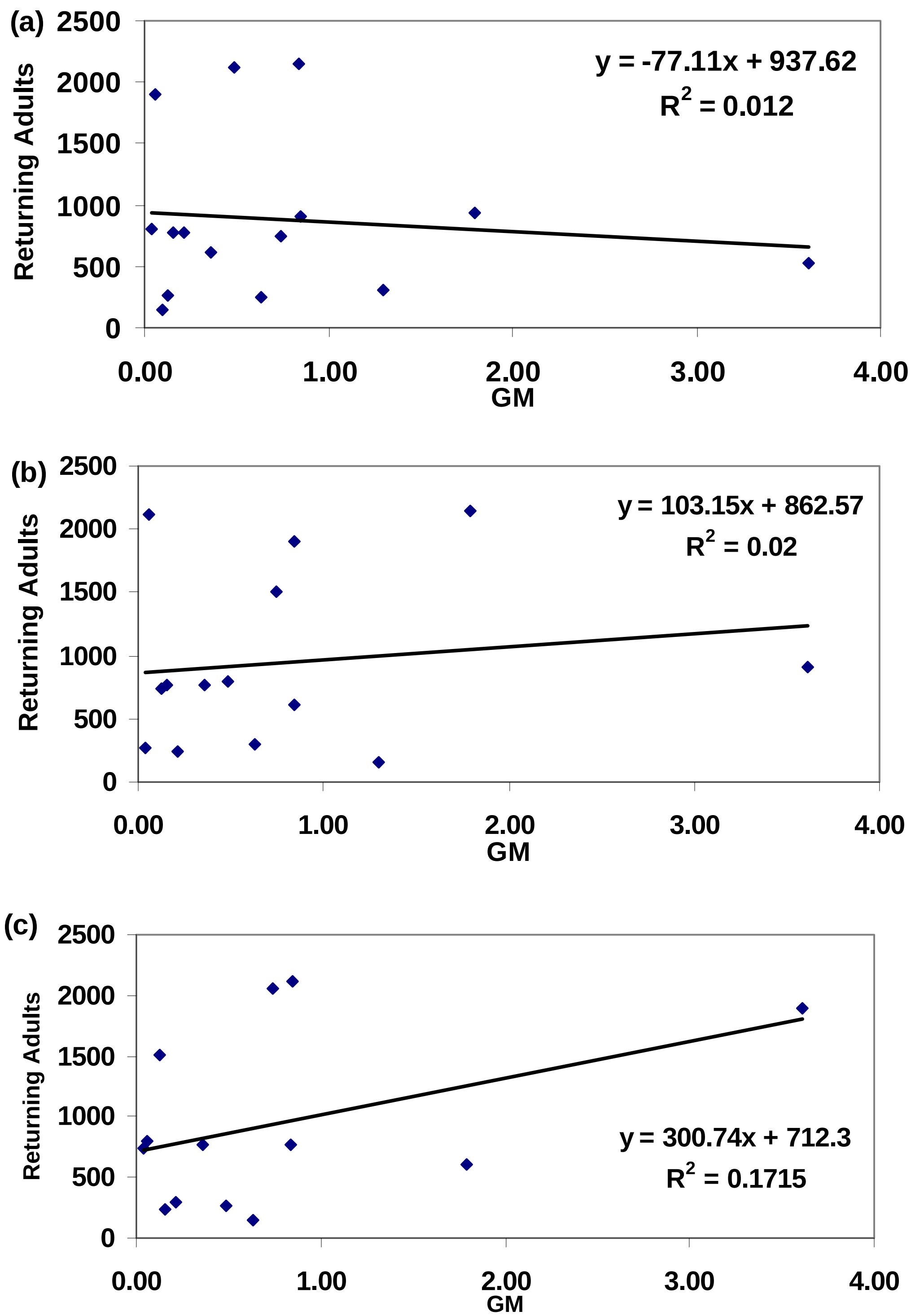


Figure 5.20 Relationship between YOY production (geometric mean) and returning adults in the Pawcatuck River, Rhode Island (a) four, (b) five, and (c) six years later.



Section 6
Status of the Connecticut River American Shad Stock

Contributors:

American Shad Stock Assessment Subcommittee
Atlantic States Marine Fisheries Commission
1444 I Street, N.W., Washington, D.C. 20005

Victor Crecco, Thomas Savoy and Jacqueline Benway
Connecticut Department of Environmental Protection, Marine Fisheries Division
P.O. Box 719, Old Lyme, Connecticut 06317

Joseph Grist
Atlantic States Marine Fisheries Commission
1444 I Street, N.W., Washington, D.C. 20005

6.1 INTRODUCTION

Annual spawning migrations of American shad (*Alosa sapidissima*) in the Connecticut River support sport and commercial fisheries in the State of Connecticut, as well as recreational fisheries in upriver states. The Connecticut Department of Environmental Protection (CTDEP) has studied American shad in the Connecticut River since 1974 to monitor annual changes in stock composition. Information on the abundance of American shad, age structure and sex ratio of the run, the size and extent of the fisheries (both sport and commercial), and annual reproductive success are important in the management of this species.

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 (Garabedian *et al*. 1998; USEPA 2000; Figure 6.1). The river drainage encompasses 11,250 square miles within New Hampshire, Vermont, Massachusetts, and Connecticut. The Connecticut River is heavily regulated; there are at least 125 reservoirs within the basin used for power generation and 16 flood control reservoirs (Garabedian *et al*. 1998). Other major systems in Connecticut include the Housatonic and Thames Rivers, which together drain 3,420 square miles (Garabedian *et al*. 1998; Figure 6.2).

Early in the Connecticut River's history, the construction of dams for hydropower significantly exacerbated water quality problems due to stagnation and the creation of faunal barriers (USEPA 2000). The construction of a dam at Turner Falls, Massachusetts in 1798, 99 miles upstream from the mouth of the Connecticut River, marked the beginning of a long-term decline in anadromous fish runs in New England (Moring 2005). By the mid-1800s, American shad were eliminated from the Massachusetts portions of the Connecticut River (Commonwealth of Massachusetts 2004; Figure 6.3). By 1870, American shad, Atlantic salmon, alewives, blueback herring, striped bass, and rainbow smelt were all declining throughout southern New England, including the Connecticut River drainage (Moring 2005; USEPA 2000). American shad returns have increased in the Connecticut River since the mid-1950s due to newly constructed and improved fish passage facilities (Hartel *et al*. 2002) that have expanded the potential migratory range (Figure 6.4), depending on fish passage efficiency. The U.S. Fish and Wildlife Service (USFWS 2004) reports that the range of American shad in the Connecticut River currently extends to below the dam at Bellows Falls (Figure 6.5).

Opening and operation of the fish-lift for anadromous fish at the Greenville Dam in Norwich in 1996 required information on the age structure and sex ratio of American shad in the Thames River system and monitoring of reproductive success. Small numbers (hundreds to several thousand) of American shad have been present in this system for many years but successful spawning has been considered limited due to salt water penetrating to the Greenville Dam. Researchers reported that the age frequencies of American shad in the Thames River were similar to those reported in the Connecticut River, supporting the idea that the Thames American shad population continues to be composed of strays from the Connecticut River (Savoy and Benway 2004).

6.2 MANAGEMENT UNIT DEFINITION

Connecticut has three major rivers (Connecticut, Housatonic, and Thames) and several minor rivers or large coastal streams (Figure 6.2). American shad are present in the Connecticut River and this natal stock represents the largest and most persistent run in the State. The Interstate-95 bridge over the Connecticut River serves as the management boundary line for American shad between the Inland Fisheries Division and Marine Fisheries Division management areas within the Connecticut Department of Environmental Protection.

One of the major impediments to upstream migration on the Connecticut River is the Holyoke Dam. The Holyoke fish passage facility began operation at Holyoke Dam in 1955. Major technological improvements to the Holyoke lift were made in 1969, 1975, and 1976 (Henry 1976) and are reflected in systematic increases in mean annual passage rates (mean number per lift day) of American shad. After 1976, no further improvements in the fish-lift were made until 2006.

The Thames River is subject to a restoration effort and, while several fishways have been constructed with many more to follow, run sizes consistently remain below 5,000 fish. The management boundary line within the Thames River drainage occurs in the Groton-New London region, at a site located approximately 500 feet north of the Route 1 and Interstate-95 bridge. The Merrit Parkway in the Milford-Stratford area functions as the management boundary line for American shad management within the Housatonic River drainage.

Given that spawning and rearing habitat in the Thames and Housatonic Rivers below main stem dams has been limited since colonial times, the American shad in these systems and many of the larger coastal systems in the state can likely be considered strays from the Connecticut River stock. The stock that will be assessed is the Connecticut River stock.

6.3 REGULATORY HISTORY

There is a long history of fishing regulations in Connecticut with one of the most significant being the establishment of “rest days” in 1922, prohibiting all commercial fishing except for dip nets. The numbers of rest days per year have varied over time from three to zero (during WWII fishing was encouraged by removal of the rest days); two rest days per year have been in effect since 1948.

Fishing for American shad is restricted to the main stem Connecticut River from the Putnam Bridge in Glastonbury and Wethersfield south to the I-95 bridge in Old Saybrook and Old Lyme and in the marine waters of the river south of the I-95 bridge. The open commercial season runs from April 1 through June 15 with nets of mesh size not less than 5 inches stretched mesh allowed. American shad may also be taken commercially in the marine district. The use of a pound net to take American shad in the marine district requires a marine pound net registration. American shad are only occasionally taken as bycatch in Long Island Sound (LIS).

The following are prohibited: (1) use of gill nets constructed of single or multiple strand monofilament from sunrise to sunset, (2) monofilament twine thickness greater than 0.28 mm (#69), (3) commercial fishing for American shad from sundown Friday to sundown Sunday except by the use of a scoop net, (4) the use of nets with mesh size less than five inches stretched mesh, and (5) fishing in other than the main body of the Connecticut River (no coves). The use of pound nets or other fixed or staked nets to take American shad is prohibited, except in the waters of LIS. An annual report of daily fishing activities and catch is required.

6.4 ASSESSMENT HISTORY

Connecticut River American shad have a long and rich history of investigations and assessments. Fredin (1954) estimated annual population size of Connecticut River American shad from 1936 to 1951 using a single Peterson estimate, the resultant estimated fishing power of a single unit of effort, and effort for all years. He used these estimates and reported commercial landings to obtain annual exploitation rates as high as $u = 0.82$. He concluded that population size was regulated by fishing.

Leggett (1976) estimated annual run size using a Peterson tag-release-recapture model in which recapture data came from the commercial fishery. Commercial harvest was adjusted based on ratios of tags to total reported harvest from dependable fishermen and recreational harvest was estimated from annual creel surveys. Leggett (1976) then estimated fishing mortality by age and sex by partitioning the population estimates and harvest to age and calculating the ratio of catch-at-age and population size-at-age. He estimated natural mortality (all mortality except in-river fishing mortality) from tagging studies and as the difference between total mortality and fishing mortality. He developed a parent progeny relationship from adult abundance data, calculated an F_{msy} of $F = 0.54$, and concluded that abundance of the Connecticut River stock had been regulated by in-river fishing mortality since the 1930s.

Gibson *et al.* (1988) developed a Shepherd stock-recruitment curve and estimated an F_{msy} of $F = 0.50$ and later ASMFC (1998) developed a F_{30} for the Connecticut shad stock of $F = 0.43$ based on Shepherd yield-per-recruit modeling. They estimated population size through 1996 by expanding annual number of fish lifted at the lowermost barrier by ratios of population estimates lift numbers in 1970 through 1983. Estimates of recreational harvest were obtained by creel survey while in-river and ocean commercial losses were developed by expanding reported landings by an underreporting rate. Estimates of fishing rates were developed as the log ratio of losses and population size. ASMFC (1998) concluded that the adult run size in the Connecticut River had fluctuated widely since 1976 and that total annual fishing mortality rates were well below F_{30}.

Leggett *et al*. (2004) observed that mean length and percent of repeat spawners had declined since the 1960s concurrent with a loss of older fish in the population. They speculated that this loss of older fish in the population was related to loss of fish lifted up over the first barrier.

6.5 STOCK-SPECIFIC LIFE HISTORY

6.5.1 Growth

Data are collected on length-at-age from all scales interpreted for age but no systematic analysis of growth has been conducted.

6.5.2 Fecundity

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

6.5.3 Genetic Information

Genetic information for American shad is limited but does suggest a homogeneous population between the Connecticut, Hudson, and Delaware rivers. Genotypic frequencies among the populations of the Connecticut, Hudson, and Delaware rivers were statistically homogenous ($P>0.05$) and highly diverse when surveyed for mtDNA variation (Waldman *et al*. 1996). Waldman *et al*. (1996) reported that their results suggested higher gene flow among American shad populations in comparison to Atlantic sturgeon and striped bass, which were not genotypically diverse but did differentiate from northern and southern populations.

6.6 HABITAT DESCRIPTION

The Connecticut River provides reproductive habitat for American shad in its middle reaches (Domermuth and Reed 1980). The distribution of spawning areas is not well known in the lower river (Marcy 1972). Some studies, including Watson (1968, 1970) have suggested American shad spawn as far inland as mile 108 of the Connecticut River. Young American shad spend their first 3 to 4 months in riverine-nursery areas, emigrating seaward as water temperatures decline in the fall (Davis and Cheek 1966; Loesch 1968). An excerpt from Moring (2005) reports:

> Those shad that survive spawning, along with immature adults, generally migrate to the Bay of Fundy, and remain there during the summer and into the fall (Melvin *et al*. 1992). During winter months, shad from New England move into an area between Long Island and the mid-Atlantic coast. Thus, shad are influenced not only by conditions in freshwater but by conditions in several areas of the Gulf of Maine and southward as well.

An excerpt from Harris and McBride (2004) also reports:

> The timing and location of spawning and the subsequent production of American shad eggs and larvae in the Connecticut River have been closely linked to water temperature and zooplankton abundance encountered by first-feeding larvae (Crecco and Savoy 1987). In this river, annual changes in year-class strength were observed to be inversely related to river flow and rainfall and positively related to temperature during the month when most larvae begin feeding (Crecco and Savoy 1987). Survival and growth of larvae were greatest when flows were low (50–100 m3/s) and temperatures were high (10–14 ºC; Crecco and Savoy 1985; Crecco and Savoy 1987). Authors suggested that survival might decrease

with increased flow because increased flow is correlated with increased turbidity, which may be harmful to larvae (Crecco *et al*. 1986).

6.7 RESTORATION PROGRAMS

6.7.1 Connecticut River

The Connecticut River Atlantic Salmon Commission (1992) recommended a series of management objectives for the American shad restoration in the Connecticut River. These included: (1) achieve and sustain an adult population of 1.5 to 2 million individuals entering the mouth of the Connecticut River annually; (2) maximum rate of exploitation shall not exceed 40 percent of the spawning population, based on a 5-year running average; (3) achieve annual passage of 40 to 60 percent of the spawning run (based on a 5-year running average) at each successive upstream barrier on the Connecticut River main stem; and (4) maximize out-migrant survival for juvenile and spent adult shad.

The Holyoke fish passage facility began operation in 1955 and daily counts of the number of American shad lifted have been made annually from 1955 to 2005 (Watson 1970; Moffit *et al*. 1982; Leggett *et al*. 2004). Major technological improvements in the Holyoke lift were been made in 1969, 1975, and 1976 (Henry 1976), and are reflected in systematic increases in mean annual passage rates (mean number per lift day) of American shad. After 1976 no further improvements in the fish-lift were made until 2006, so the time series of fish passage rates from 1976 to 2005 should be consistent.

Transplanting of Connecticut River American shad within and out of basin occurs from the Holyoke Fish-lift in Massachusetts.

6.7.2 Thames River

The Greenville Dam upstream fish passage facility began interim operations on May 16, 1996 and both the upstream and downstream facilities were completed by October 29, 1996. Fish passage evaluations indicated that the fish passage facility was effective at attracting and passing American shad upstream, passing 900 shad in 1996, over 2,800 shad in 1997, and 5,576 shad in 1998 (Kleinschmidt Associates 1999). Fish passage at Greenville Dam has not resulted in notable increases in the adult population size as would have been expected in 2000 and 2001 (Savoy and Benway 2004).

6.8 AGE

The spawning population of American shad in the Connecticut River consists of fish from three to nine years in age, although the majority of fish are between four and six. Very few fish have been collected of age-7 or greater in the last 25 years and the annual spawning run is heavily dependent upon virgin spawners.

Age structure was derived from scale samples collected at the Holyoke fish passage facility in Holyoke, Massachusetts and was used to characterize the population. Researchers sexed adult American shad, measured them to fork length (mm), and removed 10 to 15 scales from each fish. All scale samples were separated by sex and stratified into 1-cm length groups. Scale samples were cleaned with an ultrasonic cleaner and pressed onto acetate for ageing. Age determinations were made with consensus of two or more readers on projected images (43x) by counting annuli and spawning scars according to the criteria of Cating (1953). Repeat spawners were noted by the presence of spawning scar(s) at the periphery of the scale.

6.9 FISHERY DESCRIPTIONS

6.9.1 Brief Overview

A commercial gill-net fishery and a recreational hook and line fishery have harvested American shad in the Connecticut River since the late 19th century. The commercial shad fishery in the Connecticut River is a spring fishery (April-June) that extends from the river mouth to Glastonbury, Connecticut (river km 62).

6.9.2 Commercial Fishery

American shad is the only alosine species harvested by directed fisheries in Connecticut waters. A commercial gill-net fishery for American shad occurs in the inland waters of the Connecticut River. This fishery has been in existence for many years; the state of Connecticut has landings data dating back to 1880. The National Marine Fisheries Service has reported landings from Connecticut that date to 1887 (Table 6.1; Figure 6.6). More intensive monitoring of American shad abundance (numbers and pounds), age structure, and spawning history has been conducted annually from 1974 to 2004. The fishery has changed little since the adoption of outboard-powered vessels, with the exception of the change to drift gill nets from all other gear types (haul seine, fixed gill nets, traps, and pound nets).

The number of commercial American shad fishing licenses (and associated effort) has been systematically declining since the number of licenses peaked during and after World War II. Commercial license sales have declined to low levels and are expected to stay low or further decrease as fishermen retire and are not replaced.

Commercial shad fishermen are required by law to report their annual gill net landings and fishing effort (number of days fished) to the State by September. The reported commercial landings (numbers) of American shad are believed to be less than the true landings because some fishermen underreport their landings for tax purposes (Leggett 1976) and discard male shad due to their low market value. Both Leggett (1976) and Crecco *et al*. (1986) reported that in-river commercial fishermen might have underreported their landings by 35 to 67 percent annually from 1966 to 1983 based on the ratio of tag returns to reported commercial landings.

In-river commercial landings (numbers) of Connecticut River shad varied greatly from 1981 to 2005 (Table 6.2). Commercial landings in the River fell steadily from 1981 through 1999. Landings rebounded briefly thereafter and then again declined (Table 6.2). In-river commercial effort declined from 1981 through the present (Table 6.2). CPUE in this fishery peaked in 1986, declined, and then peaked at a lower level in 2003 (Table 6.2; Figure 6.7). A linear regression of CPUE on year (1981-2005) indicated no trend through the time series ($r^2 = 0.02$, slope = -0.03, $P = 0.51$). No poaching or illegal catch of American shad is thought to occur in this fishery. The fishery is somewhat self-regulating in that drift gill nets are selective in nature and licensed commercial fishermen are not likely to allow unlicensed fishers to displace them from preferred fishing reaches.

American shad are occasionally caught in low numbers in the commercial trawl fishery in eastern LIS. Annual reported landings of all commercial license holders combined being less than 500 pounds. These landings are not only very small, but are also suspected of are mis-identified for hickory shad (*Alosa mediocris*). The State of Connecticut has strict rules of confidentiality regarding the public disclosure of commercial landings reported by less than three fishermen (Greg Wojcik, pers. comm.). Given the confidentiality issue surrounding the disclosure of these small landings, we decided not to include them in this assessment.

A coastwide ocean-intercept fishery for American shad expanded from 1975 to 1988 (ASMFC 1998), but coastwide ocean-intercept landings (pounds) fell steadily thereafter. Recent management actions by coastal states, in compliance with ASMFC requirements, have mandated a complete closure of ocean-intercept fishery after 2005. The ocean-intercept fishery harvested a mixed stock of American shad using drift gill nets during late winter and early spring. This commercial ocean-intercept fishery was located mainly between South Carolina and New Jersey and harvested mostly adult shad (size range 45-60 cm, TL, average weight 1.5-2.5 kg; Krantz *et al*. 1992). The contribution of Connecticut River American shad to the ocean-intercept fishery between 1981 and 2005 (Table 6.2) was based on the total coastal landings from Virginia to Maine and the stock identification data from tagging and mtDNA results (Hattala *et al*. 1998; Hattala 2007, this volume). Specifically, the ocean landings attributed to the Connecticut River shad stock were the sum of the Virginia-Maryland ocean harvest, the Delaware-New Jersey ocean landings, and the New York-New England ocean landings, multiplied by predicted Connecticut River contribution of 0.064 and 0.03, 0.188, and 0.50, respectively.

In most years, the contribution of ocean-intercept commercial landings to the Connecticut River stock was generally lower but more stable across years than in-river shad landings (Table 6.2). The highest ocean-intercept landings (51,000 fish) from the Connecticut River stock occurred in 1988 (Table 6.2). Prior to 1999, annual ocean landings always exceeded 20,000 fish. While in-river landings fell quickly after 1993, ocean landings fell more slowly and comprised a greater proportion of the total landings on Connecticut River shad (Table 6.2). The lowest estimated ocean landings (4,000 fish) occurred in 2005 after a total closure to this fishery was mandated by ASMFC member states and jurisdictions.

6.9.3 Recreational Fishery

Angling for American shad is the only legal method of recreational take and may occur during the open season from April 1 through June 30 in rivers and streams open to fishing all year; otherwise, the open season runs from the 3rd Saturday in April through June 30. There is a daily possession limit of six American and hickory shad in the aggregate, per person, in both the Inland and Marine Districts. In the Pawcatuck River, the open season for American shad follows Rhode Island regulations and no take is allowed. Fishing licenses are required for anyone 16 years of age or older fishing in the Inland District. Licenses are issued on a calendar basis and expire on December 31.

There have been no changes to Connecticut Statutes or regulations pertaining to American shad fishing since March 19, 1999, when the existing six fish recreational creel limit was modified to include hickory shad as an aggregate creel limit for the two species.

The Connecticut River was once the most popular site for American shad recreational fishing and some believe this was the birthplace of the sport. Numbers of fishermen, effort, catch, and harvest have all varied greatly over time but, similar to commercial fishing, recreational fishing for American shad exhibits a general decrease in participation with time. Anecdotal and creel information gathered in the last ten years indicates that few fishermen have targeted American shad in the traditional shad fishing areas from Hartford to the Connecticut-Massachusetts state line in recent years and the trend is not expected to change.

Anglers that traditionally fished for American shad in this area have switched to pursue striped bass, which now provide a quality fishery from Hartford into Massachusetts. The decrease in fishing levels for American shad and particularly in the harvest is also a function of reduction in the number and percentage of the fishing population who know how to bone American shad. Creel surveys of American shad have not been available since 1996

Recreational American shad landings in numbers were estimated annually from 1980 to 1996 and periodically thereafter by a roving creel census (Savoy 1998). Creel data collection techniques have varied slightly with time, but basically have followed a modified “bus stop” technique. Sampling intensity has varied over time, becoming generally less intensive as the fishery got smaller and anglers switched their angling preferences to other species. Two weekdays, the weekend, and all holidays were sampled in early years compared to one weekday and one weekend day in recent years. Holidays have always been sampled given the larger number of people expected to be fishing. No biological sampling of the recreational harvest has been conducted since 1978

Prior to 1993, there was a thriving recreational fishery for American shad in the Connecticut River from Enfield, Connecticut (river km 99) to the Holyoke Dam (river km 140). These sport landings comprised up to 82 percent of annual total in-river landings (Table 6.2). Recreational shad landings began to fall dramatically after 1994 to a point where harvest estimates from creel surveys were unreliable and imprecise as reflected by high (>80%) proportional standard errors (PSE) about the mean harvest estimates. All American shad caught in the recreational fishery were assumed dead although most are released and some survive the catch episode. Hook and release mortality is a function of age, sex, and physiological condition of the fish, as well as external factors including water temperature, length of time “played” by the angler, skill of the angler in handling and releasing the fish, and hook type and location.

Recreational landings (numbers) of Connecticut River shad varied greatly from 1981 to 1997 (Table 6.2). 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 6.2).

In addition to commercial ocean landings, there are also ocean recreational catch estimates of American shad recorded coastwide from 1981 to 2005 by the Marine Recreational Fishery Statistics Survey (MRFSS; see Section 1). Since shad recreational catches occur coastwide across all sub-regions (South, Mid and North Atlantic) and waves (two-month periods), the ocean recreational fishery apparently harvests a mixed stock of American shad. The annual shad catches (fish harvested and released) are usually imprecise with annual PSE that often exceed 80 percent of the mean catch. Moreover, there are no length data available at this time on American shad catches from the MRFSS website so the spawning potential (i.e., adult or sub-adult) of these catches cannot be determined (see Section 1).

6.9.4 Bycatch Losses

There is the potential for significant bycatch losses of American shad in the Atlantic herring (*Clupea harengus*) fisheries in the Gulf of Maine. The Atlantic herring fishery lands annually more than 60 million pounds of herring. This represents a clear potential for significant bycatch losses to all shad stocks along the Atlantic coast (see Section 1).

6.10 FISHERY-INDEPENDENT SURVEYS

6.10.1 Adults

Annual abundance of the spawning population has been inferred from annual lift counts at the Holyoke Dam and Fish-lift since 1955. Lift numbers generally increased through 1992 when numbers peaked at 720,000 fish (Table 6.3; Figure 6.8). Numbers declined sharply in 1993 and have fluctuated since without trend. A regression of lift numbers on year showed a significant increase from 1976 through 1992 ($r^2 = 0.32$, slope = 15,657, $P = 0.02$), but no trend from 1993 through the present ($r^2 = 0.00$, slope = 888, $P = 0.88$).

There are two biases as a result of sampling location. The Holyoke Dam and Fish-lift are located at river kilometer 140. Thus all of the commercial fishing (by statute confined to below river kilometer 75) and most of the recreational fishing has already taken place, causing removals. The resultant escapement is thus a function of run minus harvest and discard mortality. The more significant bias, the percentage of the population that desires to continue upstream passage beyond river kilometer 140, is presently unquantifiable. The Connecticut River stock of American shad persisted and produced sustainable runs from time of closure of the Holyoke Dam in 1849 until effective fish passage began in 1975, suggesting that spawning occurred downriver of the dam.

Males and females returning to spawn and sampled at the Holyoke Dam Fish-lift are predominately ages four through six (Tables 6.4 and 6.5). Historically, repeat spawners were recorded up to age-8. However, a long-term disappearance of male age-8 spawners since 1978 and age-7 spawners since 1996 (1997 and 2002 for females, respectively) is evident. Male repeat spawners have been below their long-term mean (22%) since 1995 (Table 6.6; Figure 6.9). The incidence of female repeat spawners below their long-term mean (17%) increased through the time period (Table 6.7; Figure 6.9).

An excerpt from Facey and Van Den Avyle (1986) is relevant when considering the consequences of these declines in the spawning population:

Overexploitation of females could seriously affect recruitment in future years. In the Connecticut River, 64% of the annual variation in juvenile shad production was related to the number of adults reaching the spawning grounds (Marcy 1976). Leggett (1976) related the number of adults that reached spawning grounds in the Connecticut River with recruitment in the next year as:

$$R = N_e^{0.7118 \times \left(\frac{1-N}{86.59}\right)},$$

where N was the number of eggs produced by the parent stock, and R was recruitment.

Facey and Van Den Avyle (1986) also presented comparisons of American shad that spawned more than once in Atlantic Coast rivers, with the Connecticut River having the second highest repeat spawning percentage report historically (63%).

hickory shad (*Alosa mediocris*). The State of Connecticut has strict rules of confidentiality regarding the public disclosure of commercial landings reported by less than three fishermen (Greg Wojcik, pers. comm.). Given the confidentiality issue surrounding the disclosure of these small landings, we decided not to include them in this assessment.

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6.10.2 Juveniles

In-river Beach Seine

A long and consistent (1966-2005) time series of juvenile abundance indices (mean catch per seine haul) has been established in the Connecticut River (Figure 6.10). Juvenile American shad were collected weekly from July 18 through October 16 at seven fixed stations located from Holyoke, Massachusetts to Essex, Connecticut in the Connecticut River. Seine haul locations and techniques have remained similar to those employed in past Connecticut River American shad investigations (Marcy 1976; Crecco *et al*. 1981). Sites were previously chosen based on location, physical conditions, and accessibility. One seine haul per station was made during daylight hours with a 15.2-m nylon bag seine (4.6-mm mesh, 2.4-m deep, and 2.4-m bag) and 0.5-m lead ropes. Each haul was completed using a boat to set the net approximately 30 m upstream and offshore of the site. Using the lead ropes, the seine was then towed in a downstream arc to the shore and beached. With small sample sizes (less than 500 fish), all clupeids (*Alosa sapidissima*, *A. aestivalis*, *A. pseudoharengus*, and *Brevoortia tyrannus*) were returned to the laboratory. With large sample sizes, clupeids were sub-sampled volumetrically and unnecessary fish returned to the water. Water temperature, weather conditions, time, and tidal stage (when appropriate) were recorded for each station.

In the laboratory, juvenile clupeids were identified to species by the criteria of Lippson and Moran (1974) and counted. Up to 40 juvenile shad per haul were measured (TL mm). Individual seine collections containing greater than 40 shad were randomly sub-sampled for length measurements. All other clupeids were only counted. The annual relative abundance of juvenile American shad was calculated as the geometric and arithmetic mean catch per seine haul from all stations and all dates sampled each year.

Relative abundance of juvenile American shad in the Connecticut River fluctuated without trend since 1981 (Table 6.8, Figure 6.10).

Long Island Sound Trawl Survey

The Long Island Sound Trawl Survey, conducted by the CTDEP, is described by the following excerpt from Savoy and Pacileo (2003):

The LIS trawl survey is a stratified random-block design with three bottom types (sand, mud, and transitional) and four depth intervals (5–9, 9.1–18.2, 18.3–27.3, and >27.4 m). The sample sites for each monthly cruise were selected randomly in proportion to the stratum area available to the gear. The trawl survey was conducted with the 12.8-m RV James P. Galligan from 1984 to 1990 and the 15.2-m RV John Dempsey from 1990 to 2004. All tows were made with a 14-m, combination sweep, Wilcox "V" wing high-rise otter trawl fished for 30 min during daylight hours.

Three indices, with arithmetic and geometric means, were provided for American shad from the LIS trawl survey with an overall spring (Table 6.9; Figure 6.11), overall fall (Table 6.10; Figure 6.12), and age-1 fall index (Table 6.11; Figure 6.13). All three indices were highly variable, with noticeable declines since 1997 during the spring, and an overall decline over the time-series during the fall surveys.

6.11 ASSESSMENT APPROACHES AND RESULTS

We calculated estimates of total instantaneous annual mortality (Z) from age structure as the negative slope of the linear regression of ln(percent-at-age) on age. Results indicated an increasing trend of mortality in Connecticut River American shad since 1970 (Table 6.12; Figure 6.14). Estimates consistently exceeded the benchmark Z_{30} of 0.64 for New England.

6.12 BENCHMARKS

A benchmark value of Z_{30}= 0.64 was calculated for New England American shad stocks (See Section 1.1.5).

6.13 RECOMMENDATIONS

The Connecticut River population of American shad remains depressed relative to historic potential. Mortality rates appear to be excessive on this stock and mean age and mean repeat spawn have declined, especially in the last 20 years. Indices of adult abundance are not available, but both lift numbers at the lowermost dam and CPUE in the commercial fishery downriver of the dam have fluctuated without trend for the last 10 years. Indices of juvenile abundance have fluctuated without trend for at least 25 years. If fish continue to be lifted above the lowermost dam, efforts need to be made on improving downriver passage of adults.

LITERATURE CITED

ASFMC (Atlantic States Marine Fisheries Commission). 1998. Stock assessment of American shad from selected Atlantic coast rivers. ASMFC, Special Report, Washington, D.C.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

Commonwealth of Massachusetts. 2004. Deerfield River Watershed Assessment Report: 2004-2008. Executive Office of Environmental Affairs, Boston. 97 p.

Crecco, V.A., L. Gunn and T. Savoy. 1981. The Connecticut River shad study, 1980. Connecticut Department of Environmental Protection, Final Report AFC 12-87, Hartford.

Crecco, V.A. and T.F. Savoy. 1985. Effects of biotic and abiotic factors on growth and relative survival of young American shad (Alosa sapidissima) in the Connecticut River. Canadian Journal of Fisheries and Aquatic Sciences 42: 1640–1648.

Crecco, V.A. and T.F. Savoy. 1987. Review of recruitment mechanisms of the American shad: the critical period and match-mismatch hypotheses reexamined. American Fisheries Society Symposium 1: 455–468.

Crecco, V.A., T. Savoy and W. Whitworth. 1986. Effects of density-dependent and climatic factors on American shad recruitment: a predictive approach. Canadian Journal of Fisheries and Aquatic Sciences 43(2): 457-463.

Davis, J.R. and R.P. Cheek. 1966. Distribution, food habits, and growth of young clupeids, Cape Fear River system, North Carolina. Proceedings of the Annual Conference Southeastern Association Game and Fish Commission 20: 250–260.

Domermuth, R.R. and R.J. Reed. 1980. Food of juvenile American shad, Alosa sapidissima, juvenile blueback herring, Alosa aestivalis, and pumpkinseed, Lepomis gibbosus, in the Connecticut River below Holyoke Dam, Massachusetts. Estuaries 3: 65-68.

Facey, D.E. and M.J. Van Den Avyle. 1986. American shad species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic). U.S. Fish and Wildlife Service Biological Report 82 (11.45), TR EL-82-4: 18.

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

Garabedian, S.P., J.F. Coles, S.J. Grady, E.C.T. Trench and M.J. Zimmerman. 1998. Water quality in the Connecticut, Housatonic, and Thames River Basins, Connecticut, Massachusetts, New Hampshire, New York, and Vermont, 1992–1995. U.S. Geological Survey, U.S. Geological Survey Circular 1155.

Gibson, M.R., V.A. Crecco, and D.L. Stang. 1988. Stock assessment of American shad from selected Atlantic coastal rivers. Atlantic States Marine Fisheries Commission, Special Report 15, Washington, D.C.

Harris, J. and R. McBride. 2004. A review of the potential effects of water level fluctuations on diadromous fish populations for MFL determinations. Florida Fish and Wildlife Conservation Commission. Final Report for St. Johns River Water Management District Contract No. SG346AA. Tallahassee. Florida.

Hartel, K.E., D.B. Halliwell and A.E. Launer. 2002. Inland Fishes of Massachusetts. Massachusetts Audubon Society, Lincoln.

Hattala, K., R. Allen, N. Lazar and R. O'Reilly. 1998. Stock contributions for American shad landings in mixed stock fisheries along the Atlantic coast. *In:* Atlantic States Marine Fisheries Commission American shad stock assessment Peer Review Report, Washington, D.C.

Henry, S.M. 1976. Development of fish passage facilities for American shad at the Holyoke Dam on the Connecticut River. *In*: Proceedings of a Workshop on American Shad: December 14–16, 1976, University of Massachusetts, Amherst.

Kleinschmidt Associates. 1999. 1996–1998 Evaluations of upstream and downstream fish passage facilities. Greenville Dam Project FERC No. 2441–009, Norwich, Connecticut.

Krantz, C.A., J.P. Mowrer, A.A. Jarzynski, R.V. Jesien and D.R. Weinrich. 1992. Investigation of anadromous alosids in Chesapeake Bay. U.S. Fish and Wildlife Service, Annual Report, Washington, D.C.

Leggett, W.C. 1976. The American shad Alosa sapidissima, with special reference to its migration and population dynamics in the Connecticut River. *In:* D.Merriman and L.M.Thorpe, eds. The Connecticut River Ecological Study: The Impact of a Nuclear Power Plant. American Fishing Society, 1:169-225.

Leggett, W.C., T.F. Savoy, and C.A. Tomichek. 2004. The impact of enhancement initiatives on the structure and dynamics of the Connecticut River population of American shad. *In:* P.M. Jacobsen, D.A. Dixon, W.C. Leggett, B.C. Marcy, Jr. and R.R. Massengill eds., The Connecticut River Ecological Study (1965–1973) Revisited: Ecology of the Lower Connecticut River 1973–2003. pp. 391–405. American Fisheries Society, Monog. 9, Bethesda, Maryland.

Lippson, A. J. and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River estuary. Power Plant Siting Program, Maryland Department of Natural Resources. Annapolis.

Loesch, J.G. 1968. A contribution to the life history of *Alosa aestivalis*. M.S.Thesis, University of Connecticut, Storrs.

Marcy, B. 1972. Spawning of the American shad, *Alosa sapidissima*, in the lower Connecticut River. Chesapeake Science 13(2): 116–119.

Marcy, B.C., Jr. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. Am. Fish. Soc. Monogr. No. 1:141-168.

Melvin, G.D., M.J. Dadswell and J.A. McKenzie. 1992. Usefulness of meristic and morphometric characters in discriminating populations of American Shad (Alosa sapidissima)

(Osteichthyes: Clupeidae) inhabiting a marine environment. Canadian Journal of Fisheries and Aquatic Sciences 49: 266–280.

Moffit, C.M., B. Kynard, and S.G. Rideout. 1982. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. Fisheries 7(6):2-11.

Moring, J. 2005. Chapter 3: Recent Trends in Anadromous Fishes. In The Decline of Fisheries Resources. In: R. Buchsbaum, J. Pederson, and W. Robinson, eds., New England: Evaluating the Impact of Overfishing, Contamination, and Habitat Degradation. Massachusetts Institute of Technology Sea Grant College Publication 05-5. Cambridge.

Savoy, T. 1998. Anadromous fish studies in Connecticut Waters. Progress Report AFC-25.Connecticut Department of Environmental Protection. 26pp.

Savoy, T. and J. Benway. 2004. Connecticut anadromous fish investigations. Connecticut Department of Environmental Protection, AFC 26. Hartford, Connecticut.

Savoy, T. and D. Pacileo. 2003. Movements and important habitats of subadult Atlantic Sturgeon in Connecticut waters. Transactions of the American Fisheries Society, 132:1–8.

USEPA (U.S. Environmental Protection Agency). 2000. Chapter 5 - Connecticut River Case Study. In: Progress in Water Quality: An Evaluation of the National Investment in Municipal Wastewater Treatment. EPA-832-R-00-008,Washington, D.C.

USFWS (United States Fish and Wildlife Service.) 2004. 2003 Connecticut River Migratory Fish Counts. Available: http://www.fws.gov/r5crc/fish/daily.html.

Waldman, J., K. Nolan, J. Hart and I. Wircin. 1996. Genetic Differentiation of Three Key Anadromous Fish Populations of the Hudson River. Estuaries 19 (4): 759–768.

Watson, J. F. 1968. The early life history of the American shad, Alosa sapidissima (Wilson), in the Connecticut River above Holyoke, Massachusetts. M.S. Thesis, University of Massachusetts, Amherst.

Watson, J.F. 1970. Distribution and population dynamics of American shad, Alosa sapidissima (Wilson), in the Connecticut River above Holyoke Dam, Massachusetts. Ph.D. Dissertation, University of Massachusetts, Amherst.

Table 6.1 Annual commercial landings (kg) of American shad in Connecticut Waters.

Year	Landings (kg)
1887	152,861
1888	127,913
1889	88,904
1890	54,431
1891	35,380
1892	28,576
1893	64,864
1894	114,305
1895	98,883
1896	118,388
1897	116,120
1898	226,343
1899	150,139
1900	222,260
1901	196,859
1902	217,724
1903	279,413
1904	273,516
1905	219,992
1906	114,759
1907	61,689
1908	55,338
1909	55,338
1910	44,452
1911	43,545
1912	95,254
1913	83,461
1914	92,079
1915	67,132
1916	83,461
1917	102,512
1918	109,316
1919	210,013
1920	79,832
1921	32,659
1922	21,319
1923	20,865
1924	40,370
1925	66,224
1926	50,349
1927	54,431
1928	90,265
1929	144,242
1930	24,494
1931	34,019
1932	31,751
1933	60,328
1934	238,136
1935	182,798
1936	174,633
1937	173,726
1938	193,684
1939	185,519
1940	163,293
1941	198,673
1942	169,190
1943	250,837
1944	338,833
1945	349,992
1946	519,862
1947	359,563
1948	281,953
1949	213,506
1950	119,522
1951	153,314
1952	215,048
1953	163,021
1954	133,991
1955	95,345
1956	89,222
1957	149,050
1958	206,974
1959	181,800
1960	181,392
1961	210,195
1962	206,747
1963	136,441
1964	125,963
1965	159,755
1966	109,724
1967	108,862
1968	96,343
1969	86,137
1970	78,517
1971	109,180
1972	113,035
1973	116,845
1974	112,128
1975	75,070
1976	177,808
1977	150,774
1978	138,935
1979	93,803
1980	140,840
1981	147,281
1982	128,367
1983	193,230
1984	180,963
1985	182,344
1986	146,488
1987	151,454
1988	85,956
1989	82,679
1990	119,066
1991	68,166
1992	65,614
1993	43,954
1994	48,022
1995	27,958
1996	66,299
1997	85,121
1998	82,663
1999	65,426
2000	98,532
2001	26,868
2002	49,033
2003	50,406
2004	7,208

Table 6.2 Annual losses (numbers in thousands) of Connecticut River American shad.

Year	In-river Commercial Landings	Commercial Effort*	Commercial CPUE**	In-river Recreational Landings	Total In-river Landings	Commercial Ocean Landings***
1981	49.0	907	5.40	69	118.0	33.0
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	35.0
1985	38.0	590	6.44	41	79.0	41.0
1986	54.0	525	10.29	105	159.0	39.5
1987	31.5	350	9.00	93	124.5	42.0
1988	31.0	450	6.89	53	84.0	51.0
1989	30.5	400	7.63	60	90.5	39.0
1990	22.5	500	4.50	38	60.5	39.5
1991	24.0	500	4.80	85	109.0	38.5
1992	25.5	410	6.22	120	145.5	25.0
1993	17.0	400	4.25	65	82.0	27.5
1994	16.0	350	4.57	45	61.0	16.0
1995	10.5	400	2.63	14	24.5	23.0
1996	12.0	300	4.00	11	23.0	24.0
1997	16.0	300	5.33		16.0	24.5
1998	16.0	300	5.33		16.0	30.5
1999	8.0	225	3.56		8.0	28.0
2000	17.5	225	7.78		17.5	17.5
2001	11.0	200	5.50		11.0	26.5
2002	21.0	250	8.40		21.0	26.5
2003	20.0	250	8.00		20.0	14.0
2004	12.0	225	5.33		12.0	12.5
2005	11.0	200	5.50		11.0	4.0

*Gill net days

**Catch/gill net day * 100

***1995 value may be incomplete

Table 6.3 Annual number of mature American shad lifted at the Holyoke Dam Fish-lift on the Connecticut River.

Year	Number	Year	Number
1955	4,900	1980	380,000
1956	7,700	1981	380,000
1957	8,800	1982	290,000
1958	5,700	1983	530,000
1959	15,000	1984	500,000
1960	15,000	1985	480,000
1961	23,000	1986	350,000
1962	21,000	1987	280,000
1963	31,000	1988	290,000
1964	35,000	1989	350,000
1965	34,000	1990	360,000
1966	16,000	1991	520,000
1967	19,000	1992	720,000
1968	25,000	1993	340,000
1969	45,000	1994	181,000
1970	66,000	1995	190,000
1971	53,000	1996	276,000
1972	26,000	1997	299,000
1973	25,000	1998	316,000
1974	53,000	1999	194,000
1975	110,000	2000	225,000
1976	350,000	2001	273,000
1977	200,000	2002	375,000
1978	140,000	2003	287,000
1979	260,000	2004	191,290

Table 6.4 Age structure (%) of male American shad captured at the Holyoke Dam Fish-lift on the Connecticut River.

Year	Age						Mean
	3	4	5	6	7	8	
1970	0.0	72.4	17.8	6.9	0.9	1.9	4.4
1971	0.0	46.3	35.6	12.1	4.2	1.9	4.8
1972	0.0	46.6	36.7	12.3	3.3	1.1	4.8
1973	0.0	71.4	16.4	8.0	2.9	1.3	4.5
1974	0.0	42.4	41.2	9.7	4.7	1.9	4.8
1975	0.0	45.6	38.7	12.5	2.8	0.4	4.7
1976	0.0	13.9	73.8	9.0	2.5	0.8	5.0
1977	0.0	35.9	52.1	9.9	1.9	0.2	4.8
1978	0.0	63.2	32.6	4.0	0.3	0.0	4.4
1979	0.0	44.5	47.3	7.7	0.5	0.0	4.6
1980	0.0	28.1	50.5	20.7	0.7	0.0	4.9
1981	0.0	35.7	51.1	12.7	0.4	0.0	4.8
1982	0.0	9.6	73.7	15.8	1.0	0.0	5.1
1983	0.0	51.7	38.2	8.7	1.4	0.0	4.6
1984	0.0	31.3	53.5	13.1	2.0	0.0	4.9
1985	0.0	22.0	58.0	18.0	2.0	0.0	5.0
1986	9.4	32.9	32.9	24.2	0.7	0.0	4.7
1987	0.0	12.4	54.5	28.9	4.1	0.0	5.3
1988	0.0	22.4	72.4	5.3	0.0	0.0	4.8
1989	0.0	1.1	41.5	54.8	2.7	0.0	5.6
1990	1.1	27.2	59.8	10.9	1.1	0.0	4.8
1991	0.0	21.3	60.6	15.8	2.4	0.0	5.0
1992	0.0	19.9	56.5	22.1	1.5	0.0	5.1
1993	0.7	6.6	50.3	41.1	1.3	0.0	5.4
1994	0.0	4.0	64.0	32.0	0.0	0.0	5.3
1995	5.0	33.3	48.3	10.0	3.3	0.0	4.7
1996	0.9	38.1	55.8	5.3	0.0	0.0	4.7
1997	0.0	20.0	79.0	1.0	0.0	0.0	4.8
*1998	2.8	19.7	74.6	2.8	0.0	0.0	4.8
*1999	0.0	12.0	80.0	8.0	0.0	0.0	5.0
2000	2.6	43.6	53.8	0.0	0.0	0.0	4.5
2001	2.8	71.3	24.6	1.2	0.0	0.0	4.2
2002	2.6	45.2	52.0	0.2	0.0	0.0	4.5
2003	0.8	45.1	53.2	0.8	0.0	0.0	4.5
2004	0.8	17.8	80.3	1.2	0.0	0.0	4.8

* 1998 and 1999 age structures are based on low sample sizes

Table 6.5 Age structure (%) of female American shad captured at the Holyoke Dam Fish-lift on the Connecticut River.

Year	Age					Mean
	4	5	6	7	8	
1970	35.1	41.5	17.2	4.8	1.4	5.0
1971	23.8	54.8	14.0	5.8	1.5	5.1
1972	25.9	55.0	12.8	3.1	3.2	5.0
1973	28.4	30.9	28.0	7.6	5.2	5.3
1974	22.5	56.3	11.8	5.2	4.1	5.1
1975	18.5	61.7	13.5	3.7	2.7	5.1
1976	11.0	78.2	6.6	2.8	1.3	5.1
1977	8.7	66.0	22.3	1.9	1.1	5.2
1978	23.7	48.3	21.8	5.1	1.1	5.1
1979	16.5	69.2	11.3	1.8	1.1	5.0
1980	17.4	52.5	27.5	2.0	0.6	5.2
1981	24.1	49.4	19.7	5.6	1.1	5.1
1982	2.4	72.7	19.8	4.4	0.6	5.3
1983	13.9	35.1	45.7	3.8	1.5	5.4
1984	12.0	49.0	32.0	5.0	2.0	5.4
1985	2.0	55.0	31.0	11.0	1.0	5.5
1986	1.0	40.0	57.0	1.0	1.0	5.6
1987	3.8	40.3	46.2	7.5	2.2	5.6
1988	9.5	62.1	23.2	4.7	0.5	5.3
1989	1.0	27.9	58.3	11.3	1.5	5.8
1990	3.8	31.9	56.7	7.6	0.0	5.7
1991	1.4	49.3	44.3	3.6	1.4	5.5
1992	3.0	49.6	46.5	0.9	0.0	5.5
1993	6.2	42.4	46.9	3.7	0.8	5.5
1994	5.0	63.0	30.4	1.7	0.0	5.3
1995	9.7	47.6	38.4	3.6	0.6	5.4
1996	14.7	53.4	29.3	2.4	0.2	5.2
1997	9.0	82.5	8.3	0.2	0.0	5.0
*1998	1.2	76.8	22.0	0.0	0.0	5.2
*1999	3.9	72.5	21.6	2.0	0.0	5.2
2000	8.2	61.1	30.7	0.0	0.0	5.2
2001	20.4	59.9	19.7	0.0	0.0	5.0
2002	9.6	79.6	10.1	0.7	0.0	5.0
2003	7.2	82.4	10.4	0.0	0.0	5.0
2004	0.4	88.8	10.7	0.0	0.0	5.1

* 1998 and 1999 age structures are based on low sample sizes

Table 6.6 Estimated percent of male American shad repeat spawners at the Holyoke Dam Fish-lift on the Connecticut River.

Year	Age						Mean
	3	4	5	6	7	8	
1970	0	13	92	100	100	27	28
1971	0	14	68	100	100	25	45
1972	0	12	95	100	100	25	42
1973	0	13	82	100	100	40	20
1974	0	15	54	94	100	24	34
1975	0	10	31	76	100	16	26
1976	0	7	41	100	100	12	35
1977	0	12	18	88	100	15	25
1978	0	9	64	78	100	24	14
1979	0	14	44	100	100	18	30
1980	0	9	21	91	100	13	23
1981	0	10	41	83	100	19	19
1982	0	3	7	59	100	7	14
1983	0	2	33	75	100	20	12
1984	0	3	12	100	100	12	27
1985	0	10	26	64	100	22	34
1986	9	4	10	9	100	9	23
1987	0	15	42	100	100	35	54
1988	0	9	39	89	100	19	10
1989	0	7	17	78	100	22	20
1990	0	10	21	38	0	18	15
1991	0	7	14	50	100	13	16
1992	0	5	10	100	0	8	9
1993	0	9	18	56	100	15	17
1994	0	18	29	100	0	22	56
1995	0	8	43	100	100	25	15
1996	0	4	25	100	100	12	16
1997	0	5	26	100	0	7	18
*1998	0	8	39	0	0	15	17
*1999	0	0	36	100	0	10	0
2000	3	15	37	0	0	21	8
2001	0	19	38	0	0	19	14
2002	2	22	84	100	0	27	17
2003	0	2	12	0	0	3	8
2004	0	7	46	0	0	11	10

* 1998 and 1999 age structures based on small sample sizes

Table 6.7 Estimated percent of female American shad repeat spawners at the Holyoke Dam Fish-lift on the Connecticut River.

Year	**Age**					**Mean**
	4	**5**	**6**	**7**	**8**	
1970	0	13	92	100	100	27
1971	0	14	68	100	100	25
1972	0	12	95	100	100	25
1973	0	13	82	100	100	40
1974	0	15	54	94	100	24
1975	0	10	31	76	100	16
1976	0	7	41	100	100	12
1977	0	12	18	88	100	15
1978	0	9	64	78	100	24
1979	0	14	44	100	100	18
1980	0	9	21	91	100	13
1981	0	10	41	83	100	19
1982	0	3	7	59	100	7
1983	0	2	33	75	100	20
1984	0	3	12	100	100	12
1985	0	10	26	64	100	22
1986	9	4	10	9	100	9
1987	0	15	42	100	100	35
1988	0	9	39	89	100	19
1989	0	7	17	78	100	22
1990	0	10	21	38	0	18
1991	0	7	14	50	100	13
1992	0	5	10	100	0	8
1993	0	9	18	56	100	15
1994	0	18	29	100	0	22
1995	0	8	43	100	100	25
1996	0	4	25	100	100	12
1997	0	5	26	100	0	7
*1998	0	8	39	0	0	15
*1999	0	0	36	100	0	10
2000	3	15	37	0	0	21
2001	0	19	38	0	0	19
2002	2	22	84	100	0	27
2003	0	2	12	0	0	3
2004	0	7	46	0	0	11

* 1998 and 1999 age structures based on small sample sizes

Table 6.8 Annual indices of age-0 abundance for American shad on the Connecticut River.

Year	Arithmetic Mean Catch per Haul	Geometric Mean Catch per Haul
1981	12.9	6.3
1982	4.8	1.8
1983	17.5	5.2
1984	12.6	4.3
1985	15.9	7.1
1986	17.0	6.3
1987	46.8	11.1
1988	24.0	5.8
1989	61.6	5.0
1990	43.0	10.4
1991	47.5	4.0
1992	104.6	8.1
1993	80.6	9.4
1994	353.0	13.2
1995	31.7	1.3
1996	38.6	6.5
1997	66.1	7.6
1998	41.3	3.6
1999	61.5	5.6
2000	27.7	4.4
2001	53.4	2.8
2002	94.3	5.4
2003	34.1	6.8
2004	22.5	5.6
2005	50.8	10.2

Table 6.9 Summary of American shad data collected in the spring segment of the Connecticut DEP Long Island Sound Trawl Survey.

Year	Tows per Survey	Total Number Taken	Max Size (mm)	Tows with American Shad	ln(Mean)	ln(SE)	Arithmetic Mean	Proportion of Tows with American Shad	Geometric Mean
1984	32	12	11	2	0.1	0.08	0.4	0.06	0.1
1985	46	243	45	21	0.86	0.18	5.3	0.46	1.36
1986	116	265	109	36	0.45	0.08	2.3	0.31	0.57
1987	120	299	50	54	0.65	0.08	2.5	0.45	0.92
1988	120	156	53	33	0.36	0.07	1.3	0.28	0.44
1989	120	628	230	47	0.64	0.1	5.2	0.39	0.9
1990	120	109	33	31	0.29	0.06	0.9	0.26	0.34
1991	120	202	47	40	0.43	0.07	1.7	0.33	0.54
1992	80	164	36	32	0.56	0.09	2.1	0.4	0.75
1993	120	80	19	28	0.26	0.05	0.7	0.23	0.29
1994	120	675	374	40	0.52	0.09	5.6	0.33	0.68
1995	120	187	39	29	0.4	0.07	1.6	0.24	0.49
1996	120	452	331	32	0.39	0.08	3.8	0.27	0.48
1997	120	671	145	49	0.73	0.11	5.6	0.41	1.08
1998	120	392	61	47	0.62	0.09	3.3	0.39	0.86
1999	120	313	88	48	0.59	0.08	2.6	0.4	0.8
2000	120	156	33	27	0.33	0.07	1.3	0.23	0.38
2001	120	14	2	13	0.08	0.02	0.1	0.11	0.08
2002	120	336.3	62	31	0.47	0.09	2.8	0.26	0.61
2003	120	43.4	7.5	23	0.19	0.04	0.4	0.19	0.2
2004	119	83.4	13	32	0.29	0.05	0.7	0.27	0.34
2005	120	79.2	11	24	0.25	0.05	0.7	0.2	0.28

Table 6.10 Summary of American shad data collected in the fall segment of the Connecticut DEP Long Island Sound Trawl Survey

Year	Tows per Survey	Total Number Taken	Max Size (mm)	Tows with American Shad	ln(Mean)	ln(SE)	Arithmetic Mean	Proportion of Tows with American Shad	Geometric Mean
1984	70	970	152	41	1.42	0.19	13.9	0.59	3.13
1985	80	37	11	10	0.17	0.06	0.5	0.13	0.19
1986	80	79	31	12	0.24	0.07	1	0.15	0.27
1987	80	72	15	13	0.26	0.07	0.9	0.16	0.29
1988	80	1031	160	41	1.3	0.17	12.9	0.51	2.66
1989	80	1349	264	40	1.41	0.19	16.9	0.5	3.1
1990	80	297	160	22	0.5	0.11	3.7	0.28	0.65
1991	80	159	25	27	0.54	0.1	2	0.34	0.72
1992	80	216	114	22	0.43	0.1	2.7	0.28	0.54
1993	120	1062	144	34	0.75	0.13	8.9	0.28	1.11
1994	120	1048	162	63	1.04	0.12	8.7	0.53	1.84
1995	80	568	115	39	1.06	0.15	7.1	0.49	1.9
1996	80	49	16	16	0.24	0.06	0.6	0.2	0.27
1997	80	251	78	31	0.65	0.11	3.1	0.39	0.91
1998	80	509	83	29	0.8	0.14	6.4	0.36	1.22
1999	80	674	99	37	1.01	0.15	8.4	0.46	1.73
2000	80	160.4	30	20	0.44	0.1	2	0.25	0.55
2001	80	95	35	21	0.34	0.08	1.2	0.26	0.41
2002	80	256.4	58	24	0.57	0.12	3.2	0.3	0.76
2003	40	262	184	11	0.56	0.18	6.6	0.28	0.75
2004	80	272.4	86	32	0.67	0.11	3.4	0.4	0.95

Table 6.11 Summary of age-1 (160-299 mm FL) American shad collected in the fall segment of the Connecticut DEP Long Island Sound Trawl Survey, 1991-2004.

Year	Tows per Survey (N)	Total Fish Taken (N)	Tows w/species (N)	Arithmetic Mean	Proportion of Tows with American Shad	Geometric Mean
1991	80	137	26	1.71	0.325	0.64
1992	80	184	19	2.3	0.238	0.46
1993	120	948.5	33	7.9	0.275	0.96
1994	120	560.1	51	4.67	0.425	1.2
1995	80	507.1	35	6.34	0.438	1.63
1996	80	38.6	14	0.48	0.175	0.22
1997	80	190.3	30	2.38	0.375	0.74
1998	80	476.7	27	5.96	0.338	1.11
1999	80	590.6	30	7.38	0.375	1.31
2000	80	160.3	20	2	0.25	0.55
2001	80	89	20	1.11	0.25	0.38
2002	80	254.5	22	3.18	0.275	0.73
2003	40	222.1	9	5.55	0.225	0.61
2004	80	253.6	31	3.17	0.388	0.85

Table 6.12 Instantaneous rates of total mortality (Z) for American shad collected at the Holyoke Dam Fish-lift on the Connecticut River.

Year	Males		Females	
	Z	Ages	Z	Ages
1970	1.03	4-8	1.14	5-8
1971	0.85	4-8	1.17	5-8
1972	0.99	4-8	1.00	5-8
1973	0.98	4-8	0.67	5-8
1974	0.83	4-8	0.87	5-8
1975	1.21	4-8	1.07	5-8
1976	1.47	5-8	1.30	5-8
1977	1.83	5-8	1.46	5-8
1978	1.84	4-7	1.29	5-8
1979	2.27	5-7	1.42	5-8
1980	2.15	5-7	1.61	5-8
1981	2.37	5-7	1.27	5-8
1982	2.14	5-7	1.58	5-8
1983	1.24	4-7	1.70	6-8
1984	1.64	5-7	1.15	5-8
1985	1.68	5-7	1.31	5-8
1986	1.20	5-7	2.02	6-8
1987	1.29	5-7	1.53	6-8
1988	2.61	5-6	1.59	5-8
1989	1.37	5-7	1.84	6-8
1990	2.00	5-7	2.01	6-7
1991	1.63	5-7	1.31	6-8
1992	1.81	5-7	2.02	6-7
1993	1.82	5-7	2.02	6-8
1994	0.69	5-6	1.82	5-7
1995	1.34	5-7	1.57	5-8
1996	2.35	5-6	1.87	5-8
1997	4.42	5-6	2.98	5-7
1998	3.28	5-6	1.25	5-6
1999	2.30	5-6	1.81	5-7
2000			0.69	5-6
2001	2.02	5-6	1.11	5-6
2002	5.56	5-6	2.39	5-7
2003	4.14	5-6	2.07	5-6
2004	4.24	5-6	2.12	5-6

Figure 6.1 Sub-drainages and dams of the Connecticut River watershed (USFWS 2000).

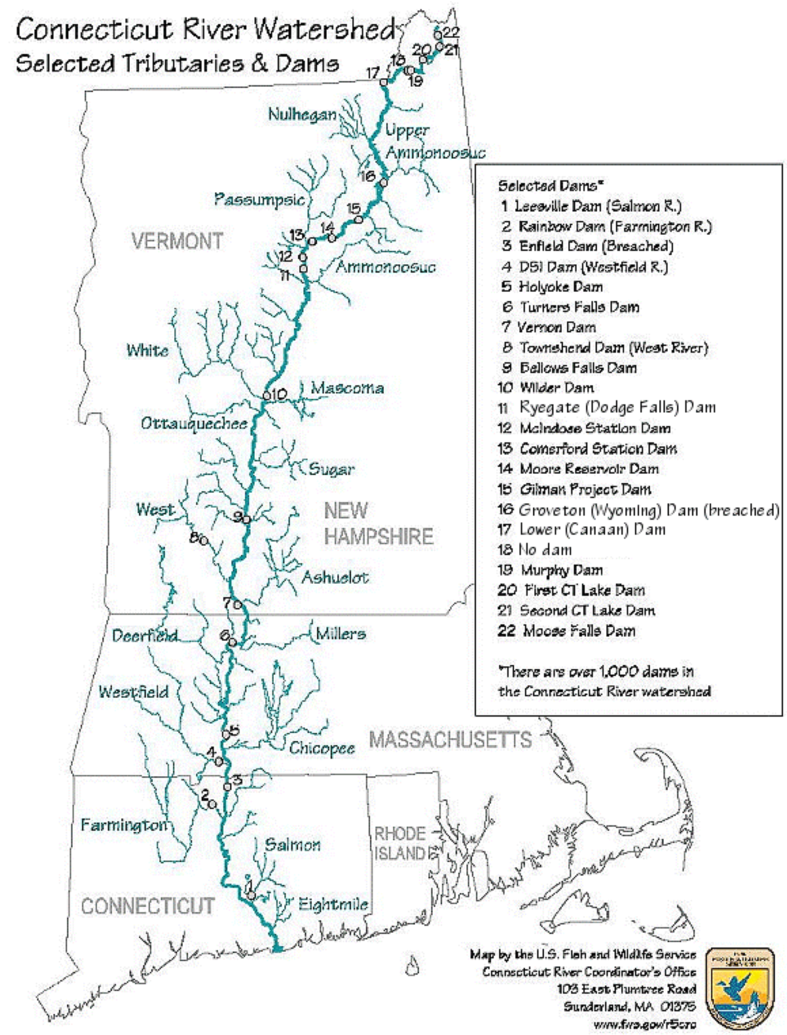


Figure 6.2 Major drainage basins in Connecticut (image source: www.riversalliance.org).

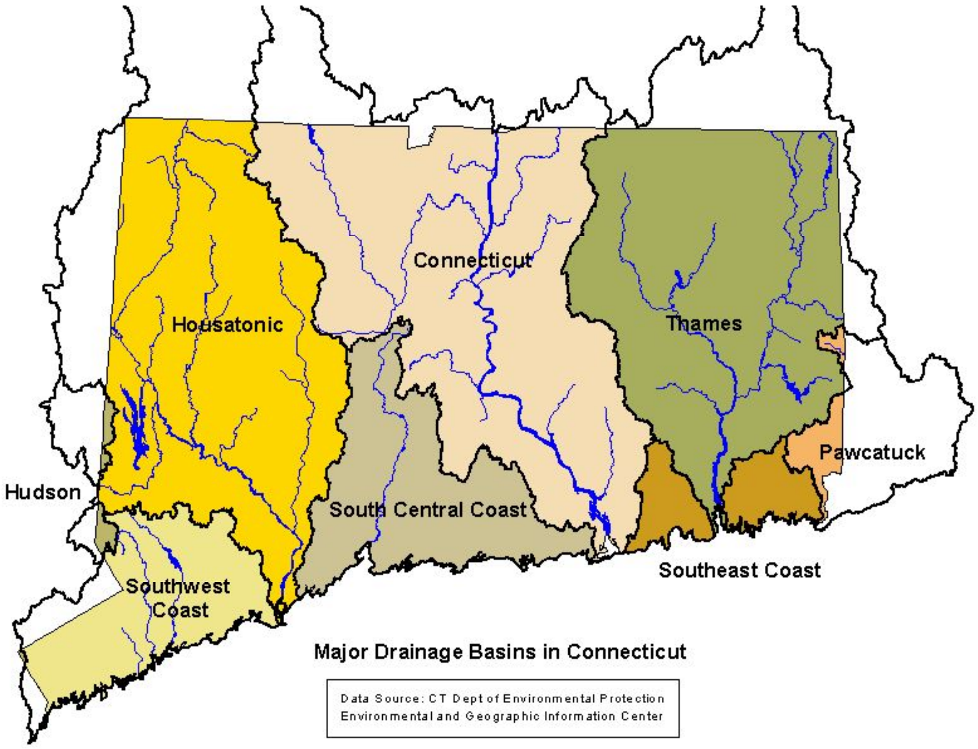


Figure 6.3 Potential migratory range limitation by dams for American shad in the Connecticut River (image source: www.fws.gov).

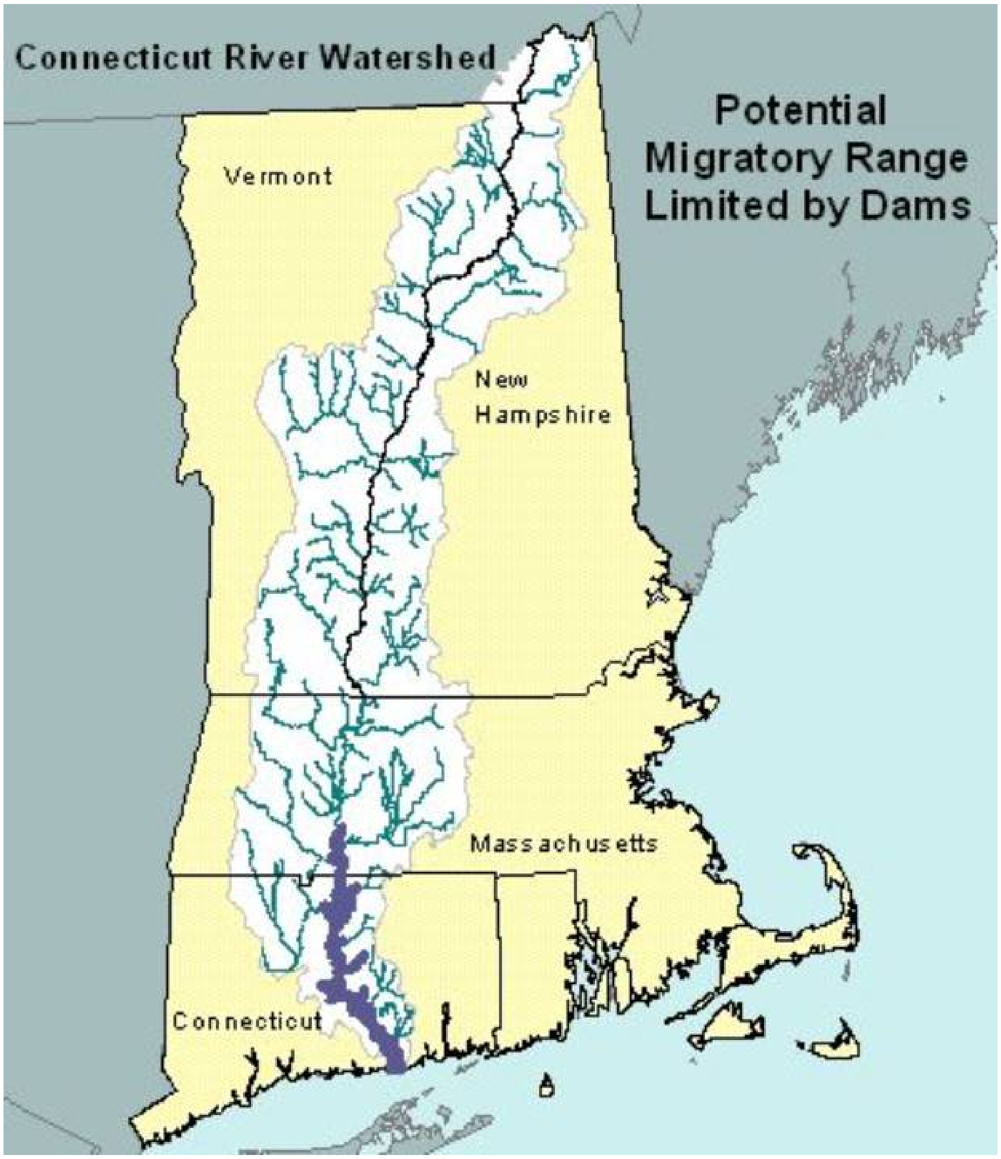


Figure 6.4 Potential migratory range after upstream fish passage additions to dams for American shad in Connecticut River (image source: www.fws.gov).

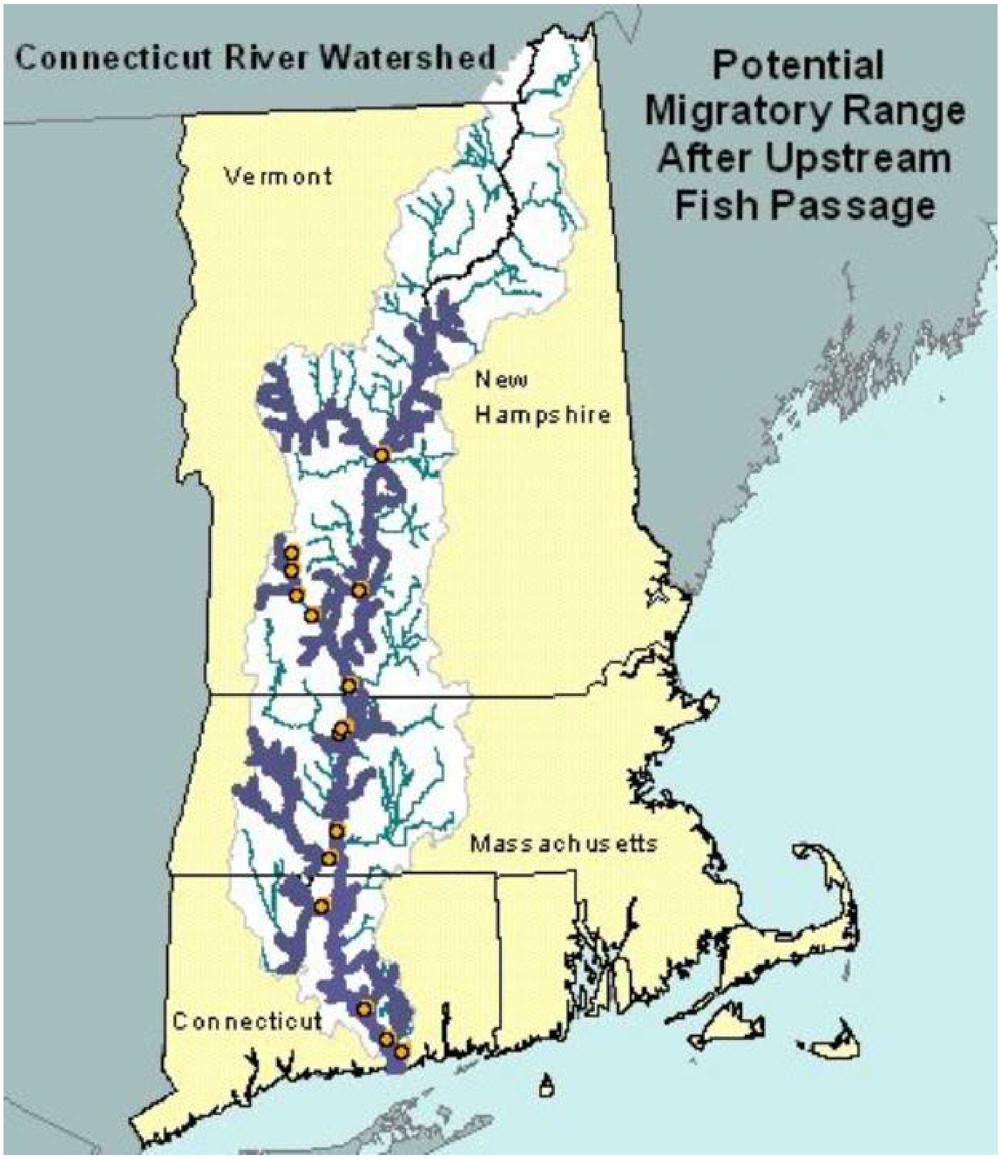


Figure 6.5 Current range of American shad in the Connecticut River (image source: www.fws.gov).

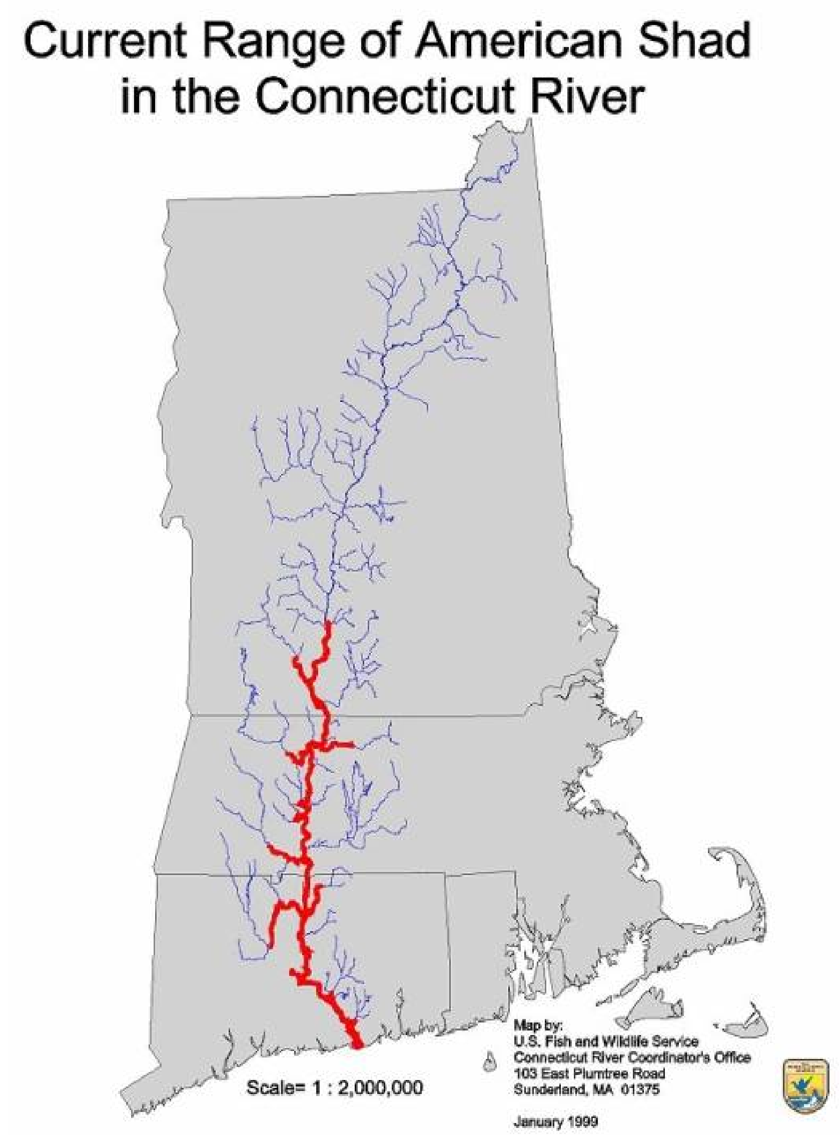


Figure 6.6 Reported historical commercial landings (kg) for the State of Connecticut.

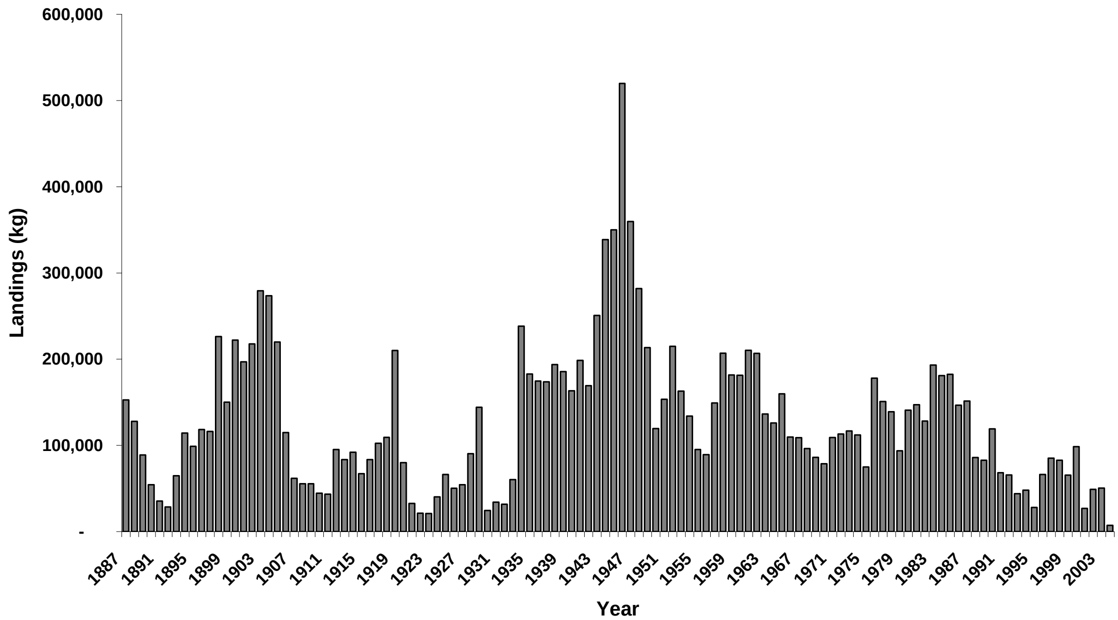


Figure 6.7 Catch per gill net day of American shad in the in-river commercial fishery in the Connecticut River.

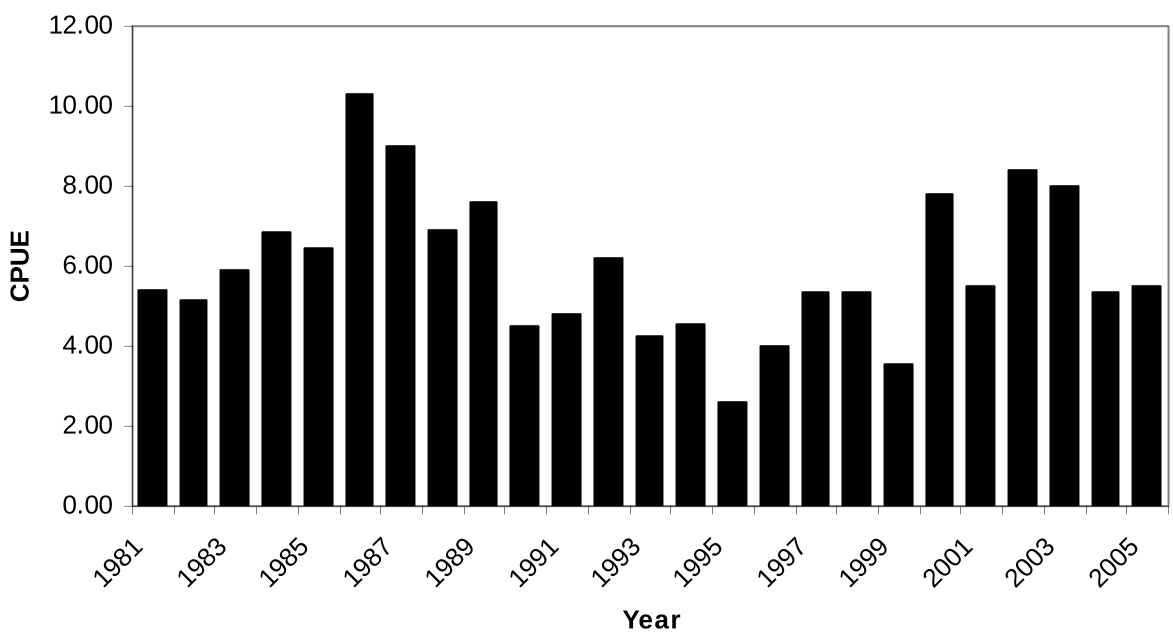


Figure 6.8 Annual number of mature American shad lifted at the Holyoke Dam Fish-lift on the Connecticut River.

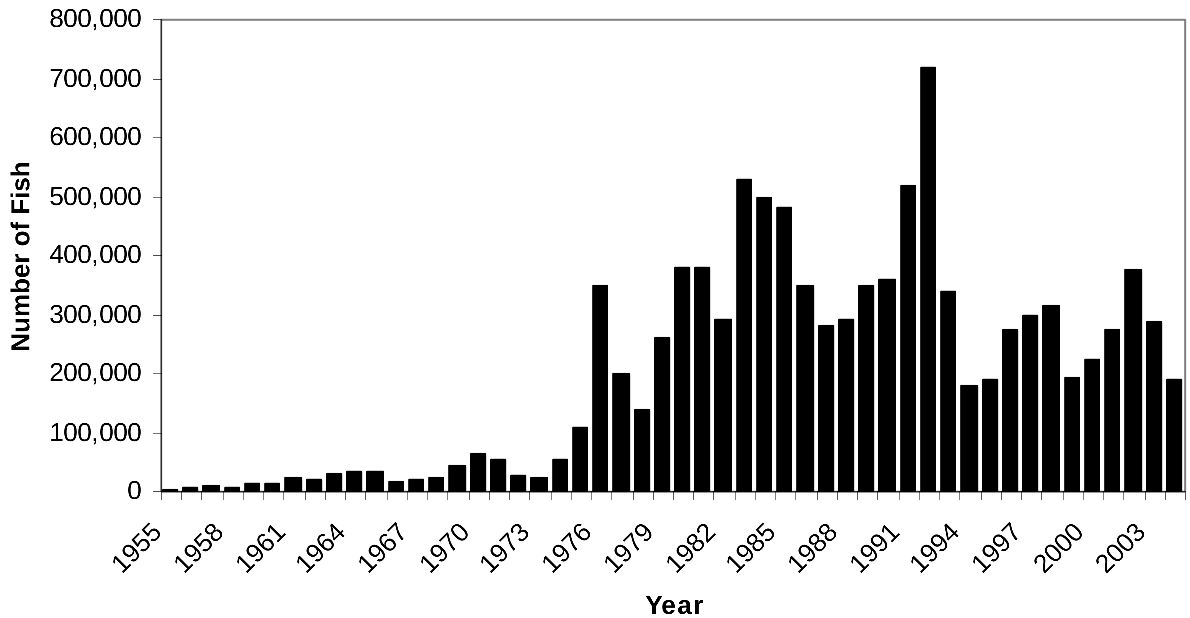


Figure 6.9 Connecticut River male and female annual percent repeat spawners.

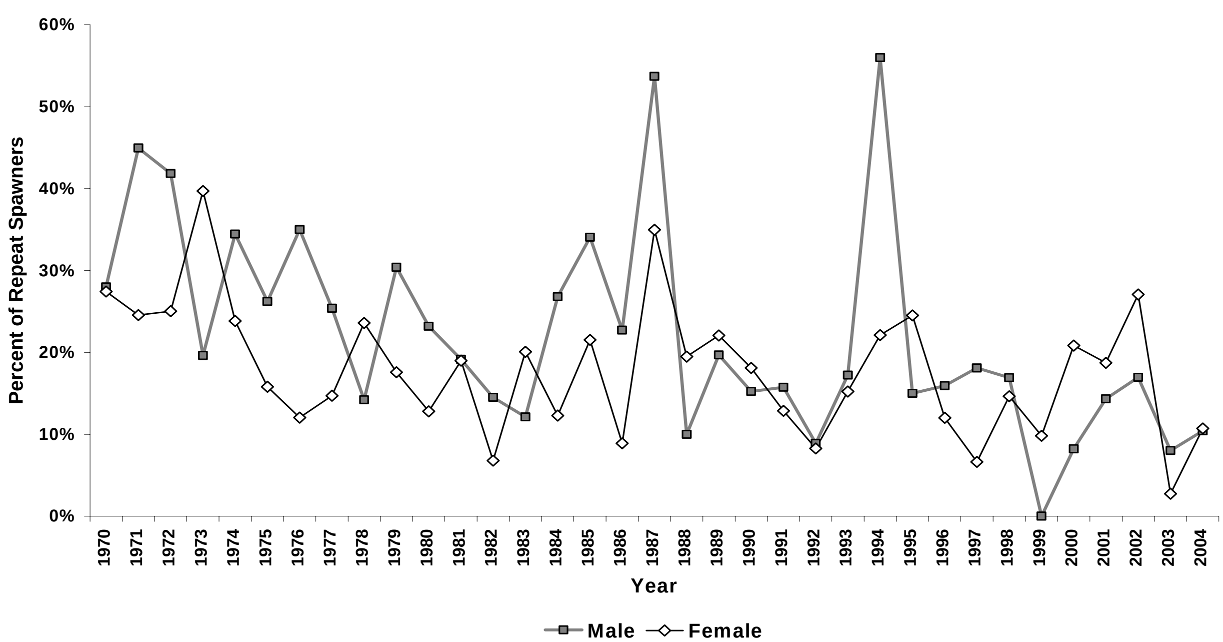


Figure 6.10 Geometric mean index of age-0 abundance of American shad in the Connecticut River.

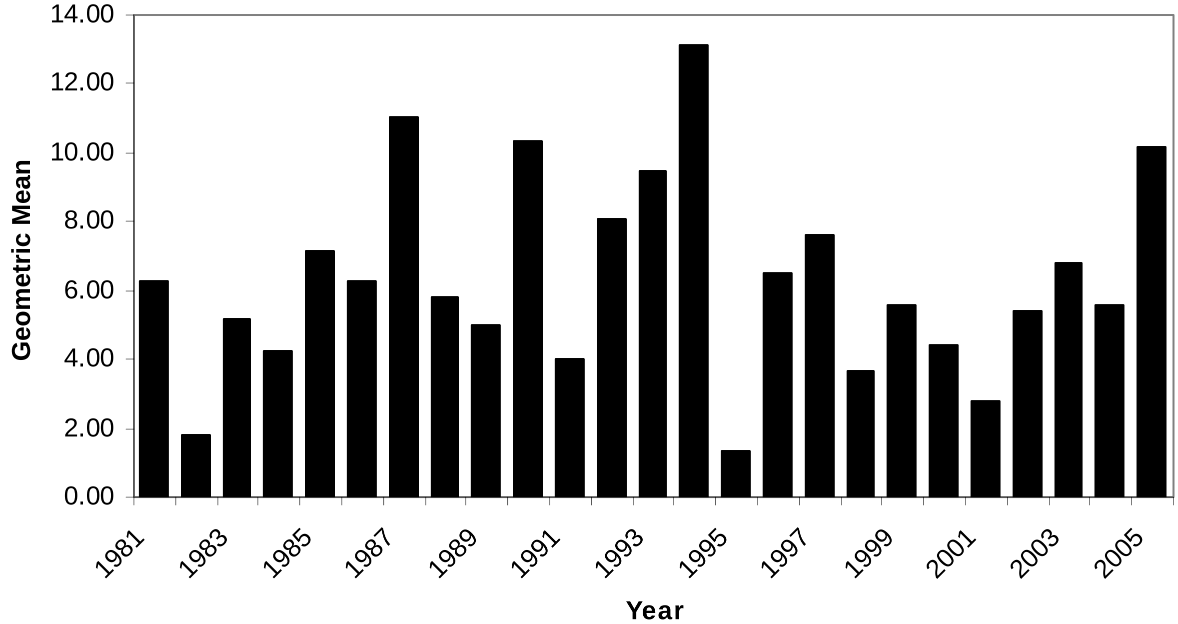


Figure 6.11 Connecticut DEP Spring Long Island Sound trawl survey juvenile abundance of American shad in geometric mean and arithmetic mean.

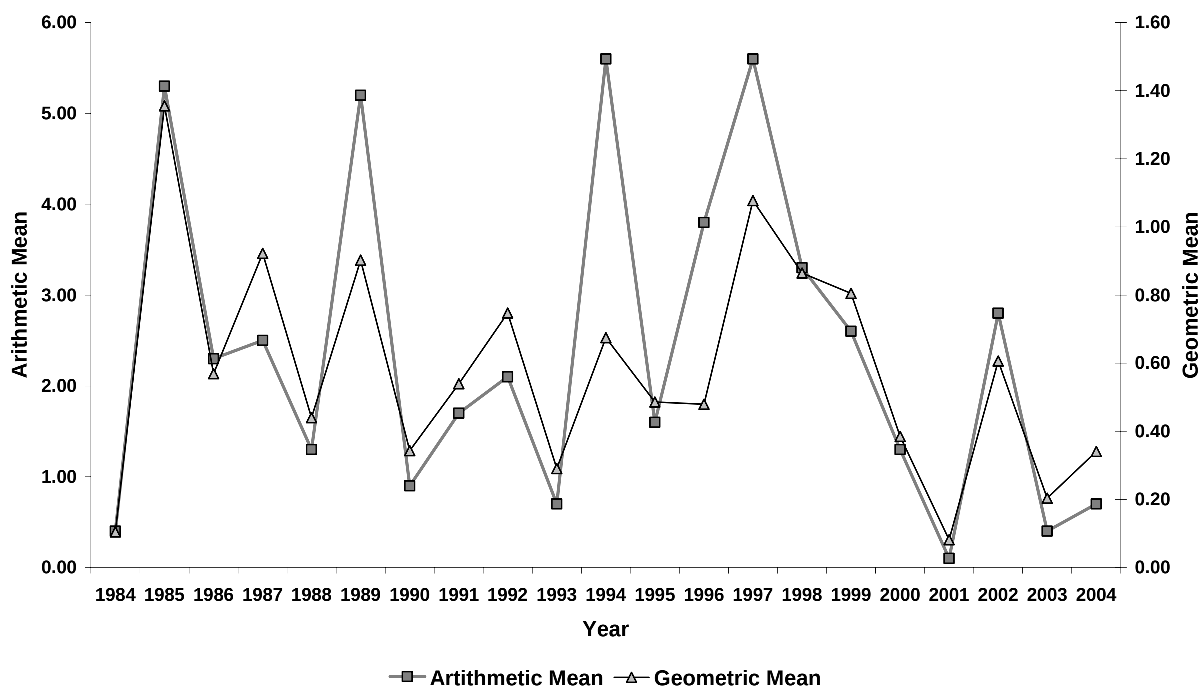


Figure 6.12 Connecticut DEP Fall Long Island Sound Trawl Survey juvenile abundance indices of American shad in arithmetic mean and geometric mean.

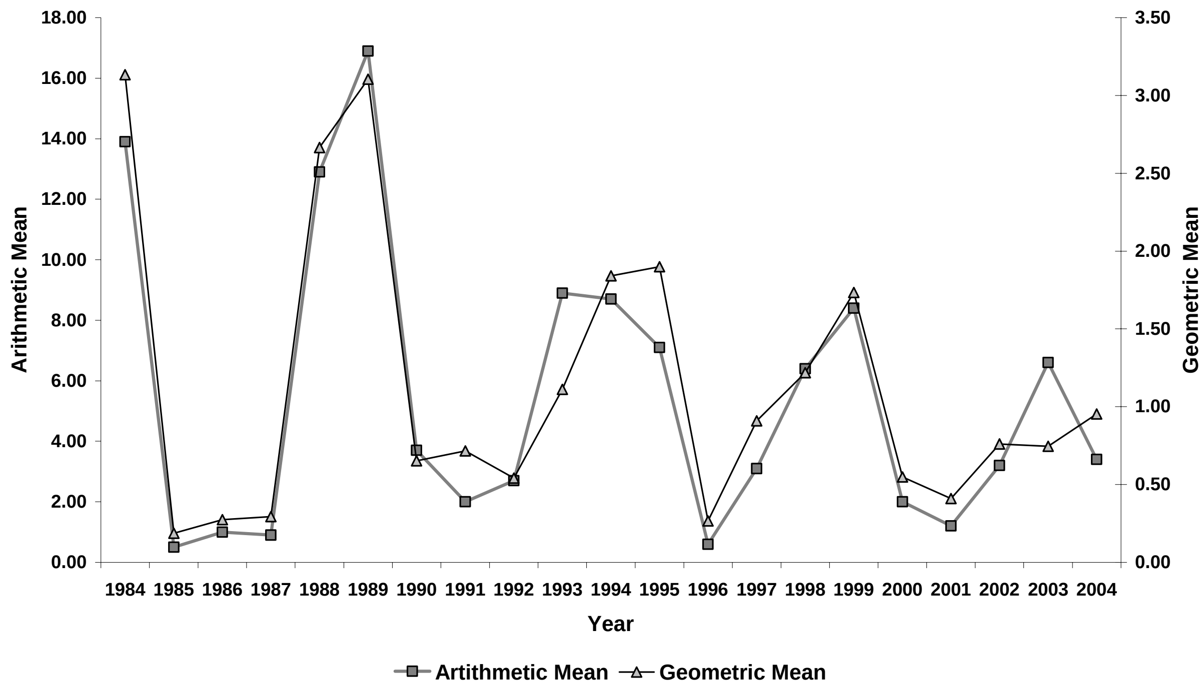


Figure 6.13 Connecticut DEP Fall Long Island Sound Trawl data for age-1 (160-299 mm FL), 1991-2004.

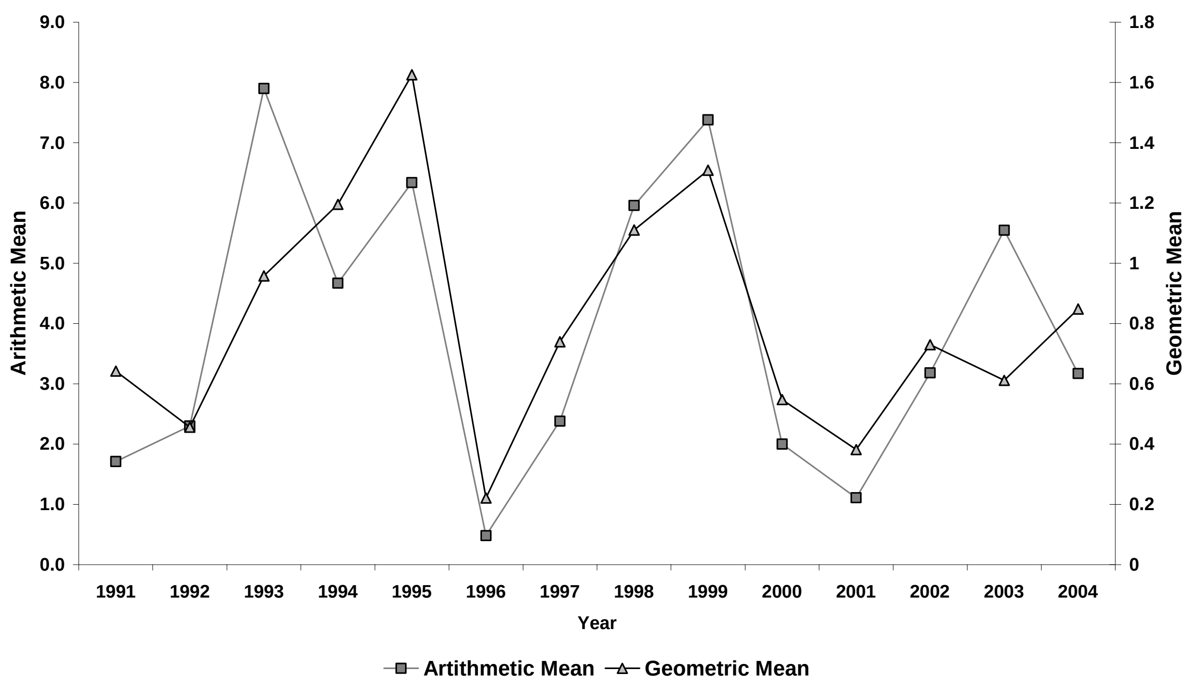
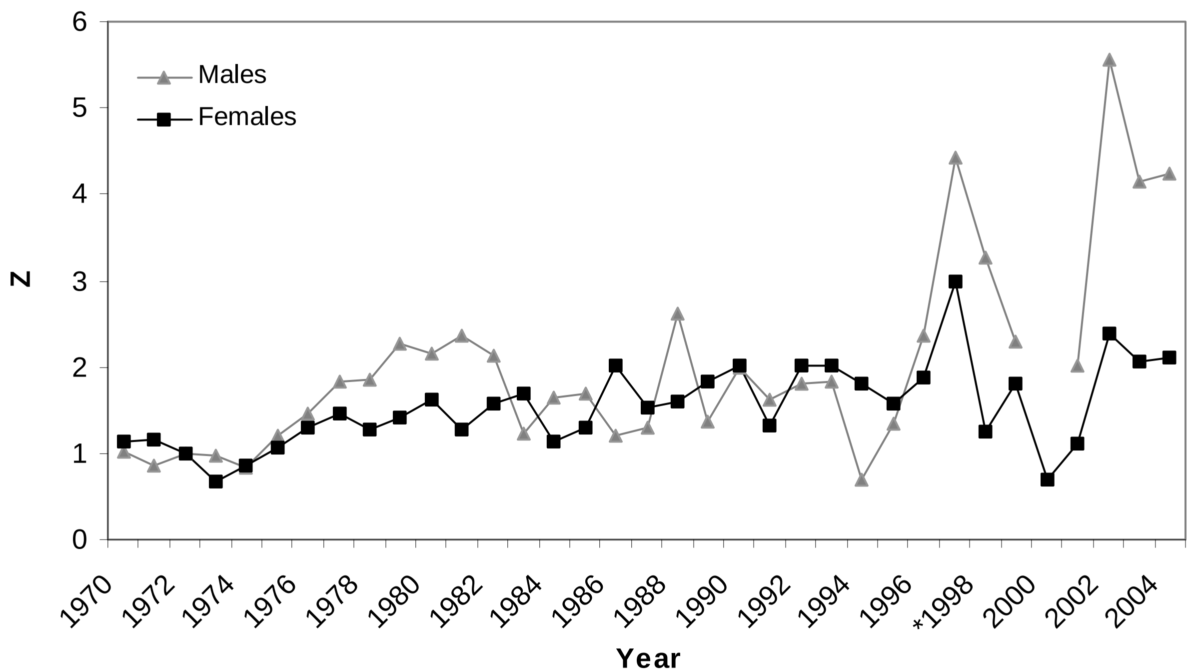


Figure 6.14 Total instantaneous Mortality (Z) for American shad collected at the Holyoke Dam Fish-lift on the Connecticut River.



Section 7
Status of the Hudson River, New York American Shad Stock

Contributors:

Kathryn A. Hattala and Andrew W. Kahnle
Hudson River Fisheries Unit, New York State Department of Environmental Conservation
21 S. Putt Corners Road, New Paltz, New York 12561

7.1 INTRODUCTION

While it is possible that European fishermen were fishing in North America and the Hudson Valley long before Columbus, the earliest known fishery in the Hudson River valley extends back to the 1600s when the Dutch first colonized the area. French Jesuits and Dutch and English explorers noted in their diaries and reports the fish that they saw. The Dutch recognized that ten commercially important fish were the same as those in Europe, including herring, eel, salmon, and cod. A few species that they didn't recognize were named the elft (American shad), twalift (striped bass), and dirtienen (either lipsfisk, wrasse, or tautog).

Archaeological digs along the Hudson in Native American middens indicates that the fishery resources in the river provided an important food source to native peoples. As the colonists took up residence in the valley, the Europeans learned about fish and fishing from the Native Americans. The Europeans brought their fishing skills and tools with them, using the same techniques as in Europe to fish for both diadromous and riverine species. Native Americans and Europeans used nets, weirs, and hooks to harvest fish (R. Daniels, pers. comm.).

Written records of the Hudson's shad fishing history only begin in the late 1800s. This record traces man's use of the stock and outlines cyclic episodes of overfishing. Overfishing, compounded by huge habitat losses, contributed to the long history of decline of the Hudson stock. Harvest in the late 1880s was high, followed by a 20-year period of either low landings, or no fishing (records are missing; Figure 7.1). This assumed low fishing period allowed the stock to rebuild to the high levels that sustained the fishery at high landings during WWII. In the years following WWII, the Hudson River American shad stock experienced a second collapse, faulted primarily to overfishing during the war and in the seven to ten year period that followed (Talbot 1954). Habitat destruction—continued filling of shallow water spawning habitat—and water quality problems associated with pollution—creating low oxygen blocks in major portions of the river (Albany and New York City)—further contributed to the decline.

In this section, we summarize the history and characteristics of the Hudson River stock of American shad, provide abundance trends, develop estimates of current Z, and make recommendations for stock recovery.

7.2 MANAGEMENT UNIT DEFINITION

The management unit of the Hudson River American shad stock consists of the Hudson River Estuary and the stock's range along the Atlantic coast. The in-river management area is defined as the area from the Verrazano Narrows in New York City to the Federal Dam at Troy, New York. The Hudson River Estuary is tidal its entire length of 246 km from the Battery (tip of Manhattan Island) in New York City to the Federal Dam at Troy (Figure 7.2). The Hudson stock of American shad ranges along the Atlantic coast from the Bay of Fundy, Canada and Gulf of Maine south to waters off Virginia and North Carolina (Dadswell *et al*. 1987).

7.3 REGULATORY HISTORY

During the 19th century, regulating the shad fishery within New York waters was the sole responsibility of the state. An anecdotal article in Harper's Weekly (1872) suggested a serious decline of the Hudson River American shad had occurred in the 1860s. Following this "collapse" (referred to parenthetically as no written records exist to document this event), the 1868 New York State legislature implemented fishing net restrictions, an escapement period, and a season to control fishing on the Hudson. However, according to U.S. Fish Commission Reports (1898), the prevailing intent of the state was not to interfere in any business, including fishing. These restrictions generally reflected the established fishing practices, setting the season to coincide with the period that shad were in the river. It is clear, that although "restrictions" were implemented, fishing largely continued unabated. Some variant of these 19th century rules still exist to the present.

After the mid-1800s "collapse," the New York Board of Fish Commissioners "engaged the services of Seth Green and set him to work to restock the Hudson River with shad, and save to the people, a food source which bade fair to be presently exhausted" in about 1872. So began New York's legacy of shad hatchery production in an attempt to restore stocks that were perceived to be exhausted. This "exhausted" condition is questionable. From 1880 through 1890, the Hudson stock produced the largest harvest in its recorded history. Anecdotal information suggests that harvest may have been even higher 20 to 30 years earlier. This suggests the spawning stock was large enough to quickly recover to produce two successive, historically high peaks in harvest within 30 years. The suggested "need" for hatchery supplementation was a reflection of the times. Most other East Coast shad stocks, primarily the Susquehanna and other Chesapeake stocks, were being severely depleted. Leaders of the U.S. Fish Commission used hatchery production rather than fishing curtailment as a solution. Shad stocking continued in New York for nearly 50 years, decreasing steadily as the focus of fish culture shifted to other warm-water and coldwater species. After 1920, mention of shad hatchery production no longer appeared in New York State Commission Reports.

Several gaps occur in the fishing record from the early 1900s until 1915—few references to active fisheries were found. Landing records from 1915 through the mid-1930s indicate shad fishing on the Hudson occurred at low levels. Studies conducted by the U.S. Bureau of Fisheries (U.S. Fish Commission 1939) indicated that:

> [A]lthough pollution and obstruction of river have doubtless contributed to the failure of reproduction…of many Atlantic coast shad streams, the decline in yield has not been limited to polluted or obstructed streams…some unpolluted rivers (Edisto) have been severely depleted yet a fine recovery has been observed in the polluted Hudson. This recovery is attributed to regulations limiting fishing to four nights a week and closing spawning areas to fishing.

This recovery did not last very long. During the years leading up to, during, and after WWII, regulations were greatly relaxed or abolished altogether. After nearly ten years of continuous, nearly unabated fishing, at near record levels, the Hudson stock experienced a collapse in the early 1950s from which it never recovered. Some fishing restrictions were put in place after this event but they had little effect on reducing fishing effort. The high fishing rate continued to remove fish faster than the stock could replace itself. In hindsight, the greatest downfall of management of the fishery was the disconnect that occurred between fishing and understanding the biology of the stock.

This disconnect between understanding fish stock dynamics and the long prevailing attitude of not interfering in, or restricting, the fishing industry has held firm since the 1800s for American shad. Perceived declines created the hatchery industry that employed commercial fishers to get their eggs. Yet most reports of fishery agencies from the late 1880s though the 1920s and 1930s stated that overfishing was a continuing problem greatly interfering with natural and artificial propagation.

It was late in this period that the Atlantic States Marine Fisheries Commission was created. In 1943, however, its objective was to assist in continued harvest of U.S. fishery resources to supply troops during WWII; its motto was “food will win the war” (ASMFC 1944). Regulatory management of the Atlantic coast shad stocks through ASMFC would wait 42 years until the adoption of an Interstate Fishery Management Plan for Shad and River Herring (FMP) in 1985. Although the FMP contained many strong recommendations, following the plan was a voluntary “gentlemen’s agreement.” This changed in 1993 with the passage of the Atlantic Coastal Fisheries Cooperative Management Act that mandated compliance by federal law. In 1998, Amendment 1 to the FMP included the first interstate regulation to close the mixed stock ocean fisheries for shad by 2005 (ASMFC 1999). The closure took a stepped approach over five years that allowed further erosion of remaining shad stocks. This slow action proved to be too little too late for the Hudson River American shad stock.

Regulations pertaining to the commercial and recreational take of American shad in New York waters are listed in Appendix I.

7.4 ASSESSMENT HISTORY

During the 1930s, the U.S. Bureau of Fisheries conducted a variety of studies on Atlantic shad stocks, primarily tracking landings to assess stock condition (U.S. Fish Commission 1939); however, few study details can be found in Commission reports. The reports recognized that exploitation rates were very high in systems experiencing declines (Maryland, Virginia, and South Carolina stocks); overfishing was the primary reason for decline and not pollution or major obstructions. The Hudson stock was lightly fished during this period of other stock declines, “contrary to the general trend” (Talbot 1954). Annual harvest from the Hudson exceeded 1,100,000 kg between 1936 until 1948, peaking at 1,758,000 kg in 1944 (Figure 7.1). Fishing continued to erode the stock following WWII.

In 1949, the Anadromous Fish Act supported initiation of the Shad Project, a program funded to determine the underlying causes of shad stock declines along the Atlantic coast. Talbot (1954) conducted the sampling program in the Hudson in 1950 and 1951. He determined that the primary cause of the decline was overfishing due to the lack of and lapse of fishing restrictions during World War II and the years following. Mark-recapture studies showed exploitation to be 0.66 and 0.46.

The first ASMFC assessment of the Hudson stock occurred in 1988 (Gibson *et al*. 1988). This assessment used a Shepherd stock recruitment model to estimate maximum sustained yield (MSY) and maximum sustainable fishing rates (F_{msy}) with inputs of long-term commercial catch-effort, age composition, and mortality data. It is not clear what natural mortality rate was used. Model fit was poor (r^2=0.35), faulted to primarily significant measurement errors of the stock and recruitment estimates or other unknown or poorly understood factors (Gibson *et al*. 1988). Exploitation rate (μ) was estimated at 0.31 (F=0.37), which was below the value of μMSY of 0.45, recommended in the 1988 report. For a historical perspective, Gibson *et al*. (1988) adjusted Talbot’s rates in the 1950s because of catchability issues associated with Talbot’s use of Peterson disc tags in his mark-recapture study. The adjusted rates were μ of 0.38 and 0.27 for 1950 and 1951, well below the recommended 1988 level. Although the adjusted 1950 μ of 0.38, the adjusted 1951 μ of 0.27, and 1988 μ of 0.31 were well below the recommended μMSY of 0.45, stock levels in the Hudson continued to decline. These changes suggest that the recommended μ values were too high for stock stability.

Walters (1995) used growth parameters, natural survival rate, and proportion of variation in relative abundance indices due to measurement error to compute maximum likelihood estimates of the recruitment anomaly sequence for several stocks, including American shad of the Hudson River. He concluded that the American shad stock had been subject to massive recruitment overfishing.

In 1997, the Hudson River electric generating companies hired consultants to assess the Hudson's American shad stock status as part of their environmental impact statement on power plant operation effects on fishes of the Hudson River (CGH&E 1999). The initial assessment looked at 17 years of data from 1980 to 1997. During an intensive review, this time series was expanded to encompass all available data for the Hudson since 1915. Deriso *et al*. (2000) estimated fishing morality and calculated equilibrium yield exploring several hypotheses regarding the spawner-recruit (S-R) relationship. Natural mortality of 0.3 was used, based on maximum age (13) observed in the Hudson stock. A Beverton-Holt S-R was used with assumptions of low, mid, and high levels of density dependence occurring in the stock. Equilibrium calculation showed that the stock was fully to over-exploited, unless one assumed high density dependence. Given that the Hudson shad stock was approaching an all-time historic low stock size, the high density dependence hypothesis was rejected.

ASMFC (1998a) completed the most recent assessment, focusing only on the period 1980 to 1997, a time window encompassing a period of depressed stock conditions when stock abundance was at historically low levels (see Figure 7.1). This assessment generated debate on data inputs, methods, and model assumptions. At the forefront of the debate was the appropriate level of natural mortality (M) to use for American shad. The approach used a Thompson-Bell yield-per-recruit to calculate a $F_{30,}$ which was defined as the overfishing rate. This was compared to an estimate of "current" F.

Although stock-specific data were available for the Hudson, all Hudson yield model inputs in Gibson *et al*. (1988) were based on a variant of the Connecticut River shad stock, which exhibit different biological stock (growth) characteristics than the Hudson shad stock (see Section 7.10). The greatest debate over inputs occurred on the value of M. For the Hudson stock, M was 0.3 for ages one to three and 0.6 for ages four to ten, although the observed maximum age for Hudson shad was 13. These were "best estimates" based on what was observed in the Connecticut River shad stock. Current F was estimated from an exploitation rate calculated from harvest estimates (combination of in-river plus estimated ocean harvest, both adjusted for underreporting) divided by an estimated population size (scaled from the estimated population size of the Connecticut River shad stock using data from the 1950s). Current F was calculated at 0.33, the overfishing definition of F_{30} was 0.39. The conclusion was that the Hudson shad stock was not over-fished, but fully exploited.

The New York State Department of Environmental Conservation (NYSDEC) disagreed with the methods used and we (Hattala and Kahnle) wrote a minority opinion objecting to the ASMFC conclusions because we felt that data inputs and methodology over-estimated the overfishing definition and underestimated the current fishing rate. To illustrate our response, we used the same methods but with inputs that were based on Hudson River data. The major difference was reliance on a value of M based on maximum observed age. We also performed a sensitivity analyses on selection of a natural mortality rate (M). Model results were very sensitive to M. For age invariant M, F_{30} increased with increasing M. F_{30} was higher where M increased with age than when M declined with age. We recommended use of either an age invariant M of 0.3 or an age specific M that decreased with age. Our F_{30} estimates equaled 0.27 based on a constant M of 0.3 and 0.25 based on age specific M. We based current F estimates on F=Z-M, where Z resulted from catch curve analysis of annual age structure minus M of 0.3. Using these definitions of overfishing compared to current F, the Hudson shad stock has been over-fished since the mid-1980s.

The issues of discord between these assessment approaches were never resolved. The cause of decline in the Hudson American shad stock, as well as other stocks, remains in debate.

7.5 STOCK-SPECIFIC LIFE HISTORY

General life history characteristics of American shad are summarized in Section 1. Hudson River American shad are spring spawners, entering the estuary early April through the end of May. Adult shad are present in the river for a period of approximately six to ten weeks over the entire spawning season, dependent on water temperature (Hattala *et al*. 1998b). Once spawning ends, most shad quickly return to ocean waters. Tracking of radio and sonic tagged shad in 1995 and 1996 indicated that post-spawning mortality for Hudson shad was low (Whalon 1999). Once back in ocean waters, Hudson shad continue their annual migration north along the coast with the rest of the mixed stock assemblage (see Section 1).

One interesting observation is that over the course of the past 130 years, the spawning period for Hudson River American shad has greatly shortened. In the 1870s, fish first appeared in March, spawning peaked in early June, and continued into July (Harpers Weekly 1872). In the 1950s, Talbot (1954) remarked that spawning continued until the end of June. Over the past 20 years, spawning has occurred a few weeks in May (ASA 2006).

7.5.1 Growth

New York State DEC has collected data on length, weight, and age annually since 1980 from the commercial catch, and annually since 1985 from a fishery-independent survey (see Sections 7.9 and 7.10). The fishery focuses on pre-spawn mature fish. The fishery-independent survey samples fish that have escaped the fishery.

Length and weight-at-age are generally greater for females than males. Fish of both sexes tend to be larger in fishery-dependent samples than in fishery-independent samples (post commercial harvest). Von Bertalanffy curves for total length-at-age and Gompertz curves for weight-at-age were calculated for all fish (Table 7.1; Figure 7.3).

7.5.2 Reproduction

Spawning begins in the Hudson Estuary in late April when water temperatures reach 15°C. It continues through the month of May and generally ceases by early June. Shad spawn in fresh water, over shallow-water shoals that occur in the upper half of the Hudson (rkm 142 to 240).

Post-spawning mortality for Hudson shad appears to be low (Whalon 1999). Extensive radio and sonic tracking of American shad was conducted in the Hudson River Estuary in 1995 and 1996 (Whalon 1999). Over the two years of the study, 110 marked fish, captured during immigration to the Hudson, were released over several weeks during the spawning period. Shad were tracked over periods of 15 to 40 days after release through the entire spawning season. Field efforts ceased when no more fish could be located. Five fish apparently died (repeatedly found in one location) within 12 to 18 hours of release. Mortalities were assumed to be related to tagging stress from the sonic or radio-gullet applied tag. In 1995, approximately 49 percent of the 55 radio-marked shad released were found and followed throughout the spawning season. Results in 1996 improved when 77% of radio-marked fish (30 released) and 84 % of sonic-marked fish (23 released) were found and tracked throughout the spawning period. The improved 1996 detection rate resulted from more intensive air and boat surveys. The percent of fish listed above for fish tracked during spawning season does not include suspected dead fish. For the live, tracked fish, all left the river after spawning, suggesting a very low rate of in-river post-spawn mortality for the Hudson stock. Residence time for adult shad in the Hudson following tagging was found to be approximately 19.8 days.

Percent of repeat spawning in the Hudson River stock varies among years. Female shad exhibited repeat spawning rates as high as 73% with up to eight spawning marks for commercially caught fish and 69% with seven spawning marks observed in fishery-independent samples. Values as low as 42% and 28% were observed for females in commercial data and the fishery-independent samples in recent years (see Sections 7.8 and 7.9).

7.5.3 Maturity Schedule

Deriso *et al*. (2000) estimated the maturity schedule using a likelihood function on age and repeat spawn data of Hudson River shad (Table 7.1). This approximates the same results of calculating age-at-first spawn (age minus the number of repeat marks) from all age data, to arrive at an approximation of percent at age-at-first spawn.

7.5.4 Fecundity

The first estimate of fecundity for Hudson River shad was from samples taken in the 1950s (Lehman 1953) after the stock had collapsed following WWII (Table 7.1). Lehman recognized that "shad have a multi-spawning or continuous period of spawn, rather than a single spawning act." He concluded that the fecundity estimates measured only a portion of the total egg production of a female in any given year (sample size was small, 22 fish; Figure 7.4).

Recently, Piper (2003) completed a study of fecundity of Hudson River American shad. Samples collected in 2000 and 2001 showed a wide range of variability at age within year and differences among years (Figure 7.4). Overall, the fish collected in 2000 and 2001 had higher fecundity estimates than those collected in 1951. It is not clear why the results of these studies are so different. Sample size may have contributed to the differences. Few samples were collected in 1951, yet fecundity was found to be directly proportional to age (r^2=0.96), length and weight of the fish. The more recent sample of 105 fish taken in 2000 and 2001 was larger. The relationship between fecundity and age was positive, but not as highly correlated to age (r^2=0.54), as the 1951 data. Since the studies had different results, we felt it was prudent to use both sets of estimates in the biomass-per-recruit model and then to compare the results (see Section 1).

7.6 HABITAT DESCRIPTION

7.6.1 Spawning and Nursery Habitat

The sandy, gravelly shoals and shallow water areas in the upper half of the Hudson River Estuary, from Kingston (km 144) to Troy (km 256; Figure 7.2) are used as spawning habitat. The nursery area extends south from here to Newburgh Bay (km 90), encompassing the freshwater portion of the Estuary. The estuary is tidal to Troy.

7.6.2 Habitat Water Quality

The Hudson has a very long history of abuse by pollution. New York City Department of Environmental Protection recognized pollution, primarily sewage, as a growing problem as early as 1909. By the 1930s, over one billion gallons of untreated sewage were dumped in the harbor every day. (NYCDEP home2.nyc.gov).

New York City was not the only source of sewage; most major towns and cities along the Hudson added their share. It was so prevalent that the Hudson was often referred to as an open sewer. Biological demand created by the sewage created oxygen blocks that occurred seasonally (generally mid to late summer) in some sections of the river. One of the best-known blocks occurred near Albany in the northern section of shad spawning and nursery habitat from 1960 through the 1970s. This block often developed in late spring and remained through the summer months, essentially cutting off the upper 25 miles of the Hudson for use as spawning and nursery habitat. A second oxygen block occurred in the lower river in the vicinity of New York City in late summer. This block could potentially have affected emigrating age-0 shad. This summer oxygen-restricted area occurred for decades until 1989 when a major improvement to a sewage treatment plant in upper Manhattan came online. It took decades, but water quality in general has greatly improved in both areas following the implementation of the Clean Water Act in the 1970s reduced sewage loading to the river.

There are other persistent chemical pollutants in the Hudson River. The best-known and most pervasive chemical contamination is from polychlorinated biphenyl (PCB). The major source of the chemical is approximately 40 miles north of the Troy Dam, where General Electric discharged up to 1.3 million pounds of PCBs into the river for over 30 years beginning in the 1940s. The EPA declared 200 miles of the Hudson below Hudson Falls and Fort Edward, New York, a Superfund site in the 1970s. The removal of the contaminated sediments via a controversial dredging clean-up project has yet to begin.

Because of the PCB contamination of fish flesh, the NYSDEC, under recommendation from the New York Department of Health, closed many of the Hudson's fisheries in 1976. American shad remain one of the few species that are allowed to be taken commercially as they do not accumulate the contaminant while in the river.

A whole host of other environmental contaminants have been found in the Hudson and its fish (PAHs, some metals, etc.), but are minor in comparison to the level of PCBs. Research is ongoing to try to determine effects of chemicals on fish.

7.6.3 Habitat Loss

Much spawning and nursery habitat was lost in the upper half of the tidal Hudson because of dredge and fill operations to maintain the river's shipping channel. Most of this loss occurred between the turn of the 19th century (NYDOS 1990) and the first half of the 20th century. Preliminary estimates are that approximately 57 percent of the shallow water habitat (1,821 hectares or 4,500 acres) north of Hudson (km 190) was lost to filling (Miller and Ladd 2004). Work is in progress to map the entire bottom of the Hudson River. Data from this project will be used to quantify existing spawning and nursery habitat.

Very little or no habitat has been lost due to dam construction. The first major dam was constructed in 1826 at rkm 256 in Troy, New York. Prior to the dam, the first natural barrier occurred at Glens Falls, 32 km above the Troy Dam. The construction of both dams is not believed to have reduced spawning or nursery habitat.

7.6.4 Habitat Alteration

The introduction of zebra mussels in the Hudson in 1991, and their subsequent explosive growth in the river, quickly caused pervasive changes in the phytoplankton (80% drop) and micro and macrozooplankton (76% and 50% drop, respectively) communities (Caraco *et al*. 1997). Water clarity improved dramatically (up by 45%) and shallow water zoobenthos increased by 10%. Given the massive changes, Strayer *et al*. (2004) explored potential effects of zebra mussel impact on young-of-year (YOY) American shad and other species. Most telling was a decrease in observed growth rate and abundance of YOY fishes, including American shad. It is not yet clear how this constraint affects annual survival and subsequent recruitment.

7.7 RESTORATION PROGRAMS

No restoration program (e.g., hatchery program) exists for the Hudson River shad stock.

7.8 AGE

Hudson River American shad are aged from scale impressions. Scale samples are removed from an area approximately one inch below the dorsal fin and placed in an individually identified envelope. In the laboratory, scale impressions are made on cellulose acetate slides and impressions examined with a microfiche reader. For each fish, two independent age determinations are made by different investigators and agreement on age and placement of annuli is sought. Readers use the age determination method developed by Cating (1954) on Hudson River shad. A third independent reader resolved differences. If differences could not be resolved the sample was not used. Where age samples were incomplete, age structure was estimated using an age-length key developed from age and length data obtained from previous sampling years.

The oldest age of Hudson River American shad (13 years) from the mid-1980s is much older than fish from most other shad stocks on the East Coast. Because of this, the ageing of these fish has been questioned (ASMFC 1998b). We feel that ageing of Hudson River American shad has been accurate for four reasons. First, the same people using the same techniques have aged our scales throughout the time series. Scales readers for Hudson shad are highly experienced compared to other agers in Atlantic coast states. Strict quality assurance procedures are followed before scales are read. The quality assurance procedure includes an annual review of Cating's method and ageing of a "test" set to assure consistency among years and readers. The variation in observed maximum age over the last 25 years in the Hudson shad was a function of change in observed number of annuli among years and not a change in methodology or of personnel. Second, several independent sources have corroborated the age estimates. NYSDEC contracted Normandeau Associates, Inc. (NAI) to age several years of Hudson River American shad scales. NAI has many years of experience of ageing shad scales for the Susquehanna River Restoration Project. They agreed with our estimates. Third, variation in annual mean age among years mirrored changes in mean length among years suggesting consistency in ageing techniques among years (See Section 1). Finally, reduced levels of Z corresponded to periods of high mean and maximum age. Conversely, periods of increased mortality corresponded with periods of low mean age suggesting that impacts of high mortality were apparent in the age data.

American shad of the Hudson River Estuary grew to age 10 in the years following WWII 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, and males reach age 10. The maximum age that American shad stock from the Hudson River can attain is unknown because age data are not available from times when the stock was not fished.

7.9 FISHERY DESCRIPTIONS

7.9.1 Introduction

Recorded landings and anecdotal reports indicate a cyclical history of collapse and rebuilding for the Hudson River's American shad stock. The first apparent fishery collapse occurred in the 1860s (Harper's Weekly 1872) and the stock rebounded by the 1880s when landings reached the highest level ever recorded. At the turn of the century, recorded landings became sporadic. It is doubtful that fishing stopped, given the landings spike in 1904 (Figure 7.1). From WWI to just before WWII, landings were fairly low for reasons that are unclear; however, if fishing occurred at low levels for this time period, this abatement would have allowed the stock to grow to the substantial size necessary to sustain the huge harvest that occurred from the late 1930s to the early 1950s.

The high levels of harvest from 1936 through the mid-1950s came in two waves. Each subsequent peak (those in 1944 and 1956) was lower than the previous and both were lower than highest peak in 1890. This suggests to us that each overfishing event removed a large portion of the stock, lessening its recovery resiliency. All declines are attributed to overfishing. Effects of pollution and habitat loss were of concern, but were secondary to overfishing. Walters (1995) suggested that the population never fully recovered from the second event following WWII. Recent landings indicate yet another decline since the mid-1980s. This last decline has brought reported American shad landings to an all time low for the Hudson River stock. Concern about the status of the stock by the few remaining Hudson River Valley commercial fishermen is high.

The present Hudson River commercial fishery exploits the spawning migration of American shad in the Hudson River Estuary, though at a much reduced level compared to previous decades. Fishing begins in late March or early April and continues approximately eight weeks until mid-May when fish come into full spawning condition. Monofilament gill nets, mostly of 5.5 inch stretch mesh, are the primary gear (both for fixed and drifted nets). The fixed gill-net fishery occurs from km 40 to km 70 (Piermont to Peekskill, Figure 7.2). In this stretch, the river is fairly wide (up to 5.5 km) with wide, deepwater (~ six to eight m) shoals bordering the channel. Fishers set their fixed gill nets in the same areas that were fished in the 1930s when fishers followed the U.S. Army Corps of Engineers' (USACOE) "designated" area program; this program was intended to avoid conflicts with commercial shipping traffic and fishing and was later used to prevent conflicts in the fishery (T. DeGroat and R. Gabrielson, pers. comm.). Currently, less than 10 active fishers participate in the fixed gear fishery. Fishers are restricted to "fish trap" areas designated to avoid conflicts with navigation; these are relatively the same areas assigned by the USACOE years ago. Nets deployed range in size from 61 to 275 m. Within the last five years this portion of the fishery has virtually disappeared due to interference and bycatch of striped bass, which are not allowed to be retained in the Hudson River commercial fishery because of contamination.

The drift gill-net fishery occurs from km 98 to km 182 (Newburgh Bay to Catskill) where the river is much narrower (1.6 to 2 km wide). At present, about 23 to 25 fishers participate in the drift gill-net fishery. Drift nets range in size from 152 to 304 m.

Two other gears were used in the recent Hudson fishery. One fisher used a haul seine near Catskill until 1997 and a small stake gill-net operation occurred in the New Jersey portion of the Hudson River near km 19 (George Washington Bridge) from after WWII until 1998.

The Hudson River Fisheries Unit (HRFU) of the NYSDEC conducts annual programs to assess the status of the Hudson River American shad stock. Fishery-dependent and independent programs sample biological characteristics of mature fish returning to spawn in the Estuary. Relative abundance of shad is tracked among years by observed catch-effort (CPUE) statistics of fish taken during the commercial fixed gear gill-net fishery in the Estuary. The spawning stock (mature fish) that escapes this fishery is sampled for age, length, weight, and sex composition. Mortality rates are calculated for this portion of the stock. The relative success of the spawn is measured by relative abundance data for age-0 fish. Pre-juvenile life stage abundance is measured by consultants to Hudson Valley power generating companies for estimates of annual mortality of each year class due to entrainment at once-through cooling facilities.

7.9.2 Commercial Fishery

Commercial fisheries for American shad in New York State waters occur in the Hudson River Estuary and in marine waters around Long Island. The shad taken in ocean fisheries are bycatch of unknown mixed stock origin. Commercial fishing restrictions for New York waters are listed in Appendix I.

Directed mixed stock fisheries, or ocean-intercept fisheries, occurred along the Atlantic coast from Virginia to New Jersey, including Delaware Bay, and were within the known migratory range of the Hudson stock, as well as other known bycatch fisheries that occur from New York to the Bay of Fundy. Undocumented bycatch in other fisheries may still occur along the entire Virginia to Nova Scotia range. A fishery that catches American shad in the ocean has the potential to harvest Hudson River American shad. The ocean-intercept fishery for American shad in the near shore Atlantic was closed in 2005. The directed mixed stock fishery in lower Delaware Bay remains open, as it was not included in the ocean closure.

Commercial Landings and License Reporting

National Marine Fisheries Service (NMFS) reported landings annually for the inland portion of the Hudson River (areas north of the George Washington Bridge) until 1993. From 1994 to the present, NYSDEC has summarized in-river landings from mandatory state catch reports for Hudson River commercial fishing licensees and sends the data to NMFS. Recording of effort data on reporting forms was phased in beginning in 1995. Full compliance for reporting of fishing effort was implemented in 2000. Commercial monitoring data (see Catch Rates below) are used to verify and adjust reporting rate for the mandatory reports. A reporting rate of 74 percent is used to adjust the landings (Hattala *et al.*1998a). Commercial landings of American shad are in Table 7.B1.

Commercial Discards

Discard rate of female shad in the Hudson River gill-net fishery is relatively low. The fishery uses mesh sizes that optimize catches of females for their roe; few (~1%) are discarded (Table 7.2). For males, discard rate has varied over time depending upon by gear and market demand. Males are sold as bait or kept for fillets or smoking. Male discard rate in the fixed gear fishery averaged about 58 percent for the period 1980 to 1990, then fell to near zero from 1991 to 1997 as males became scarce in the catch. Discards from fixed gear since 1998 have been extremely variable. In the drift fishery, male discards averaged 22 percent prior to 1990. Discards from 1992 to the present have increased to an average of 72 percent. Although the discard rate of males appears high, males make up a small proportion, approximately 23 percent, of the total catch of both gears combined.

Discard rates for the ocean-intercept fishery and ocean bycatch fisheries are unknown.

Commercial Catch Rates

Relative abundance of shad is tracked through CPUE statistics of the commercial gill-net fishery in the Hudson River Estuary. We have monitored the in-river commercial fishery annually since 1980. Information is obtained by direct observation onboard fishing boats. Technicians attempt to be onboard fishing vessels on all fishery days and when aboard, they record data on numbers of fish caught, gear type and size, and fishing time and location. Scale samples, and lengths and weights are taken from a sub-sample of the catch. CPUE is calculated as the number of fish collected per square yards multiplied by hours fished times 10^{-3}. Data within week are summarized as total catch divided by total effort for each gear type (fixed or drift gill nets). CPUE data are summarized as an annual sum of weekly CPUE because run size is determined by number (density) of spawners each week as well as duration (number of weeks) of the run. This approach mimics area under the curve calculations where sampling occurs in succeeding time periods.

We use the CPUE of the fixed gear fishery for estimating relative abundance as it provides a more accurate picture of shad moving into the river to spawn. Fixed gear is always fished in approximately the same locations in the lower Hudson each year, is passive in nature, and intercepts fish that move through the area. The CPUE in the drift fishery is more variable because it is an active gear that can be set directly into a school of fish.

Male American shad CPUE dropped quickly from 1986 to 1990 and has since remained extremely low. A linear regression of male CPUE on years was significant for the years 1986 through 1999 ($r^2 = 0.70$, slope = -2.96, $P = <0.01$) and for the years 1986 through 2001 ($r^2 = 0.43$, slope = -1.0, $P = <0.01$). CPUE for female American shad was low in the early 1980s, increased to a high in 1986, declined through 1993, then varied at a low level through the present (Table 7.3; Figure 7.5). Small peaks occurred in 1994 and 1996. It is unclear if catchability increased as stock size declined as suggested by Crecco and Savoy (1985). A linear regression of female CPUE on years was significant for the years 1986 through 1999 ($r^2 = 0.59$, slope = -1.43, $P = <0.01$) and for the years 1986 through 2001 ($r^2 = 0.36$, slope = -1.70, $P = <0.01$). Landings data do not indicate a trend.

The increase in female CPUE in 2000 and 2001 was unexpected. However, changes in ocean fishing gear regulations may have contributed to the return of more fish, or fish of a particular size range, to the Hudson. In January 2000, the Marine Mammal Protection Act required fishers using gill-nets with 5.0 inch stretch mesh or larger to switch from using monofilament twine to multifilament twine and increase the twine diameter size or they would have to use smaller mesh. Most coastal shad fishers (R. Allen, pers. comm.) chose smaller mesh to continue using the fine monofilament twine that is more effective at catching shad. How this regulation will affect future returns to the river remains to be seen.

Sample sizes of CPUE data collections for 2002 through 2005 were very small and the data were not used because we did not feel that they represented annual abundance of shad immigrating into the river. Reduced sample size in the fixed gear fishery occurred because fishers changed fishing patterns as shad became more difficult to catch (fewer fish) and to avoid catching striped bass, which were more abundant, because striped bass from the Hudson River are not allowed to be retained or sold due to PCB contamination.

There was concern that striped bass abundance might have affected catch rates for American shad; however, examination of the data indicated that catch rates of female American shad and striped bass in fixed gill nets were positively correlated (Figure 7.6). We evaluated the correlations during two time periods. The first time period was from 1980 to 1990 when American shad and striped bass were present in both very low and then very high levels of abundance. During this time, striped bass abundance began to increase due to increased fishing restrictions implemented along the Atlantic coast (ASMFC 1989, 1995). The correlation of shad

CPUE and striped bass CPUE was positive (r^2 = 0.49). In the second time period (1991-2001), shad and striped bass had similar catch rates (r^2 = 0.44). Gear saturation by striped bass did not appear to affect shad catch rates.

The interference of striped bass, although not a factor in catchability of shad, is problematic for fishers. Continuous catches of striped bass often result in gear damage (ripped meshes, large holes) and additional labor to remove the bass. To avoid these problems, many fishers no longer fish or greatly reduced their time fishing.

A few other long-term estimates of fishing effort in the Hudson River exist; however, the data present some challenges. Record keeping has not been consistent over time and there is little information on whether it is actual or presumed use of gear. Available effort data are listed on Table 7.B2. Early records from 1915 to 1951 were summaries of number of licenses sold or nets licensed (data were compiled by the U.S. Bureau of Commercial Fisheries, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service). Klauda *et al*. (1976) summarized these effort statistics from 1931 to 1975 as total square yards of net licensed obtained by the NMFS during their annual survey of Hudson River shad fishers (Figure 7.7 A). He further adjusted them by allowable fishing time. Various escapement closures of 60 to 36 hour per week occurred during this time period. Concurrent with Klauda's effort series, NYSDEC records were available for linear feet of licensed net for the period 1931 to 1964 (Figure 7.7 A). Since 1976, NYSDEC-HRFU license summaries include the number of licenses sold along with the amount of net licensed (Figure 7.7 A). Starting in 1995, NYSDEC required daily catch and effort statistics on annual mandatory report forms.

Using his long-term effort series, Klauda *et al*. (1976) attempted to calculate a CPUE index to track abundance of Hudson River shad for the period 1931 to 1975. Landings were divided by effort; effort defined as net area (square yards) multiplied by total allowable fishing hours per week (Figure 7.7 B). We attempted to continue the time series of Klauda *et al*. (1976) through the present by using the same method by converting licensed linear feet to square yards by multiplying the linear feet by fourteen (average depth of net; HRFU, unpub. data) then dividing by nine (Figure 7.7 B). Often, increases in effort followed peaks in catch. The resulting CPUE series presents an interesting scenario of similar repeating peaks that occurred in the 1940s and the mid-1950s, followed by slightly lower peaks in the late 1970s and mid-1980s (Figure 7.7 C).

We also examined the relationship between observed CPUE collected since 1980 (see Catch Rates above) with the Klauda *et al*. CPUE series described above. No correlation existed between the two data series leaving little faith in the long-term reported CPUE estimates (Figure 7.8). Reported versus observed CPUE periodically varied in opposite directions. Reported catch and effort records, from 1980 to the present, indicate that 20 to 60 percent of the licenses sold annually are actually used (Figure 7.9) thus the total amount of effort fished has been less than the number of licenses indicate. Over the past ten years, increasing numbers of fishers purchased shad and herring net licenses to catch river herring. This further confounds use of licensed gear as an effort index for shad. Our monitoring supports reported effort for the last two decades. Adjusting for the percent actually used would have considerably increased the CPUE for the period 1980 to the present when landings were actually quite low. No adjustment can be made for the earlier time period because we do not know what proportion of the licensed gear was actually fished.

Catch-per-unit-effort data must be interpreted with great caution. Hilborn and Walters (1992) warned that CPUE indices could actually remain stable, or even increase, during periods of stock decline. Crecco and Savoy (1985) also found that catchability of American shad could increase when stock size decreases.

Hudson shad were caught in the mixed stock fisheries on the coast and Delaware Bay. No catch rates were calculated due to a lack of effort data. See Section 1.

Hudson River Size and Age Structure

An increase in size and weight of both sexes of American shad sampled in the Hudson River commercial fishery occurred for the period 1980 to 1990. This was followed by a decline to a smaller size for the years 1992 through 2001 (Table 7.4; Figure 7.10). A slight increase in size occurred in 2002 to 2005. The same general trend occurred for both sexes.

We also examined mean total length and weight-at-age and noted a decline in both since the mid 1980s from both fishery-dependent and fishery-independent samples (Figure 7.11). The decline is likely caused by a concomitant increase in rate of fishing mortality as older, larger fish disappeared through the 1990s. Observed changes were not caused by changes in recruitment (see Section 7.10.1). Mean length and weight-at-age are summarized for the entire time series by sex and sexes combined for the fishery-dependent and fishery-independent data (Tables 7.B3).

The fishery-dependent data indicated a wide range of ages of shad (both sexes) occurred through the late 1980s. This changed in the 1990s with a consistent move toward younger fish (Table 7.5). In all years, the majority of fish caught are ages five through seven; however, over the period 1990 to 1998, few fish older than age seven were caught. Estimated ages indicate that from 1999 through 2005 some older (larger) fish reappeared in the catch. The percent of repeat spawners was fairly stable at greater than 60% for males and between 42 to 73% for females (Tables 7.5 and 7.6). These high percentages are expected as the fishery uses large mesh gill nets that catch the larger fish of each age group, which tend to be the repeat spawners. The highest value of mean repeat spawn for females occurred in 1987 at 1.85 and dropped to a low of 0.71 in 1992 (Table 7.6). For males, the high value also occurred in 1987 at 2.78 and also dropped to a low of 1.2 in 1992. Ages for 1996 through 2005 were estimated by age-length keys developed from length and age data from 1980 to 1995. Data on incidence of repeat spawning are not available after 1995; ageing is in progress.

7.9.3 Recreational Fishery

The magnitude of the recreational fishery is unknown for most years. NYSDEC contracted with Normandeau Associates, Inc. to conduct creel surveys on the Hudson in 2001 and 2005. Most recreational fishing for American shad occurs in the upper half of the Hudson River Estuary above Kingston (rkm 152) to the Federal Dam at Troy (rkm 243). Catch in 2001 was 19,766 fish with a 6.5 percent retention rate (Table 7.7). Catch dropped in 2005 to 6,582, although the retention rate was higher at 7.7 percent. Catch rates were dramatically different in the two years. In 2001, boat CPUE was 1.498 and shore CPUE was 1.534. In 2005, the rates were much lower at 0.586 for boats and 0.584 for shore fishers.

No known recreational data for American shad exist in New York ocean waters. Recreational catches of American shad reported from ocean waters along Long Island are suspect because hickory shad are frequently caught in the fall and misidentification is likely.

7.10 FISHERY-INDEPENDENT SURVEYS

7.10.1 Spawning Stock Survey

The fish sampled in this program represents the spawning stock, or production, portion of the population that has escaped from ocean and in-river commercial fisheries. Sampling occurs within the spawning reach (km 145-232) from late April through early June, concentrated from km 146 to km 182. Fish are collected by a 154-m or 305-m haul seine at beaches located throughout this area. The haul seine exhibits relatively low size selectivity in sampling fish (Kahnle *et al*. 1988) when compared to other gear types. Since we calculate mortality rates for this portion of the stock, we used chi-square analyses of weekly age structure within each year to see if age structure changed among weeks. This let us evaluate if variation in sample timing within year affected annual age structure. Age structure did not differ significantly among weeks in half of the years (1985, 1987, 1989, 1990, 1999-2001, and 2004; Table 7.B3). Years in which a significant difference in age structure occurred tended to be years in which most of the fish were taken in a single week. Since the sample week that collected the most fish was probably also the week with highest spawner abundance, we surmised that the age structure from that week also reflected the age structure of the spawning stock. Although the program began in 1983, sampling effort through 1984 was very limited. The most useful data are from 1985 to the present.

Size and Age Distribution

All shad collected are identified by sex, and most all are weighed, measured, and sampled for scales. Male shad ranged from 360 to 660 mm TL (Table 7.8). Females were generally larger and ranged from 400 to over 680 mm TL. Both sexes were largest during the period 1984 to 1989 (Table 7.8). Mean total length and weight for both sexes were fairly consistent from 1984 through 1988 (Figure 7.12). Size declined from 1989 through 1993, increased slightly until 1994, and then remained relatively stable through 2001. Size of both sexes increased in 2003 through 2005. The decline in TL and weight-at-age in spawning stock samples was more pronounced than in fishery-dependent (gill net) samples (Figure 7.11). A general downward trend occurred from 1988 through 1993 with some improvement through 2005. It is not clear what caused these changes, but since the change occurred fairly quickly it suggests a change in fishing.

Age structure of the spawning stock comprised a wide range of ages during the period 1984 through 1989 (Table 7.9). Ages were estimated by age-length keys in 2003 and 2005. From 1990 to 2001, a noticeable shift to younger fish occurred. Incidence (percent) of repeat spawning, along with mean average repeat, dropped with the absence of older fish (Tables 7.9 and 7.10). For the 1985 to1995 time period, a high of 58% female repeat spawners occurred in 1988, and a high of 52% for males occurred in 1989. Virgin fish dominated the samples from 1991 to 1997. Mean repeats began to climb after 1997 and then reached a record high of 2.18 in 2004 (Table 7.10). This increase occurred because of fewer virgin fish.

Mean age of fish over the entire time series showed a similar declining trend in the late 1980s, followed by a steady period of younger mean age through 2000, then a sharp increase in 2003 and 2004 (Figure 7.13). We investigated the influence of year-class strength and its effect on mean age since the decline in mean age could have been caused by appearance of strong year classes of young fish in recent years as well as by a loss of older fish. We divided catch-at-age in the spawning stock samples by a juvenile (age-0) abundance index (JAI) for the same year class. We used an index of post-yolksac larvae (PYSL) as the age-0 measure because it includes all year-classes present in the adult samples. The PYSL is highly correlated with the juvenile abundance index (see Section 7.10.3) and is the longer data series, extending back to 1974. The JAI began in 1980. Adjusted mean age followed the same decline as that of unadjusted mean age (Figure 7.13). This suggests that the change to younger fish resulted from a loss of older fish from the spawning stock rather than an influx of younger fish. The dramatic increase in 2003 and 2004 indicates just the opposite. Younger, smaller virgin fish are missing, confirmed by the jump in the mean repeats. These changes are rather abrupt and the underlying cause is not clear.

Mortality Estimates

We calculated total instantaneous mortality (Z) within year as the negative slope of natural log of catch-at-age (A) on age and natural log of number of repeat spawners-at-age (RS) on repeats (Crecco and Gibson 1988). From 1984 to 1989, estimates of total instantaneous mortality (Z) were relatively stable with Z_A and Z_{RS} averaging about 0.6 for females (Table 7.11; Figure 7.14). For the same time period, estimates for males were generally higher although annual estimates ranged between 0.4 and 0.8 (Figure 7.14). Z-estimates were extremely variable from 1990 through 1999, but levels were generally much higher than in the 1980s. Z-estimates increased to a high of 1.42 (Z_A) for females in 1995 and a high of 1.41 (Z_A) for males in 1993. Z-estimates remain high through the present, dropping below 1.0 in 2004 and 2005 for both sexes (Table 7.11).

7.10.2 American Shad Tagging Program

Survival Estimates

In 1995, New York initiated a three-year, large-scale (greater than 1500 shad tagged per year) tagging program within the Hudson River in an attempt to estimate population size and exploitation rate on the Hudson shad stock. Estimates of population size and exploitation rate were never achieved because of the failure to meet many population estimate modeling assumptions in such an open system as the Hudson. A complete description of methods and results is found in Hattala *et al*. 1998b. Abundance estimates ranged from several hundred thousand to over one million fish, depending on the model used.

After 1997, we continued to tag shad annually in the Hudson River during the annual spawning stock survey (see Section 7.10.1). The consistent annual data on released and recaptured tagged fish allowed the calculation of annual survival rates using the software program MARK (White 2004).

The initial three-year tag-recapture periods covered 1995 through 1997. The model of constant S among years best fit the data and produced an estimate of S at 0.22, or a Z of 1.53 (Table 7.12). Similar results were obtained with the addition of the 1998 through 2001 tag-recapture data, where S estimates ranged from 0.23 (Z = 1.47) to 0.35 (Z = 1.06). All of the estimates are within the range of the Z-estimates obtained from catch curve analysis of the age and repeat spawn data for the same time period in all analyses. After 2001, models using a constant S no longer fit the data well. We added a model with two time periods (before and after 2001) to see if the changes in ocean fishing rules (implementation of the Harbor Porpoise Take Reduction Act in 2000) affected survival of shad. Model fit improved, and indicated to us that a change in survival occurred. The S-values in the latter period were dramatically lower (Z = 0.13) and were much lower than the Z-estimates from age. The model output data suggests that some change is beginning to occur in the stock.

Tag Return Distribution

During the three year intensive study, most tag returns came from within river during the same release year (Figure 7.15); however, 13 percent of the Hudson returns were recaptured in ocean waters from Nova Scotia to Virginia. In a similar tagging program, 19 percent of shad tagged and released in lower Delaware Bay were recaptured in the Hudson (see Section 8).

7.10.3 Juvenile Abundance

Since 1980, the NYSDEC has obtained an annual measure of relative abundance of juvenile (age-0) American shad in the Hudson River Estuary. In the first four years of the program, juvenile shad were sampled river-wide (rkm 0-252), bi-weekly from August through October, after the peak in abundance occurred. The sampling program was altered in 1984 to concentrate in the freshwater middle and upper portions of the Estuary (km 88-225), the major nursery area for juvenile shad (Figure 7.2). Timing of sampling was also changed—the survey begins in late June or early July and is conducted biweekly through late October each year. The sampling gear is a 30.5 m by 3.1 m beach seine of 0.64 cm stretch mesh. Sites are sampled during the day at approximately 28 standard sites in preferred juvenile shad habitat. Catch-effort is expressed as annual geometric and arithmetic means of number of fish per seine haul for annual weeks 26 through 42 (July through October), the period encompassing the major peak of juvenile presence in the middle and upper estuary.

The geometric mean JAI for the NYSDEC YOY program averaged around 16 in the first five years, then increased and varied at a higher level from 1986 to 1990 (Table 7.13; Figure 7.16). Since then, annual measures have been extremely variable, bouncing between high and low values over a period of ten years until 2001. The JAI dropped very low in 2002 and has remained at depressed levels since then.

In addition to the JAI, additional data on year class abundance in the Hudson Estuary are available. These data are abundance measures of all early life stages: egg (EGG), yolk-sac larvae (YSL), post-yolk-sac larval shad (PYSL), and age-0 fish (beach seine survey, BSS). Data are collected and summarized by contractors for the Hudson River Generating (HRG) companies (Table 7.14a). The Long River Survey (LRS) samples ichthyoplankton river-wide from the George Washington Bridge (km 19) to Troy (km 246) following a stratified random design (ASA 2006). The survey began in 1974 and runs through the present. Ichthyoplankton are sampled from all strata (shore, shoals, bottom, and channel). Sampling gears are either a 1-m epibenthic sled or a 1-m Tucker trawl. Each larval index is the density of eggs or fish collected per 1000 cubic meters of water sampled river-wide. The HRG beach seine survey (BSS) randomly samples beaches in thirteen river segments spread out the entire 246 km of river from July through October. It was designed to sample for YOY striped bass. The seine used is similar to the NYSDEC YOY program, except that the stretch mesh size is slightly larger (0.95 cm rather than 0.63 cm).

All abundance measures (EGG, YSL, PYSL, BSS and YOY) contain some degree of uncertainty in measurement accuracy due to life stage habitat preference, sample gear, and sample timing. The EGG index may only measure a portion of the total production because the sampling gear can only sample along the spawning shoals and not over them (most areas are too shallow for the sampling vessel). The YSL index has similar problems; fish are still small enough to be on the shoals that are inaccessible to sampling gear. Existing flow conditions also influence YSL and egg catchability. By the PYSL stage, larvae are able to move and may be more evenly distributed as they begin to choose a preferred location. Young-of-year have the greatest mobility choice. The two young-of-year sampling programs are different from each other. The NYSDEC YOY program samples beaches within the freshwater nursery area (Newburgh, km 88 and north) whereas the BSS has random site design, sampling a variety of habitats not necessarily where shad could be found, and it samples the entire estuary from New York City to Troy, although sampling is more highly concentrated in the brackish water portion of the Hudson. The BSS began in August for most years of the survey (1974 through 1997), but is now similar in timing to NYSDEC YOY survey (CHGE 1999).

We examined the relationship between all JAIs. Most were poorly correlated (r^2<0.50; Table 7.14b). The best relationship was between the PYSL and the NYSDEC YOY. Since 1980, trends in the two indices (YOY and PYSL) track well for all years (Fig 7.16). For the time period of 1980 through 2005, the two indices were correlated (r^2=0.56; Table 7.14b)

The PYSL index sampling began in 1974. Initial values for the period 1974 through 1979 were low. This index showed a variable but increasing trend from 1979 until 1990, followed by a drop to low levels from 1991 to the present (Figure 7.16).

Validation of Juvenile Abundance Index

Many state agencies collect data on young-of-year abundance but few have attempted to validate whether they actually measure year class strength. Validation requires a long time series of abundance indices at age-0 and at some later adult age. Fortunately, in New York we have both. We attempted to validate the NYSDEC YOY index by comparing relative abundance at age-0 to relative abundance of fish of the same year-class returning as mature adults to spawn. As described in the section above, several long time series of year-class abundance measures exist for the Hudson stock. We feel the best measures for age-0 fish are the YOY and PYSL indices described above. We also have calculated a third abundance measure, for adult fish by year-class, from CPUE data from the commercial fishery (see Commercial catch rate in Section 7.9.2 above).

Since shad mature and return to the river between ages four and eight (sometimes older), we developed an index of each returning year-class as they appeared in the fishery over several years. Segregated by sex, we multiplied percent-at-age within year by the annual CPUE to create individual year-class abundance indices for each year of available data. The adult year-class index is the sum of the segregated indices by year-class for ages five through seven, which are the most abundant ages in the commercial catch. The resulting adult year-class indices include year-classes from 1975 through 1996 (Table 7.15). Since the adult indices include the year-classes back to 1975 and given the degree of concurrence between the YOY and PYSL indices, we used the PYSL index as the measure at age-0 for the validation procedure. A simple correlation was made between the age-0 (PYSL) and adult index for year-classes 1975 to 1996. For all years, no significant relationship was evident ($r^2 = 0.03$ for females, $r^2 = 0.00$ for males and $r^2 = 0.02$ for sexes combined; Figure 7.17). However, we expected a poor correlation given the changes in mortality observed in catch-curve analysis of the adult stock age structure beginning in 1990, when the 1985 year-class would return. We therefore confined our analyses to year-classes produced from 1975 to 1984. These year-classes avoided the change in mortality that occurred in the period 1985 to 1992. The relationship dramatically changes to a nearly one-to one relationship ($r^2 = 0.84$ for females, $r^2 = 0.73$ for males and $r^2 = 0.83$ for sexes combined; Figure 7.17). This suggests that the PYSL and YOY indices are actual measures of year-class strength and, after the 1984 year-class left the Hudson, a dramatic drop in ocean survival occurred for the Hudson stock.

Entrainment Estimates

A river-wide ichthyoplankton survey occurs annually in the Hudson River Estuary, conducted by consultants under contract with the Hudson River Generating companies, see section 7.10.3 above. In order better define impacts of the once-through cooling systems on fish, estimates of mortality on various ichthyoplankton life stages were calculated using two models, the Empirical Transport Model and the Conditional Entrainment Mortality Rate (CEMR) model. Detailed methodology for both models can be found in CHG&E (1999).

Estimates of mortality are expressed as conditional entrainment mortality rates, or the percent reduction in a year-class that would be due to mortality from entrainment through once-through cooling water systems if no other causes of mortality operated. Losses for the Hudson River Estuary can occur at one major office complex air conditioning unit, two nuclear power plants, one waste-fuel power plant, and five fossil-fuel power plants located throughout the Hudson Valley above New York City. CEMR at these facilities combined has ranged from 16 to 52 percent during the period 1974 to 1997 (Table 7.14a). An estimated average of 20% was assumed for the period 1952 to 1973 when major power plant once-through cooling systems came on line (CHG&E 1999). Total losses have declined over the past few years as one fossil fuel plant located within the spawning area was retrofitted with closed cycle cooling.

7.11 ASSESSMENT APPROACHES AND RESULTS

7.11.1 Empirical Spawning Stock Abundance and Biomass Indices

We calculated empirical spawning stock abundance (SSA) and biomass (SSB) indices for the Hudson River shad stock using the relative abundance index of female shad in the fixed gear commercial gill-net fishery, age structure of females in the commercial fishery and the spawning stock (see Sections 7.9 and 7.10), and observed annual mean weight-at-age. These indices allowed us to evaluate the usefulness of various early life stage indices as surrogates of adult abundance.

We used age structure from the haul seine collections for age structure of the spawning stock. We did not use catch rates from this gear as abundance indices because the survey objective was to catch as many fish as possible in the short spring sample period The sample design for this survey was not randomized and we sampled at locations and during environmental conditions when we expected to catch fish

Empirical Index Method

We assumed that catch rates (CPUE) of age five through seven American shad in the gill-net fishery were proportional to relative annual abundance of these age classes in the spawning population because the modal age in the catch varied between five and seven throughout the time series. Total annual CPUE in the fishery was apportioned to ages five, six, and seven from the proportion of observed catch-at-age (ages five to seven) in the commercial catch (Table 7.16). Relative CPUE for other ages in the spawning population were estimated by year as:

$$\text{CPUE}_{\text{agex}} = (\text{CPUE5+6+7}) * ((p_{\text{pop-agex}} / (p_{\text{pop-ages5+6+7}})),$$

where:
$\text{CPUE}_{\text{agex}}$ = catch per unit effort of a given age in the population;
CPUE5+6+7 = CPUE for ages five, six and seven combined in observed catch;
$p_{\text{pop agex}}$ = percent of age x observed in spawning stock collections;
$p_{\text{pop ages5+6+7}}$ = percent of ages five, six, and seven combined observed in spawning stock collections.

We calculated the index of spawning stock abundance as the sum of CPUE-at-age for ages three through ten. To calculate a biomass index, CPUE-at-age is multiplied by observed annual weight-at-age (WAA, kilograms) before summation. We could only calculate these indices through 2001 because of small sample sizes in the commercial monitoring program after that year rendered CPUE5+6+7 unreliable.

We evaluated potential use of early life stage indices (EGG, YSL, PYSL, YOY) as surrogate adult indices with a simple linear regression of the early life stage index on the spawning stock index for the period 1985 through 2001. We assumed that a positive and strong correlation would be indicative of a causal relationship.

Empirical SSA and SSB Results

The empirical estimate of spawning stock abundance index (ESSA) peaked in 1986, declined through 1993, fluctuated without trend through 1999, and then increased (Table 7.16; Figure 7.18). The jump in 2000 and 2001 was unexpected, but it may have been related to changes in gill-net restrictions in ocean waters related to the Harbor Porpoise Take Reduction Plan as these restrictions required smaller mesh gill nets, allowing larger fish to escape the fishery and return to the Hudson (see Section 7.9). A linear regression of ESSA on years was significant for the years 1986 through 1999 (r^2 = 0.62, slope = -2.75, P = <0.01) and for the years 1986 through 2001 (r^2 = 0.24, slope = -1.46, P = 0.05)

The ESSA correlated best with the EGG index (R^2 = 0.59, Figure 7.18) indicating that a positive relationship existed between the observed spawning stock and the resulting egg production measured in the river. Some variation between the two indices (ESSA and EGG) occurred throughout the time series (Figure 7.18); however, this may be the result of the short duration of the egg phase, environmental influences of temperature and flow on the EGG index, or both. Relationships between the ESSA with other age-0 abundance indices were poor (r^2 = 0.06, YSL index; r^2 = 0.16, PYSL index; and r^2 = 0.21, YOY index).

The empirical spawning stock biomass index (ESSB; Figure 7.18) displayed a similar pattern as the ESSA with the exception of 1986 through 1989 when the biomass index was much higher relative to the rest of the biomass time series. In these years of the biomass time series, there were more large, older fish present in the spawning stock (see Section 7.10). A linear regression of ESSB on years was significant for the years 1986 through 1999 (r^2 = 0.64, slope = -6.2, P = <0.01) and for the years 1986 through 2001 (r^2 = 0.35, slope = -3.76, P = 0.02).

The EGG index correlated better with the biomass index (r^2 = 0.66; Figure 7.18) than with the abundance index since egg production is more a function of fish biomass than of fish length. The relationships between the ESSB and the other age-0 indices were poor (r^2 = 0.04,YSL index; R^2 = 0.21, PYSL index; and R^2 = 0.20, YOY index). We used the relationship between the EGG index and the ESSB to project the ESSB from 1999 through 2005 (Figure 7.18). The projected index increased slightly in 2000, but not as much as the ESSB, suggesting that the high values in 2000 and 2001 were a function of commercial sampling error rather than an actual rise in abundance.

7.12 BENCHMARK

A benchmark was calculated 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 (see Section 1). The benchmark of Z_{30} is 0.54. Current Z-values are well above this reference point. The EGG index is at its lowest level in 20 years.

7.13 CONCLUSIONS AND RECOMMENDATIONS

Over the last 20 years, the Hudson River stock of American shad has shown consistent signs of excessive mortality on mature fish. As mortality rose above acceptable levels during the late 1980s, mean size, mean age, and abundance fell. Recruitment dropped to and remained at its lowest levels of the time series during the last four years. We contend that the high adult mortality was caused by fishing (see Section 1.5) and that this excessive fishing has now affected recruitment.

The excessive mortality of the last 20 years perpetuates almost a century of successive periods of overfishing on the Hudson River stock of American shad. Results of this fishing pressure have left the stock in a historically depressed condition with high uncertainty regarding its recovery. Few year-classes currently remain at high enough abundance to rebuild the spawning stock.

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 suspected of affecting the Hudson River stock of American shad be restricted to curtail any further damage to this stock. These fisheries include those in the Hudson, both commercial and recreational take, as well as known remaining mixed stock fisheries outside of the Hudson system such as those in lower Delaware Bay. A concerted effort needs to be made to identify bycatch in the other numerous fisheries that may harvest Hudson River American shad (e.g., Atlantic herring fishery) and identified bycatch fisheries need to be restricted to minimize catch of American shad. Even if fishing proves not to be the principle cause of the shad stock decline, it is the only cause that managers can control.

We also recommend that a fishery-independent CPUE survey be developed to track spawning stock abundance.

LITERATURE CITED

ASA (Applied Science Associates). 2006. 2005 Year Class Report for the Hudson River Estuary Monitoring Program. Prepared fro Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York, Inc, New York Power Authority, Niagara Power Corporation, and Southern Energy. New York.

ASMFC (Atlantic States Marine Fisheries Commission). 1944. Proceedings of the Atlantic States Marine Fisheries Commission, Third annual meeting, New York City.

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Source document for the Interstate Fishery Management Plan for American Shad and River Herring. Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1989. Interstate Fishery Management Plan for Striped Bass. Amendment 4. Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1995. Interstate Fishery Management Plan for Striped Bass. Amendment 5. Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1998a. American shad stock assessment. ASMFC, Peer Review Report. Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1998b. American shad and Atlantic sturgeon stock assessment. ASMFC, Terms of reference and advisory report. Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring. Fishery management Report No. 35. Washington, D.C.

Caraco, N.F., J.J. Cole, P.A. Raymond, D. L Strayer, M.L. Pace, S.E.G. Findlay and D.T. Fischer. 1997, Zebra mussel invasion in a large turbid river: phytoplankton response to increased grazing. Ecology 78:588-602.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

CGH&E (Central Hudson Gas and Electric Corporation, Consolidated Edison Company of New York Inc, New York Power Authority, and Southern Energy New York) 1999. Draft environmental impact statement for the State Pollutant Discharge Elimination System Permits of Bowline Point, Indian Point 2&3 and Roseton Steam Electric Generating Stations. Poughkeepsie, New York

Crecco, V. and M. Gibson. 1988. Methods of estimating fishing mortality rates on American shad stocks. *In* 1988 Supplement to the American shad and river herring Management Plan. Atlantic States Marine Fisheries Commission, Fisheries Management Report 12, Washington, D.C.

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

Dadswell, M., G.Melvin, P. J. Williams, and D.E. Themelis. 1987. Influences of origin, life history, and chance on the Atlantic coastal migration of American shad. *In:* Common Strategies of anadromous and catadromous fishes, American Fisheries Society, Symposium 1.

Deriso, R., K. Hattala, and A. Kahnle. 2000. Hudson River shad assessment and equilibrium calculations. Prepared through ESSA Technologies, Ltd. for the New York State Dept. of Environmental Conservation, Toronto, Canada.

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

Harpers Weekly. 1872. Seth Green's shad nursery, April 27, 1872, page 325. *Harper's Weekly Newspaper*, New York.

Hattala, K., R. Allen, N. Lazar and R. O'Reilly. 1998a. Stock contributions for American shad landings in mixed stock fisheries along the Atlantic coast. *In:* Atlantic States Marine Fisheries Commission's American shad stock assessment Peer Review Report, Washington, D.C.

Hattala, K., A. Kahnle, D.R. Smith, R. Jesien and V. Whalon. 1998b. Total mortality, population size and exploitation rates of American shad in the Hudson River Estuary. Special Interim Report to the Atlantic States Marine Fisheries Commission from the NY State Dept. of Environmental Conservation, New Paltz, New York.

Hillborn R., and C. Walters. 1992. Quantitative Fisheries Stock Assessment, Chapman and Hall, Inc. New York.

Kahnle, A., D. Stang, K. Hattala, and W. Mason. 1988. Haul seine study of American shad and striped bass spawning stocks in the Hudson River Estuary. New York State Department of Environmental Conservation, Summary report for 1982-1986, New Paltz.

Klauda, R.J., M. Nittel, K.P. Campbell. 1976. Commercial fishery for American shad in the Hudson River: fish abundance and stock trends. *In:* (USFWS) U.S. Fish and Wildlife Service and (NMFS) National Marine Fisheries Service. Proceedings of a workshop on American shad. Amherst, Massachusetts.

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

Miller, D., and J. Ladd. 2004. Channel morphology in the Hudson River Estuary: past changes and opportunity for restoration. *In* Currents—newsletter of the Hudson River Environmental Society, Vol. XXXIV, No. 1. Available: http://www2.marist.edu/~en04/CUR34-1.pdf.

Olney, J.E., and R.S. McBride. 2003. Intraspecific variation in batch fecundity of American shad *(Alosa sapidissima*): revisiting the paradigm of reciprocal trends in reproductive traits. American Fisheries Society Symposium 35: 185-192.

Piper, T.C. 2003. Fecundity of American shad in the Delaware and Hudson River, USA. Master's Thessi, University of Maryland Eastern Shore, Princess Anne.

Strayer, D.L., K.A. Hattala, and A.W. Kahnle. 2004. Effects of an invasive bivalve (*Dreissena polymorpha*) on fish in the Hudson River estuary. Can. J. Fish. Aquat. Sci. 61:924-941.

Talbot, G. 1954. Factors associated with fluctuations in abundance of Hudson River shad. US Fishery Bulletin 101(56):373-413.

Walters, C. 1995. Estimation of historical stock size and recruitment anomalies from relative abundance time series. Canadian Journal of Fisheries and Aquatic Science 52: 1523-1534.

Whalon, V.M. 1999. The use of biotelemetry to determine riverine movements of adult American shad, *Alosa sapidissima*, in the Hudson River, USA. Master's Thesis, University of Maryland Eastern Shore, Princess Anne.

White, G. 2004. Program MARK – analysis of data from marked individuals. Available: http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm.

USCFF (US Commission of Fish and Fisheries). 1871-1940. Reports of the Commissioner. USCFF. Available: http://docs.lib.noaa.gov/rescue/cof/data_rescue_fish_commission_annual_reports.html.

Table 7.1 Hudson River American shad growth and life history data.

von Bertalanffy Growth - Length-at-age				Gompertz Growth - Weight-at-age						
Parameters	TL (mm) - all fish			Parameters	Weight (g)					
L_∞	587.4	642.0	641.3	W_o	19.4	31.6	24.0			
K	0.4	0.3	0.3	G	4.9	4.6	4.9			
t_0	-0.1	-0.1	-0.1	sg	0.4	0.4	0.4	Maturity*		Fecundity**
Age	Male	Females	All		Male	Female	All	Male	Female	
1	190.5	200.2	190.7		87.7	141.9	109.6	0%	0%	
2	308.8	329.6	312.7		248.3	390.6	312.1	0%	0%	
3	391.8	421.0	401.7		508.9	773.8	640.7	4%	0%	95491
4	450.1	485.7	466.6		834.4	1227.5	1050.6	48%	15%	157637
5	491.0	531.5	513.9		1173.4	1676.0	1476.2	86%	63%	219783
6	519.7	563.8	548.4		1484.3	2068.1	1865.2	97%	91%	281929
7	539.9	586.7	573.6		1745.4	2383.4	2190.6	99%	98%	344075
8	554.1	602.9	591.9		1951.6	2622.9	2446.8	100%	100%	406221
9	564.0	614.4	605.3		2107.8	2798.1	2640.1	100%	100%	468367
10	571.0	622.4	615.0		2222.7	2922.9	2781.8	100%	100%	530513
11	575.9	628.2	622.1		2305.5	3010.2	2883.7	100%	100%	592659
12	579.3	632.2	627.3		2364.4	3070.7	2955.9	100%	100%	654805
13	581.7	635.1	631.1		2405.9	3112.1	3006.5	100%	100%	716952
14	583.4	637.1	633.9		2434.9	3140.4	3041.9	100%	100%	779098

Table 7.2 Observed discard of American shad in the (a) fixed gear and (b) drift gear commercial gill-net fisheries in the Hudson River Estuary, 1980-2005.

(a)

Year	Fixed Gear fishery						
	Observed Catch Composition			% Discarded Within Sex		% Discard of Total Catch	
	Total Catch	% Male	% Female	% Male	% Female	% Male	% Female
1980	2848	17.7	82.3	45.7	2.6	8.1	2.1
1981	2316	22.9	77.1	50.9	1.8	11.7	1.4
1982	3633	26.7	73.3	55.4	1.8	14.8	1.3
1983	2962	40.0	60.0	65.3	0.0	26.1	0.0
1984	3349	27.9	72.1	60.9	0.0	15.6	0.0
1985	5619	30.4	69.6	60.4	2.9	17.4	1.9
1986	6591	31.5	68.5	75.9	1.2	23.4	0.8
1987	8409	19.5	80.5	55.6	2.2	10.8	1.7
1988	8248	29.4	70.6	78.5	0.5	23.0	0.3
1989	4547	25.2	74.8	35.2	1.0	8.4	0.7
1990	2773	19.1	80.9	49.8	0.0	9.4	0.0
1991	2331	10.9	89.1	0.8	0.2	0.1	0.2
1992	2808	7.0	93.0	0.0	0.0	0.0	0.0
1993	1078	6.4	93.6	0.0	0.0	0.0	0.0
1994	1358	9.4	90.6	0.0	0.0	0.0	0.0
1995	1188	11.4	88.6	0.0	0.0	0.0	0.0
1996	1624	8.9	91.1	0.0	0.1	0.0	0.1
1997	1117	11.8	88.2	0.0	0.1	0.0	0.1
1998	1306	24.5	75.5	65.0	0.0	15.9	0.0
1999	1362	8.6	91.4	0.9	1.0	0.1	1.0
2000	1257	12.4	87.6	23.1	0.4	2.9	0.3
2001	1575	10.0	90.0	32.7	0.2	3.2	0.2
2002	333	57.4	42.6	79.9	0.0	41.7	0.0
2003	69	14.5	85.5	0.0	0.0	0.0	0.0
2004	52	7.7	92.3	75.0	0.0	5.8	0.0
2005	0	0.0	0.0		0.0	0.0	0.0

Table 7.2 (cont.) Observed discard of American shad in the (a) fixed gear and (b) drift gear commercial gill-net fisheries in the Hudson River Estuary, 1980-2005.

(b)

Year	Drift Gear fishery						
	Observed Catch Composition			% Discarded Within Sex		% Discard of Total Catch	
	Total Catch	% Male	% Female	% Male	% Female	% Male	% Female
1980	593	36.6	63.4	5.5	0.3	2.0	0.2
1981	2539	38.5	61.5	42.5	0.5	16.4	0.3
1982	2038	47.4	52.6	1.0	0.0	0.5	0.0
1983	1698	67.9	32.1	11.1	5.0	7.5	1.6
1984	1063	53.2	46.8	58.1	0.0	31.0	0.0
1985	517	41.0	59.0	25.0	1.0	10.3	0.6
1986	1712	37.3	62.7	6.3	0.3	2.3	0.2
1987	943	37.5	62.5	20.1	5.1	7.5	3.2
1988	1911	24.5	75.5	20.3	0.0	5.0	0.0
1989	439	29.2	70.8	36.7	0.0	10.7	0.0
1990							
1991							
1992	878	18.5	81.5	41.4	0.0	7.6	0.0
1993	168	25.0	75.0	100.0	0.0	25.0	0.0
1994							
1995	638	14.7	85.3	100.0	0.0	14.7	0.0
1996	632	28.3	71.7	17.3	0.0	4.9	0.0
1997	593	30.9	69.1	74.3	0.5	22.9	0.3
1998	1821	35.9	64.1	97.7	0.0	35.1	0.0
1999	2353	18.7	81.3	52.4	0.0	9.7	0.0
2000	2350	36.5	63.5	53.8	0.0	19.6	0.0
2001	2616	42.5	57.5	77.9	0.1	33.1	0.0
2002	2119	60.2	39.8	89.3	4.3	53.7	1.7
2003	785	51.5	48.5	62.1	0.0	32.0	0.0
2004	1515	51.3	48.7	68.3	0.0	35.0	0.0
2005	2694	53.0	47.0	67.3	0.2	35.7	0.1

Table 7.3 Annual summary of observed catch-per-unit-effort (CPUE) of American shad in the commercial gill fishery in the Hudson River Estuary, 1980-2005. (a) Fixed gear - males; (b) fixed gear - females; (c) drift gear - males; and (d) drift gear - females.

(a)

Year	Number of Trips	Annual Weekly CPUE: Fixed Gear - Males									SUM
		Week of Year									
		13	14	15	16	17	18	19	20	21	
1980	26			1.20	2.13	0.35	0.13	0.07	0.14	0.10	4.12
1981	24		0.64	3.62	0.67	0.56	0.07	0.08	0.47	0.06	6.17
1982	37			0.26	1.45	0.85	0.41		0.07		3.04
1983	38			1.79	0.48	2.21	0.69	0.48			5.65
1984	57				0.24	1.40	1.64	0.08	0.06		3.42
1985	54		2.14	5.35	1.44	0.77		0.17	0.79		10.66
1986	49	9.19	5.30	7.37	1.73	0.41	0.05	0.57	0.23		24.85
1987	49		4.62	3.98	3.42	0.55	0.27	0.33			13.17
1988	38		3.23	8.14	4.11	2.57	0.80	0.55			19.40
1989	30		1.05	1.25	3.39	2.51	1.10				9.30
1990	23		1.37	1.50	0.26	0.40					3.53
1991	22		0.90	0.77	0.50	0.06	0.09				2.32
1992	33		0.13	0.41	0.27	0.39	0.12				1.32
1993	8				0.73	0.18					0.91
1994	9				0.66	0.13	0.07				0.86
1995	10			0.61	0.66	0.13					1.40
1996	19			0.28	1.02	0.56	0.18	0.15			2.19
1997	26			0.20	0.31	0.30	0.10				0.91
1998	17			0.54	1.22	1.83					3.59
1999	27				0.26	0.36	0.18				0.80
2000	16		1.01	2.46	1.41	0.76	0.85				6.49
2001	21			2.55	0.78	0.28					3.61
2002*	4			7.31							*
2003*	1				1.04						*
2004*	2				2.25	0.36					*
2005*											*

*Total catch and CPUE are not representative of entire season due to low sample size.

Table 7.3 (cont.) Annual summary of observed catch-per-unit-effort (CPUE) of American shad in the commercial gill fishery in the Hudson River Estuary, 1980-2005. (a) Fixed gear - males; (b) fixed gear - females; (c) drift gear - males; and (d) drift gear - females.

(b)

Year	Number of Trips	Annual Weekly CPUE: Fixed Gear - Females									SUM
		Week of Year									
		13	14	15	16	17	18	19	20	21	
1980	26			3.38	8.98	4.68	1.27	0.35	0.93		19.59
1981	24		0.62	3.58	2.09	5.45	0.99	1.03	0.71		14.47
1982	37			0.41	2.04	2.37	3.04		0.16		8.02
1983	38			1.18	0.81	2.67	1.93	2.57			9.16
1984	57			0.02	0.52	3.19	4.85	0.72	0.19		9.49
1985	54		2.28	6.91	4.82	6.39		1.22	4.97	0.06	26.65
1986	49	7.82	7.61	8.83	7.69	7.65	2.56	8.50	1.61		52.27
1987	49		11.81	6.90	14.85	6.06	3.92	3.83			47.37
1988	38		3.74	11.59	6.77	10.36	5.77	3.99			42.22
1989	30		0.83	1.39	7.51	11.84	12.22				33.79
1990	23		2.88	4.86	3.98	4.89					16.61
1991	22		6.86	4.14	4.61	1.53	1.17				18.31
1992	33		1.10	2.79	2.69	6.53	1.50				14.61
1993	8				8.55	4.47					13.02
1994	9				10.44	3.88	9.04	0.88			24.24
1995	10			4.95	4.19	2.35					11.49
1996	19			2.19	5.21	5.38	4.43	3.04			20.25
1997	26			1.99	2.43	1.91	0.78				7.11
1998	17			2.00	6.41	3.82					12.23
1999	27				2.29	3.76	4.76				10.81
2000	16		2.77	5.96	8.51	4.21	10.16				31.61
2001	21		0.12	12.54	5.90	7.18					25.74
2002*	4			5.35							*
2003*	1				6.13						*
2004*	2				24.75	3.96					*
2005*											*

*Total catch and CPUE are not representative of entire season due to low sample size.

Table 7.3 (cont.) Annual summary of observed catch-per-unit-effort (CPUE) of American shad in the commercial gill fishery in the Hudson River Estuary, 1980-2005. (a) Fixed gear - males; (b) fixed gear - females; (c) drift gear - males; and (d) drift gear - females.

(c)

Year	Number of Trips	Annual Weekly CPUE: Drift Gear - Males									SUM
		Week of Year									
		13	14	15	16	17	18	19	20	21	
1980	10			5.14	11.53	12.14	24.38	2.38	1.61		57.18
1981	29			6.77	7.27	4.15	5.88	20.07	8.17	6.28	58.59
1982	29				9.24	20.10	3.40	1.47	0.48	1.07	35.76
1983	17				24.86	23.69	10.78	3.57	1.89	18.43	83.22
1984	7				9.52	7.18	87.74				104.44
1985	7		7.00	31.50	24.63	7.54					70.67
1986	8		34.60	11.02	24.46	28.57	5.85	28.16			132.66
1987	6			28.20	12.86	4.08	6.29	6.66			58.09
1988	15		11.67	8.39	4.74	6.35	1.92				33.07
1989	7		0.40		14.29	7.03	3.11				24.83
1990*	0										*
1991*	0										*
1992	11				3.31	8.74	1.80				13.85
1993*	1					15.12					*
1994*	0										*
1995*	5								8.60		*
1996*	5						8.41	5.18			*
1997*	3						7.34				*
1998	6				16.03	19.85					35.88
1999	11				4.99	8.08	5.32				18.39
2000	19			2.51	14.06	7.73	9.15				33.45
2001	14			8.42	27.43	10.87					46.72
2002	9		5.07	28.96	63.55	18.45					116.03
2003	7			5.54	15.04	17.89	11.10				49.57
2004	13		2.05	5.08	11.52	20.27					38.92
2005	20			8.06	17.94	10.26	11.09				47.35

*Total catch and CPUE are not representative of entire season due to low sample size.

Table 7.3 (cont.) Annual summary of observed catch-per-unit-effort (CPUE) of American shad in the commercial gill fishery in the Hudson River Estuary, 1980-2005. (a) Fixed gear - males; (b) fixed gear - females; (c) drift gear - males; and (d) drift gear - females.

(d)

Year	Number of Trips	Annual Weekly CPUE: Drift Gear - Females									SUM
		Week of Year									
		13	14	15	16	17	18	19	20	21	
1980	10			15.43	13.33	12.14	71.21	6.69	3.21		122.01
1981	29			7.64	12.06	13.87	12.40	20.14	13.28	5.97	85.36
1982	29				2.82	13.83	9.21	13.50	3.11	6.42	48.89
1983	17				7.32	7.73	13.87	7.86	17.71	0.55	55.04
1984	7				4.76	4.81	112.07				121.64
1985	7		10.50	16.50	27.65	13.46					68.11
1986	8		18.09	13.43	66.25	36.73	42.21	81.43			258.14
1987	6			22.60	19.29	10.32	19.60	14.72			86.53
1988	15		13.67	11.30	14.40	31.74	11.14				82.25
1989	7		0.40		18.84	14.17	21.40				54.81
1990*	0										*
1991*	0										*
1992	11				10.57	41.54	15.60				67.71
1993*	1					45.36					*
1994*	0										*
1995*	5								49.76		*
1996*	5						38.15	7.19			*
1997*	3						16.45				*
1998	6				27.97	36.22					64.19
1999	11				12.72	34.47	29.70				76.89
2000	19			2.7	20.11	11.87	32.68				67.36
2001	14			8.94	34.03	25.75					68.72
2002	9		5.07	13.5	34.75	16.15		6.23			75.70
2003	7			2.46	13.73	15.13	21.6				52.92
2004	13		2.05	2.32	12.08	18.15					34.60
2005	20			3.19	11.77	12.63	19.29				46.88

*Total catch and CPUE are not representative of entire season due to low sample size.

Table 7.4 Mean total length (TL, mm) and weight (g) of (a) male (b) female and (c) both sexes of American shad collected in the Hudson River Estuary.

(a)

Year	Commercial Fishery						Spawning Stock					
	TL			Weight			TL			Weight		
	N	Mean	STD	N	Mean	STD	N	Mean	STD	N	Mean	STD
						Males						
1980	110	516.6	27.7	110	1572.5	265.8						
1981	225	527.2	26.0	225	1512.8	254.4						
1982	173	534.3	31.6	172	1778.3	295.7						
1983	153	533.9	34.1	152	1754.7	345.1	20	523.4	34.1	20	1493.0	290.4
1984	138	533.0	37.0	139	1831.9	408.2	86	513.9	44.8	85	1429.7	398.1
1985	117	534.9	31.7	115	1835.8	335.8	182	489.3	48.4	147	1170.9	420.2
1986	154	541.5	34.8	153	1919.0	413.4	416	491.4	46.5	393	1299.1	386.7
1987	71	564.7	27.8	71	2124.5	332.5	279	501.4	46.6	276	1286.9	396.4
1988	118	539.4	26.8	118	1909.2	365.8	227	505.9	38.7	219	1370.6	369.6
1989	192	549.4	28.5	174	2042.5	373.7	162	500.7	49.7	162	1246.9	410.9
1990	40	543.7	39.8	40	1909.3	492.1	39	481.4	49.9	38	1047.1	387.6
1991	29	547.0	40.8	27	1792.2	402.0	119	461.3	36.7	117	894.8	221.5
1992	143	512.5	38.5	138	1459.6	385.9	995	460.1	29.4	848	884.8	235.6
1993	35	522.3	30.3	35	1601.1	296.3	318	459.4	27.2	316	799.0	189.2
1994	15	514.2	19.2	8	1572.5	213.3	93	461.7	26.7	87	890.1	202.7
1995	113	516.6	21.9	78	1670.6	189.0	286	471.5	34.9	280	989.0	249.1
1996	63	521.4	22.9	63	1627.1	274.6	295	460.1	37.5	292	890.8	438.5
1997	124	514.7	31.8	124	1520.5	293.5	77	454.9	38.8	76	915.2	285.6
1998	84	504.6	28.7	84	1533.5	282.1	164	457.1	32.0	160	946.4	223.2
1999	157	515.6	30.4	157	1470.0	276.8	183	469.4	34.5	180	912.7	213.6
2000	202	510.7	30.6	192	1531.3	300.6	216	476.4	35.4	207	1058.3	260.4
2001	194	520.5	26.2	194	1469.9	241.3	570	477.1	35.1	538	969.3	241.8
2002	72	527.7	41.0	72	1734.3	316.6						
2003	57	526.6	35.5	57	1732.1	381.9	274	495.4	35.6	271	1201.8	301.2
2004	124	524.4	30.4	128	1676.3	280.7	282	502.4	42.5	283	1250.6	335.2
2005	195	526.7	28.8	195	1678.2	306.1	224	491.3	48.5	223	1168.4	350.8

Table 7.4 (cont.) Mean total length (TL, mm) and weight (g) of (a) male (b) female and (c) both sexes of American shad collected in the Hudson River Estuary.

(b)

Year	Commercial Fishery						Spawning Stock					
	TL			Weight			TL			Weight		
	N	Mean	STD	N	Mean	STD	N	Mean	STD	N	Mean	STD
						Females						
1980	272	550.3	26.0	272	2101.5	337.6						
1981	579	563.0	29.8	579	2086.8	398.7						
1982	426	569.9	32.8	420	2307.4	454.1						
1983	389	566.9	37.2	388	2300.1	506.1						
1984	399	579.1	36.3	411	2507.0	513.9	61	587.0	42.3	61	2361.4	541.0
1985	474	572.4	40.3	473	2489.2	598.0	105	572.6	45.7	78	2024.6	629.1
1986	480	586.6	38.1	476	2635.2	572.0	287	568.5	44.0	277	2040.1	542.4
1987	470	595.1	39.4	469	2647.8	550.7	283	571.4	45.5	277	1946.4	504.8
1988	254	582.2	40.3	253	2571.2	575.0	316	572.3	39.1	309	2006.4	525.0
1989	332	577.9	31.6	300	2502.6	469.7	189	566.8	40.5	187	1891.2	541.8
1990	223	584.9	40.1	223	2530.7	552.6	48	555.4	46.2	49	1656.7	440.8
1991	223	568.7	39.4	220	2265.6	469.1	101	536.5	35.7	100	1483.1	335.3
1992	364	545.5	32.4	361	1957.1	402.1	444	525.9	33.3	439	1429.7	370.1
1993	73	555.4	34.1	73	1962.5	396.9	144	514.8	31.0	139	1173.5	261.0
1994	114	542.5	24.6	104	1798.5	307.2	89	513.7	23.2	83	1248.0	240.7
1995	149	544.2	21.4	107	1993.9	275.8	459	528.0	26.8	451	1476.2	308.7
1996	355	540.2	29.1	355	1959.2	347.5	131	533.2	43.5	126	1547.1	505.1
1997	242	536.5	34.9	242	1908.8	400.0	64	522.0	47.2	63	1440.2	438.0
1998	275	530.5	36.7	275	1904.2	442.0	145	529.8	36.8	143	1532.5	404.2
1999	306	542.5	33.0	305	1868.0	379.6	193	518.9	35.0	191	1312.6	315.6
2000	305	542.6	27.9	293	2033.4	386.4	217	534.5	30.0	213	1502.9	300.8
2001	355	547.4	32.8	356	1898.5	360.3	486	541.7	35.0	462	1498.6	349.1
2002	137	562.1	31.6	137	2265.0	467.6						
2003	65	565.0	34.1	63	2254.8	518.4	342	559.7	38.8	339	1830.4	453.2
2004	166	557.5	40.0	169	2132.7	502.0	545	569.2	43.6	540	1919.6	528.5
2005	205	558.6	38.0	206	2193.7	521.5	382	564.3	41.9	380	1840.8	479.4

Table 7.4 (cont.) Mean total length (TL, mm) and weight (g) of (a) male (b) female and (c) both sexes of American shad collected in the Hudson River Estuary.

(c)

Year	Commercial Fishery						Spawning Stock					
	TL			Weight			TL			Weight		
	N	Mean	STD	N	Mean	STD	N	Mean	STD	N	Mean	STD
Both Sexes												
1980	382	540.6	30.6	382	1949.1	398.5						
1981	804	553.0	33.0	804	1926.2	446.1						
1982	611	559.5	36.5	604	2154.0	479.8						
1983	543	557.6	39.3	541	2146.2	526.4	20	523.4	34.1	20	1493.0	290.4
1984	540	567.4	41.8	554	2336.3	573.0	150	543.0	57.9	149	1806.0	656.7
1985	597	564.6	41.6	594	2359.7	611.8	287	519.7	62.1	225	1466.8	645.7
1986	642	575.0	42.3	637	2451.9	621.1	703	522.9	59.2	670	1605.5	585.1
1987	541	591.1	39.5	540	2579.0	555.9	564	536.5	57.9	555	1615.4	560.8
1988	372	568.6	41.6	371	2360.6	602.3	543	544.6	50.9	528	1742.7	562.1
1989	525	567.3	33.8	475	2331.2	492.3	373	536.3	55.0	370	1581.9	571.4
1990	263	578.6	42.6	263	2436.2	587.2	88	522.0	60.0	88	1388.3	512.8
1991	252	566.2	40.1	247	2213.9	484.6	225	495.7	51.9	222	1164.6	402.7
1992	509	536.2	37.3	501	1819.4	454.5	1443	480.5	43.2	1290	1070.7	386.9
1993	108	544.7	36.3	108	1845.4	403.4	467	476.7	38.1	460	913.9	273.7
1994	129	539.2	25.6	112	1782.3	306.3	184	487.2	35.9	172	1064.2	283.5
1995	267	532.4	25.6	186	1857.1	289.8	763	506.5	40.7	749	1287.2	369.8
1996	418	537.4	29.0	418	1909.2	357.6	433	482.6	51.8	425	1085.7	547.0
1997	366	529.1	35.4	366	1777.2	410.5	143	485.5	54.0	141	1151.2	443.6
1998	359	524.5	36.6	359	1817.4	439.0	313	491.8	50.4	307	1227.5	438.1
1999	463	533.4	34.6	462	1732.8	395.7	383	494.5	42.6	377	1117.9	336.7
2000	508	529.9	32.9	486	1835.8	431.7	439	505.3	43.7	426	1281.0	357.5
2001	549	537.9	33.2	550	1747.3	382.7	1061	506.8	47.5	1002	1213.2	396.6
2002	209	550.2	38.7	209	2082.2	491.0						
2003	122	547.0	39.5	120	2006.5	526.6	621	531.0	49.1	614	1549.8	501.3
2004	290	543.4	39.7	297	1936.0	477.6	835	546.4	53.4	831	1687.0	566.6
2005	400	543.0	37.4	401	1943.0	501.4	613	537.2	56.7	609	1590.0	542.6

Table 7.5 Age structure and repeat spawn data of (a) male and (b) female American shad from fishery-dependent sampling (commercial gill net) in the Hudson River Estuary, 1980-2005.

(a)

Year	Age											Total	Mean Age	Mean Repeat Spawn	Virgin (%)	Repeat (%)
	3	4	5	6	7	8	9	10	11	12	13					
							Male									
1980		9	26	29	28	10						102	6.0	1.42	0.23	0.77
1981		12	23	45	57	23	1					161	6.4	1.74	0.19	0.81
1982	1	11	24	29	33	20	17	3				138	6.6	2.03	0.22	0.78
1983		9	37	23	16	19	9	5	2			120	6.5	1.87	0.29	0.71
1984		1	28	24	11	16	6	3	1			90	6.5	1.99	0.23	0.77
1985		5	20	27	21	10	4	2				89	6.3	1.84	0.29	0.71
1986		7	28	25	18	10	4	1	2			95	6.2	1.87	0.17	0.83
1987			4	16	11	12	10	2	3			58	7.4	2.78	0.05	0.95
1988	1	3	19	44	25	12	7	3				114	6.5	1.96	0.15	0.85
1989		1	21	64	43	38	11	2				180	6.8	2.19	0.13	0.87
1990		1	8	8	6	5	1					29	6.3	1.69	0.31	0.69
1991	2	2	1	5	9	6						25	6.4	2.32	0.16	0.84
1992	2	20	28	39	30	9	1					129	5.8	1.20	0.33	0.67
1993		3	3	13	11	2	0					32	6.2	1.66	0.16	0.84
1994			2	6	5	0	1					14	6.4	1.79	0.07	0.93
1995		4	22	44	26	9	1					106	6.2	1.47	0.25	0.75
1996*	0.2	7.9	22.7	20.6	8.9	2.3	0.4	0.1	0.0			63	5.6			
1997*	1.2	15.6	32.6	37.6	24.7	9.5	2.3	0.4	0.0			124	5.9			
1998*	0.3	11.1	29.2	26.5	11.8	3.9	0.9	0.2	0.0			84	5.7			
1999*	0.8	17.0	47.9	48.5	28.3	11.0	2.9	0.6	0.1			157	5.9			
2000*	0.7	25.9	69.5	62.2	30.2	10.0	2.1	0.4	0.0			201	5.7			
2001*	0.5	14.6	51.1	67.5	41.1	14.4	3.8	0.7	0.2			194	6.0			
2002*	0.0	3.8	9.5	13.4	9.4	4.4	1.3	0.2	0.0			42	6.1			
2003*	0.3	5.3	11.7	15.0	13.6	8.0	2.5	0.5	0.1			57	6.3			
2004*	0.3	8.7	32.2	38.2	24.9	11.3	3.4	0.8	0.1			120	6.1			
2005*	0.4	12.0	46.1	62.0	44.4	21.9	6.6	1.4	0.1			195	6.2			

*1996 through 2005 ages estimated with a length-age key, ageing in progress.

Table 7.5 (cont.) Age structure and repeat spawn data of (a) male and (b) female American shad from fishery-dependent sampling (commercial gill net) in the Hudson River Estuary, 1980-2005.

(b)

Year	Age 3	4	5	6	7	8	9	10	11	12	13	Total	Mean Age	Mean Repeat Spawn	Virgin (%)	Repeat (%)
Female																
1980		6	100	101	36	11	3					257	5.8	0.72	0.50	0.50
1981		7	104	160	87	56	12	4				430	6.3	1.10	0.41	0.59
1982		11	101	105	79	48	17	8	1			370	6.4	1.23	0.39	0.61
1983	1	9	104	97	31	28	14	16	1			301	6.2	0.97	0.58	0.42
1984		6	57	99	48	20	23	9	2	2		266	6.5	1.30	0.48	0.52
1985		18	91	107	68	26	20	11	6	2		349	6.4	1.25	0.44	0.56
1986		8	87	91	49	27	16	6	1	2		287	6.3	1.33	0.41	0.59
1987		2	63	104	74	46	27	30	12	3	2	363	7.1	1.85	0.27	0.73
1988	1	7	52	74	60	32	13	4				243	6.5	1.52	0.28	0.72
1989		2	69	113	82	36	7	3				312	6.4	1.29	0.41	0.59
1990		3	42	61	48	28	9	4	1	1		197	6.6	1.61	0.33	0.67
1991		17	59	62	45	12	8	1	1			205	6.0	1.18	0.46	0.54
1992		11	148	115	51	13	6	2				346	5.8	0.71	0.55	0.45
1993		5	16	23	11	6	1					62	6.0	1.16	0.35	0.65
1994			28	46	24	5	2					105	6.1	0.96	0.42	0.58
1995		3	53	54	23	4	2	1				140	5.9	0.73	0.54	0.46
1996*	2.5	22.2	154.2	122.0	41.8	9.3	1.9	0.8	0.1			355	5.6			
1997*	0.5	18.6	111.7	69.7	29.6	8.6	2.2	0.8	0.2	0.0	0.0	242	5.6			
1998*	5.0	26.6	129.2	72.0	29.0	8.8	3.0	1.1	0.2	0.0	0.0	275	5.5			
1999*	1.5	19.2	135.1	97.4	36.2	10.8	3.7	1.7	0.3	0.1	0.0	306	5.7			
2000*	1.5	18.0	137.9	100.3	32.8	9.6	3.2	1.3	0.2	0.0	0.0	305	5.6			
2001*	1.5	19.9	137.5	124.2	52.7	13.8	3.5	1.6	0.3	0.1	0.0	355	5.8			
2002*		2.1	23.5	27.6	15.2	6.0	1.7	0.6	0.1	0.0	0.0	77	6.1			
2003*	0.5	2.5	19.4	22.5	11.9	5.0	2.0	0.9	0.1	0.1	0.0	65	6.1			
2004*		7.6	60.6	46.0	22.9	11.3	5.4	2.5	0.4	0.2	0.0	157	6.0			
2005*	0.5	8.6	70.5	68.4	33.0	14.6	6.4	3.1	0.6	0.3	0.1	206	6.0			

*1996 through 2005 ages estimated with a length-age key, ageing in progress.

Table 7.6 Number, mean and percent repeat spawn data for (a) male and (b) female American shad from fishery dependent (commercial gill net) sampling in the Hudson River Estuary. RS = repeat spawn.

Year	Number of Repeat Spawning Marks at Age									Total	Mean RS	Virgin (%)	Repeat (%)
	0	1	2	3	4	5	6	7	8				
Male Repeat Spawners													
1980	23	32	30	15	2					102	1.42	0.23	0.77
1981	31	28	61	34	7					161	1.74	0.19	0.81
1982	31	23	26	32	21	5				138	2.03	0.22	0.78
1983	35	22	23	16	15	6	3			120	1.87	0.29	0.71
1984	21	20	14	17	12	5		1		90	1.99	0.23	0.77
1985	26	12	20	15	13	3				89	1.84	0.29	0.71
1986	32	52	52	28	16	8	2			190	1.87	0.17	0.83
1987	3	12	15	6	13	5	4			58	2.78	0.05	0.95
1988	17	24	39	18	12	4				114	1.96	0.15	0.85
1989	24	26	56	46	22	6				180	2.19	0.13	0.87
1990	9	5	5	6	4					29	1.69	0.31	0.69
1991	4	3	4	9	5					25	2.32	0.16	0.84
1992	42	36	35	15	1					129	1.20	0.33	0.67
1993	5	6	16	5	0	0				32	1.66	0.16	0.84
1994	1	4	6	3	0					14	1.79	0.07	0.93
1995	26	25	36	17	2					106	1.47	0.25	0.75
1996- 2005	Analysis incomplete, ageing in progress												
Female Repeat Spawners													
1980	129	83	35	7	3					257	0.72	0.50	0.50
1981	175	117	79	41	14	4				430	1.10	0.41	0.59
1982	145	95	68	32	23	7				370	1.23	0.39	0.61
1983	175	44	31	28	14	9				301	0.97	0.58	0.42
1984	127	46	36	21	22	10	2	2		266	1.30	0.48	0.52
1985	152	84	48	23	25	14	3			349	1.25	0.44	0.56
1986	118	57	56	28	16	10		2		287	1.33	0.41	0.59
1987	98	97	51	54	26	21	11	4	1	363	1.85	0.27	0.73
1988	68	63	59	29	19	5				243	1.52	0.28	0.72
1989	128	43	82	44	13	2				312	1.29	0.41	0.59
1990	65	39	29	43	16	3	1	1		197	1.61	0.33	0.67
1991	94	40	35	17	16	2	1			205	1.18	0.46	0.54
1992	189	100	35	15	6	1				346	0.71	0.55	0.45
1993	22	17	17	4	1	1				62	1.16	0.35	0.65
1994	44	26	32	1	2					105	0.96	0.42	0.58
1995	76	37	20	4	2	1				140	0.73	0.54	0.46
1996- 2005	Analysis incomplete, ageing in progress												

Table 7.7 Creel survey data for American shad caught in the recreational fishery in the Hudson River Estuary, 2001 and 2005.

Year	Boat	Shore	Total	Retention Rate	Directed Fishing Rates (catch/hour)			Mean Size (TL -mm)
					Time Period	Boat	Shore	
2001 (Mar 16- Jun 30)								
Catch	13034	6732	**19766**			1.498	1.534	511.7
Harvest	1047	242	**1289**	6.5%				
2005 (Mar 16 - Jun 17)								
Catch	2899	3683	**6582**		Early Spring*	-	0.123	541.3
Harvest	485	23	**508**	7.7%	Late Spring*	0.586	0.584	

*Early spring: Mar 16 - Apr 30; late spring May 1- Jun 17.

Table 7.8 Length frequency of (a) male and (b) female Hudson River American shad collected during the spawning stock survey.

(a)

TL (mm)	Year																						
	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300-319																							
320-339																							
340-359													1										
360-379			2	4	3	1		1		5					1		1	1	1				
380-399			2	9	1	1	3	1	4	5	3		9	6	3	1	1		6		1	2	5
400-419		1	5	15	4	3	5		11	37	17	3	14	27	15	11	5	7	14			9	13
420-439		4	16	25	7	1	12	3	23	195	51	13	30	71	8	34	33	28	54		14	9	21
440-459	1	8	27	32	33	19	15	9	19	291	90	32	39	64	12	52	32	38	100		30	21	28
460-479	2	6	30	73	51	22	18	8	26	233	85	25	64	41	16	35	41	43	136		48	41	20
480-499	1	8	29	93	45	61	17	5	19	128	50	12	64	36	16	12	41	38	111		58	52	27
500-519	3	16	22	65	36	43	35	2	12	66	14	6	46	23	1	7	14	35	84		51	42	41
520-539	7	18	19	37	47	33	20	2	2	23	7	1	16	18	4	10	8	19	35		42	46	30
540-559	3	17	16	27	19	20	16	6	2	4		1	2	6	1	1	5	6	22		18	34	21
560-579	3	3	6	19	11	14	12	1	1	6	1		1	2		1	2		7		11	19	11
580-599		3	5	13	17	7	8	1		2				1				1				6	6
600-619		1	3	4	3	2	1														1	1	1
620-639		1			1																		
640-659					1																		
660-679																							
>680																							
TOTAL	**20**	**86**	**182**	**416**	**279**	**227**	**162**	**39**	**119**	**995**	**318**	**93**	**286**	**295**	**77**	**164**	**183**	**216**	**570**	**0**	**274**	**282**	**224**

Table 7.8 (cont.) Length frequency of (a) male and (b) female Hudson River American shad collected during the spawning stock survey.

(b)

TL (mm)	Year																						
	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
300-319																							
320-339																							
340-359																							
360-379																							
380-399																							
400-419										1	1												
420-439			1										1		1				1		1	1	
440-459		1			2	1	1		1	3	2		4	5	4	1	2	3	5		1	2	1
460-479				1	2	2		2	1	24	10	6	20	9	5	11	13	4	11		7	6	6
480-499			4	10	5	5	4	5	10	76	33	19	36	18	14	13	49	13	37		14	20	17
500-519		2	8	22	16	9	9	6	20	88	43	27	92	22	13	29	48	43	70		28	46	35
520-539		6	14	43	30	41	35	6	32	105	24	27	164	19	9	41	31	55	94		42	81	47
540-559		4	15	68	71	62	42	5	12	88	16	9	86	20	5	23	22	60	110		72	72	76
560-579		12	15	40	57	65	38	7	9	39	11		44	20	3	9	14	25	105		64	86	65
580-599		12	18	33	32	66	21	8	11	9	4	1	9	9	4	13	9	12	33		66	93	56
600-619		9	15	24	22	29	20	4	3	5			3	6	4	3	3	1	10		25	69	36
620-639		8	9	20	18	17	12	5	1	4				1	2	1	2		8		18	52	31
640-659		6	3	17	12	10	2		1	1				1		1		1	2		3	22	9
660-679		1	3	9	13	7	3			1				1							1	3	3
>680					3	2	2																
TOTAL		**61**	**105**	**287**	**283**	**316**	**189**	**48**	**101**	**444**	**144**	**89**	**459**	**131**	**64**	**145**	**193**	**217**	**486**	**0**	**342**	**553**	**382**

Table 7.9 Age structure and repeat spawn percent of American shad from spawning stock sampling in the Hudson River Estuary, 1983-2005. RS = repeat spawn.

Year	Age											Total	Mean Age	Mean RS	Virgin (%)	Repeat (%)
	3	4	5	6	7	8	9	10	11	12	13					
Male																
1983		2	5	5	4	2	2					20	6.25	1.75	0.20	0.80
1984	3	18	23	22	9	7	1	1				84	5.55	1.10	0.45	0.55
1985	13	54	53	24	12	8	2	1				167	5.03	0.78	0.59	0.41
1986	9	77	72	39	15	6	3		1			222	5.05	0.74	0.61	0.39
1987	5	51	59	31	17	6	6	2	2			179	5.38	0.97	0.55	0.45
1988	2	42	97	42	26	7	4	2				222	5.43	0.83	0.58	0.42
1989	2	33	46	36	23	17	5	1				163	5.74	1.19	0.48	0.52
1990		7	16	7	7	1						38	5.45	0.74	0.63	0.37
1991	12	46	33	16	4	1						112	4.62	0.29	0.79	0.21
1992	13	172	232	68	7	1	2					495	4.79	0.27	0.78	0.22
1993	5	92	156	47	17	2						319	4.95	0.44	0.68	0.32
1994	2	32	36	7	3							80	4.71	0.53	0.69	0.31
1995	23	96	82	31	9							241	4.61	0.46	0.68	0.32
1996	23	162	64	15	4	1						269	4.32	0.49	0.62	0.38
1997	4	24	30	10	1			1				70	4.79	0.47	0.69	0.31
1998	7	78	48	12	4							149	4.52	0.69	0.52	0.48
1999	2	64	80	19	2	2						169	4.77	0.87	0.43	0.57
2000	22	79	67	15	1	1						185	4.44	0.63	0.56	0.44
2001	41	209	146	71	24	4						495	4.68	0.86	0.44	0.56
2002	No sampling															
2003*	5.2	63.4	107.7	62.0	25.8	7.9	1.4	0.4	0.2			274	5.26			
2004	7	39	86	60	35	32	4	2	1			266	5.77	1.60	0.29	0.71
2005*	11.2	58.0	69.7	46.9	23.6	9.5	3.6	1.1	0.4			224	5.29			
Female																
1983												0				
1984		1	7	15	14	8	5	3	1			54	6.98	1.85	0.31	0.69
1985	1	10	16	27	17	11	5	4	3			94	6.49	1.51	0.34	0.66
1986		17	56	65	26	17	10	2	4			197	6.14	1.07	0.53	0.47
1987		13	61	46	25	20	14	6	1	2	1	186	6.46	0.87	0.55	0.45
1988		16	90	104	56	14	11	6	5	2		302	6.23	1.14	0.42	0.58
1989		8	57	52	45	19	7	6	3			197	6.36	1.20	0.49	0.51
1990		2	16	11	13	5	1	1				49	6.20	0.96	0.55	0.45
1991	1	10	31	34	14	3	1	1				95	5.72	0.51	0.72	0.28
1992		21	169	161	67	8	6	2				434	5.76	0.54	0.62	0.38
1993		9	59	53	18	9						148	5.72	0.60	0.60	0.40
1994			49	19	7	2						77	5.51	0.62	0.60	0.40
1995	3	64	215	132	34	3						451	5.31	0.51	0.63	0.37
1996		30	50	20	8	4	2	1				115	5.27	0.94	0.47	0.53
1997		13	32	13	6	5	6					75	5.68	0.79	0.63	0.37
1998		28	65	24	7	5	1					130	5.22	1.01	0.41	0.59
1999		35	108	28	13		1					185	5.12	0.85	0.41	0.59
2000		46	113	25	5	2	1					192	4.99	0.78	0.47	0.53
2001	7	76	175	122	40	6	3	1				430	5.34	1.11	0.37	0.63
2002	No sampling															
2003*	0.9	23.7	103.0	108.2	66.5	23.4	11.5	3.4	1.4	0.1		342	6.05			
2004	1	21	97	117	128	63	48	24	3	1	1	502	6.78	2.18	0.23	0.77
2005*	0.6	25.6	113.1	111.5	71.9	30.5	19.0	6.4	3.2	0.2		382	6.18			

* Ages estimated using an age-length key, ageing in progress.

Table 7.10 Number, mean, and percent repeat spawn of American shad from spawning stock sampling in the Hudson River Estuary.

Year	Repeat Spawning at Age									Total	Mean RS	Virgin (%)	Repeat (%)
	0	1	2	3	4	5	6	7	8				
Male Repeat Spawners													
1983	4	6	3	5	2					20	1.75	0.20	0.80
1984	38	17	16	10	2	1				84	1.10	0.45	0.55
1985	99	33	17	11	4	3				167	0.78	0.59	0.41
1986	135	41	25	10	11					222	0.74	0.61	0.39
1987	98	33	26	8	8	4	2			179	0.97	0.55	0.45
1988	128	40	30	14	8	2	0			222	0.83	0.58	0.42
1989	78	31	18	19	15	2				163	1.19	0.48	0.52
1990	24	4	7	2	1	0				38	0.74	0.63	0.37
1991	89	17	4	1	1					112	0.29	0.79	0.21
1992	387	84	22		2					495	0.27	0.78	0.22
1993	217	72	23	7						319	0.44	0.68	0.32
1994	55	12	10	2	1					80	0.53	0.69	0.31
1995	164	48	25	4						241	0.46	0.68	0.32
1996	168	76	19	5	1					269	0.49	0.62	0.38
1997	48	16	3	2		1				70	0.47	0.69	0.31
1998	78	44	22	5						149	0.69	0.52	0.48
1999	73	53	37	4	2					169	0.87	0.43	0.57
2000	103	52	27	2	1					185	0.63	0.56	0.44
2001	216	172	71	32	4					495	0.86	0.44	0.56
2002						No sampling							
2003*													
2004	76	63	53	46	22	5	1			266	1.60	0.29	0.71
2005*													
Female Repeat Spawners													
1983										0			
1984	17	10	8	6	9	4				54	1.85	0.31	0.69
1985	32	24	15	11	5	7				94	1.51	0.34	0.66
1986	104	42	18	11	14	6	1	1		197	1.07	0.53	0.47
1987	96	36	23	9	5	2	2			173	0.87	0.55	0.45
1988	127	86	45	26	11	5	4			304	1.14	0.42	0.58
1989	97	27	34	25	6	5	3			197	1.20	0.49	0.51
1990	27	6	10	4	1	1				49	0.96	0.55	0.45
1991	68	14	8	3	1	1				95	0.51	0.72	0.28
1992	268	118	35	6	5	2				434	0.54	0.62	0.38
1993	89	35	18	6						148	0.60	0.60	0.40
1994	46	19	8	3	1					77	0.62	0.60	0.40
1995	284	113	47	7						451	0.51	0.63	0.37
1996	54	30	20	7	3	1				115	0.94	0.47	0.53
1997	47	11	6	8	3					75	0.79	0.63	0.37
1998	53	36	31	7	3					130	1.01	0.41	0.59
1999	76	71	30	7		1				185	0.85	0.41	0.59
2000	91	63	29	7	2					192	0.78	0.47	0.53
2001	157	125	103	37	6	2				430	1.11	0.37	0.63
2002						No sampling							
2003*													
2004	115	83	86	99	73	35	11	0	2	504	2.18	0.23	0.77
2005*													

*Ageing in progress.

Table 7.11 Estimates of total instantaneous mortality (Z), annual survival (S), and fishing mortality (F, assume M=0.3) of American shad collected in the spawning stock survey in the Hudson River Estuary.

Year	Catch Curve - Age					Catch Curve - Spawning Marks				
	Ages	Z	SE	S	F	Spawning Marks	Z	S	SE	F
Spawning Stock - Males										
1984	5-10	0.72	0.12	0.49	0.42	1-5	0.77	0.15	0.46	0.47
1985	4-10	0.70	0.07	0.50	0.40	1-5	0.62	0.05	0.54	0.32
1986	4-9	0.68	0.05	0.51	0.38	1-4	0.49	0.14	0.61	0.19
1987	5-11	0.60	0.05	0.55	0.30	1-6	0.54	0.15	0.58	0.24
1988	5-10	0.79	0.05	0.45	0.49	1-5	0.73	0.11	0.48	0.43
1989	5-10	0.72	0.14	0.48	0.42	1-5	0.57	0.21	0.57	0.27
1990	5-8	0.83	0.26	0.44	0.53	2-5	0.97	0.16	0.38	0.67
1991	4-8	0.98	0.14	0.38	0.68	1-4	0.99	0.25	0.37	0.69
1992	5-9	1.37	0.30	0.25	1.07	1-4	1.24	0.03	0.29	0.94
1993	5-8	1.41	0.18	0.24	1.11	1-3	1.17	0.01	0.31	0.87
1994	5-7	1.24	0.23	0.29	0.94	1-4	0.91	0.18	0.40	0.61
1995	4-7	0.81	0.18	0.45	0.51	1-3	1.24	0.34	0.29	0.94
1996	4-8	1.29	0.05	0.27	0.99	1-4	1.43	0.04	0.24	1.13
1997	5-10	0.65	0.32	0.52	0.35	1-5	0.63	0.20	0.53	0.33
1998	4-7	1.03	0.13	0.36	0.73	1-3	1.09	0.23	0.34	0.79
1999	5-8	1.33	0.31	0.26	1.03	1-4	1.21	0.25	0.30	0.91
2000	4-8	1.29	0.25	0.27	0.99	1-4	1.45	0.27	0.24	1.15
2001	4-8	0.97	0.16	0.38	0.67	1-4	1.21	0.21	0.30	0.91
2002										
2003	5-11	1.13	0.07	0.32	0.83					
2004	5-11	0.80	0.10	0.45	0.50	1-6	0.82	0.17	0.44	0.52
2005	5-11	0.90	0.06	0.41	0.60					
Spawning Stock - Females										
1984	7-11	0.53	0.07	0.59	0.23	1-5	0.17	0.09	0.84	-0.13
1985	6-11	0.46	0.04	0.63	0.16	1-5	0.36	0.09	0.70	0.06
1986	6-11	0.63	0.12	0.53	0.33	1-7	0.63	0.10	0.53	0.33
1987	5-13	0.56	0.06	0.57	0.26	1-6	0.64	0.06	0.53	0.34
1988	6-12	0.63	0.06	0.53	0.33	1-6	0.65	0.04	0.52	0.35
1989	5-11	0.54	0.06	0.58	0.24	2-6	0.65	0.11	0.52	0.35
1990	5-10	0.63	0.13	0.53	0.33	1-5	0.59	0.18	0.56	0.29
1991	6-10	0.97	0.15	0.38	0.67	1-5	0.74	0.10	0.48	0.44
1992	5-10	0.98	0.13	0.38	0.68	1-5	1.01	0.14	0.36	0.71
1993	5-8	0.67	0.13	0.51	0.37	1-3	0.88	0.13	0.41	0.58
1994	5-8	1.06	0.05	0.35	0.76	1-4	0.98	0.04	0.37	0.68
1995	5-8	1.42	0.31	0.24	1.12	1-3	1.39	0.30	0.25	1.09
1996	5-10	0.78	0.03	0.46	0.48	1-5	0.87	0.07	0.42	0.57
1997	5-9	0.43	0.14	0.65	0.13	1-4	0.36	0.16	0.70	0.06
1998	5-9	0.99	0.10	0.37	0.69	1-4	0.89	0.18	0.41	0.59
1999	5-9	1.15	0.07	0.32	0.85	1-5	1.09	0.06	0.34	0.79
2000	5-9	1.20	0.12	0.30	0.90	1-4	1.18	0.09	0.31	0.88
2001	5-10	1.11	0.09	0.33	0.81	1-5	1.11	0.16	0.33	0.81
2002										
2003	6-12	1.13	0.14	0.32	0.83					
2004	7-13	0.91	0.11	0.40	0.61	3-8	0.82	0.07	0.44	0.52
2005	5-12	0.83	0.12	0.44	0.53					

Table 7.12 Tag-recapture matrix and model summary for American shad tagged in the Hudson River. For outputs from MARK software, S-survival, r-recovery, t-vary with time, .-constant, p-period 1=before 1995-1999, 2=after 1999.

Year	**Releases**	**Recaptures**											
		1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
1995	2516	51	12	2	1	0	0	0	0	0	0	0	**66**
1996	1500		23	4	0	0	0	0	0	0	0	0	**27**
1997	1944			34	10	2	0	0	0	0	0	0	**46**
1998	237				0	0	0	0	0	0	0	0	**0**
1999	392					2	0	1	0	0	0	0	**3**
2000	468						0	2	1	0	0	0	**3**
2001	515							1	2	3	1	1	**8**
2002	63								0	0	0	0	**0**
2003	574									1	3	1	**5**
2004	728										3	3	**6**
2005	493											2	**2**
Totals	**9429**	**51**	**35**	**40**	**11**	**4**	**0**	**4**	**3**	**4**	**7**	**7**	**166**

Survival Estimate Output from MARK Software				
Years	**Model**	**S(I)**	**SE**	**Z**
1995-1997	S(.)r(.)	0.22	0.05	1.53
	S(.)r(t)	0.23	0.05	1.46
1995-1998	S(.)r(.)	0.23	0.04	1.47
1995-1999	S(.)r(.)	0.23	0.03	1.48
	S(.)r(t)	0.27	0.05	1.30
1995-2001	S(.)r(t)	0.35	0.05	1.06
1995-2002	S(p)r(.) 1	0.25	0.03	1.38
	S(p)r(.) 2	0.88	0.05	0.12
1995-2003	S(p)r(.) 1	0.22	0.03	1.50
	S(p)r(.) 2	0.88	0.04	0.13
1995-2004	S(p)r(.) 1	0.22	0.03	1.50
	S(p)r(.) 2	0.88	0.04	0.13

Table 7.13 NYSDEC young-of-year indices for American shad collected in the Hudson River Estuary.

Year	Number of Hauls	Number Collected	Number of Zero Hauls	Geometric Mean	LCI	UCI	Arithmetic Mean	SE
1980	20	1071	0	23.9	12.9	43.5	53.6	18.1
1981	21	1098	3	19.1	8.7	40.1	52.3	14.2
1982	23	583	3	12.2	6.3	22.8	25.4	5.1
1983	133	5289	4	18.1	14.2	22.9	39.6	4.8
1984	124	2039	13	7.8	6.1	9.9	16.4	2.0
1985	177	10652	10	26.7	21.6	32.8	59.8	7.0
1986	186	14273	4	46.3	39.0	55.0	77.2	5.5
1987	95	3622	7	20.2	15.5	26.3	38.1	5.9
1988	192	14099	10	27.6	22.1	34.5	73.4	10.2
1989	212	19601	4	46.5	39.1	55.3	92.6	9.1
1990	202	16501	7	41.2	34.6	49.2	81.7	9.6
1991	240	15051	17	24.1	19.5	29.6	62.7	5.5
1992	245	18408	14	35.2	29.3	42.2	75.1	8.0
1993	205	5107	21	11.6	9.5	14.2	24.9	2.2
1994	217	9363	1	26.1	22.5	30.3	43.2	2.9
1995	238	3884	56	5.7	4.6	7.1	16.3	2.2
1996	187	14589	8	42.0	34.7	50.8	78.0	6.5
1997	210	6717	8	13.7	11.3	16.6	32.0	3.7
1998	219	1954	51	3.7	3.0	4.5	8.9	1.1
1999	239	15926	16	20.9	16.9	25.8	66.6	8.7
2000	241	7580	39	12.3	10.0	15.0	31.5	3.4
2001	227	15692	5	38.0	32.2	44.7	69.1	4.9
2002	219	2591	95	2.9	2.2	3.8	11.8	1.7
2003	244	4004	49	6.7	5.5	8.2	16.4	1.7
2004	229	3223	41	5.3	4.3	6.5	14.1	1.6
2005	237	4783	37	8.3	6.6	10.1	20.4	2.1

* YOY mean: number per haul, weeks 26-42.

Table 7.14 (a) Ichthyoplankton density (Number/1000 cubic meters) of various life stages of American shad collected in the Long River Survey for the Hudson River Generating companies (ASA 2006) and annual estimates of American shad conditional entrainment mortality rates (CHGE *et al.* 1999). Indices expressed as density (number per 1000^3) and CEMR expressed as percent. (b) R^2 Values comparing age-0 indices for Hudson River American shad.

(a)

Year	EGG Index	SE (eggs)	YSL Index	SE (YSL)	PYSL Index	SE (PYSL)	BSS Index	SE (BSS)	CEMR
1974	0.10	0.03	0.00	0.00	0.17	0.07	11.50	0.83	3.1
1975	0.06	0.02	0.03	0.00	0.28	0.18	10.63	1.43	36.5
1976	0.04	0.01	0.02	0.00	0.16	0.05	13.33	0.87	35.6
1977	0.04	0.00	0.02	0.00	0.17	0.03	13.70	1.39	7.1
1978	0.04	0.01	0.03	0.00	0.09	0.03	23.67	2.66	18.9
1979	0.05	0.01	0.05	0.01	0.49	0.07	11.65	1.74	29.5
1980	0.05	0.01	0.11	0.01	0.48	0.22	10.75	2.46	37.7
1981	0.16	0.08	0.11	0.01	0.78	0.31	17.62	2.17	15.5
1982	0.12	0.04	0.15	0.02	0.59	0.12	16.31	1.92	11.4
1983	0.36	0.11	0.13	0.02	0.57	0.09	19.68	3.89	18.9
1984	0.47	0.11	0.24	0.02	0.38	0.17	8.69	1.84	21.0
1985	0.26	0.04	0.25	0.04	0.67	0.17	8.08	1.30	19.6
1986	0.77	0.33	0.12	0.02	1.05	0.15	19.06	3.74	10.7
1987	0.35	0.08	0.06	0.01	0.18	0.08	13.47	2.28	30.0
1988	0.26	0.05	0.09	0.03	0.73	0.34	7.72	1.01	38.8
1989	0.33	0.06	0.08	0.01	1.04	0.79	22.05	2.41	39.2
1990	0.27	0.06	0.40	0.05	1.17	0.73	18.67	1.74	47.7
1991	0.09	0.02	0.04	0.01	0.32	0.12	11.97	3.16	32.9
1992	0.08	0.02	0.08	0.01	0.62	0.21	13.92	1.05	52.0
1993	0.12	0.03	0.01	0.00	0.23	0.12	7.07	0.87	9.6
1994	0.23	0.04	0.04	0.01	0.37	0.13	17.56	3.28	21.5
1995	0.12	0.03	0.02	0.00	0.19	0.06	3.79	0.43	12.3
1996	0.26	0.04	0.01	0.00	0.26	0.06	11.77	1.93	6.5
1997	0.04	0.01	0.01	0.00	0.15	0.03	12.54	2.04	16.9
1998	0.09	0.01	0.01	0.00	0.09	0.03	2.36	0.42	
1999	0.09	0.02	0.00	0.00	0.18	0.07	8.81	2.44	
2000	0.12	0.02	0.01	0.00	0.09	0.03	5.93	0.93	
2001	0.04	0.01	0.01	0.00	0.46	0.18	24.40	1.83	
2002	0.03	0.00	0.02	0.00	0.10	0.04	4.79	0.47	
2003	0.07	0.02	0.01	0.00	0.09	0.03	8.69	1.20	
2004	0.03	0.01	0.01	0.00	0.14	0.06	3.40	0.61	
2005	0.04	0.01	0.00	0.00	0.03	0.02	3.21	0.60	

(b)

Index	EGG	YSL	PYSL	BSS
NYSDEC YOY	0.23	0.11	0.56	0.53
EGG		0.25	0.35	0.08
YSL			0.51	0.07
PSYL				0.29

Table 7.15 Abundance indices for spawning adult (ages 5-7) American shad in the Hudson River.

Year-class	**Ages 5-7**		
	Female	**Male**	**Both**
1975	14.72	3.50	18.22
1976	6.72	2.27	8.99
1977	6.85	2.03	8.88
1978	11.89	5.17	17.06
1979	19.13	9.01	28.13
1980	33.18	11.43	44.61
1981	39.84	15.21	55.05
1982	29.96	10.62	40.58
1983	25.32	7.27	32.59
1984	16.64	2.89	19.53
1985	11.23	1.74	12.98
1986	12.44	0.80	13.24
1987	16.62	0.96	17.58
1988	15.87	0.80	16.66
1989	13.28	1.01	14.30
1990	12.18	1.19	13.37
1991	12.13	1.57	13.70
1992	7.77	1.52	9.28
1993	12.59	2.47	15.06
1994	18.99	3.02	22.00
1995	24.35	5.13	29.48
1996	13.01	3.53	16.54

Table 7.16 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-5	Age-6	Age-7	Age-5	Age-6	Age-7	Ages 5 & 6	ESSA Age (5-7)	ESSB Age (5-7)	ESSB Estimate*
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							
1985	26.65	6.95	8.17	5.19	40.82	28.45	28.71	33.05	31.82	64.3	
1986	52.27	15.84	16.57	8.92	55.74	50.23	67.62	52.78	55.40	112.9	
1987	47.37	8.22	13.57	9.66	25.47	55.76	73.01	38.49	45.03	89.3	
1988	42.22	9.03	12.86	10.42	30.52	37.58	56.59	34.30	39.30	80.2	
1989	33.79	7.47	12.24	8.88	25.83	46.36	38.88	35.62	36.57	69.2	
1990	16.61	3.54	5.14	4.05	10.84	22.91	15.25	15.76	15.60	25.9	
1991	18.31	5.27	5.54	4.02	16.15	15.47	27.27	15.80	17.83	26.6	
1992	14.61	6.25	4.86	2.15	16.05	13.09	13.95	14.61	14.49	20.9	
1993	13.02	3.36	4.83	2.31	8.43	13.49	18.99	10.82	11.95	14.2	
1994	24.24	6.46	10.62	5.54	10.16	43.04	60.95	19.34	23.23	30.1	
1995	11.49	4.35	4.43	1.89	9.12	15.14	25.04	11.41	12.63	19.1	
1996	20.25	8.80	6.96	2.39	20.23	40.02	34.30	25.89	26.75	41.5	
1997	7.11	3.28	2.05	0.87	7.69	11.82	10.88	8.88	9.12	13.6	
1998	12.23	5.75	3.20	1.29	11.50	17.36	23.93	13.08	13.87	21.5	
1999	10.81	4.77	3.44	1.28	8.17	22.74	18.21	11.17	11.79	16.6	18.5
2000	31.61	14.29	10.40	3.40	24.28	79.84	130.57	34.35	37.71	58.0	25.3
2001	25.74	9.97	9.01	3.82	24.49	31.74	41.06	27.47	29.08	43.7	9.3
2002*											8.3
2003*											15.9
2004*											8.1
2005*											9.9

*Data from 2002-2005 insufficient to generate CPUE and spawning stock indices, see text for methods.

Figure 7.1 Historic commercial fishery landings of American shad in the Hudson River Estuary, 1880-2005.

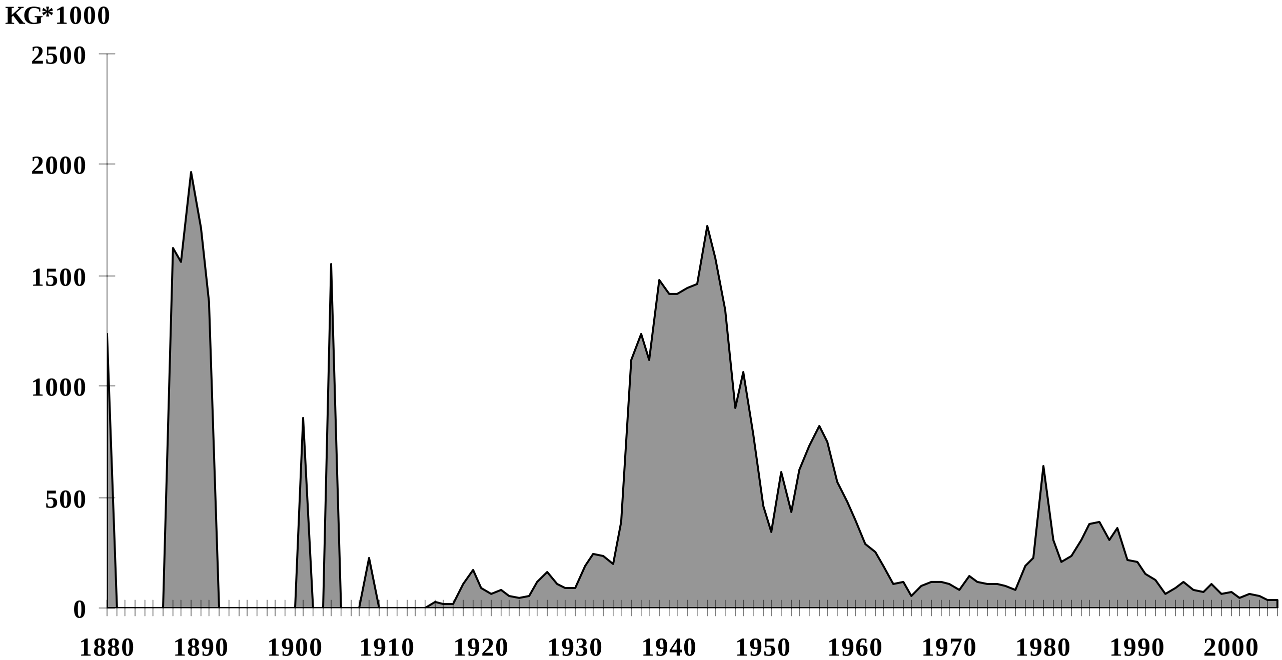


Figure 7.2 Hudson River Estuary with spawning, nursery and fishery areas for American shad.

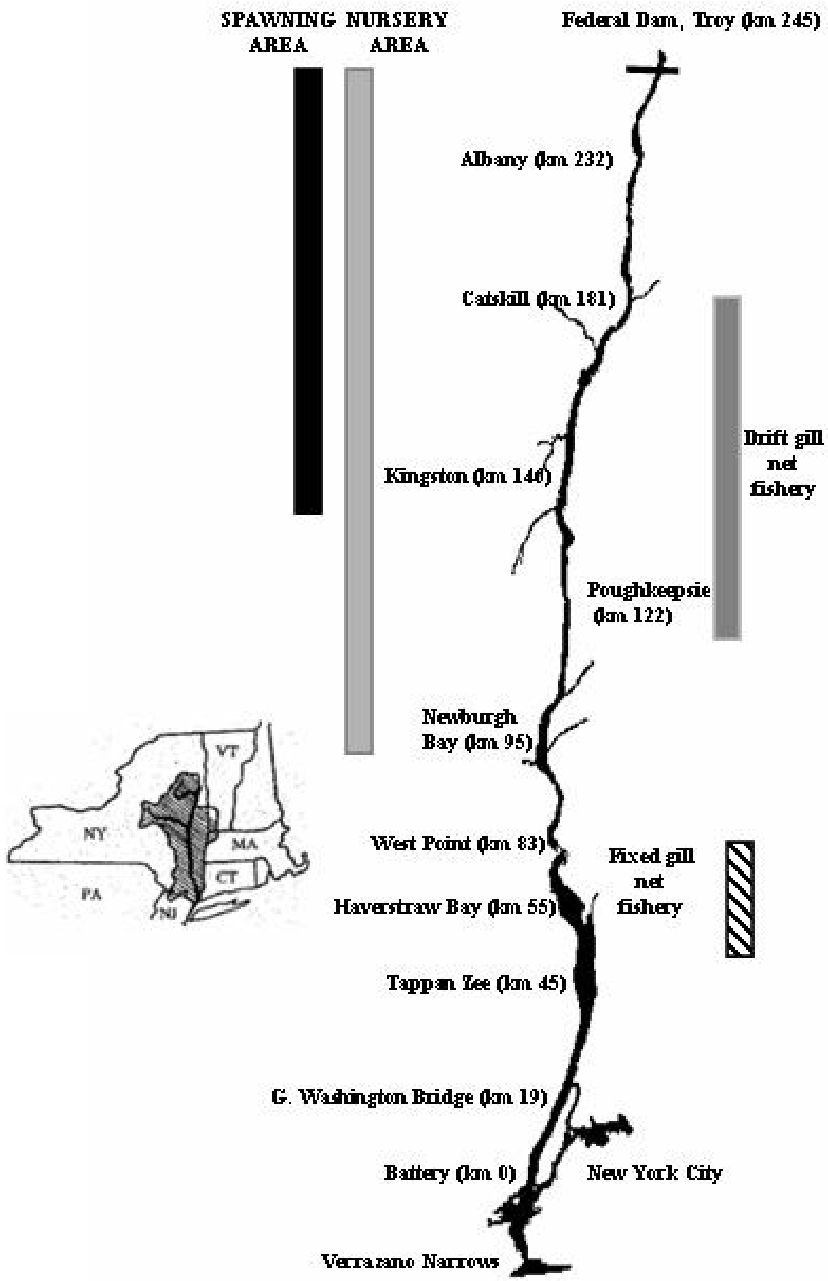


Figure 7.3 Von Bertalanffy and Gompertz growth functions for Hudson River American shad.

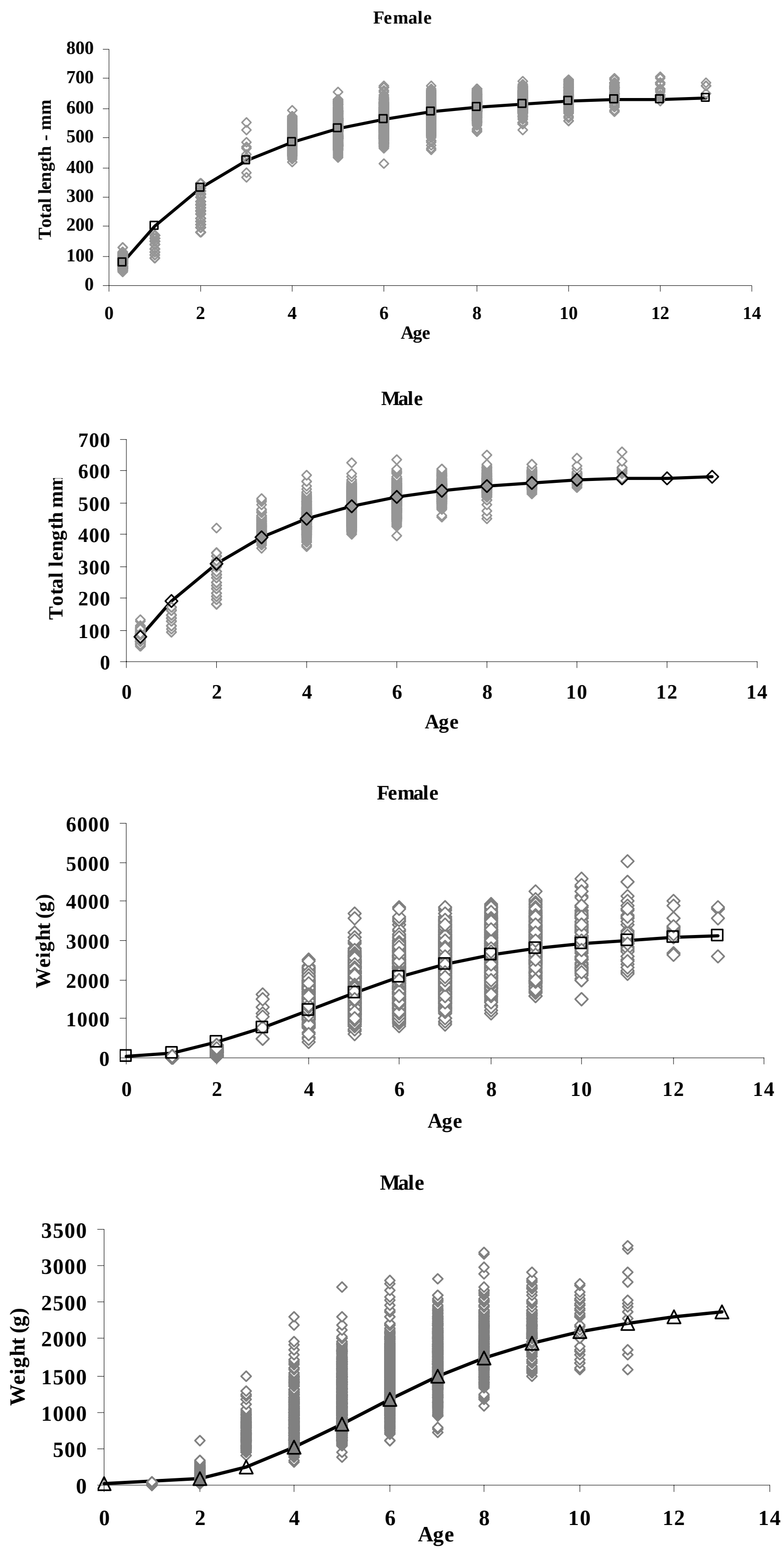
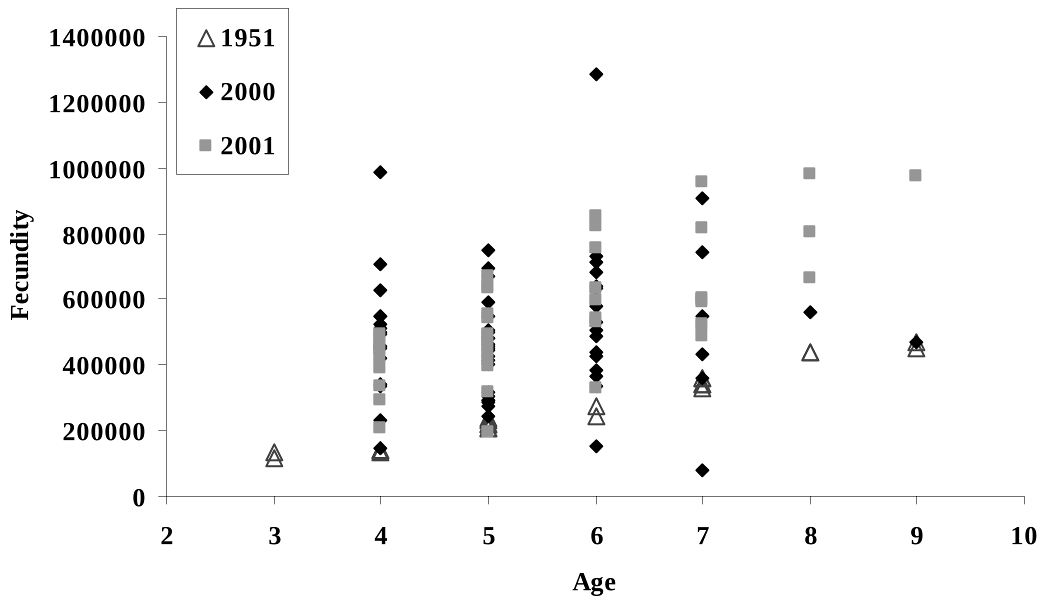


Figure 7.4 Fecundity estimates of Hudson River American shad.



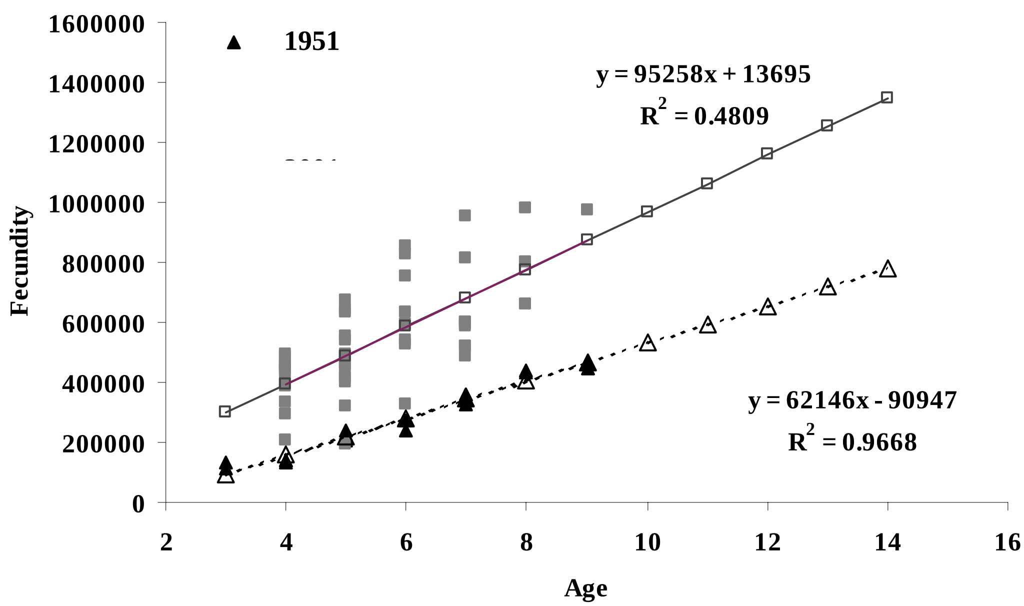
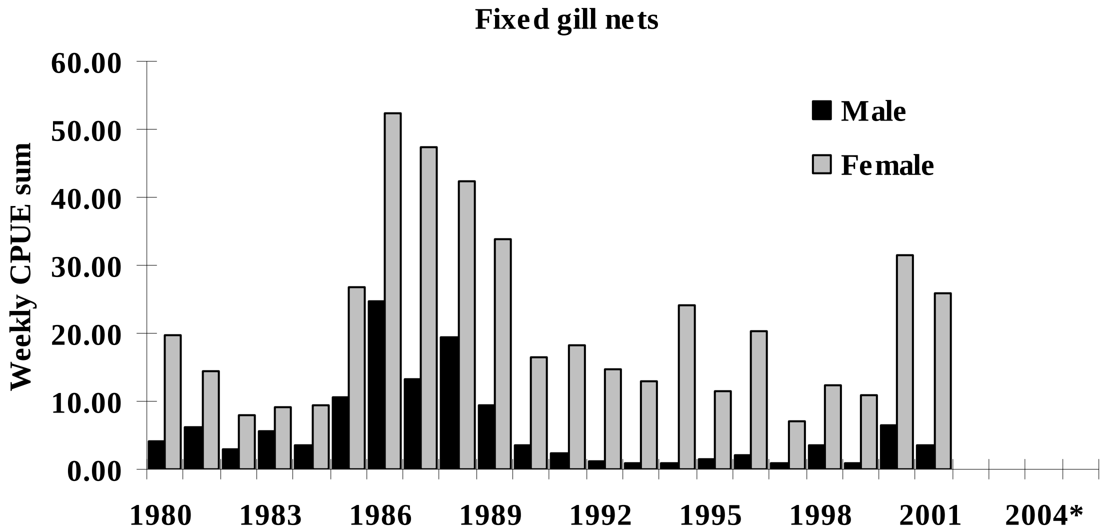


Figure 7.5 Weekly sum of CPUE of American shad caught in the commercial gill-net fishery in the Hudson River Estuary, 1980-2005. (Data not reported for fixed gear 2002-2005; drift gear 1990-1991,1993-1997; small sample size). Trend statistics in table below.

Years	Fixed gill nets	R2	Slope	*P*
1986-2001	Male	0.43	-1.00	0.005
	Female	0.36	-1.70	0.01
1986-1999	Male	0.70	-2.96	0.0001
	Female	0.59	-1.43	0.001



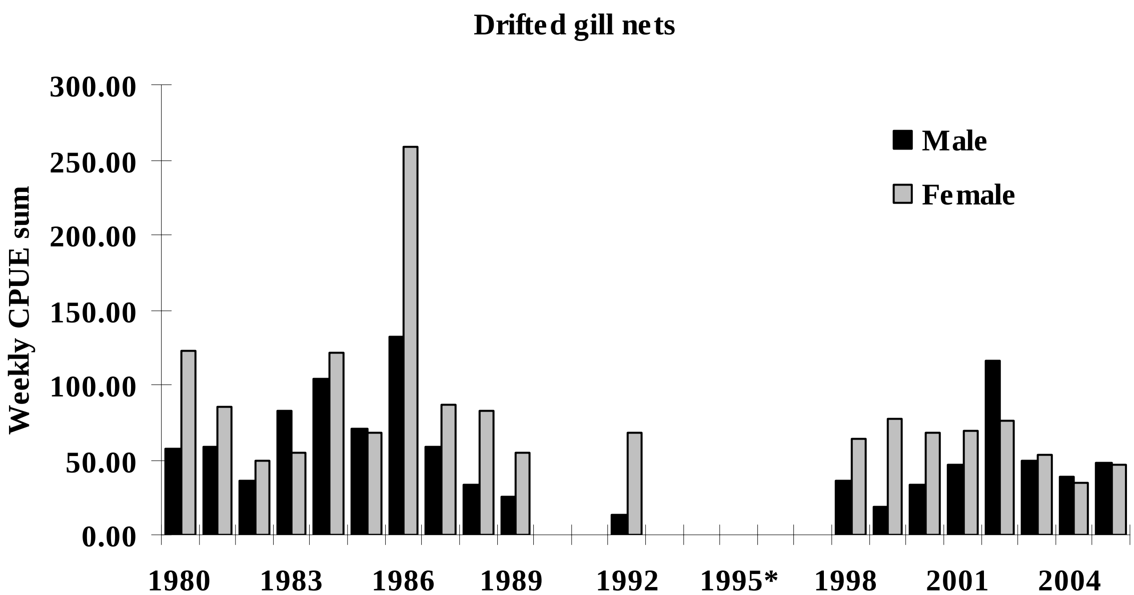


Figure 7.6 Relationship of catch per unit effort (square yard x hour x 10^{-3}) of American shad and striped bass in the American shad gill-net fishery in the Hudson River Estuary.

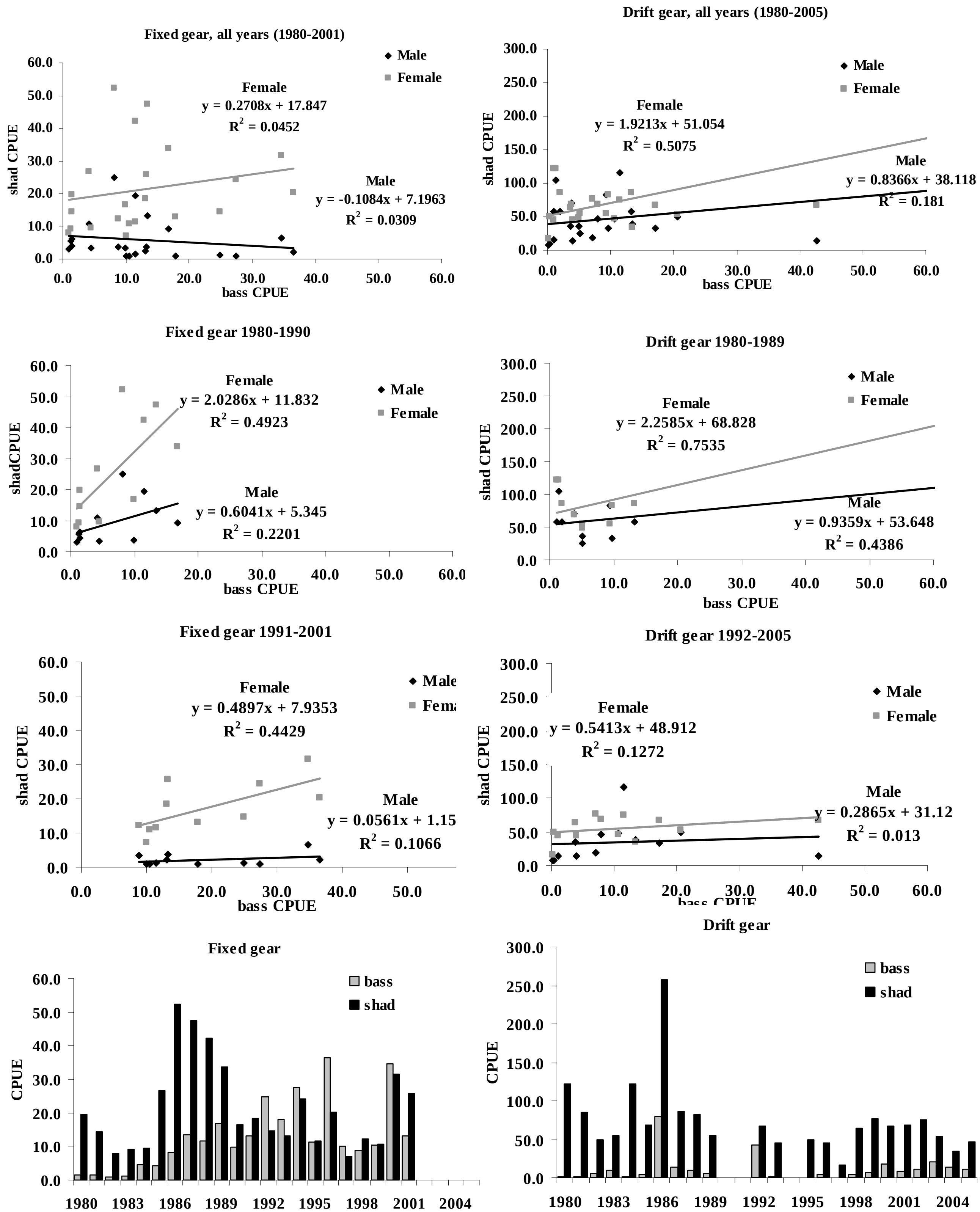


Figure 7.7 Long-term effort, landings, and conversion to CPUE data from the American shad commercial fishery in the Hudson River Estuary, 1931-2005.

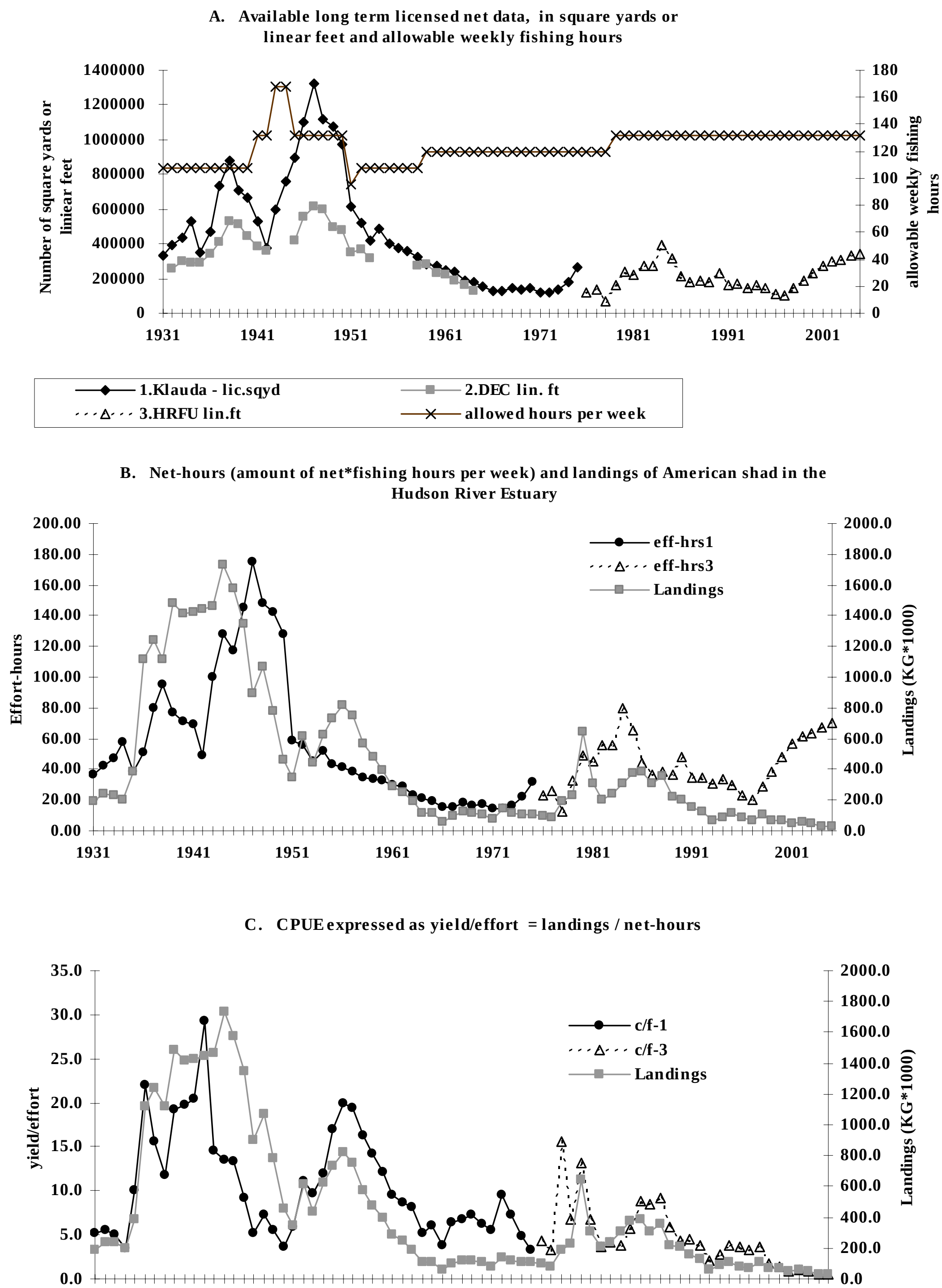


Figure 7.8 Comparison of CPUE data for American shad in the Hudson River Estuary: observed CPUE (number of shad/qyd*hours*10^{-3}) vs. catch/licensed effort = (landings/avg. annual weight)/(sqyd of licensed net *allowable hrs fished* 10^{-6}), 1980-2001. (2002-2005 excluded small sample size).

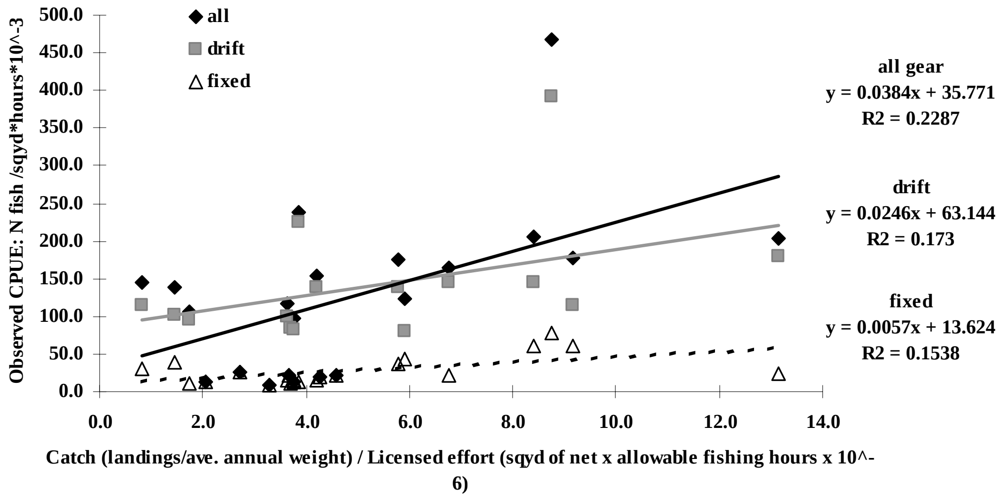


Figure 7.9 Total number of shad & herring gill net licenses sold for use in the Hudson River Estuary, with information on actual reporting of use.

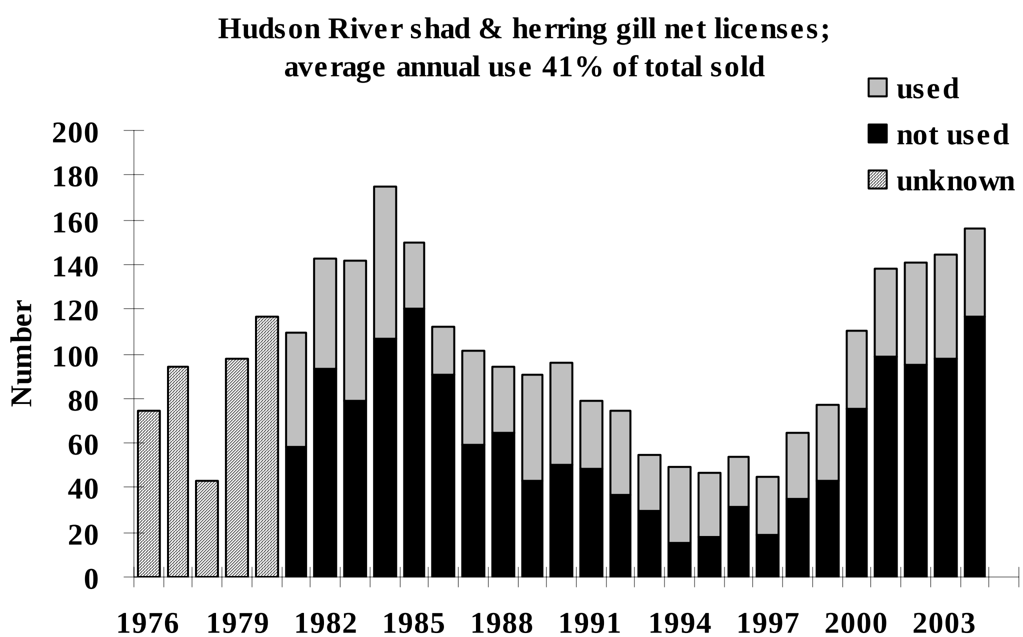
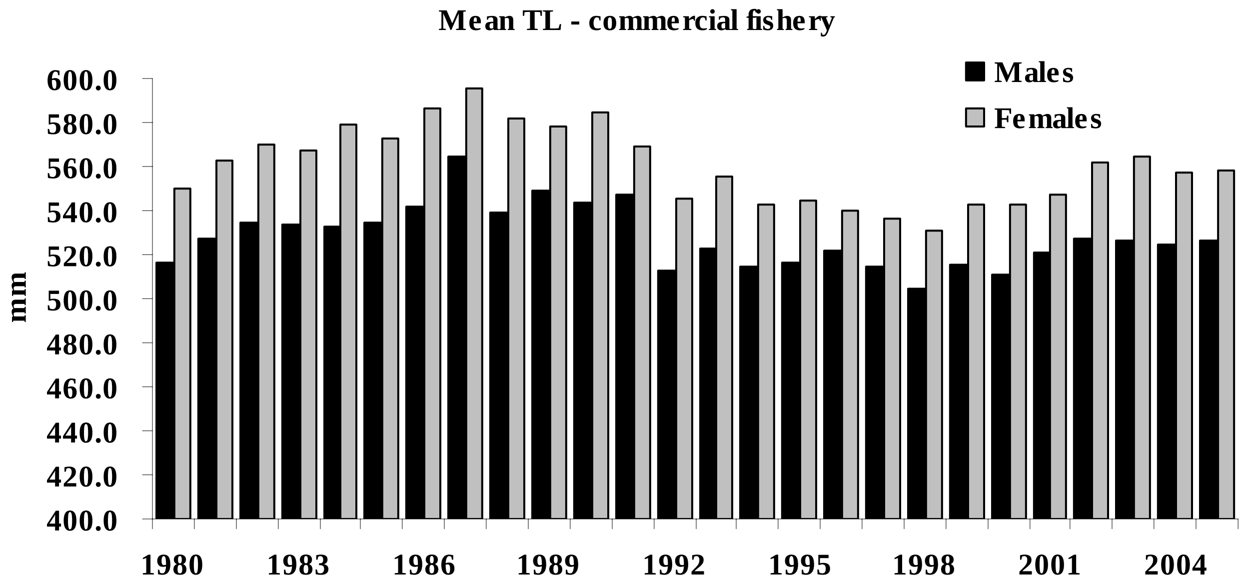


Figure 7.10 Mean total length and weight of American shad caught in the commercial gill-net fishery in the Hudson River Estuary, 1980-2005.



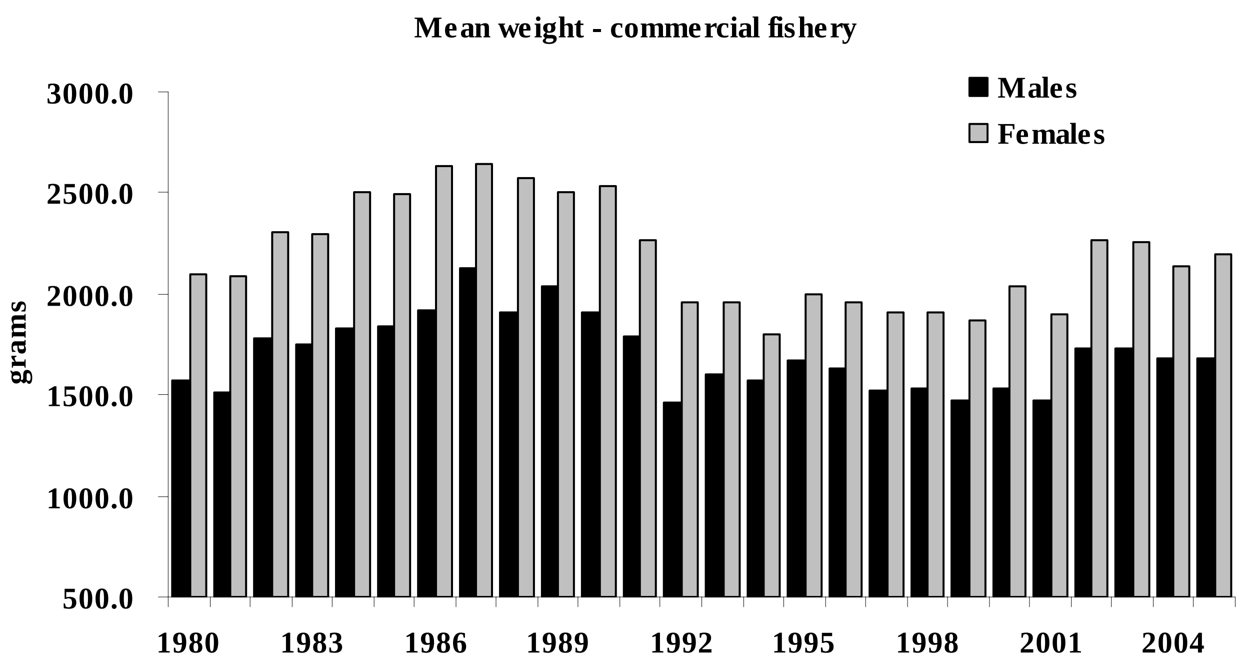


Figure 7.11 Mean total length (mm) and weight (g)-at-age for American shad, ages five through seven, collected in fishery-dependent (commercial fishery gill net, cf) and fishery-independent (spawning stock, ss) survey in the Hudson River Estuary.

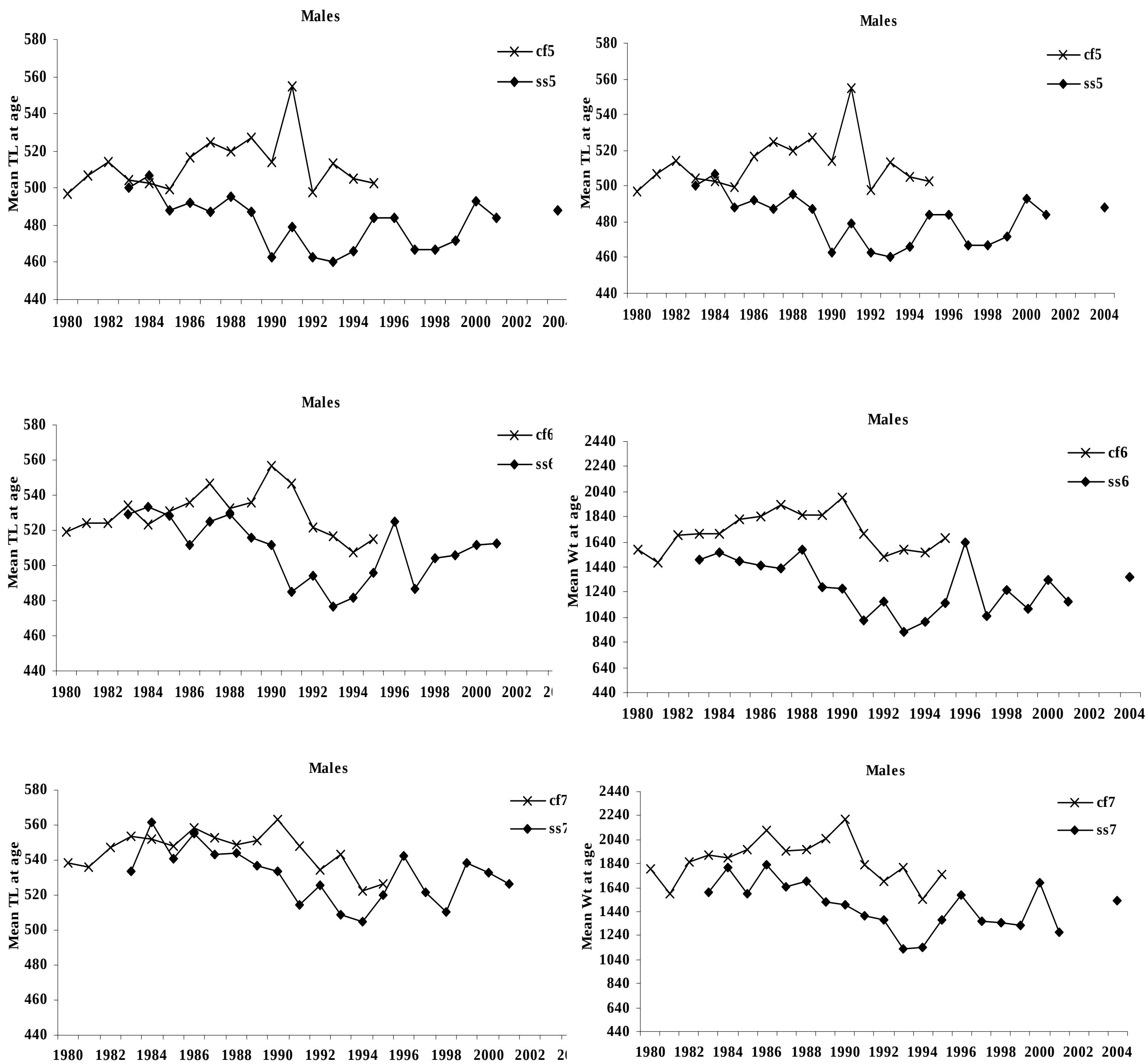


Figure 7.11 cont. Mean total length (mm) and weight (g)-at-age for American shad, ages five through seven, collected in fishery-dependent (commercial fishery gill net) and fishery-independent (spawning stock) survey in the Hudson River Estuary.

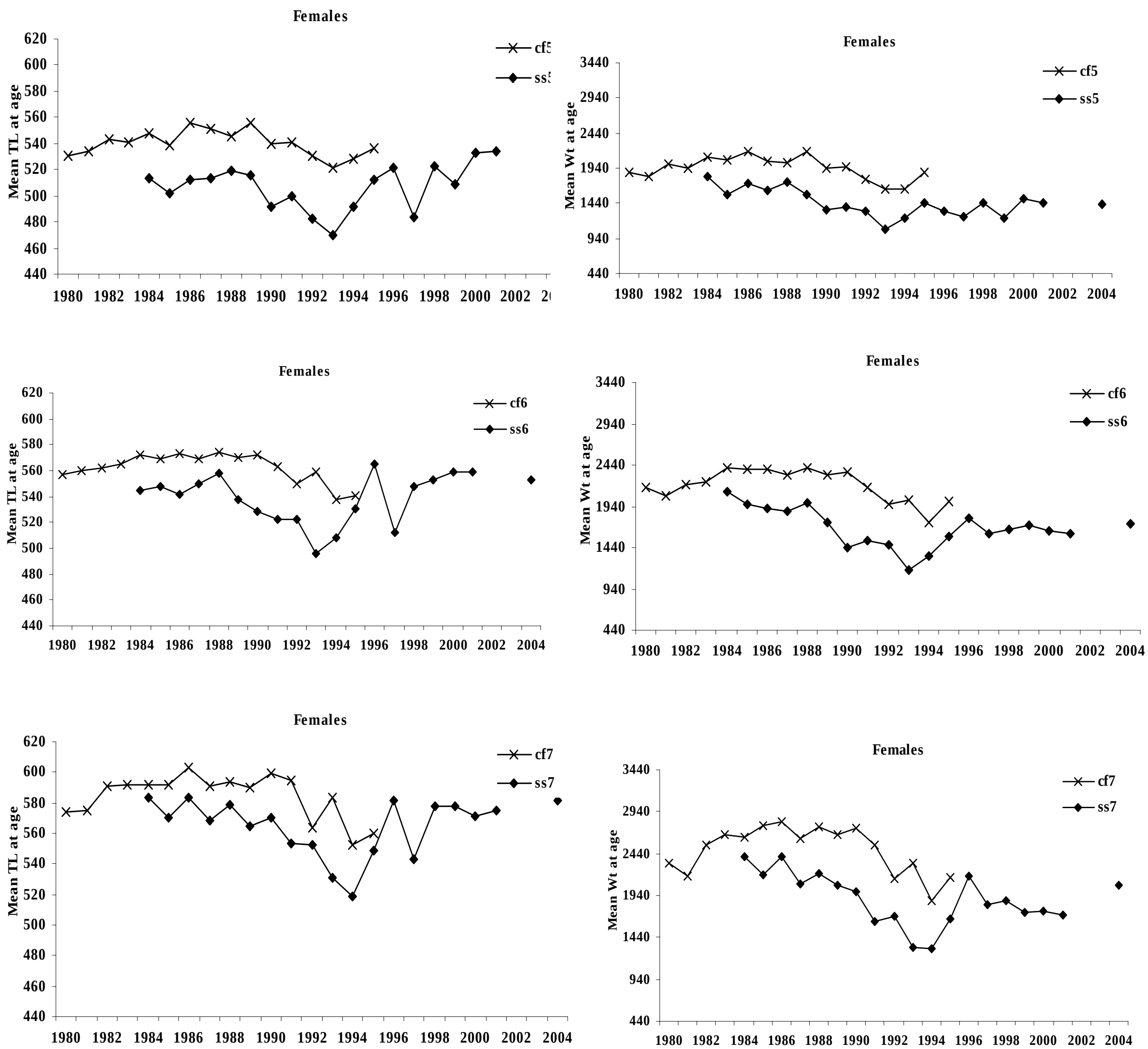
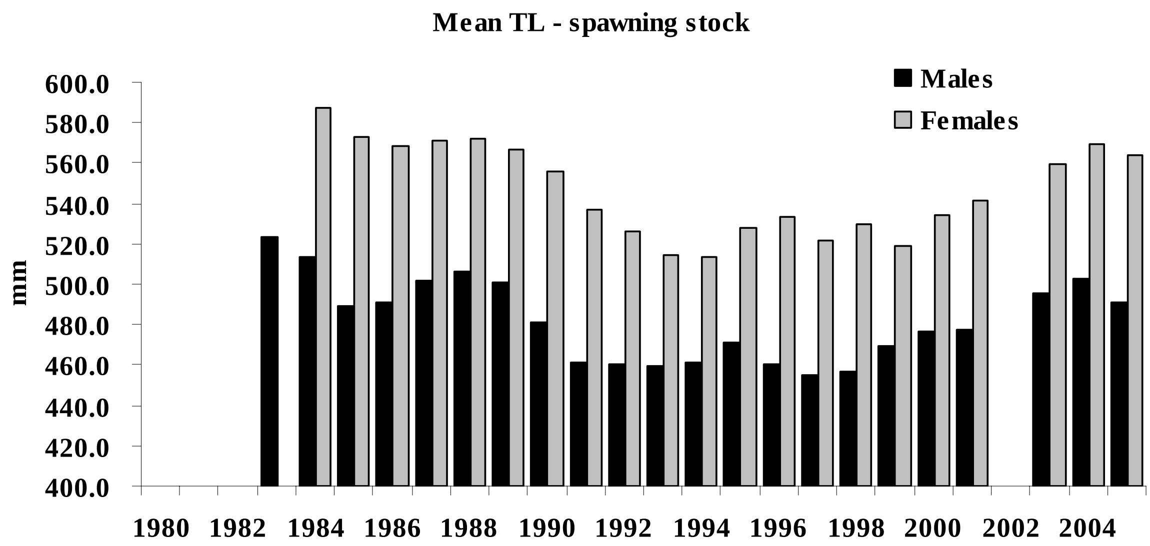


Figure 7.12 Mean total length and weight of American shad collected in the spawning stock survey in the Hudson River Estuary, 1983-2005.



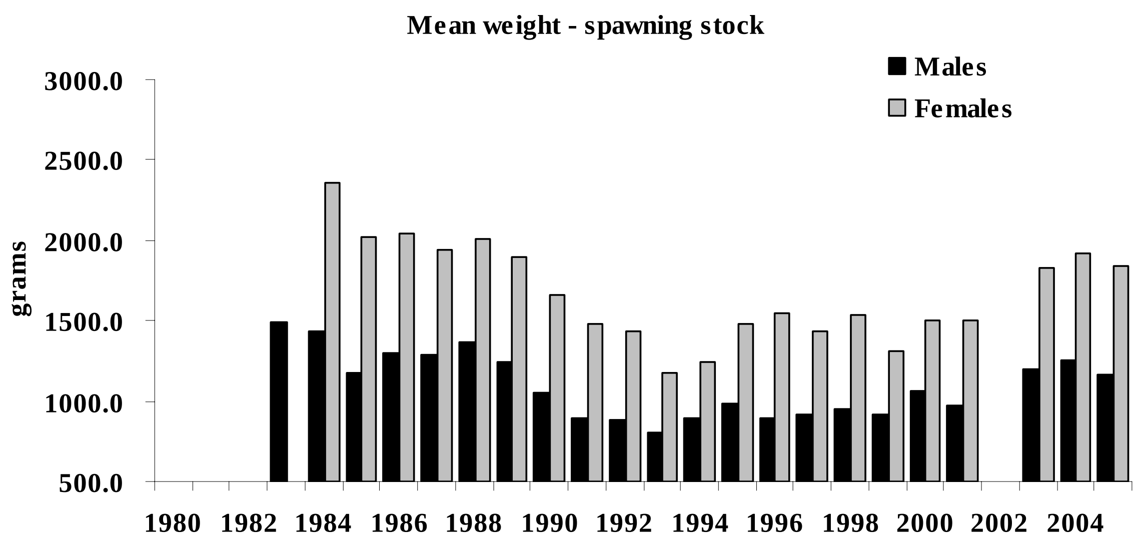
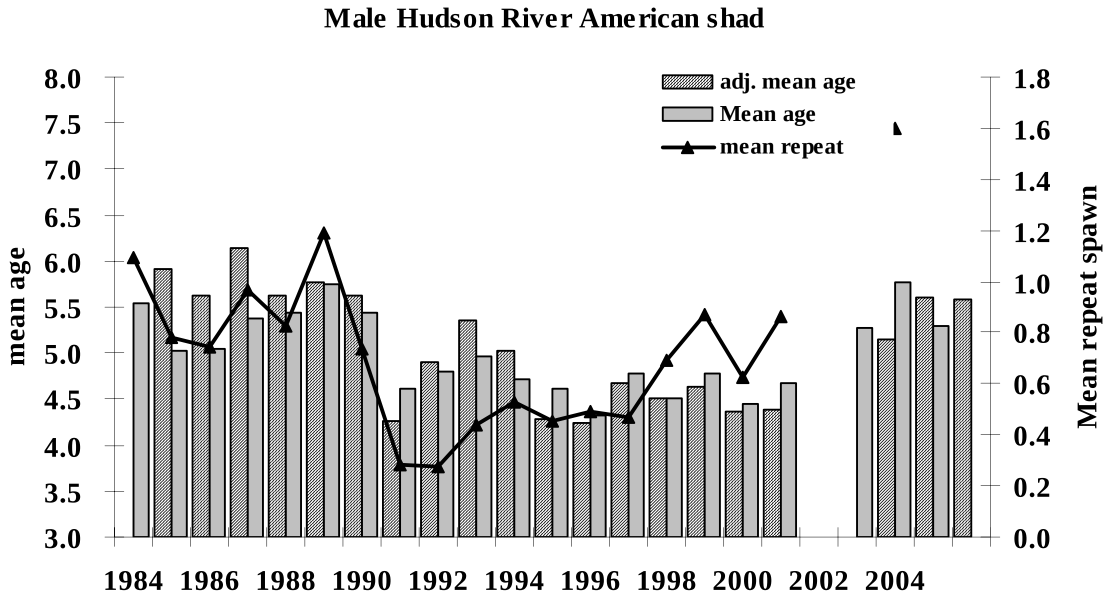


Figure 7.13 Mean age, mean adjusted age, and mean repeat spawn of American shad collected in the spawning stock survey in the Hudson River Estuary, 1984-2004. (No data in 2002, estimated age in 2003 &2005).



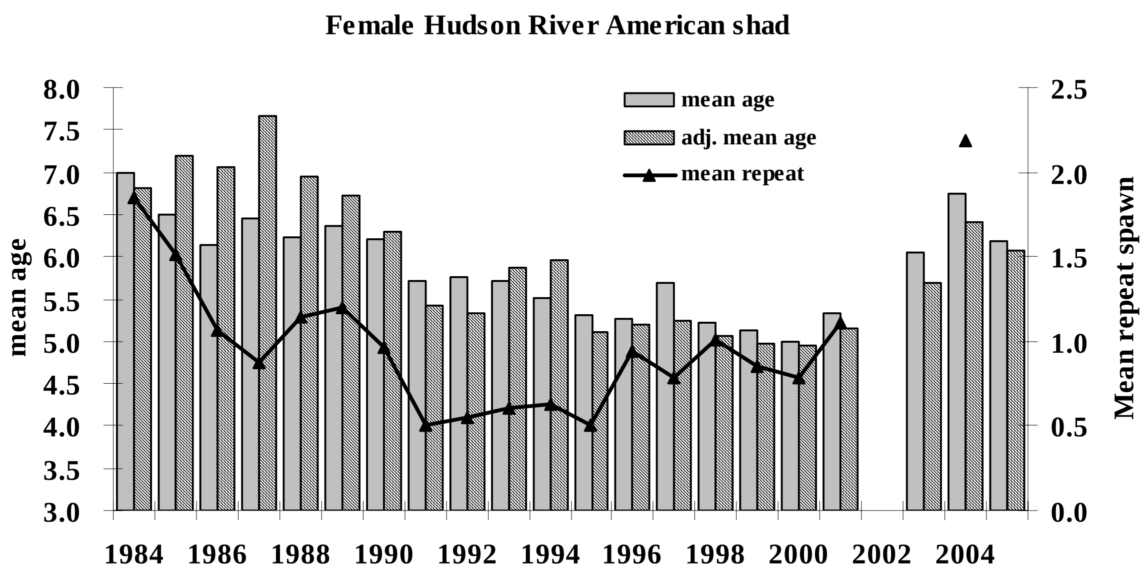
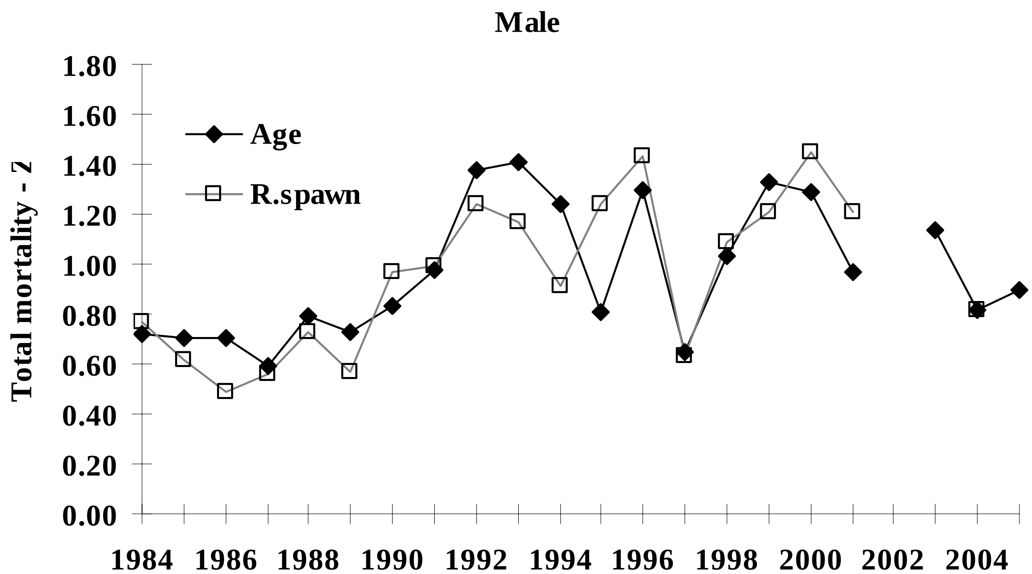


Figure 7.14 Total mortality rates, calculated using catch curves for age and repeat spawn data for Hudson River American shad, 1984-2005.



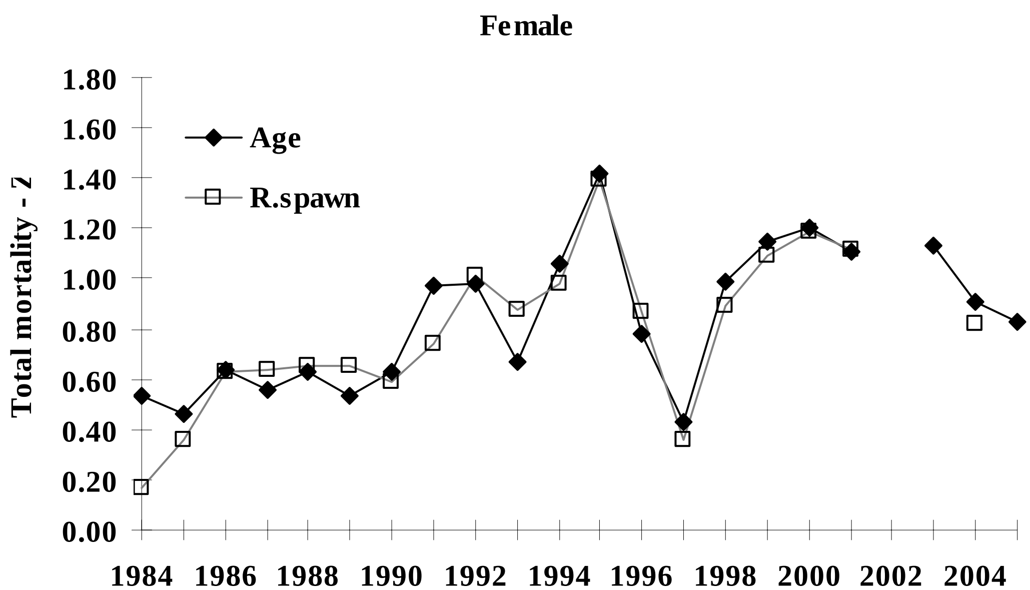


Figure 7.15 The number and location of recaptured American shad tagged and released in the Hudson River, 1995-2005.

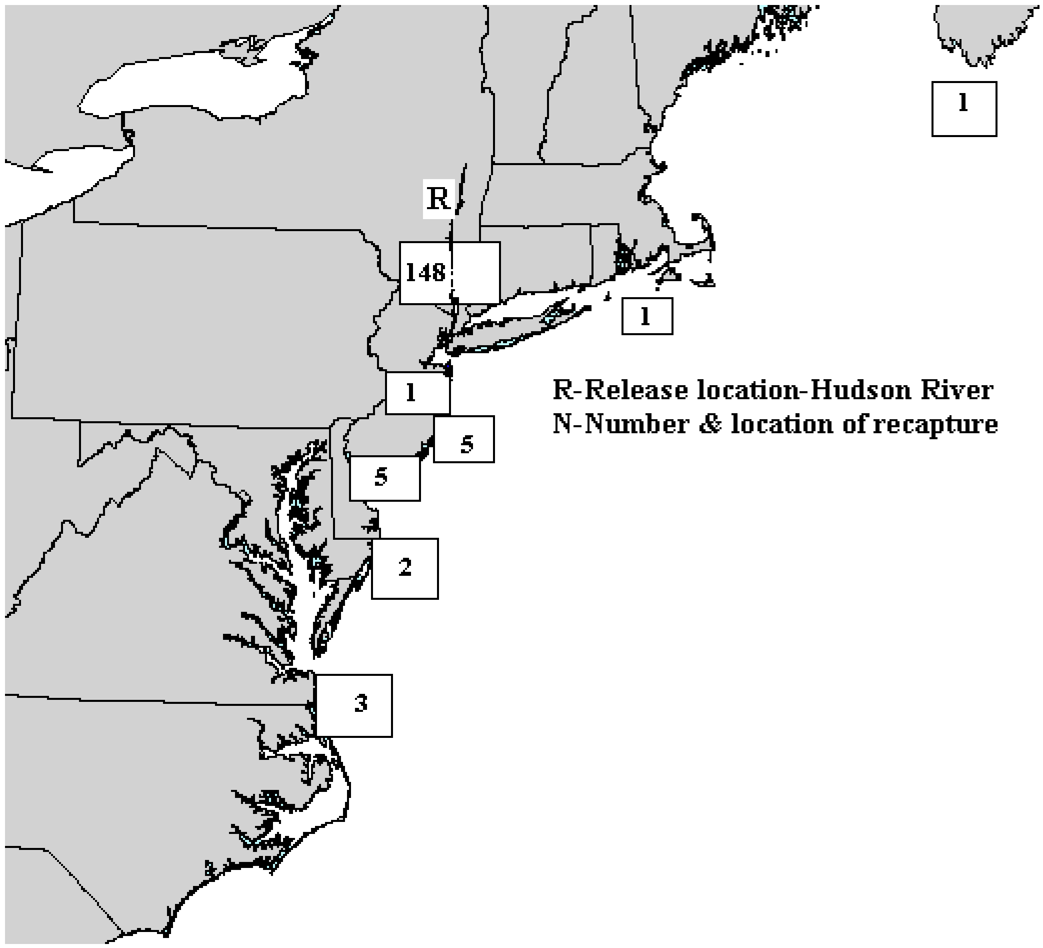


Figure 7.16 Young-of-year indices for American shad collected in the Hudson River Estuary, 1980-2005.

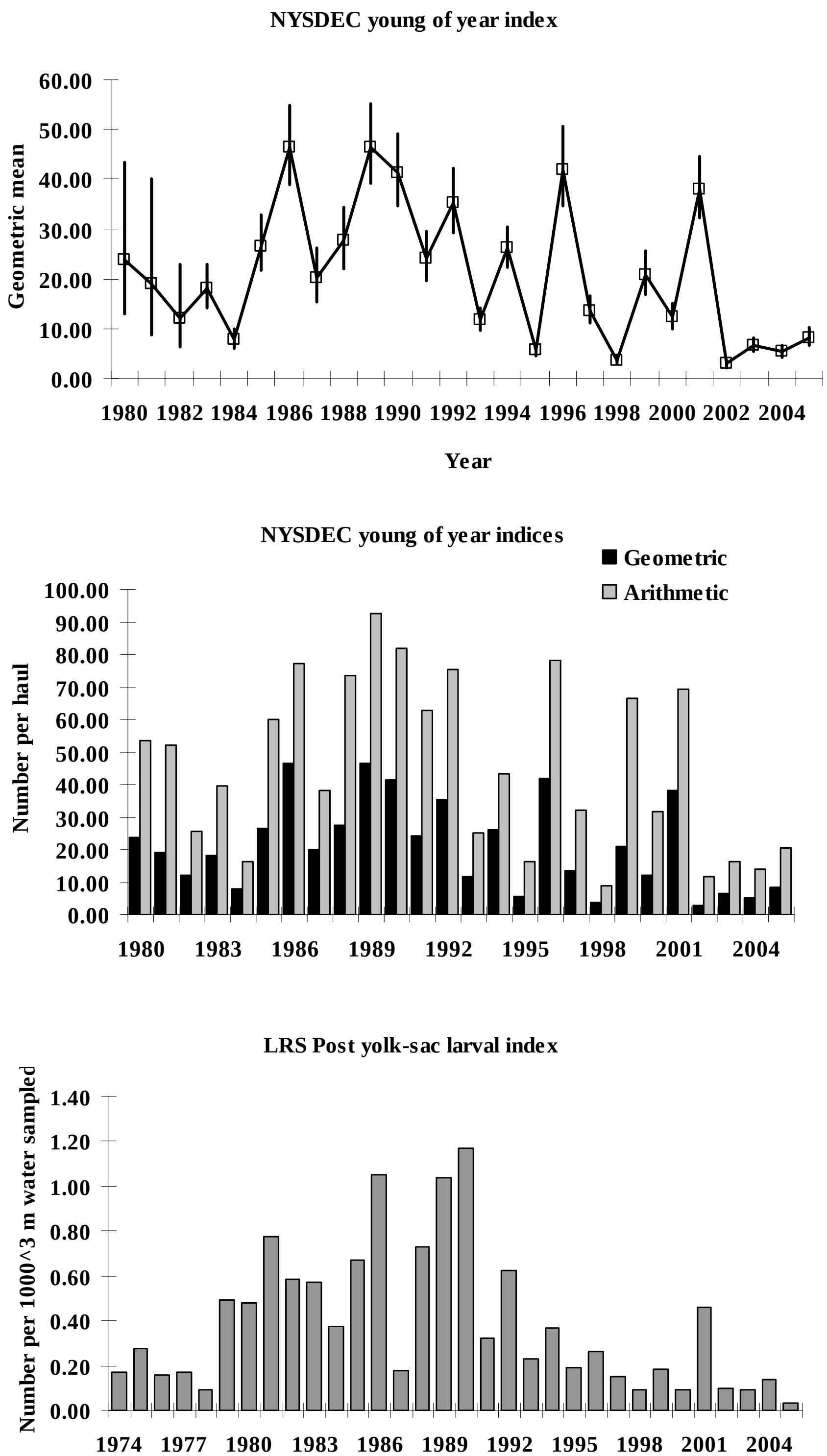


Figure 7.17 Comparison of the post-yolk-sac larval (PYSL) age-0 index with the spawning adult age 5-7 index (females, males and all fish) of the same cohort. Left panel – all year-classes, right panel – year-classes to 1984.

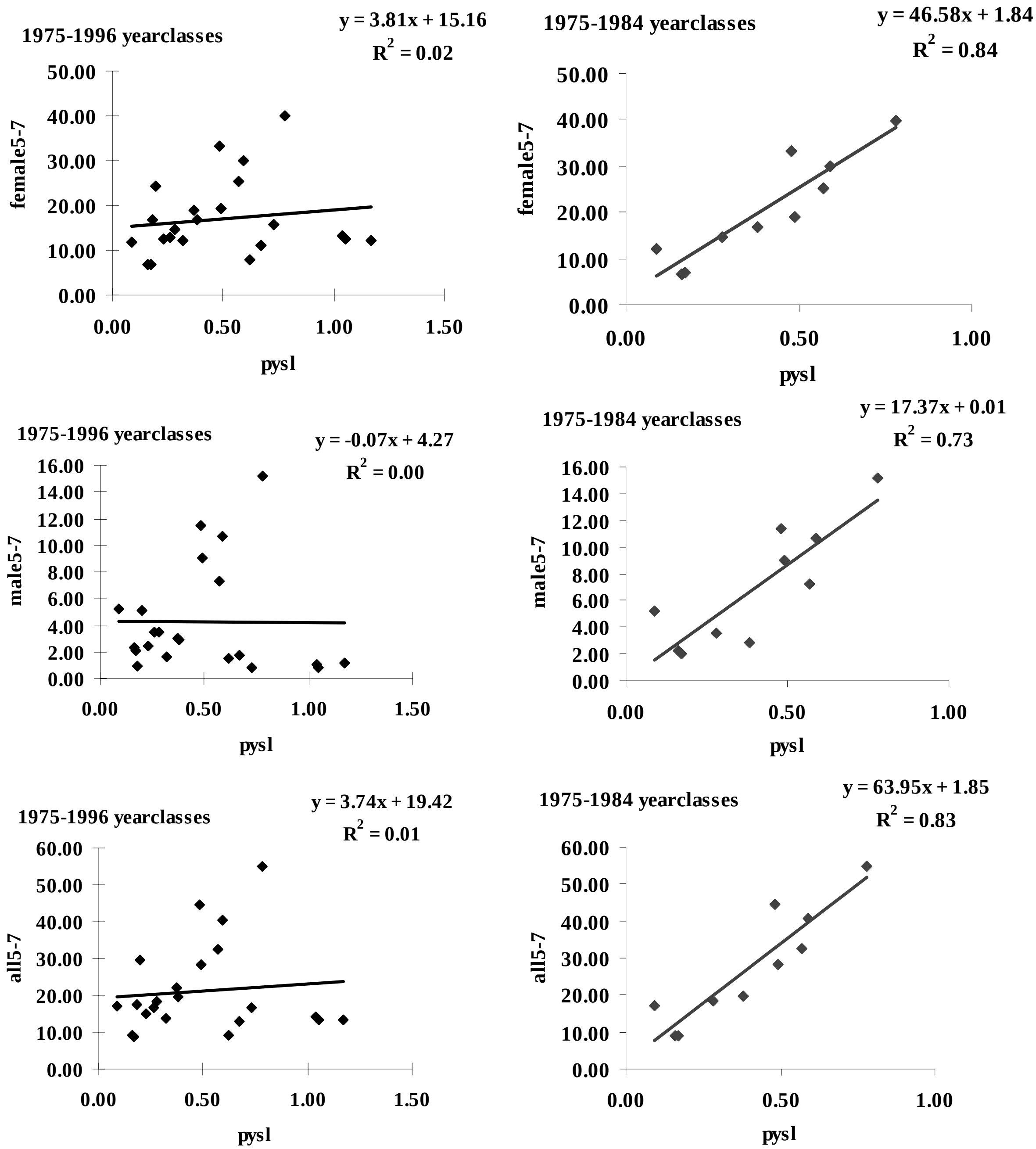
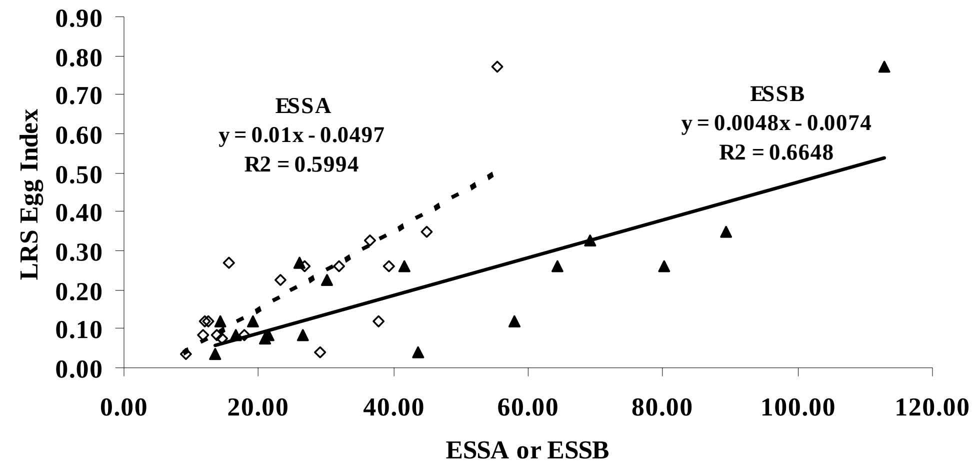
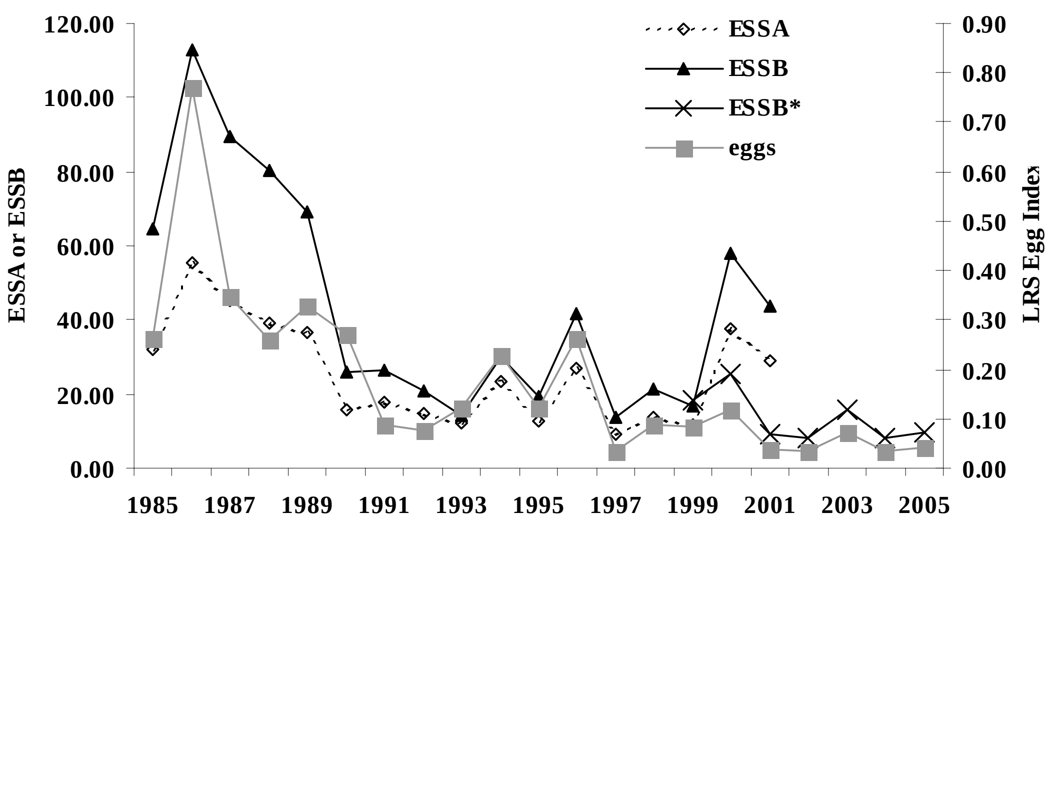


Figure 7.18 Comparison of the Hudson River American shad Empirical spawning stock abundance (ESSA) and biomass (ESSB) indices with LRS egg abundance index (density n/1000^3m): correlation and trend. ESSB* - estimated for 2002-2005. Trend statistics in table below.

Years	Index	R2	Slope	*P*
1986-2001	ESSA	0.24	-1.46	0.05
1986-1999		0.62	-2.75	0.0008
1986-2001	ESSB	0.35	-3.76	0.02
1986-1999		0.64	-6.20	0.0006





APPENDIX I

Summary of fishery regulations for American Shad in New York State

Commercial Harvest

Hudson River Estuary (George Washington Bridge north to Troy Dam, rkm 19-245):

Season: March 15-June15

36-hour escapement period (Friday 0600-Saturday 1800, prevailing time)

Net size restriction: limit of 1200 feet

Mesh size restriction: mesh >5 inch stretch mesh

Net deployment restriction: distance between fishing gear >1500 feet

Area restrictions: drift gear allowed only in certain portions of the river

Area closures: no fishing in a portion of the spawning area (Kingston Flats)

Marine Waters (Hudson River south of George Washington Bridge and waters including New York Harbor and around Long Island)

Shad allowed to be landed as bycatch as long as landings are less than 5% of the total landings of all fish landed for the trip

Delaware River (New York portion, north of Port Jervis)

No commercial fishery exists, but no rules prohibit it

Recreational Harvest

Statewide for inland waters:

Bag limit of 6 fish per day

No season

Table 7B.1 Historic commercial fishery landings (kg) of American shad in the Hudson River Estuary, 1880-2005. 1915-1949: Talbot, G.A. Factors associated with fluctuations in abundance of Hudson River Shad. Fish. Bull. 101(56):373-413. (data from USFWS). 1950-1993: annual report from NMFS. 1994-present: NY landings: NYSDEC State reports & NJ landings from NMFS.

Year	Total	Year	Total	Year	Total
1880	1240142.4	1922	79464	1965	113854
1881		1923	55216	1966	58514
1882		1924	42806	1967	96753
1883		1925	56398	1968	121111
1884		1926	120395	1969	116484
1885		1927	162414	1970	109499
1886		1928	111690	1971	78881
1887	1626609.6	1929	89244	1972	141432
1888	1563105.6	1930	93670	1973	115668
1889	1964995.2	1932	240296	1974	105190
1890	1713247.2	1933	235273	1975	105961
1891	1381212	1934	198677	1976	97479
1892		1935	384381	1977	84097
1893		1936	1119439	1978	190240
1894		1937	1239326	1979	225984
1895		1938	1119031	1980	644475
1896		1939	1483590	1981	305545
1897		1940	1412692	1982	205118
1898		1941	1421356	1983	236144
1899		1942	1445124	1984	307677
1900		1943	1463019	1985	375247
1901	854582	1944	1727944	1986	385183
1902		1945	1577258	1987	309438
1903		1946	1348164	1988	356589
1904	1556755	1947	898941	1989	219225
1905		1948	1067956	1990	203820
1906		1949	783535	1991	156641
1907		1950	457637	1992	129078
1908	225893	1951	346596	1993	62692
1909		1952	618166	1994	90072
1910		1953	437679	1995	112885
1911		1954	622067	1996	83690
1912		1955	735558	1997	67799
1913		1956	818793	1998	105484
1914		1957	750935	1999	66501
1915	31148	1958	570084	2000	69555
1916	18222	1959	476688	2001	45997
1917	19679	1960	393362	2002	59241
1918	106415	1961	284952	2003	49998
1919	170088	1962	250387	2004	33040
1920	90649	1963	187972	2005	32172
1921	59332	1964	110996		

Table 7B2 Historical records of type of commercial gill nets and licenses sold for the New York and New Jersey portions of the Hudson River Estuary.

	Talbot 1954 (a)				Fishery Statistics (b)	NYSDEC-HRFU Summary (c)				NYSDEC Spec. Lic. (d)
							Number of licenses by type			
YEAR	NY-T5 Number of nets *	NY-T3 Number of shad lic.	NJ-T5 Number of nets *	Standard Fishing Units	Number of nets *	Number licensed fishermen	shad/herr	gill	total	Number of nets *
1915	79		7	3840						
1916	76		3	2910						
1917	213		2	6810						
1918	272		1	7554						
1919	359		14	12633						
1920	190		10	7230						
1921	159		8	5973						
1922	133		8	5271						
1923	110		5	4020						
1924	97	97	4	3459						
1925	98	98	4	3486						
1926	99	99	4	3513						
1927	136	136	7	5142						
1928	129	129	7	4953						
1929	122	122	5	4344						
1930	121	121	7	4737						
1931	120	120	4	4080						
1932	123	123	6	4581						
1933	146	146	13	6672						
1934	144	144	14	6828						
1935	140	140	15	6930						
1936	162	162	36	11934						
1937	200	200	36	12960						
1938	261	261	52	17967						
1939	254	254	43	15888						
1940	216	216	46	14718						
1941	231	231	46	15213						
1942	220	220	48	15180	478					
1943	230	230	32	16380	233					
1944	263	263	38	19026	445					
1945	242	242	35	13761	295					
1946	357	357	52	20361	344					
1947	366	366	52	20658	379					
1948	357	357	44	19041	378					
1949	315	315	46	17985						
1950	295	295	40	16335	241					
1951	215	215	25	8160	174					
1952					162					
1953					158					
1954					181					
1955					158					
1956					152					
1957					142					
1958					135					
1959					130					

	Talbot 1954 (a)				Fishery Statistics (b)	NYSDEC-HRFU Summary (c)				NYSDEC Spec. Lic. (d)
YEAR	NY-T5 Number of nets *	NY-T3 Number of shad lic.	NJ-T5 Number of nets *	Standard Fishing Units	Number of nets *	Number licensed fishermen	Number of licenses by type shad/herr	gill	total	Number of nets *
1960										
1961					100					
1962										
1963										
1964					58					
1965					55					
1966										
1967					41					
1968					50					
1969					53					
1970					55					87
1971					42					74
1972					50					64
1973										116
1974										141
1975										120
1976						48	74	34	108	106
1977						54	94	39	133	127
1978						27	43	11	54	107
1979						60	98	62	160	163
1980						86	117	70	187	155
1981						81	109	63	172	
1982						106	143	88	231	
1983						98	142	85	227	
1984						112	175	86	261	
1985						95	150	63	213	
1986						79	112	56	168	
1987						72	101	31	132	
1988						65	94	28	122	
1989						72	91	31	122	
1990						83	96	64	160	
1991						90	79	68	147	
1992						101	74	96	170	
1993						123	55	79	134	
1994						121	49	79	128	
1995						112	47	75	122	
1996						134	54	88	142	
1997						112	45	74	119	
1998						140	65	119	184	
1999						145	77	68	181	
2000						231	110	123	233	
2001						222	138	112	250	
2002						261	141	120	261	
2003						248	144	104	248	
2004						210	156	118	274	
2005						287	161	109	270	

Table 7B2 Continued

	AMOUNT OF LICENSED NET							
	Klauda (e)			DEC Annual State Rpts (f)	NYSDEC HRFU (c)	Escapement (g)		
						NY		NJ
	Licensed Square Yards			Licensed	Licensed	Closed	Fishing	Closed
YEAR	fixed	drift	total	feet	feet	Hours/wk	Hours/wk	Hours/wk
1915						48	120	0
1916						48	120	0
1917						48	120	0
1918						60	108	0
1919						60	108	0
1920						60	108	0
1921						60	108	0
1922						60	108	0
1923						60	108	0
1924						60	108	0
1925						60	108	0
1926						60	108	0
1927						60	108	0
1928						60	108	0
1929						60	108	0
1930						60	108	0
1931	19167	315298	334465			60	108	0
1932	18748	376884	395632	253142		60	108	0
1933	28760	406871	435631	298949		60	108	0
1934	27330	505050	532380	292790		60	108	0
1935	65255	288480	353735	286459		60	108	0
1936	103180	368490	471670	338018		60	108	0
1937	137375	597529	734904	413501		60	108	0
1938	151472	729111	880583	531780		60	108	0
1939	159210	552804	712014	509156		60	108	0
1940	232808	430379	663187	444873		60	108	60
1941	94511	432106	526617	385717		36	132	36
1942	183381	191103	374484	355118		36	132	36
1943	132859	462970	595829			0	168	0
1944	284601	475835	760436			0	168	0
1945	214400	677700	892100	419029		36	132	36
1946	422800	680500	1103300	554924		36	132	36
1947	519360	806000	1325360	617844		36	132	36
1948	322160	800360	1122520	599830		36	132	36
1949	425686	653500	1079186	499280		36	132	36
1950	387828	583080	970908	479135		36	132	36
1951	224915	390400	615315	351280		72	96	72
1952	180217	339910	520127	363580		60	108	60
1953	99600	316225	415825	314110		60	108	60
1954	104267	379889	484156			60	108	60
1955	150008	252777	402785			60	108	60
1956	168826	210151	378977			60	108	60
1957	158495	199913	358408			60	108	60
1958	140793	182768	323561	274865		60	108	60
1959	132225	146022	278247	277720		48	120	48

	AMOUNT OF LICENSED NET							
	Klauda (e)			DEC Annual State Rpts (f)	NYSDEC HRFU (c)	Escapement (g)		
						NY		NJ
	Licensed Square Yards			Licensed	Licensed	Closed	Fishing	Closed
YEAR	fixed	drift	total	feet	feet	Hours/wk	Hours/wk	Hours/wk
1960	125463	145109	270572	231745		48	120	48
1961	122661	125873	248534	219886		48	120	48
1962	127281	113059	240340	189990		48	120	48
1963	85677	105338	191015	158720		48	120	48
1964	74555	103484	178039	131450		48	120	48
1965	62203	94822	157025			48	120	48
1966	55791	74480	130271			48	120	48
1967	52893	73748	126641			48	120	48
1968	61555	87720	149275			48	120	48
1969	61209	71390	132599			48	120	48
1970	62474	83965	146439			48	120	48
1971	41911	76315	118226			48	120	48
1972	46994	76316	123310			48	120	48
1973	41703	92024	133727			48	120	48
1974	115913	66348	182261			48	120	48
1975	132574	132696	265270			48	120	48
1976					121700	48	120	
1977					138300	48	120	
1978					65350	48	120	
1979					160933	36	132	
1980					238479	36	132	
1981					219840	36	132	
1982					270740	36	132	
1983					272990	36	132	
1984					389960	36	132	
1985					316800	36	132	
1986					214120	36	132	
1987					179000	36	132	
1988					189400	36	132	
1989					180280	36	132	
1990					232200	36	132	
1991					166290	36	132	
1992					166988	36	132	
1993					149150	36	132	
1994					161900	36	132	
1995					146695	36	132	
1996					111000	36	132	
1997					100047	36	132	
1998					141369	36	132	
1999					185405	36	132	
2000					233637	36	132	
2001					276000	36	132	
2002					301942	36	132	
2003					307196	36	132	
2004					329194	36	132	
2005					340028	36	132	

Table 7B2 Continued

NEW YORK GILL NET LICENSES
Two types of gill net licenses are available in New York State:
1) shad gill net license - valid for the spring shad season (Mar 15-Jun 15)
2) gill net licenses - valid for most of the year.

* Please note that "Number of nets" with "*" above and reference below are NOT KNOWN by net type i.e shad gill net license vs. gill net license or a total of both.

REFERENCES

(a) TALBOT, G.B. 1954. Factors associated with fluctuations in abundance of Hudson River shad. Fishery Bulletin 101. U.S. Dept of Interior. Standard Fishing Units = no. nets * allowed fishing hours * adjustment factor (NJ)

(b) FISHERY STATISTICS OF THE UNITED STATES
1956-1967: U.S. Dept. of Interior, U.S. Fish & Wildlife Service
1968-1972: U.S. Dept. of Commerce, National Marine Fisheries Service

(c) NYSDEC-HRFU SUMMARY: Hudson River Fisheries Unit summary of available Special Licenses Unit (SLU) receipts of number and type of licenses sold. HRFU copies of yearly records mostly complete, but cannot be verified as all records held by SLU were destroyed. Amount of net is summary of what appeared on licenses in HRFU files.

(d) NYSDEC-SPECIAL LICENSES: Summary of number of licenses sold by SLU, previous to file purging, cannot be verified.

(e) KLAUDA, R.J., M. NITTEL, K.P. CAMPBELL. 1976. Commercial fishery for American shad in the Hudson River: fish abundance and stock trends. Proceedings of a workshop on American shad. USFWS/NMFS. Amherst MA. Cited source as NYSDEC: NO records of this type exist, Sq. yards may have been be estimated from linear feet.

(f) DEC ANNUAL STATE REPORTS: Annual Conservation Dept. Reports to the Senate and Assembly. Bureau of Fisheries Library. Albany NY. Annual reports are from 1885 to 1964. References are incomplete. Discontinued printing reports in 1964.

(g) 1915-1951: Talbot 1954, 1951-1975: Klauda 1976, 1976-present: NYSDEC

Table 7B3 Mean total length and weight at age for American shad collected in fishery dependent (commercial gill net) and fishery independent surveys in the Hudson River Estuary.

Mean TL_FD	1980			1981			1982			1983			1984			1985			1986		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes combined																					
3							1	403.0		1	462.0										
4	15	491.8	34.6	19	481.5	29.7	23	499.1	34.3	18	497.8	27.6	6	508.2	26.4	24	513.2	15.6	15	516.5	29.0
5	126	523.8	18.8	127	529.4	20.6	128	537.5	21.9	142	531.1	25.8	85	532.6	27.6	113	531.7	27.9	117	545.0	30.2
6	130	548.5	23.8	205	552.5	21.8	137	554.0	26.5	120	559.2	22.0	121	562.3	27.8	136	561.7	31.4	117	564.8	27.9
7	64	558.4	24.5	144	559.6	27.4	114	578.5	26.5	47	578.6	25.1	57	584.4	30.5	88	581.3	33.2	67	591.4	32.0
8	21	572.8	26.1	79	583.7	27.8	69	584.6	29.4	47	592.6	28.4	34	596.3	29.9	36	594.5	32.0	37	614.5	31.5
9	3	613.3	14.3	13	610.1	19.9	35	591.7	33.9	23	602.9	31.9	29	618.6	35.8	24	603.3	33.5	20	631.2	31.6
10				4	621.0	47.6	11	613.8	37.7	21	616.8	40.9	13	632.9	42.0	13	619.5	31.6	7	639.7	30.8
11							1	604.0		3	625.0	40.9	3	610.7	33.5	6	658.0	38.4	3	636.3	26.8
12													2	653.5	14.9	2	631.5	12.0	2	671.0	19.8
13																					
Males																					
3							1	403.0													
4	9	472.3	24.5	12	467.1	21.0	11	479.6	28.4	9	479.1	17.5	1	480.0		5	503.0	6.5	7	500.4	33.0
5	26	497.3	12.3	23	506.4	11.1	24	513.7	16.6	37	504.6	19.5	28	502.4	15.7	20	499.1	24.0	28	516.1	24.8
6	29	518.8	17.8	45	524.4	16.5	29	524.5	19.2	23	534.2	15.2	24	523.0	24.5	27	530.5	21.9	25	535.5	23.1
7	28	538.6	11.4	57	535.6	14.4	33	547.3	19.2	16	553.4	13.2	11	551.8	12.6	21	548.1	23.1	18	558.4	24.0
8	10	551.4	11.3	23	550.0	12.8	20	555.4	19.3	19	564.5	17.2	15	574.5	28.7	10	570.1	19.8	10	579.2	18.8
9				1	575.0		17	563.7	19.3	9	570.7	14.7	6	575.8	18.2	4	577.3	12.0	4	590.0	22.1
10							3	577.0	2.0	5	569.0	15.9	3	576.7	12.1	2	589.0	5.7	1	594.0	
11										2	620.0	56.6	1	596.0					2	622.0	14.1
Females																					
3										1	462.0										
4	6	521.0	26.1	7	506.1	26.8	11	523.3	21.4	9	516.4	22.8	5	513.8	25.2	18	515.6	16.7	8	530.6	16.3
5	100	530.7	13.3	104	534.4	18.7	101	543.3	19.3	104	540.4	20.9	56	547.3	18.7	91	539.1	23.5	87	555.4	24.6
6	101	557.0	17.7	160	560.4	15.8	105	562.5	22.3	97	565.1	19.1	97	572.0	18.4	107	569.6	28.6	91	573.4	22.8
7	36	573.8	20.6	87	575.3	21.9	79	591.4	16.9	31	591.6	19.2	46	592.2	28.3	67	591.7	28.7	49	603.5	25.5
8	11	592.2	19.3	56	597.6	18.9	48	597.3	23.6	28	611.6	15.6	19	613.5	17.0	26	603.9	31.1	27	627.5	24.4
9	3	613.3	14.3	12	613.0	17.6	17	616.3	20.0	14	623.6	20.3	23	629.8	30.5	20	608.5	34.1	16	641.4	24.6
10				4	621.0	47.6	8	627.6	35.0	16	631.7	34.1	9	648.1	32.2	11	625.1	31.2	6	647.3	25.5
11							1	604.0	.	1	635.0		2	618.0	43.8	6	658.0	38.4	1	665.0	
12													2	653.5	14.9	2	631.5	12.0	2	671.0	19.8
13																					

Table 7B3 Continued

Mean TL_FD	1987			1988			1989			1990			1991			1992			1993		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes combined																					
3				2	416.0	73.5	1	458.0					2	473.5	44.6	2	438.5	9.2			
4	2	538.0	41.0	10	528.9	25.5	3	560.7	9.9	4	516.8	20.7	19	519.8	34.0	31	475.6	37.8	8	499.0	38.0
5	67	549.7	18.4	71	538.3	26.0	90	548.9	26.2	50	535.2	29.7	60	540.8	22.5	176	525.3	26.6	19	520.0	20.4
6	120	566.2	25.2	118	558.3	28.4	177	557.8	29.7	69	570.0	22.3	67	561.7	25.8	150	542.5	25.1	36	543.9	30.8
7	85	586.4	22.3	85	580.8	31.7	125	576.6	30.4	54	595.4	28.1	54	586.9	30.3	81	552.3	29.4	22	563.3	26.2
8	58	609.0	30.1	44	602.9	35.0	74	588.7	29.4	33	610.6	23.6	18	603.2	27.2	22	583.4	26.0	8	578.6	41.5
9	37	621.8	32.9	20	613.5	45.1	18	600.6	31.4	10	626.4	24.4	8	632.0	26.8	7	596.6	31.5	1	645.0	
10	32	644.2	26.3	7	632.4	37.9	5	630.6	42.2	4	625.5	10.9	1	664.0		2	666.0	5.7			
11	15	646.3	33.0							1	684.0		1	674.0							
12	3	661.3	24.3							1	662.0										
13	2	663.0	15.6																		
Males																					
3				1	468.0								2	473.5	44.6	2	438.5	9.2			
4				3	504.3	26.8	1	554.0		1	505.0		2	464.5	44.6	20	461.4	30.5			
5	4	524.8	24.7	19	519.6	19.8	21	527.2	30.6	8	514.3	33.1	1	555.0		28	497.6	25.9	3	513.0	28.6
6	16	546.3	18.8	44	532.4	19.2	64	535.8	22.1	8	556.5	31.5	5	546.8	15.7	38	521.6	23.4	13	517.0	23.6
7	11	552.8	17.2	25	548.8	19.0	43	551.4	21.0	6	562.8	18.6	9	547.8	18.4	30	534.1	23.1	11	543.5	19.9
8	12	566.0	18.7	12	564.4	22.9	38	569.6	18.1	5	577.8	25.2	6	585.8	24.4	9	564.3	8.9	2	525.0	9.9
9	10	581.4	19.1	7	561.0	14.2	11	582.0	23.6	1	571.0					1	584.0				
10	2	601.0	25.5	3	595.0	13.8	2	595.5	2.1												
11	3	605.7	5.5																		
Females																					
3				1	364.0																
4	2	538.0	41.0	7	539.4	17.6	2	564.0	11.3	3	520.7	23.5	17	526.3	27.3	11	501.5	37.0	5	518.4	22.1
5	63	551.3	17.0	52	545.1	24.7	69	555.5	20.8	42	539.2	27.7	59	540.5	22.7	147	530.4	23.4	16	521.3	19.5
6	104	569.3	24.7	74	573.8	20.6	113	570.2	26.1	61	571.8	20.6	62	562.9	26.1	112	549.7	21.5	23	559.0	23.2
7	74	591.4	18.3	60	594.2	25.8	82	589.8	26.0	48	599.5	26.5	45	594.8	25.9	50	563.7	27.4	11	583.2	13.5
8	46	620.2	21.0	32	617.3	26.9	36	608.9	25.3	28	616.5	18.2	12	611.8	25.1	13	596.6	25.8	6	596.5	29.3
9	27	636.8	22.6	13	641.7	25.5	7	629.9	15.4	9	632.6	15.7	8	632.0	26.8	6	598.7	34.0	1	645.0	
10	30	647.1	24.0	4	660.5	17.0	3	654.0	38.7	4	625.5	10.9	1	664.0		2	666.0	5.7			
11	12	656.5	28.6							1	684.0		1	674.0							
12	3	661.3	24.3							1	662.0										
13	2	663.0	15.6																		

Table 7B3 Continued

Mean TL_FD	1994			1995			Mean weight (g)>>	1980			1981			1982			1983		
AGE	N	MEAN	STD	N	MEAN	STD		N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes combined																			
3														1	640.0		1	1300.0	
4				7	512.0	30.6		15	1424.0	377.6	19	1276.3	412.2	23	1512.2	313.0	18	1497.8	335.3
5	30	527.1	16.1	78	527.1	25.7		126	1782.5	274.4	127	1725.4	311.4	125	1915.7	267.1	142	1821.3	303.4
6	52	534.3	22.5	98	528.9	19.7		130	2033.5	353.1	205	1938.7	358.4	135	2092.6	363.6	119	2134.9	314.6
7	29	547.1	21.7	51	542.1	24.3		64	2098.6	353.3	144	1939.1	418.5	113	2345.5	430.2	47	2410.6	479.8
8	5	591.8	22.9	13	534.9	27.9		21	2257.6	497.4	79	2217.2	521.3	69	2449.5	495.0	47	2628.1	547.4
9	3	584.7	32.8	3	587.0	30.8		3	2910.0	441.9	13	2545.4	521.2	34	2474.8	592.9	23	2645.2	639.2
10				1	630.0						4	2580.0	852.0	11	2838.2	594.1	21	2830.5	653.0
11														1	2900.0	.	3	2803.3	492.2
12																			
13																			
Males																			
3														1	640.0				
4								9	1176.7	175.1	12	1048.3	212.3	11	1338.2	277.3	9	1237.8	152.8
5	2	505.0	7.1	22	502.9	25.5		26	1400.4	134.4	23	1283.9	178.4	23	1588.6	175.7	37	1502.2	160.9
6	6	507.3	23.4	44	515.1	14.4		29	1574.5	209.5	45	1472.7	154.5	28	1695.4	221.3	23	1702.6	164.8
7	5	522.4	8.7	26	526.5	18.4		28	1795.7	123.8	57	1585.4	169.7	32	1858.0	172.9	16	1910.0	178.6
8				9	525.2	26.2		10	1845.0	209.5	23	1703.5	153.0	20	1976.0	154.2	19	2105.8	244.4
9	1	547.0		1	553.0						1	1610.0		17	2034.1	192.5	9	1966.7	250.9
10														3	2240.0	197.0	5	2012.0	257.2
11																	2	2755.0	685.9
Females																			
3																	1	1300.0	
4				3	532.0	6.2		6	1795.0	273.6	7	1667.1	380.6	11	1720.0	209.7	9	1757.8	251.9
5	28	528.7	15.4	53	536.6	17.6		100	1881.9	205.4	104	1823.0	242.2	99	1989.7	226.0	104	1933.6	259.8
6	46	537.9	20.1	54	540.2	16.0		101	2165.4	264.4	160	2069.8	281.9	104	2199.9	322.8	96	2238.4	246.1
7	24	552.3	19.9	23	559.8	17.9		36	2334.2	287.1	87	2170.8	367.8	79	2544.1	339.6	31	2669.0	366.5
8	5	591.8	22.9	4	556.5	19.5		11	2632.7	361.0	56	2428.2	469.3	48	2655.1	450.5	28	2982.5	385.2
9	2	603.5	5.0	2	604.0	12.7		3	2910.0	441.9	12	2623.3	458.4	16	2883.9	525.1	14	3081.4	359.3
10				1	630.0						4	2580.0	852.0	8	3062.5	531.3	16	3086.3	507.8
11														1	2900.0		1	2900.0	
12																			
13																			

Table 7B3 Continued

Mean Wt_FD	1984			1985			1986			1987			1988			1989			1990		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes combined																					
3													2	860.0	537.4	1	1130.0				
4	7	1742.9	294.7	24	1735.2	199.5	15	1794.0	444.8	2	1880.0	169.7	10	1915.0	341.9	2	2150.0	42.4	4	1635.0	198.2
5	86	1929.0	339.0	111	1951.4	407.0	114	2043.6	391.1	66	2024.2	226.9	71	1928.6	322.6	77	2123.4	428.9	50	1855.0	336.3
6	122	2262.4	389.0	133	2283.2	431.1	117	2269.2	420.0	120	2277.5	330.5	117	2197.4	391.6	160	2150.6	351.9	69	2318.3	381.5
7	59	2496.1	505.9	89	2582.0	534.7	67	2635.5	536.0	85	2538.1	342.9	85	2524.0	546.7	118	2457.1	459.1	54	2680.0	394.8
8	36	2672.2	503.8	36	2748.5	555.5	37	2985.1	550.1	58	2757.6	485.9	44	2871.1	544.5	67	2631.0	493.2	33	2851.5	400.4
9	29	2987.0	519.2	24	3009.6	816.1	20	3245.5	543.5	37	2900.3	566.9	20	2994.0	750.7	18	2829.4	605.5	10	2901.0	590.7
10	13	3270.0	764.0	13	3132.3	641.9	7	3467.1	574.0	32	3303.4	499.8	7	3137.1	566.9	5	3234.0	787.9	4	3030.0	147.2
11	3	2913.3	630.0	6	3789.2	947.5	3	3333.3	442.4	15	3252.0	590.8							1	3800.0	
12	2	3410.0	212.1	2	3350.0	42.4	2	2985.0	431.3	3	3593.3	411.0							1	3380.0	
13										2	3830.0	14.1									
Males																					
3													1	1240.0							
4	1	1360.0		5	1496.0	170.4	7	1652.9	609.4				3	1543.3	153.7	1	2180.0	.	1	1420.0	
5	28	1562.6	158.9	19	1455.3	157.1	27	1638.6	270.1	4	1782.5	399.0	19	1659.5	234.7	17	1936.5	786.0	8	1446.3	174.3
6	24	1706.3	190.9	26	1816.4	257.0	25	1840.8	280.5	16	1938.1	284.9	44	1857.5	211.7	58	1855.5	224.2	8	1990.0	406.4
7	11	1886.4	329.9	21	1957.1	238.1	18	2112.5	241.1	11	1943.6	186.5	25	1957.6	462.9	41	2054.9	208.9	6	2208.3	295.5
8	16	2318.1	514.5	10	2205.0	268.4	10	2309.8	272.6	12	2135.0	153.8	12	2246.7	395.6	35	2257.6	216.3	5	2302.0	522.1
9	6	2303.3	283.0	4	2305.0	110.0	4	2495.0	245.7	10	2234.0	306.5	7	2112.9	195.2	11	2412.7	309.3	1	1900.0	
10	3	2240.0	140.0	2	2310.0	212.1	1	2730.0		2	2560.0	56.6	3	2573.3	172.4	2	2550.0	127.3			
11	1	2520.0					2	3100.0	254.6	3	2566.7	185.8									
Females																					
3													1	480.0							
4	6	1806.7	264.6	18	1791.9	158.0	8	1917.5	199.9	2	1880.0	169.7	7	2074.3	262.2	1	2120.0		3	1706.7	167.7
5	57	2107.4	250.3	90	2057.1	368.2	85	2184.1	322.5	62	2039.8	207.3	52	2026.9	294.2	60	2176.3	237.6	42	1932.9	301.9
6	97	2407.4	279.2	106	2396.7	388.4	91	2393.5	368.2	104	2329.7	306.1	73	2402.3	327.3	102	2318.3	296.9	61	2361.3	359.8
7	48	2635.8	431.0	68	2774.9	445.4	49	2827.6	484.0	74	2626.5	263.4	60	2760.0	381.7	77	2671.2	409.5	48	2739.0	366.8
8	20	2955.5	261.7	26	2957.5	492.4	27	3235.2	391.0	46	2920.0	403.6	32	3105.3	384.9	32	3039.5	370.0	28	2949.6	289.4
9	23	3165.3	405.2	20	3150.5	824.0	16	3433.1	417.5	27	3147.0	422.4	13	3468.5	420.2	7	3484.3	246.3	9	3012.2	503.4
10	9	3556.7	589.8	11	3281.8	574.5	6	3590.0	518.3	30	3353.0	475.6	4	3560.0	258.2	3	3690.0	673.6	4	3030.0	147.2
11	2	3110.0	749.5	6	3789.2	947.5	1	3800.0		12	3423.3	527.1							1	3800.0	
12	2	3410.0	212.1	2	3350.0	42.4	2	2985.0	431.3	3	3593.3	411.0							1	3380.0	
13										2	3830.0	14.1									

Table 7B3 Continued

Mean Wt_FD	1991			1992			1993			1994			1995		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes combined															
3	2	1200.0	396.0	2	860.0	28.3									
4	19	1796.8	419.6	31	1189.7	405.8	8	1420.0	354.9				7	1694.3	363.8
5	59	1969.3	266.1	169	1711.8	326.5	19	1608.4	241.6	24	1641.7	169.5	56	1791.4	234.9
6	65	2134.8	340.1	149	1859.7	305.2	36	1857.8	359.2	45	1725.1	246.9	70	1850.3	238.8
7	54	2423.9	468.1	81	1966.2	361.4	22	2068.2	340.7	26	1843.5	273.3	31	1917.7	292.6
8	17	2529.4	452.5	21	2373.3	452.6	8	2180.0	629.2	5	2260.0	365.0	8	1823.8	257.9
9	8	3037.5	215.0	7	2640.0	498.0	1	2580.0		3	2373.3	514.7	2	2465.0	657.6
10	1	3480.0	.	2	4070.0	240.4							1	3340.0	
11	1	3784.0	.												
12															
13															
Males															
3	2	1200.0	396.0	2	860.0	28.3									
4	2	1080.0	339.4	20	998.0	263.4	3	1120.0	307.9				4	1515.0	403.8
5	1	1960.0		24	1276.3	348.7	3	1440.0	235.8	1	1480.0		15	1546.7	141.2
6	5	1710.0	152.6	36	1525.0	224.4	13	1573.9	267.9	3	1560.0	346.4	32	1671.3	131.5
7	9	1825.6	159.2	30	1687.7	232.2	11	1803.6	216.5	3	1546.7	110.2	17	1748.2	161.9
8	5	2242.0	422.2	9	1988.9	165.0	2	1530.0	240.4				5	1730.0	218.9
9				1	2160.0					1	1780.0		1	2000.0	
10															
11															
Females															
3															
4	17	1881.2	345.1	11	1538.2	393.8	5	1600.0	255.0				3	1933.3	50.3
5	58	1969.5	268.4	144	1784.0	261.8	16	1640.0	236.4	23	1648.7	169.7	41	1881.0	195.4
6	60	2170.2	327.6	113	1966.4	244.7	23	2018.3	302.5	42	1736.9	239.6	38	2001.1	202.0
7	45	2543.6	414.1	50	2136.6	321.9	11	2332.7	207.1	23	1882.2	264.9	13	2151.5	278.3
8	12	2649.2	424.1	12	2661.7	375.6	6	2396.7	563.3	5	2260.0	365.0	3	1980.0	280.0
9	8	3037.5	215.0	6	2720.0	493.8	1	2580.0		2	2670.0	42.4	1	2930.0	
10	1	3480.0		2	4070.0	240.4							1	3340.0	
11	1	3784.0													
12															
13															

Table 7B3 Continued (Fishery Independent data)

Mean TL_FI	1983			1984			1985			1986			1987			1988			1989		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																					
2																					
3				3	424.7	22.2	14	420.3	23.4	9	423.8	30.6	5	409.4	31.6	2	450.0	82.0	2	416.5	44.6
4	2	459.5	6.4	19	453.1	28.2	63	464.7	32.9	94	474.9	40.9	65	465.7	28.8	58	480.6	39.1	42	455.0	39.7
5	5	500.6	21.8	30	513.7	25.9	69	501.4	35.9	128	511.9	33.4	121	513.7	32.1	187	519.4	33.8	102	516.2	35.0
6	5	529.2	8.9	37	544.8	24.0	51	548.1	33.4	104	541.2	35.7	77	549.4	25.5	146	558.0	28.6	85	538.1	28.1
7	4	533.3	15.9	23	583.4	29.4	29	569.9	33.9	41	583.2	39.0	42	568.7	28.4	82	578.6	31.6	66	564.9	35.7
8	2	559.5	13.4	15	590.8	39.5	19	590.0	32.7	23	598.7	33.3	26	603.9	23.9	21	597.5	48.9	34	580.7	35.7
9	2	573.5	2.1	6	611.0	43.5	7	621.6	32.6	13	620.1	29.6	20	631.8	32.4	15	613.3	19.4	10	597.2	16.7
10				4	601.0	34.5	5	620.8	34.2	2	665.0	9.9	8	633.8	39.6	8	634.1	35.7	7	657.3	37.5
11				1	647.0	.	3	650.3	32.4	5	645.8	20.8	3	620.7	43.0	5	662.8	20.5	3	634.3	16.0
12													2	692.5	10.6	2	675.5	41.7			
13													1	685.0							
Males																					
2																					
3				3	424.7	22.2	13	419.8	24.3	9	423.8	30.6	5	409.4	31.6	2	450.0	82.0	2	416.5	44.6
4	2	459.5	6.4	17	458.1	20.8	53	455.8	26.9	77	464.1	35.3	52	458.3	22.1	42	466.1	32.0	32	440.4	27.6
5	5	500.6	21.8	23	507.0	22.3	53	488.2	25.9	72	491.7	25.4	59	487.3	19.9	97	495.7	19.5	43	487.4	28.7
6	5	529.2	8.9	22	533.5	17.6	24	528.3	27.3	39	511.9	30.8	31	525.4	17.9	42	529.3	25.1	35	515.7	21.3
7	4	533.3	15.9	9	561.8	27.5	12	541.2	12.8	15	555.0	22.0	17	543.1	18.6	26	544.0	19.5	22	536.9	22.8
8	2	559.5	13.4	7	555.0	20.4	8	571.8	29.4	6	570.3	15.2	6	569.5	15.0	7	549.9	49.1	17	555.8	29.8
9	2	573.5	2.1	1	548.0		2	578.0	24.0	3	596.0	8.9	6	589.2	8.7	4	593.0	7.0	5	588.6	13.1
10				1	559.0		1	590.0					2	595.0	63.6	2	591.0	1.4	1	593.0	
11										1	614.0		2	596.0	7.1						
Females																					
3				3	424.7	22.2	14	420.3	23.4	9	423.8	30.6	5	409.4	31.6	2	450.0	82.0	2	416.5	44.6
4				19	453.1	28.2	63	464.7	32.9	94	474.9	40.9	65	465.7	28.8	58	480.6	39.1	42	455.0	39.7
5				30	513.7	25.9	69	501.4	35.9	128	511.9	33.4	121	513.7	32.1	187	519.4	33.8	102	516.2	35.0
6				37	544.8	24.0	51	548.1	33.4	104	541.2	35.7	77	549.4	25.5	146	558.0	28.6	85	538.1	28.1
7				23	583.4	29.4	29	569.9	33.9	41	583.2	39.0	42	568.7	28.4	82	578.6	31.6	66	564.9	35.7
8				15	590.8	39.5	19	590.0	32.7	23	598.7	33.3	26	603.9	23.9	21	597.5	48.9	34	580.7	35.7
9				6	611.0	43.5	7	621.6	32.6	13	620.1	29.6	20	631.8	32.4	15	613.3	19.4	10	597.2	16.7
10				4	601.0	34.5	5	620.8	34.2	2	665.0	9.9	8	633.8	39.6	8	634.1	35.7	7	657.3	37.5
11				1	647.0	.	3	650.3	32.4	5	645.8	20.8	3	620.7	43.0	5	662.8	20.5	3	634.3	16.0
12													2	692.5	10.6	2	675.5	41.7			
13													1	685.0							

Table 7B3 Continued (Fishery Independent data)

Mean TL_FI	1990			1991			1992			1993			1994			1995			1996		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																					
2																					
3				14	426.9	31.4	13	419.5	22.0	5	419.6	12.9	2	435.5	13.4	25	426.2	38.5	24	424.9	16.6
4	9	451.7	49.6	57	452.8	32.9	188	446.2	26.1	90	443.1	24.6	32	447.6	20.4	149	474.0	35.1	194	451.2	29.9
5	32	491.9	45.1	66	499.1	30.4	383	482.1	31.8	206	470.0	25.8	85	491.7	30.2	255	512.4	29.2	115	500.5	34.5
6	18	528.8	38.4	51	521.9	35.3	215	522.2	29.5	100	495.8	30.8	27	508.2	28.3	135	530.8	30.3	36	548.0	30.0
7	19	570.0	38.9	18	553.4	37.3	63	552.9	27.4	34	530.7	31.1	11	518.7	18.6	39	548.8	24.9	11	567.1	26.4
8	7	579.0	41.3	4	592.3	15.1	5	575.6	32.1	9	553.0	26.8	2	555.5	36.1				5	607.6	40.5
9	1	627.0		1	651.0		8	603.5	26.7										2	635.0	21.2
10	1	635.0		1	612.0		2	653.5	19.1										1	526.0	
11																					
12																					
13																					
Males																					
2																					
3				12	417.5	22.0	13	419.5	22.0	5	419.6	12.9	2	435.5	13.4	23	418.5	28.8	23	424.5	16.9
4	7	434.0	39.8	46	443.8	26.6	168	441.5	21.4	83	439.6	21.4	32	447.6	20.4	92	455.7	26.6	162	443.9	24.4
5	16	462.8	25.6	33	479.2	25.1	224	463.1	21.9	152	460.0	18.6	36	466.1	22.2	77	484.2	25.8	64	484.3	29.0
6	7	512.0	52.1	16	485.1	27.2	66	494.4	24.5	47	476.3	20.6	7	481.4	18.5	31	496.2	27.5	15	525.4	24.5
7	7	533.3	35.8	4	514.8	43.3	7	525.7	28.3	16	508.8	25.3	3	505.0	27.2	8	520.4	12.4	4	542.5	21.0
8	1	547.0		1	574.0		1	560.0		2	518.0	14.1							1	564.0	
9							2	571.0	17.0												
10																					
11																					
Females																					
3				14	426.9	31.4	13	419.5	22.0	5	419.6	12.9	2	435.5	13.4	25	426.2	38.5			
4	9	451.7	49.6	57	452.8	32.9	188	446.2	26.1	90	443.1	24.6	32	447.6	20.4	149	474.0	35.1	30	491.4	25.4
5	32	491.9	45.1	66	499.1	30.4	383	482.1	31.8	206	470.0	25.8	85	491.7	30.2	255	512.4	29.2	50	521.0	30.2
6	18	528.8	38.4	51	521.9	35.3	215	522.2	29.5	100	495.8	30.8	27	508.2	28.3	135	530.8	30.3	20	564.9	22.7
7	19	570.0	38.9	18	553.4	37.3	63	552.9	27.4	34	530.7	31.1	11	518.7	18.6	39	548.8	24.9	7	581.1	17.6
8	7	579.0	41.3	4	592.3	15.1	5	575.6	32.1	9	553.0	26.8	2	555.5	36.1				4	618.5	37.4
9	1	627.0		1	651.0		8	603.5	26.7										2	635.0	21.2
10	1	635.0		1	612.0		2	653.5	19.1										1	526.0	
11																					
12																					
13																					

Table 7B3 Continued (Fishery Independent data)

Mean TL_FI	1997			1998			1999			2000			2001			2004		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																		
2																1	420	
3	4	416.5	10.2	7	419.6	21.6	3	430.3	6.4	22	431.7	14.9	48	443.4	38.9	8	430.8	24.6
4	38	448.9	42.4	108	459.9	38.6	100	467.5	34.3	128	479.6	35.2	287	471.3	31.3	60	470.0	39.5
5	63	484.6	28.5	114	499.1	37.5	191	492.6	29.6	181	518.0	29.1	323	511.1	36.1	188	506.0	28.1
6	23	513.1	35.1	36	533.4	37.0	49	533.3	33.1	40	540.9	32.8	193	541.9	31.0	178	540.0	32.7
7	7	549.4	47.0	12	559.4	51.3	15	572.9	22.9	6	564.8	17.5	64	556.7	32.2	164	572.8	29.1
8	5	594.4	18.2	5	579.2	24.9	2	543.5	30.4	3	580.3	21.4	10	558.8	38.0	95	582.7	34.6
9	6	607.0	18.5	1	632.0		1	602.0		1	610.0		3	622.7	40.0	51	613.1	26.2
10	1	556.0											1	650.0		25	623.4	26.9
11																4	623.0	35.2
12																1	637.0	
13																1	677.0	
Males																		
2																1	420	
3	4	416.5	10.3	7	419.6	21.6	2	428.0	7.1	22	431.7	14.9	41	434.1	29.8	7	428.6	25.7
4	24	425.6	31.6	78	443.3	23.4	64	454.0	32.4	79	461.6	24.6	209	459.3	23.2	39	450.2	29.3
5	29	466.6	22.0	48	466.8	24.5	79	471.4	23.6	67	493.0	22.4	146	483.6	24.5	86	487.8	23.8
6	10	486.6	28.9	12	504.3	19.0	19	505.7	29.6	15	511.6	23.3	71	512.8	24.8	59	514.7	27.8
7	1	522.0		4	510.3	54.7	2	538.5	23.3	1	533.0		24	526.4	21.7	35	540.1	19.9
8							2	543.5	30.4	1	556.0		4	553.3	12.4	32	548.1	23.0
9													79	486.7	37.6	4	556.8	20.5
10	1	556.0														2	568.5	13.4
11																1	572.0	
Females																		
3	4	416.5	10.3										7	498.0	43.0	1	446.0	
4	38	448.9	42.5	28	504.4	36.5	35	493.2	20.4	46	511.7	27.6	76	503.7	27.6	21	506.7	28.2
5	57	484.0	29.0	65	522.4	26.2	108	508.4	23.5	112	532.8	21.7	175	534.2	27.0	97	521.0	21.7
6	19	511.8	37.6	24	548.0	35.3	28	552.5	20.0	25	558.5	24.0	122	558.9	19.6	117	552.6	27.6
7	6	543.2	48.2	7	577.6	22.8	13	578.2	18.4	5	571.2	8.8	40	574.9	22.2	128	581.6	24.6
8	3	604.0	16.5	5	579.2	24.9				2	592.5	4.9	6	562.5	49.6	63	600.3	24.8
9	6	607.0	18.5	1	632.0		1	602.0		1	610.0		3	622.7	40.0	47	617.9	20.5
10	1	556.0											1	650.0		23	628.1	22.0
11																3	640.0	11.1
12																1	637.0	
13																1	677.0	

Table 7B3 Continued (Fishery Independent data)

Mean WT_FI	1983			1984			1985			1986			1987			1988			1989		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																					
2																					
3				3	744.0	124.9	13	705.5	97.3	9	862.2	186.6	5	744.0	192.6	2	860.0	339.4	2	590.0	141.4
4	2	1005.0	120.2	18	946.4	228.3	54	977.1	330.3	82	1182.2	339.7	62	1004.9	242.0	57	1137.5	322.9	42	922.1	272.9
5	5	1324.0	191.9	30	1455.4	327.0	49	1257.8	300.5	119	1470.9	369.2	120	1383.3	328.1	178	1494.5	394.8	101	1352.8	358.8
6	5	1498.0	72.9	37	1779.5	377.4	38	1739.3	504.5	98	1745.8	392.4	77	1700.7	374.6	142	1864.6	381.7	84	1541.4	373.0
7	4	1605.0	208.9	23	2167.2	459.6	23	1873.2	473.3	39	2180.0	476.9	42	1904.8	333.1	81	2049.3	481.6	65	1868.3	461.6
8	2	1795.0	289.9	15	2372.7	637.6	15	2268.5	584.4	21	2283.8	485.5	26	2268.5	404.9	21	2295.7	549.2	34	1984.1	433.9
9	2	1865.0	275.8	6	2370.8	698.7	5	2854.6	733.7	13	2643.1	378.2	20	2449.5	385.9	15	2475.3	503.8	11	2050.0	284.1
10				4	2547.5	646.7	3	2270.0	177.5	2	3620.0	311.1	8	2406.3	247.2	8	2630.0	642.5	7	3222.9	529.7
11				1	2780.0		3	2620.0	374.7	5	3004.0	491.8	3	2163.3	833.9	5	2868.0	444.0	3	2326.7	223.0
12													2	3210.0	155.6	2	3530.0	523.3			
13													1	2600.0							
Males																					
2																					
3				3	744.0	124.9	12	699.3	98.9	9	862.2	186.6	5	744.0	192.6	2	860.0	339.4	2	590.0	141.4
4	2	1005.0	120.2	16	985.9	192.4	45	872.7	210.0	66	1082.7	257.1	50	946.9	183.7	41	1036.6	277.4	32	821.6	163.5
5	5	1324.0	191.9	23	1341.8	196.9	37	1160.1	224.4	64	1246.7	223.6	59	1139.7	178.9	92	1264.7	220.4	43	1124.7	245.9
6	5	1498.0	72.9	22	1549.6	227.0	18	1489.5	279.2	37	1456.0	239.5	31	1425.5	193.9	41	1577.1	236.2	35	1278.0	212.1
7	4	1605.0	208.9	9	1804.4	308.2	12	1589.8	219.6	15	1834.0	324.3	17	1648.8	168.2	25	1694.0	287.3	22	1522.7	262.3
8	2	1795.0	289.9	7	1837.1	278.7	6	1859.2	269.9	5	1998.0	233.5	6	1976.7	275.5	7	1932.9	526.5	17	1755.3	283.0
9	2	1865.0	275.8	1	1635.0		2	2315.0	530.3	3	2383.3	332.5	6	2075.0	80.4	4	2142.5	132.8	5	2058.0	273.4
10				1	1780.0		1	2071.0					2	2205.0	502.1	2	2010.0	155.6	1	2480.0	
11										1	2380.0		2	1685.0	134.4						
Females																					
3							1	780.0													
4				1	860.0		9	1499.2	335.0	16	1592.5	336.8	12	1246.7	309.0	16	1396.3	291.2	8	1322.5	286.2
5				7	1828.6	403.3	12	1559.3	312.9	55	1731.8	332.5	60	1625.8	256.7	86	1740.4	392.6	50	1560.0	340.6
6				15	2116.7	289.9	20	1964.2	559.9	61	1921.6	362.2	46	1886.1	353.0	101	1981.3	368.0	44	1752.7	351.1
7				14	2400.4	386.5	11	2182.3	488.3	24	2396.3	429.9	25	2078.8	304.6	56	2207.9	467.3	41	2063.4	443.4
8				8	2841.3	456.8	9	2541.4	585.3	16	2373.1	513.8	20	2356.0	400.9	14	2477.1	479.4	15	2306.7	354.4
9				5	2518.0	669.2	3	3214.3	671.3	10	2721.0	370.0	14	2610.0	350.3	11	2596.4	538.2	6	2043.3	318.7
10				3	2803.3	484.4	2	2369.5	60.1	2	3620.0	311.1	6	2473.3	116.4	6	2836.7	606.7	6	3346.7	456.0
11				1	2780.0		3	2620.0	374.7	4	3160.0	400.3	1	3120.0		5	2868.0	444.0	3	2326.7	223.0
12													2	3210.0	155.6	2	3530.0	523.3			
13													1	2600.0							

Table 7B3 Continued (Fishery Independent data)

Mean WT_FI	1990			1991			1992			1993			1994			1995			1996		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																					
2																					
3	.	.	.	14	702.9	176.7	13	638.5	129.7	4	640.0	71.2	1	720.0		25	780.4	280.0	24	642.5	112.7
4	9	901.1	356.7	57	869.1	222.7	189	810.1	189.7	90	695.8	166.6	29	804.8	151.2	146	1039.3	322.6	191	818.4	230.7
5	31	1118.7	382.6	65	1181.2	283.2	380	1074.7	301.6	204	859.2	197.5	80	1091.5	270.8	250	1324.6	320.9	112	1161.1	405.9
6	18	1371.7	342.6	51	1360.6	350.5	212	1372.5	350.2	97	1046.6	221.8	26	1228.5	282.3	133	1471.2	331.2	36	1730.3	833.3
7	20	1811.0	391.0	16	1607.5	278.4	63	1655.2	396.5	33	1229.4	264.2	10	1234.0	180.6	38	1603.4	282.6	12	1977.8	411.5
8	7	1838.6	362.3	4	1750.0	233.5	5	1808.0	655.2	9	1572.2	366.9	2	1420.0	311.1				5	2312.0	667.3
9	1	2400.0		1	2260.0		8	2141.3	457.5										2	2820.0	28.3
10	1	2400.0		1	2160.0		2	2805.0	431.3										1	1140.0	
11																					
12																					
13																					
Males																					
2																					
3				12	652.5	121.1	13	638.5	129.7	4	640.0	71.2	1	720.0	.	23	725.2	203.7	23	645.2	114.5
4	7	741.4	180.2	46	803.7	170.4	169	773.0	130.1	83	669.2	136.8	29	804.8	151.2	89	882.6	219.2	162	759.8	158.3
5	15	864.0	165.2	33	987.9	173.3	222	902.3	168.4	151	789.6	138.2	34	911.8	216.8	75	1046.7	200.0	64	1039.7	412.8
6	7	1265.7	369.5	16	1010.6	194.2	65	1168.1	413.7	47	920.9	138.6	7	1002.9	54.7	31	1157.7	219.8	15	1638.0	1248.9
7	7	1492.9	405.5	2	1410.0	99.0	7	1375.7	199.4	16	1130.0	263.3	3	1146.7	161.7	8	1367.5	157.1	4	1580.0	268.8
8	1	1530.0		1	1440.0		1	1380.0		2	1230.0	14.1							1	2000.0	
9							2	1815.0	176.8												
10																					
11																					
Females																					
3				1	1130.0											1	1630.0				
4	2	1460.0	141.4	10	1175.0	192.7	20	1123.0	301.8	7	1011.4	172.8				56	1289.0	306.9	27	1177.8	276.5
5	16	1357.5	376.2	30	1391.3	228.4	157	1319.9	278.8	51	1066.7	206.2	46	1224.4	227.6	169	1450.8	288.5	47	1337.0	326.3
6	11	1439.1	323.7	34	1524.1	286.4	145	1466.3	274.4	47	1171.9	221.5	18	1332.2	280.9	98	1580.4	296.7	20	1801.0	343.5
7	13	1982.3	262.7	14	1635.7	286.0	56	1690.2	402.1	17	1322.9	235.3	6	1303.3	182.2	29	1667.9	281.4	8	2176.8	315.3
8	5	2028.0	162.2	3	1853.3	133.2	4	1915.0	704.3	7	1670.0	359.6	2	1420.0	311.1				4	2390.0	743.8
9	1	2400.0		1	2260.0		6	2250.0	479.6										2	2820.0	28.3
10	1	2400.0		1	2160.0		2	2805.0	431.3										1	1140.0	
11																					
12																					
13																					

Table 7B3 Continued (Fishery Independent data)

Mean WT_FI	1997			1998			1999			2000			2001			2004		
AGE	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD	N	MEAN	STD
Sexes Combined																		
2																1	600.0	
3	4	677.5	68.5	5	724.0	155.8	3	743.3	63.5	19	742.6	96.1	48	755.7	201.2	8	827.5	181.1
4	37	866.6	283.0	107	995.3	348.3	97	918.3	215.6	125	1080.8	276.0	265	965.6	264.7	60	996.8	271.7
5	56	1128.8	282.9	112	1260.8	354.0	190	1091.7	260.5	179	1376.0	298.7	307	1251.8	340.8	187	1286.4	282.9
6	19	1316.8	365.7	35	1524.9	337.1	48	1463.3	444.1	38	1534.0	298.5	181	1446.9	346.6	178	1606.5	385.4
7	6	1750.0	306.7	12	1731.7	441.0	15	1678.0	260.8	6	1747.7	158.5	57	1539.3	365.1	161	1953.3	439.4
8	3	2073.3	30.6	5	2040.0	476.0	2	1580.0	311.1	3	1913.3	355.7	10	1655.0	607.1	95	1998.3	442.7
9	6	2146.7	400.3	1	2400.0		1	2300.0		1	2260.0		3	2073.3	248.3	52	2320.2	430.1
10	1	1660.0											1	2760.0		26	2479.2	555.2
11																4	2390.0	438.9
12																1	2640.0	
13																1	3560.0	
Males																		
2																1	600.0	
3	4	677.5	68.5	5	724.0	155.8	2	725.0	77.8	19	742.6	96.1	41	701.9	149.0	7	794.3	167.2
4	24	723.5	220.5	77	854.6	157.2	62	809.5	154.6	77	937.8	183.3	193	867.1	175.6	39	856.9	180.4
5	28	1022.1	249.8	47	1000.0	192.8	79	906.5	157.7	67	1164.2	212.9	138	1009.4	211.2	86	1134.3	204.3
6	10	1050.0	197.4	12	1255.8	173.1	19	1101.1	191.6	14	1335.7	232.6	65	1163.1	243.8	60	1364.3	247.1
7	1	1360.0		4	1350.0	414.6	2	1320.0	113.1	1	1680.0		22	1269.1	169.8	35	1536.3	230.0
8							2	1580.0	311.1	1	1600.0		4	1395.0	123.7	32	1582.5	208.6
9																4	1715.0	245.7
10	1	1660.0														2	1590.0	14.1
11																1	1860.0	
Females																		
3													7	1070.9	182.8	1	1060.0	
4	12	1143.3	176.2	28	1355.7	427.3	34	1122.9	155.6	45	1332.1	233.9	72	1229.5	283.0	21	1256.7	216.4
5	27	1241.9	280.7	64	1451.7	325.4	108	1227.5	239.8	110	1506.6	270.4	168	1453.4	292.8	96	1422.4	279.4
6	9	1613.3	262.9	23	1665.2	317.1	27	1714.1	407.4	24	1649.6	273.7	116	1606.0	289.6	116	1734.5	386.5
7	5	1828.0	268.2	7	1877.1	325.1	13	1733.1	231.6	5	1761.2	173.3	35	1709.2	353.2	125	2069.7	414.6
8	3	2073.3	30.6	5	2040.0	476.0				2	2070.0	325.3	6	1828.3	751.1	63	2209.5	375.3
9	6	2146.7	400.3	1	2400.0		1	2300.0		1	2260.0		3	2073.3	248.3	48	2370.6	403.8
10													1	2760.0		24	2553.3	510.4
11																3	2566.7	319.0
12																1	2640.0	
13																1	3560.0	

Table 7B4 MARK model outputs for Hudson River American shad.

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Z Lower	Z Upper
1995-1997							
S(.)r(.)							
S	0.216	0.047	0.138	0.322	1.53	1.98	1.13
r	0.023	0.002	0.019	0.028			
S(.)r(t)							
S	0.232	0.053	0.144	0.351	1.46	1.94	1.05
r1	0.026	0.004	0.019	0.036			
r2	0.022	0.004	0.016	0.030			
r3	0.021	0.003	0.016	0.029			
S(t)r(.)							
S1	0.225	0.053	0.137	0.346			
S2	0.204	0.085	0.084	0.417			
S3	0.293	0.161	0.083	0.656			
r	0.024	0.003	0.019	0.030			
S(t)r(t)							
S1	0.309	0.101	0.150	0.531			
S2	0.151	0.069	0.058	0.337			
S3	0.974	0.000	0.974	0.974			
r1	0.029	0.006	0.020	0.043			
r2	0.018	0.004	0.012	0.028			
r3	0.661	0.000	0.661	0.661			
1995-1998							
S(.)r(.)							
S	0.229	0.038	0.163	0.313	1.47	1.82	1.16
r	0.023	0.002	0.019	0.027			
S(.)r(t)							
S	0.263	0.050	0.177	0.371			
r1	0.028	0.004	0.020	0.037			
r2	0.022	0.004	0.016	0.030			
r3	0.022	0.003	0.016	0.029			
r4	0.017	0.005	0.009	0.031			
S(t)r(.)							
S1	0.237	0.054	0.148	0.357			
S2	0.220	0.079	0.102	0.411			
S3	0.393	0.107	0.212	0.610			
S4	0.630	0.162	0.304	0.869			
r	0.025	0.003	0.020	0.031			
S(t)r(t)							
S1	0.331	0.106	0.162	0.559			
S2	0.136	0.057	0.057	0.290			
S3	0.982	0.003	0.976	0.987			
S4	0.990	1.267	0.000	1.000			
r1	0.030	0.006	0.020	0.046			
r2	0.017	0.004	0.011	0.027			
r3	1.000	0.003	0.000	1.000			
r4	0.467	61.792	0.000	1.000			
1995-1999							
S(.)r(.)							

Model	AICc	Delta AICc	AICc Weight	#Par	Dev.
1995-1997					
S(.)r(.)	1324.96	0.00	0.63	2	2.51
S(.)r(t)	1327.85	2.90	0.15	4	1.40
S(t)r(t)	1328.46	3.50	0.11	5	0.00
S(t)r(.)	1328.52	3.56	0.11	4	2.06
1995-1998					
S(t)r(t)	1479.68	0.00	0.41	7	4.61
S(.)r(.)	1479.73	0.05	0.40	2	14.68
S(t)r(.)	1481.94	2.27	0.13	5	10.89
S(.)r(t)	1483.32	3.64	0.07	5	12.26
1995-1999					
S(t)r(t)	1541.22	0.00	0.50	9	5.62

Model/			95% CI			Z				Delta	AICc		
Parameter	**S(I)**	**SE**	**Lower**	**Upper**	**S(I)**	**Lower**	**Upper**	**Model**	**AICc**	**AICc**	**Weight**	**#Par**	**Dev.**
S	0.228	0.034	0.167	0.302	1.48	1.79	1.20	S(t)r(.)	1542.60	1.37	0.25	6	13.01
r	0.022	0.002	0.019	0.026				S(.)r(.)	1543.76	2.53	0.14	2	22.18
S(.)r(t)								S(.)r(t)	1544.37	3.14	0.10	6	14.78
S	0.272	0.047	0.189	0.372	1.30	1.67	0.99						
r1	0.027	0.004	0.021	0.037									
r2	0.022	0.004	0.016	0.030									
r3	0.022	0.003	0.016	0.030									
r4	0.016	0.005	0.009	0.030									
r5	0.009	0.004	0.003	0.023									
S(t)r(.)													
S1	0.234	0.053	0.146	0.353									
S2	0.205	0.073	0.097	0.382									
S3	0.377	0.098	0.210	0.589									
S4	0.595	0.167	0.274	0.851									
S5	0.848	0.093	0.575	0.959									
r	0.025	0.003	0.020	0.030									
S(t)r(t)													
S1	0.331	0.106	0.162	0.559									
S2	0.130	0.055	0.055	0.279									
S3	0.982	0.003	0.975	0.987									
S4	0.201	0.201	0.021	0.746									
S5	0.992	2.535	0.000	1.000									
r1	0.030	0.006	0.020	0.046									
r2	0.017	0.004	0.011	0.027									
r3	1.000	0.000	1.000	1.000									
r4	0.006	0.002	0.003	0.012									
r5	0.530	175.457	0.000	1.000									
1995-2000													
S(t)r(t)								S(t)r(t)	1576.41	0.00	0.57	10	10.19
S1	0.375	0.116	0.186	0.612				S(t)r(.)	1578.00	1.59	0.26	7	17.79
S2	0.160	0.061	0.073	0.318				S(.)r(t)	1578.83	2.42	0.17	7	18.62
S3	0.983	0.003	0.976	0.988				S(.)r(.)	1597.22	20.81	0.00	2	47.03
S4	0.155	0.155	0.018	0.650									
S5	0.076	104.065	0.000	1.000									
S6	0.747	0.000	0.747	0.747									
r1	0.032	0.007	0.021	0.051									
r2	0.017	0.004	0.011	0.027									
r3	1.000	0.001	0.999	1.001									
r4	0.006	0.002	0.003	0.012									
r5	0.006	0.622	0.000	1.000									
r6	0.000	0.000	0.000	0.000									
S(t)r(.)													
S1	0.259	0.054	0.168	0.379									
S2	0.254	0.079	0.131	0.434									
S3	0.413	0.100	0.238	0.612									
S4	0.583	0.167	0.266	0.843									
S5	0.861	0.087	0.597	0.963									
S6	1.000	0.000	1.000	1.000									
r	0.025	0.003	0.021	0.031									

Model/			95% CI			Z				Delta	AICc		
Parameter	S(I)	SE	Lower	Upper	S(I)	Lower	Upper	Model	AICc	AICc	Weight	#Par	Dev.
S(.)r(t)													
S	0.304	0.050	0.217	0.409	1.19	3.01	1.53						
r1	0.029	0.005	0.021	0.039									
r2	0.022	0.004	0.016	0.031									
r3	0.022	0.003	0.016	0.030									
r4	0.018	0.005	0.010	0.032									
r5	0.008	0.004	0.003	0.022									
r6	0.000	0.000	0.000	0.000									
S(.)r(.)													
S	0.250	0.034	0.189	0.322	1.39	3.39	1.66						
r	0.021	0.002	0.018	0.024									
1995-2001													
S(t)r(t)								S(t)r(t)	1650.78	0	0.74152	11	11.222
S1	0.375	0.116	0.186	0.612				S(t) r(.)	1652.99	2.21	0.24523	8	19.451
S2	0.157	0.060	0.071	0.312				S(.)r(t)	1658.83	8.05	0.01325	8	25.288
S3	0.983	0.003	0.976	0.988				S(.)r(.)	1681.06	30.28	0	2	59.539
S4	0.147	0.108	0.031	0.484									
S5	0.995	0.003	0.983	0.998									
S6	1.000	0.000	1.000	1.000									
S7	0.001	8.334	0.000	1.000									
r1	0.032	0.007	0.021	0.051									
r2	0.017	0.004	0.011	0.027									
r3	1.000	0.000	1.000	1.000									
r4	0.006	0.002	0.003	0.011									
r5	1.000	0.000	1.000	1.000									
r6	0.053	313.610	0.000	1.000									
r7	0.003	0.024	0.000	1.000									
S(t)r(.)													
S1	0.257	0.054	0.166	0.375									
S2	0.240	0.073	0.127	0.408									
S3	0.392	0.090	0.235	0.575									
S4	0.540	0.166	0.241	0.813									
S5	0.844	0.094	0.572	0.956									
S6	1.000	0.000	1.000	1.000									
S7	0.893	0.054	0.732	0.962									
r	0.025	0.002	0.021	0.030									
S(.) r(t)													
S	0.345	0.050	0.255	0.449	1.06	3.00	1.37						
r1	0.031	0.005	0.023	0.042									
r2	0.023	0.004	0.016	0.031									
r3	0.022	0.004	0.016	0.030									
r4	0.017	0.005	0.009	0.029									
r5	0.008	0.004	0.003	0.020									
r6	0.000	0.000	0.000	0.000									
r7	0.010	0.004	0.004	0.024									
S(.) r(.)													
S	0.276	0.034	0.215	0.346	1.29	3.39	1.54						
R	0.020	0.002	0.017	0.024									

Table 7B4 Continued

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Lower	Upper
1995-2002							
{S(t)r(t)}							
1:S	0.375	0.116	0.186	0.612			
2:S	0.160	0.061	0.073	0.318			
3:S	0.983	0.003	0.976	0.988			
4:S	0.103	0.094	0.015	0.458			
5:S	0.251	0.286	0.017	0.868			
6:S	1.000	0.000	1.000	1.000			
7:S	0.055	119.966	0.000	1.000			
8:S	0.468	241.609	0.000	1.000			
9:r	0.032	0.007	0.021	0.051			
10:r	0.017	0.004	0.011	0.027			
11:r	1.000	0.000	0.999	1.001			
12:r	0.006	0.002	0.003	0.010			
13:r	0.008	0.006	0.002	0.037			
14:r	0.002	48.045	0.000	1.000			
15:r	0.004	0.469	0.000	1.000			
16:r	0.089	191.018	0.000	1.000			
{S(p)r(.)} p=2 periods 1995-1999, 200-2003							
1:S	0.251	0.034	0.190	0.324	1.38	3.38	1.66
2:S	0.885	0.049	0.750	0.952	0.12	3.02	0.29
3:r	0.022	0.002	0.019	0.026			
{S(.)r(t)}							
1:S	0.317	0.047	0.233	0.414	1.15	3.06	1.46
2:r	0.030	0.005	0.022	0.040			
3:r	0.022	0.004	0.016	0.031			
4:r	0.022	0.003	0.016	0.030			
5:r	0.018	0.005	0.010	0.031			
6:r	0.008	0.004	0.003	0.021			
7:r	0.000	0.000	0.000	0.000			
8:r	0.008	0.004	0.003	0.021			
9:r	0.019	0.011	0.006	0.059			

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
{S(t)r(t)}	1680.3	0.000	0.317	1.000	13	13.312
{S(p)r(.)}	1680.5	0.270	0.276	0.872	3	33.632
{S(.)r(t)}	1683.1	2.860	0.076	0.239	9	24.199
{S(t)r(.)}	1683.1	2.860	0.076	0.239	9	24.201
{S(.)r(.)}	1703.4	23.110	0.000	0.000	2	58.471

p=2 periods 1995-1999, 2000-2002

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Lower	Upper	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
{S(t)r(.)}														
1:S	0.252	0.053	0.163	0.369										
2:S	0.218	0.065	0.116	0.371										
3:S	0.321	0.079	0.188	0.492										
4:S	0.356	0.205	0.088	0.761										
5:S	0.747	0.161	0.358	0.940										
6:S	1.000	0.000	1.000	1.000										
7:S	0.891	0.061	0.707	0.965										
8:S	0.908	0.059	0.713	0.975										
9:r	0.024	0.002	0.020	0.029										
{S(.)r(.)}														
1:S	0.262	0.032	0.204	0.330										
2:r	0.020	0.002	0.017	0.023										
1995-2003														
{S(p)r(.)}								{S(p)r(.)}	1704.0	0	0.894	1.000	3	34.160
1:S	0.224	0.033	0.166	0.294	1.50	3.42	1.80	{S(p)r(t)}	1709.1	5.11	0.070	0.078	11	23.239
2:S	0.880	0.043	0.769	0.941	0.13	3.16	0.26	{S(t)r(t)}	1711.6	7.59	0.020	0.022	17	13.681
3:r	0.022	0.002	0.019	0.026				{S(t)r(.)}	1712.0	8.08	0.016	0.018	11	26.209
{S(p)r(t)}								{S(.)r(t)}	1717.5	13.52	0.001	0.001	10	33.652
1:S	0.261	0.043	0.186	0.354	1.34	3.14	1.68	{S(.)r(.)}	1740.5	36.52	0.000	0.000	2	72.686
2:S	0.963	0.332	0.000	1.000	0.04	1.10	14.83							
3:r	0.027	0.004	0.020	0.037				p=2 periods 1995-1999, 2000-2003						
4:r	0.022	0.004	0.016	0.030										
5:r	0.022	0.003	0.016	0.029										
6:r	0.017	0.005	0.009	0.031										
7:r	0.009	0.004	0.003	0.023										
8:r	0.000	0.000	0.000	0.000										
9:r	0.095	0.831	0.000	1.000										
10:r	0.070	0.590	0.000	1.000										
11:r	0.064	0.533	0.000	1.000										
{S(t)r(t)}														
1:S	0.000	0.000	0.000	0.000										
2:S	0.331	0.106	0.162	0.559										
3:S	0.130	0.055	0.055	0.279										

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Lower	Upper	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
4:S	0.982	0.003	0.975	0.987										
5:S	0.109	0.100	0.016	0.477										
6:S	0.247	0.297	0.014	0.882										
7:S	0.640	0.445	0.039	0.987										
8:S	0.996	0.002	0.987	0.999										
9:S	0.997	0.002	0.989	0.999										
10:S	0.990	2.271	0.000	1.000										
11:r	0.030	0.006	0.020	0.046										
12:r	0.017	0.004	0.011	0.027										
13:r	1.000	0.002	0.000	1.000										
14:r	0.005	0.002	0.003	0.010										
15:r	0.008	0.006	0.002	0.037										
16:r	0.000	0.000	0.000	0.000										
17:r	1.000	0.029	0.000	1.000										
18:r	1.000	0.031	0.000	1.000										
19:r	0.269	63.639	0.000	1.000										
{S(t)r(.)}														
1:S	1.000	0.000	1.000	1.000										
2:S	0.228	0.052	0.143	0.345										
3:S	0.174	0.060	0.085	0.323										
4:S	0.277	0.071	0.161	0.433										
5:S	0.320	0.191	0.078	0.725										
6:S	0.683	0.189	0.280	0.923										
7:S	1.000	0.000	1.000	1.000										
8:S	0.882	0.063	0.694	0.961										
9:S	0.903	0.060	0.709	0.973										
10:S	0.902	0.053	0.741	0.968										
11:r	0.023	0.002	0.019	0.027										
{S(.)r(t)}														
1:S	0.329	0.046	0.245	0.425	1.11	3.07	1.41							
2:r	0.030	0.005	0.022	0.041										
3:r	0.022	0.004	0.016	0.031										
4:r	0.022	0.003	0.016	0.030										
5:r	0.015	0.005	0.008	0.027										

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Lower	Upper	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
6:r	0.008	0.004	0.003	0.021										
7:r	0.000	0.000	0.000	0.000										
8:r	0.008	0.004	0.003	0.021										
9:r	0.014	0.008	0.005	0.045										
10:r	0.009	0.004	0.003	0.023										
{S(.)r(.)}														
1:S	0.265	0.032	0.207	0.333	1.33	3.44	1.57							
2:r	0.019	0.002	0.016	0.022										
1995-2004														
{S(p.)r(.)}								{S(p.)r(.)}	1775.3	0.000	0.880	1.000	3	38.382
1:S	0.222	0.033	0.165	0.292	1.50	3.43	1.80	{S(p_t)r(.)}	1780.0	4.700	0.084	0.095	7	35.074
2:S	0.879	0.037	0.785	0.935	0.13	3.29	0.24	{S(p.)r(t)}	1782.5	7.220	0.024	0.027	12	27.568
3:r	0.022	0.002	0.019	0.026				{S(t)r(.)}	1784.6	9.250	0.009	0.010	11	31.606
{S(p_t)r(.)}								{S(t)r(t)}	1786.5	11.150	0.003	0.004	19	17.448
1:S	0.223	0.033	0.165	0.293				{S(.)r(t)}	1794.9	19.570	0.000	0.000	11	41.929
2:S	1.000	0.000	1.000	1.000				{S(.)r(.)}	1823.4	48.030	0.000	0.000	2	88.415
3:S	0.837	0.081	0.614	0.943										
4:S	0.860	0.082	0.618	0.959										
5:S	0.875	0.064	0.690	0.957										
6:S	0.884	0.054	0.732	0.955										
7:r	0.022	0.002	0.019	0.026										
{S(p.)r(t)}														
1:S	0.260	0.043	0.185	0.353										
2:S	0.834	0.185	0.267	0.986										
3:r	0.027	0.004	0.020	0.037										
4:r	0.022	0.004	0.016	0.030										
5:r	0.022	0.003	0.016	0.029										
6:r	0.017	0.005	0.009	0.031										
7:r	0.009	0.004	0.003	0.023										
8:r	0.000	0.000	0.000	0.000										
9:r	0.023	0.026	0.002	0.184										
10:r	0.019	0.019	0.003	0.126										
11:r	0.018	0.017	0.003	0.108										
12:r	0.016	0.015	0.003	0.092										

Model/ Parameter	S(I)	SE	95% CI Lower	Upper	Z S(I)	Lower	Upper	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
{S(t)r(.)}														
1:S	0.228	0.052	0.142	0.344										
2:S	0.171	0.059	0.084	0.318										
3:S	0.265	0.065	0.157	0.410										
4:S	0.265	0.167	0.063	0.660										
5:S	0.616	0.218	0.209	0.907										
6:S	1.000	0.000	1.000	1.000										
7:S	0.868	0.070	0.666	0.956										
8:S	0.890	0.067	0.678	0.969										
9:S	0.897	0.055	0.732	0.965										
10:S	0.902	0.047	0.764	0.963										
11:r	0.023	0.002	0.019	0.027										
{S(t)r(t)}														
1:S	0.331	0.106	0.162	0.559										
2:S	0.130	0.055	0.055	0.279										
3:S	0.982	0.003	0.975	0.987										
4:S	0.107	0.098	0.016	0.470										
5:S	0.239	0.289	0.014	0.876										
6:S	0.508	0.349	0.063	0.941										
7:S	0.995	0.003	0.986	0.998										
8:S	0.807	0.579	0.003	1.000										
9:S	0.997	0.002	0.989	0.999										
10:S	0.995	0.000	0.995	0.995										
11:r	0.030	0.006	0.020	0.046										
12:r	0.017	0.004	0.011	0.027										
13:r	1.000	0.003	0.000	1.000										
14:r	0.005	0.002	0.003	0.010										
15:r	0.008	0.006	0.002	0.036										
16:r	0.000	0.000	0.000	0.000										
17:r	1.000	0.002	0.997	1.003										
18:r	0.017	0.054	0.000	0.901										
19:r	1.000	0.057	0.000	1.000										
20:r	0.480	0.000	0.480	0.480										
{S(.)r(t)}														

Model/ Parameter	S(I)	SE	95% CI Lower	95% CI Upper	Z S(I)	Lower	Upper	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	#Par	Deviance
1:S	0.356	0.047	0.271	0.452										
2:r	0.031	0.005	0.023	0.043										
3:r	0.023	0.004	0.016	0.032										
4:r	0.022	0.004	0.016	0.030										
5:r	0.014	0.004	0.008	0.025										
6:r	0.007	0.004	0.003	0.020										
7:r	0.000	0.000	0.000	0.000										
8:r	0.008	0.004	0.003	0.021										
9:r	0.014	0.008	0.004	0.042										
10:r	0.009	0.004	0.003	0.024										
11:r	0.008	0.004	0.003	0.019										
{S(.)r(.)}														
1:S	0.286	0.032	0.228	0.353										
2:r	0.018	0.001	0.015	0.021										

Table 7B.5 Results of chi-square analyses on weekly age structure of annual spawning stock survey samples of American shad in the Hudson River, New York.

Year	Ages	Number of weeks sampled	Number of fish caught	DF	*X*^2	*P*
1985	3-9	4	246	18	25.21	0.119
1986	3-9	5	410	24	42.74	0.011
1987	3-10	5	400	28	20.93	0.828
1988	4-9	7	509	30	51.32	0.009
1989	4-9	5	361	20	24.38	0.226
1990	4-8	5	86	16	11.80	0.758
1991	3-7	4	211	12	31.26	0.002
1992	4-9	5	911	20	85.34	<0.001
1993	4-8	4	467	12	28.40	0.005
1994	4-7	5	157	12	88.40	<0.001
1995	3-7	6	705	20	125.09	<0.001
1996	3-7	4	380	12	26.47	0.009
1997	4-8	4	136	12	27.20	0.007
1998	3-8	3	282	10	13.09	0.219
1999	4-8	3	342	8	2.59	0.957
2000	3-7	4	378	12	11.87	0.456
2001	3-8	3	921	10	15.76	0.107
2002			No sampling			
2003			Age data not complete			
2004	3-11	3	776	16	20.05	0.218
2005			Age data not complete			

Section 8
Status of the Delaware River American Shad Stock

Contributors:

Russell L. Allen, Heather Corbett, and Mark Boriek
New Jersey Division of Fish and Wildlife
Nacote Lab Route 9 MM 51, Port Republic, New Jersey 08241

Craig Shirey, Michael Stangl, and Greg Murphy
Delaware Department of Natural Resources and Environmental Control
89 Kings Highway, Dover, Delaware 19901

Michael L. Hendricks, David Arnold, and Michael Kaufmann
Pennsylvania Fish and Boat Commission
1735 Shiloh Road, State College, Pennsylvania 16801

8.1 INTRODUCTION

In the late 1890s, the Delaware River had the largest annual commercial shad harvest of any river on the Atlantic Coast with estimates ranging up to 19 million pounds in a given year. The harvest began to decline rapidly in the early 1900s due to water pollution, overfishing, and dams on major tributaries (Chittenden 1974). Despite improved state legislation and regulation, and a massive program of artificial propagation of shad stocks in the late 1800s, the shad fishery eventually collapsed under the combined pressures. By the 1940s, the commercial shad fisheries were mainly limited to the lower reaches of the River and Bay below Pennsylvania (Ellis in Delaware River Fish and Wildlife Cooperative 1982). By 1950, the urban reach of the Delaware River was one of the most polluted stretches of river in the world.

During the late 1800s there was evidence indicating that shad were spawning in the freshwater tidal areas of the main stem as well as several tributaries of the lower Delaware River. It was presumed that the principal spawning area was located just south of Philadelphia prior to 1900. The prevalence of spawning in tidewater near Burlington was documented by the huge fishery there, as well as the hatchery effort that took place at that location (Gay 1892). Heavy organic loading around Philadelphia, Pennsylvania caused severe declines in dissolved oxygen (D.O.) during the 1940s and 1950s. The ensuing "D.O. blocks" made parts of the lower Delaware River uninhabitable for fish during the warmer months of the year (Sykes and Lehman 1957). A remnant of the American shad run in the Delaware River survived by migrating upstream early in the season, when water temperatures were low and flows were high, before the D.O. block set up. These fish, because of their early arrival, migrated far up the Delaware to spawn. Out-migrating juveniles survived by moving downriver late in the season during high flows and low temperatures, thus avoiding the low oxygen waters present around Philadelphia earlier in the fall. Pollution continued to be a major factor until passage of the Federal Clean Water Act in 1972. This Act was instrumental in the elimination of the "pollution block" of low or no dissolved oxygen in the region around Philadelphia. By 1973 the majority of spawning took place above the Delaware Water Gap more than 115 river miles upstream. American shad can now freely pass through this area during the spring spawning run as well as the fall out-migration.

Although the Delaware River shad population had shown signs of recovery during the 1980s and into the early 1990s, recent estimates of the adult stock have been well below the target of 750,000 adult American shad at Lambertville, set by the Delaware Basin Fish and Wildlife Management Cooperative in 1982. Recent observations indicate that shad spawning has returned to the tidal areas of the Delaware River, but the magnitude of this spawning is unknown.

8.2 MANAGEMENT UNIT DEFINITION

The Delaware River Drainage Basin (Basin) consists of the Delaware River, including the East and West branches above Hancock, New York, and its tributaries to the mouth of Delaware Bay, encompassing some 13,539 square miles and 216 tributaries (Figure 8.1). The Basin includes the states of Delaware, New Jersey, New York, and Pennsylvania. The Delaware River is the longest un-dammed river east of the Mississippi and stretches for 330 miles. For the purposes of this report, the terminus of Delaware Bay is delineated by a line drawn from the lighthouse at Cape May Point, New Jersey to Breakwater Light at Cape Henlopen, Delaware (Colregs Demarcation Line).

8.3 REGULATORY HISTORY

8.3.1 Commercial Fishery

The State of Delaware has no regulations that have been specifically adopted to reduce or restrict the landings of American shad in the Delaware Estuary. However, there are regulations that apply to the commercial fishery in general that limit commercial fishing, such as limited entry and limitations on the amount of gear. Drift nets are prohibited from Saturday through 1600 hours Sunday. Additional area restrictions include:

1. No fixed gill nets from January 1 through May 31, and not more than 200 feet of net from June through September on the Delaware River.
2. The striped bass spawning grounds—C&D Canal upstream to the state line—are closed to all gill nets from April 1 to May 31.
3. No fixed gill nets from May 10 through September 30 in Delaware Bay.

The State of New Jersey instituted limited entry and mandatory reporting for the American shad commercial fishery in 2000. Prior to that there were no regulations specifically adopted to reduce or restrict the landings of American shad. As of December 31, 2006, there were 83 permits issued for New Jersey waters (45 commercial and 38 incidental permits). Of the 81 permit holders no more than 23 fishermen have used their permits in the Delaware Estuary in any given year with an average of 19 permit users from 2000 to 2005. The shad permit allows the holder to fish in any state waters where the commercial harvest of shad is allowed as long as the permit holder meets all other net requirements.

New Jersey also has regulations that apply to the commercial fishery in general such as limited entry, limitations on the amount of gear, and gear restrictions in defined areas. Additional restrictions include:

1. From November 1 to April 30, only haul seines with a mesh size≥ 2 ¾ inch stretch and a 420 feet maximum length can be used in the Delaware River. This is currently limited to one commercial fishery based in Lambertville.
2. From February 1 through December 15, gill nets may be used in Delaware Bay and River. From February 1 through February 29, gill nets with 5 inch stretch mesh may be used; from March 1 through December 15, gill nets larger than 3 ¼ inch stretch mesh may not be used. From February 12 through May 15, the maximum net length allowed is 2400 feet; from May 16 through December 15, the maximum net length is 1200 feet.

Pennsylvania and New York do not permit the commercial harvest of American shad within the Delaware River Basin.

8.3.2 Recreational Fishery

All Basin states have enacted recreational bag limits in accordance with Amendment 1 to the ASMFC Interstate Fishery Management Plan for American Shad and River Herring. The States of New Jersey, New York, and Pennsylvania have adopted six fish bag limits with no size limits or closed seasons. Delaware has a ten fish limit, combined American and hickory shad, with no size limit or closed season. Very little effort is expended by recreational anglers for American shad in Delaware waters.

8.4 ASSESSMENT HISTORY

The Delaware River was included in the 1988 and 1998 ASMFC coastwide stock assessments for American shad (Gibson *et al*. 1988; ASMFC 1998). The 1988 Assessment utilized the Shepherd stock-recruitment model to estimate maximum sustainable yield (MSY) and maximum sustainable fishing rates (F_{msy}). That assessment estimated F_{msy} for the Delaware River to be equal to 0.795 with exploitation at 0.548. The 1998 Assessment utilized the Thompson-Bell yield-per-recruit model to derive an overfishing definition (F_{30}) for American shad. Average fishing mortality from 1992 to 1996 for the Delaware River was estimated at F=0.17, which includes out of basin estimates of harvest, and was considered well below the F_{30} value of F=0.43.

8.5 HABITAT DESCRIPTION

The Delaware River Drainage Basin (Basin) consists of the Delaware River, including the East and West branches above Hancock, New York, and its tributaries to the mouth of Delaware Bay, encompassing some 13,539 square miles and 216 tributaries (Figure 8.1). The Basin includes the states of Delaware, New Jersey, New York, and Pennsylvania. The Delaware River is the longest un-dammed river east of the Mississippi and stretches for 330 miles. For the purposes of this report, the terminus of Delaware Bay is delineated by a line drawn from the lighthouse at Cape May Point, New Jersey to Breakwater Light at Cape Henlopen, Delaware (Colregs Demarcation Line).

Many of the Delaware River tributaries contained spawning runs of American shad until pollution, overfishing and dams restricted the population and destroyed spawning habitat. Efforts have been undertaken to restore shad in some of these systems by removing dams or installing fish ladders. This assessment only includes limited restoration data from the Schuylkill and Lehigh Rivers, which are the two largest tributaries. At 208 km in length, the Schuylkill is the largest tributary to the Delaware River and had abundant runs of American shad until the early 1800s when canal dams constructed to bring coal to the markets in Philadelphia effectively ended the Schuylkill spawning runs. The Lehigh River at 151 km in length is the second largest tributary to the Delaware River and had abundant runs of American shad until the 1820s, when 20 canal dams were constructed by the Lehigh Coal and Navigation Company to bring coal from the upper drainage to Philadelphia markets.

8.6 RESTORATION PROGRAMS

8.6.1 Egg Collection History

Eggs collected from Delaware River shad have been used in restoration efforts on two Delaware River tributaries, the Lehigh and Schuylkill rivers, as well as in the Susquehanna River Basin, Raritan River, and other systems. Since 1973, egg-take operations on the Delaware River have resulted in the use of an average of 765 adult shad per year. Eggs from these shad are fertilized and transported to the Pennsylvania Fish and Boat Commission (PFBC) Van Dyke Anadromous Research Station. After hatching, the resulting larvae are reared until 10 to 30 days of age and stocked in areas above dams on the Susquehanna and Lehigh Rivers where fish passage projects are in place or are planned. When high water events occur, the larvae are held in the hatchery until the water recedes. Since 1985, the top priority for Delaware River larvae has been the Lehigh and Schuylkill rivers with more than 20 million fry stocked during this time (Table 8.1). Since 2000, all Delaware River shad fry have been allocated to the Lehigh, Schuylkill, and Delaware rivers.

8.6.2 Egg Collection and Hatchery Culture

American shad used to stock the Lehigh and Schuylkill Rivers were cultured by methods developed at the PFBC's Van Dyke Hatchery, which are similar to those reported by Howey (1985). Eggs were obtained from adult American shad collected by anchored gill nets set parallel to the current in the Delaware River at Smithfield Beach (rm 228). Ripe adults were strip-spawned and the eggs were fertilized and water-hardened at the collection site. Eggs were delivered to the Van Dyke Hatchery for incubation at 15 to 17 ^{o}C and hatching occurred in about seven days. Larvae were reared at 18 to 21^{o}C in circular, 1,200-L tanks at densities of 100,000 to 500,000 larvae per tank, and fed *Artemia* spp. and Zeigler AP-100 larval fish food, beginning on day 3 or 4 (Wiggins *et al*. 1986).

Stocking of hatchery-reared American shad larvae in the Lehigh and Schuylkill Rivers began in 1985. Releases occurred at Northampton (Lehigh River km 38.6) or between Gibralter and Hamburg (Schuylkill River km 108-158). Larvae were stocked annually, during May or June at 7 to 21 days of age. Between 1985 and 2005, 15.2 million marked hatchery shad larvae were stocked into the Lehigh River and 4.8 million were stocked into the Schuylkill River.

8.6.3 Hatchery Evaluation

All hatchery-reared American shad larvae are immersed in tetracycline antibiotics to mark their otoliths to distinguish hatchery-reared shad from wild, naturally-produced shad (Hendricks *et al*. 1991). Since 1987, larvae were marked by 4 to 6 hour immersion in 200 to 256 mg L^{-1} oxytetracycline or tetracycline hydrochloride. Multiple marks are produced by subsequent immersions 3 or 4 days apart. Adult fish taken during independent sampling are analyzed for percent hatchery contribution. These data are found in Section 8.9.3.

Recapture sampling sites included the Delaware River at Raubsville (electrofisher, rm 176.6), and at Smithfield Beach (gill net, rm 218), the Lehigh River below Chain Dam (electrofisher), and the Schuylkill River below Fairmount Dam (electrofisher). Approximately 100 adult American shad are collected annually from the Lehigh and Schuylkill rivers in single sampling events by a daytime boat electrofisher.

Specimens are decapitated and the heads are frozen prior to otolith extraction and mark detection. Sagittal otoliths are extracted and mounted on a microscope slide and ground on both sides to produce a thin sagittal section (Hendricks *et al*. 1991). Each section is then examined by a single reader with an epi-fluorescent microscope with a 100W mercury vapor lamp and an FITC (fluorescein isothiocyanate) fluorcluster under UV light for the presence and pattern of tetracycline marks.

8.6.4 Future Plans

It is the PFBC's intention to continue to utilize Delaware River eggs for the shad restoration efforts on the Delaware River and its tributaries, specifically the Lehigh River and Schuylkill River. These rivers receive stockings of the first 1.5 million larvae produced from eggs provided by Delaware River shad. After the Lehigh and Schuylkill allotments have been met, remaining excess eggs will be used to support other restoration efforts.

8.7 AGE

Fish from the Delaware system have been aged using scales and otoliths. Recent findings have determined that the ageing of scales from Delaware River American shad can not be substantiated (McBride *et al*. 2005) and although otolith technology is considered better, the principal scientists behind otolith ageing are not satisfied with the process at this time. Without confidence in the scale ageing technique (Cating 1953), the American Shad Stock Assessment Subcommittee (SASC) agreed that alternative methods would be preferable to assess the Delaware River stock.

8.8 FISHERY DESCRIPTION

8.8.1 Commercial Fishery

The commercial fishery for American shad in Delaware Estuary occurs during the spring spawning migration from late February into May depending on weather and market conditions. All landings, except a small haul seine fishery in the upper Delaware River, are by gill net, both anchor and drift, depending on location and state regulation.

The State of Delaware has no specific regulations that have been adopted to reduce or restrict commercial landings of American shad in the Delaware Estuary. Delaware has a limited entry license system for the commercial gill net fishery. However, since fishermen are allowed to transfer their striped bass allocation to other licensed fishermen, the number of active gill net fishermen was actually much less as evidenced by the number of fishermen that landed American shad in either the Delaware Bay or Delaware River. American shad landings typically rank among the top three species in terms of pounds landed from the Bay and River and form an important component of the commercial fishery in Delaware. However, most shad are landed in conjunction with striped bass, which has a commercial season that begins March 1 and extends through April 31.

The State of New Jersey instituted limited entry and mandatory reporting for the American shad commercial fishery in 2000. Since that time, records indicate that the season has started as early as February 15 in 2001 and ended as late as May 15 in 2002. Data collected from the logbooks show that the mesh size in the Delaware Bay fishery ranges from 5.25 to 6 inch stretch. The majority of fishing effort was concentrated in the drift fishery.

There is no information on bycatch or discards of shad in any commercial fisheries within the Delaware Estuary, although it is known that male shad are discarded when they are no longer profitable to commercial fishermen. Some shad (male and female) are also discarded during the striped bass fishery in Delaware for the same reason. It is also important to consider impacts of the Delaware Bay commercial fishery on other stocks of American shad along the East Coast. As the fish move further up the Bay, the more likely fishers are to be harvesting Delaware River stock but those fishers in the lower Bay area could also be harvesting significant numbers of shad from other river systems.

Commercial Landings

Commercial landings data for the Delaware Estuary can be found in Table 8.2. Delaware's commercial landings are estimated annually from mandatory commercial catch reports under the provisions enacted by the Delaware General Assembly in 1984. Every fisherman holding a commercial food-fishing license is required to submit a monthly report specifying where he fished, the type and amount of fishing gear deployed, and the pounds landed of each species taken for each day fished. Delaware Basin-specific landings data are unavailable prior to 1985.

The National Marine Fisheries Service (NMFS) estimated American shad landings in the Delaware River and Bay for the State of New Jersey through 1998. In 1999, NMFS estimates were combined with voluntary logbook data from New Jersey's commercial fishermen. Since 2000, the data have been collected via mandatory logbooks through the limited entry program. There are no estimates of underreporting in New Jersey's commercial fisheries; however, it is assumed that harvest in the upper reaches of Delaware Bay, prior to 2000, was actually higher than the NMFS data suggests due to lack of sampling by NMFS. This can be evidenced by New Jersey's mandatory logbook data since 2000 that indicate the five highest landing years occurred during this time period, with a peak of more than 90,000 pounds in 2004.

Landings data for the Delaware Basin should be used with caution since New Jersey landings are most likely underreported prior to 1999 and there are no estimates of harvest for the State of Delaware before 1985. In recent years, landings declined from the peak of 638,185 pounds in 1990 to a low of only 87,127 pounds in the drought year of 2002. The majority of years since the early 1990s have been below average when compared to the time series since 1985, when data were first available for both states.

Landings can be further partitioned by area to determine the amount of harvest on the Delaware stock (Table 8.3; Figure 8.2). Shad harvested in the Delaware River or Upper Bay area are considered to be mostly Delaware stock while those from the Lower Bay areas are mixed stock and the origin of these fish may vary annually. The fisheries of lower Delaware Bay are further discussed in the mixed stock fishery section of the overall assessment. Although the shad harvest has declined throughout the lower section of the estuary since 1990, the reported landings have increased in the upper Delaware Bay and River, due to mandatory reporting by New Jersey upper Delaware Bay fishers. The decrease in the lower Delaware Bay is a factor of the increase in the striped bass population, which are considered game fish in New Jersey and may not be harvested commercially.

Sex ratios for the commercial fisheries in New Jersey are compared in Table 8.4. These ratios are somewhat misleading due to the fact many male shad are discarded because of their low market value or because fishermen have already harvested enough shad to fulfill their crab bait needs. The ratio of females to males in New Jersey's gill-net fishery has remained high except for 2002, although there has been a slight decrease in recent years. There is no immediate known reason for this decrease but it may be due to an increase in the percentage of bucks used for crab bait or fishers obtaining a better price in the marketplace. In contrast, male shad in the State of Delaware normally sell for around one dollar per pound and are generally not used as crab bait.

The sex ratios from the haul seine have varied without trend since 1997. Sample sizes are small and only represent fish that are harvested and not the overall sex ratio. Recent ratios are compared to data from the same area during mark-recapture operations in Section 8.9.3.

Estimation of Effort

Commercial fishing effort for Delaware is calculated from the mandatory monthly landings data using net yards as the indicator of measure. Net-yards were the yards of net fished on that day the landings occurred. Delaware does not require overall net dimensions from which square feet or square yards of net used could be determined. Effort data for New Jersey's commercial fishery are estimated from mandatory logbooks, which started in 2000. There are also a few years of voluntary reporting from 1996 to 1999. The logbooks require net length and depth statistics therefore effort estimates are presented in pounds per square foot of netting.

Effort data from Delaware and New Jersey are shown in Table 8.5 and Figure 8.3. Original catch-per-unit-effort (CPUE) for Delaware were calculated using all Delaware Bay and River fishermen. The data were partitioned to examine the in-river CPUE as well as a revised CPUE estimate of the Delaware River drift-net fishery to determine a time period when shad catches were typically the greatest. The CPUE from this time period was then used to determine possible trends in stock abundance. There are also four estimates for New Jersey, including an overall CPUE for the Delaware Bay, which was partitioned to show estimates for the upper and lower Delaware Bay areas. The last estimate is for the Lewis haul seine fishery in Lambertville; this dataset has the longest time series of any dataset in the assessment (1925-2005).

The overall Delaware CPUE varied without trend until 2002, then increased in recent years, while both the revised drift net and in-river CPUEs peaked in the early 1990s and then decreased throughout the rest of the time series. By contrast, the New Jersey commercial gill-net fishery in the upper bay showed an increase in CPUE from 1999 to 2004 with a slight decrease in 2005. The other gill-net CPUEs have generally varied without trend throughout the time period.

The Lewis haul seine fishery records date back to 1890. Effort data has been documented since 1925. The fishery employs seine nets of different length depending on the water flow and depth. Although this may be problematic, the length of the time series still gives a good indication of spawning run strength in the Delaware River (Table 8.6; Figure 8.4). The Lewis haul seine fishery CPUE averaged 4.64 shad per haul from 1935 to 1947 but declined to an average of only 0.67 shad per haul through 1960. The CPUE started to increase steadily in the early 1970s to its peak in 1992 before declining drastically to the low levels of today.

Size, Age and Repeat Spawning Data

Length data are collected from commercial fisheries by the States of Delaware (gill net in Delaware Bay and River) and New Jersey (haul seine in the Delaware River). Although age and repeat spawning was determined for shad collected from these surveys, the data were not used for the Delaware River assessment. Without confidence in the scale ageing technique (Cating 1953), the SASC agreed that alternative methods would be preferable to assess the Delaware River stock. Also, scale samples and associated age data collected from the Delaware Bay commercial fishery were not necessarily from the Delaware River stock so these data were also eliminated from the data analysis. However, any changes in size structure from these commercial fisheries may show trends for the Delaware stock as well as the overall coastal American shad stock.

Mean length data of the commercial fisheries, along with comparisons to data from fishery-independent surveys are found in Section 8.10.

8.8.2 Recreational Fishery

The majority of recreational fishing effort for American shad in the Delaware River occurs along a 160-mile stretch from Trenton, New Jersey to Hancock, New York. This fishery takes place generally from late March to early June of each year.

The recreational shad fishery fluctuates with the changing population of shad that return during their spawning run. During the 1970s, as the shad population increased, so did the recreational fishery. This continued through the mid-1990s but the effort has decreased in recent years due to the population decrease.

Many recreational surveys have been conducted within the Delaware River by various entities for different reasons and with different methodology since 1965. Two comprehensive angler utilization surveys were conducted in 1985 and 1996 in the non-tidal portion (approximately 200 miles) of the

Delaware River while an access point survey in conjunction with an aerial effort survey was conducted by Versar, Inc. in 2002 (Volstad *et al*. 2003). The 2002 survey was conducted to estimate effort, catch, and harvest of American shad and other species targeted by anglers in the Delaware River during mid-March through October 2002. The study area included all tidal and non-tidal waters from the Delaware Memorial Bridge to Downsville, New York. Of the 279 miles of river included in the survey, approximately 64 miles were influenced by tidal flow.

Recreational data from all surveys can be found in Table 8.7 and Figure 8.5, along with a combined CPUE from two recreational fishing guides in the upper reaches of the Delaware. Although not comprehensive, the data does give some insight into the recreational fishery over time with estimates of catch, harvest, effort, and male to female ratios. Length frequencies of the 2002 harvest can be found in Figure 8.6. The guide CPUE will be compared to other analysis later in this assessment.

8.8.3 Characterization of Other Losses

Losses associated with poaching and hook and release mortality for Delaware River are largely unknown. The most recent catch of American shad was estimated at 35,281 fish (RSE = 22%) in 2002. The estimated number released was 28,654 fish (81%). Mortality rates of these recreationally caught and released American shad are unknown in the Delaware River.

There have been at least two studies which developed estimates of hook and release mortality in the Susquehanna River (Lukacovic 1998) and Hudson River (USFWS/NYDEC 2000; NYDEC, pers. comm.). These studies produced estimates of release mortality less than two percent. Based on those results and the proximity of those systems to the Delaware River the SASC estimated the number of American shad lost to hook and release mortality in 2002 to be approximately 573 fish.

8.9 FISHERY-INDEPENDENT SURVEYS

8.9.1 Juvenile Indices

New Jersey has conducted juvenile abundance monitoring in the Delaware River since 1980 (Table 8.8; Figure 8.7). A monitoring program (300-foot bagless beach seine) for juvenile American shad is conducted in the upper Delaware River during August, September, and October at representative stations (Trenton, Byram, Phillipsburg, Delaware Water Gap, and Milford). No sampling was conducted at the Byram station during 2000 through 2004 due to heavy siltation. This station was eliminated from the program since a suitable replacement beach was not located. The original geometric means were revised for the 1980 to 2005 time period to reflect this change.

In the lower portion of the Delaware River (from Trenton to Artificial Island), data are collected during the annual striped bass recruitment survey (100 foot bagged beach seine), during a similar time period as the upper Delaware River survey. Each juvenile abundance index (JAI) is calculated using a geometric mean. Previous reports have used all of the stations from this survey even though shad do not commonly occur in some areas. The stations farthest downriver of this sampling program have been removed for this assessment to give a more accurate picture of juvenile production in the lower Delaware River.

The upper juvenile CPUE has remained fairly stable and shows a dominant year class in 1996 with additional large year classes in 1990, 1986, 1997, 1987, 1993, and 2005. Production seemed to be poor in the early years of the survey with additional poor year classes in 2002, 1998, 1992, and 1994. Juvenile production below Trenton was virtually non-existent prior to 1989. Since that time, the index has also remained fairly stable except for a dominant year class in 1996, and has correlated well with the data from the upper Delaware River since 1994 (Figure 8.8). Other year classes to note include good juvenile production years (2000, 2003, 1989, and 2005) as well as the poor year during the drought of 2002.

Delaware has conducted a juvenile fish trawl survey since 1978. The survey was originally designed to monitor blue crab abundance in the Delaware Bay but was expanded to include juvenile fish beginning in 1980. In 1989, six stations were added in the lower Delaware River upstream of the Chesapeake and Delaware Canal to better monitor year class strength of juvenile striped bass and other anadromous fish. Stations are sampled monthly from April through October using a 16-ft otter trawl towed for 10 minutes. As with the other surveys, the trawl JAI is calculated using a geometric mean. The mean catch per tow of both young-of-year (YOY) and age-1 American shad is presented in Table 8.9.

Bottom trawl surveys are not an efficient method for taking juvenile alosines and estimating abundance although they may allow for qualitative evaluation of recruitment and survival. Examination of catch rates by station and month were used to determine the spatial and temporal distribution of the species. The months of April and May were used to calculate an age-1 index. October was considered the month that YOY recruited to the survey.

8.9.2 Length Frequency

Sub-samples of juvenile American shad from the upper Delaware River sampling survey were measured to determine length frequency (fork length) since 1980 (Figure 8.9). The time series has varied without trend with the largest mean length in 1980 and the smallest in 2004. There appeared to be an inverse relationship between year class strength and mean size of YOY American shad in the upper Delaware River (Figure 8.10), but it was not significant (r^2= 0.2967).

8.9.3 Adult Data

Data are collected on adult American shad during the spring spawning run within the Delaware River and also the Lehigh River. Fishery-independent data include a population index estimated from tag and release programs and hydroacoustic passage. The actual population estimates (Table 8.10), especially those calculated from hydroacoustic sampling, have come under scrutiny in recent years. Other independent data include gill-net CPUE in the upper Delaware, and fish counts and CPUE from the first dam on the Lehigh River.

An index of population abundance (Table 8.11; Figure 8.11) was derived through mark-recapture techniques (1975 to 1992) and hydroacoustic monitoring (1992 to 2005). Although the estimates should not be used as absolute indices of adult abundance in the Delaware, the population index is offered here to determine usefulness and potential correlation with other indices. One major problem regarding the population estimates is that they only take into account shad that pass the Route 202 Bridge in Lambertville, New Jersey (rm 149.7). It should be noted that spawning does occur in the Delaware River below the Route 202 Bridge. The extent and magnitude of spawning in tidal waters is unknown at this time.

Another limitation of the population estimates is the removal of shad by both the recreational and commercial fisheries in the Delaware Bay and lower Delaware River areas below the sampling location. To magnify the problem, the amount of the commercial harvest that occurs in this area most likely contains fish from other systems. The reverse is true for shad taken in mixed stock fisheries in coastal waters prior to the closure of ocean fisheries in 2005. Mark-recapture estimates from various shad tagging programs in mixed stock coastal waters found that the mixed assemblages of shad were composed of between 0 and 47.4 percent of Delaware River stock origin in any given year.

Hydroacoustic estimates of the shad population have triggered additional problems with regards to accurately depicting the Delaware River stock. The program was initiated in 1992 and has been completed every year since 1998. Methodology and assumptions have changed somewhat throughout the time period but all estimates from 1992 to the present are now based on the latest assumptions.

The accuracy of the hydroacoustic population estimates has been questioned as a result of the assumptions inherent in the model. The consensus of the Basin states is that the estimates should be used for relative trend analysis only and not absolute estimates of abundance. The controversial assumptions include: transducers potentially marking other species of fish (gizzard shad, striped bass, etc.); American shad swim speed (assumed to be about 1.0 m/sec); transducer coverage of the water column; possible double counting of shad milling in the study area or post spawn downrunners; mean size changes over time; and shad being repulsed by the hydroacoustic equipment.

Although some of these topics have been addressed, there is enough uncertainty involved to cause the SASC to look at other potential indicators of run strength. The SASC also looked at CPUE data from the hydroacoustics including weighted mean unit densities (WMUD), geometric means of the daily shad passage, and number of shad marked per hour of hydroacoustic operation (CPUE). These estimates are found in Table 8.12 and Figure 8.12.

The WMUD is calculated by taking the sum of the mean target density per stratum multiplied by the corresponding stratum weight. This is described as stratification with proportional allocation and results in a self-weighted sample. The WMUD is then used to calculate the actual population estimate. Geometric means were calculated three different ways including all days of operation, only April and May, and first day of shad arrival until the last day they are recorded.

American shad counts were made at the Easton Dam fish ladder on the Lehigh River starting in 1995 (Table 8.13). Installing a lighting system and crowding rack to force fish closer to the counting window has enhanced precision in the turbid and shady conditions. Fish passage was monitored by video camera set to record one frame every 0.6 or 1.0 second (s). Most recordings were made at one frame every 0.6 s, with the 1.0 s mode used only for the beginning and end of the migration. Counts were made by viewing the entire videotape, during the entire run from mid-April through June. Frame by frame manipulation of the videotape allowed a complete count of all fish passing the viewing window. A CPUE (number of shad per hour) for the Easton lift is also calculated and included in Table 8.13 and Figure 8.13.

The PFBC collected samples of the Delaware adult population using gill nets gear at Smithfield Beach (rm 218, 1997-2005) and electrofishing gear at Raubsville (rm 176.6, 1998-2001). At Smithfield Beach, approximately thirteen to fourteen 200-foot gill nets were set per night with mesh sizes ranging from 4.5 to 6.0 inches (stretch). Nets were anchored on the upstream end and allowed to fish parallel to shore in a concentrated array. Attributes measured include length, weight, age, gender, repeat spawning, and hatchery marks. Gill net collections efficiently provided the largest sample for biological information and also provided brood fish for restoration needs. At Raubsville, electrofishing runs were conducted from 1997 through 2001. The river was sampled 4 to 5 times from April to May with one electrofishing event per week. Sampling events were terminated when 15 American shad were caught or after one hour of electrofishing, whichever came first.

Catch-per-unit-effort data were calculated as the number of shad per foot net hour multiplied by 10,000 for Smithfield Beach and is located with the Easton data in Table 8.13 and Figure 8.13. Since the electrofishing time series lasted only four years a CPUE was not included in this assessment. Sex ratios and mean length of the catch for both gill-net and electrofishing collections are detailed in Table 8.14. Generally, electrofishing collections yielded annual catches with proportions of males to females approaching equal numbers while females tend to dominate during annual gill-net operations. Because of the sex ratio tendencies of the gear, mean length also differs throughout the time period when both surveys were conducted. Mean lengths are compared with commercial fishery data later in this assessment.

Additionally, the adult sampling examined shad otoliths to confirm presence of tetracycline hatchery marks. A total of 2,518 fish were examined from 1997 to 2005 with 93 otoliths containing marks (Table 8.15). This confirms that the hatchery program has been supplementing natural production, although at low levels for most years.

Age Composition

The SASC initially used all available data knowing that there are limitations and controversy attached to some of the data inputs. The first and probably most crucial decision regarding the data inputs was the elimination of all age data from the Delaware River assessment. Without confidence in these ageing techniques, the SASC agreed that alternative methods would be preferred to assess the Delaware River stock of American shad.

Tagging

New Jersey initiated American shad tagging in Delaware Bay as part of the ASMFC Interstate Cooperative Tagging Program in 1995, utilizing drifting gill nets during February through May of each year. Tagging was performed at Reed's Beach located in Cape May County, a short distance from ocean waters. A total of 4,019 American shad were marked from 1995 to 2005 (Table 8.16). Through June 5, 2005, there have been 240 American shad returns reported (5.97% of tagged fish). The reported range for recaptured American shad tagged in Delaware Bay was from the Santee River in South Carolina to the St. Lawrence River near Quebec, Canada. Additional information can be found in Section 1. These tagging efforts indicate that shad taken in this portion of Delaware Bay are of mixed origin. However, the proportion of out-of-basin shad throughout the Bay and River undoubtedly changes depending on location relative to river mile upstream.

8.10 ASSESSMENT APPROACHES AND RESULTS

The main purpose of the assessment is to determine the status of the Delaware stock of American shad since the last ASMFC assessment conducted in 1998. To accomplish this, the SASC analyzed as many data trends as possible. Some datasets, such as landings from a commercial haul seine fisherman, date back to the 1800s, while more recent independent data only date back to the 1990s. It is obvious from historical data that the American shad population had declined drastically since the late 1800s and continued at a depressed level until the early 1970s. Although some long-term data series such as the Lewis haul seine fishery and landings data are available for analysis in this assessment, a comparison period of 1975 to 2005 was chosen for this analysis since at least two datasets have relatively reliable estimates for this period.

While the ageing data were eliminated from the Delaware River assessment because of a lack of confidence in the ageing techniques, the SASC initially used all other available data knowing that there are limitations and controversy attached to some of the data inputs, especially population estimates.

The SASC used two simple tests to look at the linear relationships among the indices:

1. Pearson product moment coefficient of correlation (r)
2. Coefficient of determination or goodness of fit (r^2): the proportion of variation in one index explained by the variation in the other index

A cutoff of 0.5 was used for both correlation tests since less than 50% agreement between data series is equivalent to random chance. Pearson and R-Square correlations were run to determine which datasets provided some aspect of reliability with each other and to eliminate datasets with limited usefulness. Comparisons of adult abundance, juvenile abundance indices, and CPUE data resulted in a suite of trends that the SASC considered to be reliable indicators of shad stock abundance for the Delaware system since 1975.

All estimates were standardized (Z-transformed) with a value of two added to eliminate any negative numbers. Two estimates of adult shad abundance (Lewis haul seine fishery CPUE and the index of population) were compared with each other and also averaged together as an indicator of the spawning run (Figure 8.14). The results show a population increase from the lows of the late 1970s to a peak abundance level in 1989. This was followed by a significant decrease in abundance through 1994. The adult abundance estimates have continued to decline and are currently at levels equivalent to the early 1980s. It should be noted that methodologies have changed over time for the population index and therefore may be a factor in the magnitude of the decline.

Other indices of the adult population with relatively long time series of data have also shown a recent decline in abundance. The recreational CPUE (1979-2000, not continuous) and the revised Delaware commercial CPUE (1989-2005) peaked in the early 1990s only to decline in later years (Figure 8.15). The revised Delaware CPUE was determined from commercial landings that occurred during the three years that the striped bass fishery was closed (1985, 1988, and 1989) to determine the period when American shad catches were the greatest. Examination of the data showed that the landings were the greatest between April 1 and April 26. The CPUE of commercial drift-net landings in other years during that time period when both shad and striped bass could be landed was considered to more accurately reflect trends in abundance of shad. There are a few other short time series datasets that are more difficult to analyze since the decline in adult abundance occurred prior to these indices being developed; however, most of these indices show a declining trend or have varied without trend in recent years. A few also show a slight upswing in adult shad abundance in 2001. This could be a result of the 1996 year class, which was the highest ever for the two YOY seine surveys.

The SASC analyzed various datasets to determine potential causes of the decline including overfishing and striped bass predator-prey interactions. The first step was to determine if there was a problem with juvenile shad production. The SASC examined YOY data to determine if recruitment was a factor in the decline during the mid 1990s. The New Jersey juvenile abundance indices were Z-transformed with a value of two added to eliminate any negative numbers and averaged to obtain a better comparison. The index trend increased from 1980 through 1996 and varied without trend through the present (Figure 8.16). This indicates that the Delaware River has not experienced major problems with juvenile production through the decline in adult abundance to the present.

Pearson product-moment correlation analysis of the Delaware trawl data revealed no significant correlation between the shad YOY and age-1 indices. Indices were probably highly influenced by gear selectivity and seasonal or annual changes in salinity patterns. The indices may complement other surveys in the Estuary, particularly in years of low salinity when the species may disperse lower in the Estuary.

To determine if spawning stock size was related to YOY production, values of Z-transformed adult abundance for 1980 to 2005 were compared with the Z-transformed JAI for the same time period (Figure 8.17). The analysis shows no significant relationship between juvenile production and observed adult abundance. The SASC lagged the Z-transformed YOY data (1980-2000) to determine if the JAI was related with returning adults (1985-2005) five years later (Figure 8.18). Once again no significant correlation was found between YOY cohorts and returning adults Since there did not seem to be a relationship between YOY and adult abundance, the only conclusion that can be made is that YOY production has been stable throughout the time series and does not appear to be a factor in stock decline but additional information is needed to make any clear conclusions.

The SASC also examined data to determine if the decline in adult shad abundance during the 1990s 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.

For this assessment, 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 (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 (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 (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 for 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 a predator-prey relationship. Analysis of American shad 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 (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 (Figure 8.23). Analysis 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-shad interactions.

The striped bass-American shad analyses show that when shad YOY production is high, there are ample striped bass around 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. It 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.

Comparisons of length data collected from commercial fisheries by the States of Delaware (gill net in Delaware Bay) and New Jersey (haul seine in Delaware River), as well as from two independent sources by the State of Pennsylvania in the upper Delaware River are found in Figures 8.24 (males) and 8.25 (females). Although age and repeat spawning was determined for shad collected from all of these surveys, the data were not used for this assessment of the Delaware River. Also, scale samples collected from the Delaware Bay commercial fishery are not necessarily from the Delaware River stock so the were not included in this assessment. However, any changes in size structure from the commercial fishery may show trends for the overall coastal American shad stock.

Mean total length of shad taken during tagging operations in the Delaware River (1979-1983) was compared with more recent collections of shad throughout the Delaware Estuary. Original fork lengths of early data were converted to total length based on shad lengths collected during 1995 to 2005 shad tagging in Delaware Bay using the regression formula:

$$TL = 1.027*FL + 50.664$$

Recent mean lengths of males collected from the various commercial fisheries and independent sampling appear to show no major differences in the two sampling periods. However females collected during recent harvest from the Lewis haul seine fishery are somewhat smaller than those from the 1979 to 1983 time period. Tagging operations during 1979 through 1983 were performed in the same manner as the

Lewis haul seine fishery today. Other recent trends of American shad total length somewhat mirror the later Lewis length data, except for the collections taken by gill net at Smithfield Beach. Differences in annual mean lengths for seine, electrofishing, and gill net caught shad can vary widely due to many conditions especially the selective properties of the gear. It is crucial to remember that independent sampling operations usually measure all fish caught while commercial sampling only collects data from harvest.

8.11 BENCHMARKS

It is clear from Lewis haul seine CPUE (Table 8.6, Figure 8.4), recreational fisheries data (Table 8.7, Figures 8.5 and 8.15), adult abundance indices (Table 8.11, Figures 8.11 and 8.14), and Delaware commercial CPUE (Figure 8.15), that the Delaware River shad stock has declined through the 1990s and remains at low levels. Despite this decline, recruitment failure has not occurred (Table 8.8, Figure 8.7), nor is there evidence to suggest that in-river fishing mortality is the cause of the stock decline.

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. For example, the Lewis haul seine fishery is the longest running CPUE of commercial fisheries in the Delaware River. It was suggested that the a benchmark of four (4) fish per haul for three consecutive years be used as a trigger to reduce harvest while a thirty (30) fish per haul trigger be used for relaxation of the regulations. There are many caveats surrounding the data set however, such as variable net length and effort, that the SASC was uncomfortable using the CPUE as a stand alone benchmark.

Other examples of CPUEs for the Delaware River included in this document:

- Six commercial fishery CPUEs from the Delaware River and Bay (Table 8.5, Figure 8.3)
- Three CPUE estimates from the recreational fishery (Table 8.7, Figure 8.5)
- Estimates of YOY abundance (Table 8.8, Figures 8.7 and 8.16)
- Index of population abundance (Table 8.11, Figure 8.11)
- Abundance CPUEs from hydroacoustic monitoring (Table 8.12, Figure 8.12)
- CPUEs from the Smithfield Beach gill netting and the Lehigh River fish ladder at Easton (Table 8.13, Figure 8.13)

Several of these indices do not use a consistent methodology and may reflect a recent change in methodology or the index itself may not be available in the future 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 reviewers 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.

8.12 CONCLUSIONS AND RECOMMENDATIONS

The SASC looked at trend data from more than twenty-five sources including fishery-independent and fishery-dependent datasets. Some data, such as landings from a commercial haul seine fisherman, date back to the 1800s while more recent independent data only date back to 1999. Commercial data included harvest estimates from the Delaware Estuary, Delaware River, and Lewis haul seine fishery. There were also estimates of CPUE from the haul seine fishery and gill-net fishery for both Delaware and New Jersey. Recreational fishery data were limited to logbook data during years of population estimates, and some recent trends from shad guide fishermen in the upper Delaware River.

Fishery-independent data included estimates of the population from tag and release programs and hydroacoustic passage. Many of the population estimates have come under scrutiny in recent years. However, population indices were used in this assessment to determine their usefulness and potential correlation with other indices. Other independent data included gill-net CPUE in the upper Delaware River and fish counts and CPUE from the first dam on the Lehigh River, a major tributary of the Delaware River. There are three surveys that collected data on YOY including a seine survey in the upper Delaware River that specifically targeted American shad. Another seine survey targets YOY striped bass in the lower Delaware River but also collected large numbers of shad and correlated well with the upper river survey since 1994. The third index was derived from a trawl survey in the lower river and also collected data on yearling shad.

It is evident that the Delaware River stock of American shad declined through the 1990s and remains at low levels. The majority of analyses conducted by the SASC produced results that were consistent with the hypothesis of stock decline. There does not seem to be an identifiable cause of the decline nor an indication as to why the stock has remained at low levels in recent years. Adult shad indices exhibited a significant decrease in abundance through the mid 1990s to levels equivalent to the late 1970s. The cause of the decline has not been identified, nor is there an indication as to why the stock has remained at low levels in recent years.

Juvenile production increased from 1980 through 1996 and has since varied without trend. There does not appear to be a correlation between juvenile abundance and returning adults in subsequent years. The SASC analyzed data from striped bass surveys and compared them to the adult and YOY shad data. Although some analyses show potential interactions between shad and striped bass, there are no empirical data to attribute the shad decline in the Delaware River solely to striped bass as in Connecticut River.

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.
- The Delaware River Basin Cooperative's Technical Committee reviews this assessment for guidance in developing a new management plan for the Delaware River Basin.
- Continue to stock tributaries to the Delaware River with fish from the Delaware system.

LITERATURE CITED

ASMFC (Atlantic States Marine Fisheries Commission). 1998. American Shad Stock Assessment. ASMFC, Peer Review Report, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 1999. Amendment 1 to the Interstate Fishery Management Plan for Shad and River Herring. Washington, D.C.

Cating, J.P. 1953. Determining age of American shad from their scales. U.S. Fish Wildlife Service, Fishery Bulletin 54(85):187-199.

Chittenden, M.E. Jr. 1974. Trends in the abundance of American shad, *Alosa sapidissima*, in the Delaware River basin. Chesapeake Science 15 (2):96-103.

Crecco, V. and M. Gibson. 1988. Methods of estimating Fishing Mortality Rates on American Shad Stocks Appendix B. In ASMFC (Atlantic States Marine Fisheries Commission) 1988 supplement to American Shad and River Herrings Fishery Management Plan October. Washington, D.C.

Delaware River Fish & Wildlife Management Cooperative. 1982. A Fishery Management Plan for the American Shad (*Alosa sapidissima*) in the Delaware River Basin – June 1982. Dover, Delaware.

Gay, J. 1892. The shad streams of Pennsylvania. *In* Report of the State Commissioners of Fisheries for the years 1889-90-91. Harrisburg, Pennsylvania.

Gibson, M.R., V.A. Crecco, and D.L. Stang. 1988. Stock assessment of American shad from selected Atlantic coastal rivers. Atlantic States Marine Fisheries Commission, Special Report 15, Washington, D.C.

Hendricks, M.L., T.R. Bender, Jr. and V.A. Mudrak. 1991. Multiple marking of American shad otoliths with tetracycline antibiotics. North American Journal of Fisheries Management 11:212-219.

Hendricks, M.L. 1995. The contribution of hatchery fish to the restoration of American shad in the Susquehanna River. Pages 329-336 *in* H. L. Schram, Jr., and R. G. Piper, editors. Uses and effects of cultured fish in aquatic ecosystems. American Fisheries Society, Symposium 15. Bethesda, Maryland.

Hendricks, M.L., R.L. Hoopes and D.A. Arnold. 2002. Homing of Hatchery reared American Shad to the Lehigh River, a tributary to the Delaware River. North American Journal of Fisheries Management 22:243-248.

Howey, R.G. 1985. Intensive culture of juvenile American shad. Progressive Fish Culturist 47: 203-212.

Lukacovic, R. 1998. Mortality of American Shad (*Alosa sapidissima*) caught and released by Anglers below Conowingo Dam. Maryland Department of Natural Resources Fisheries Service, Fisheries Technical Report Series 21 Annapolis, Maryland.

McBride, R.S., M.L. Hendricks and J.E. Olney. 2005. Testing the validity of Cating's (1953) method of age determination of American shad using scales. Fisheries 30(10):10-18.

Sykes, J.E. and B.A. Lehman. 1957. Past and present Delaware River shad fishery and considerations for its future. U.S. Fish and Wildlife Service, Research Report 46:25. Washington, D.C.

USFWS (United States Fish and Wildlife Service) and NYDEC (New York Department of Environmental Conservation). 2000. Mortality Associated With Catch and Release of American Shad and Striped Bass in the Hudson River. Washington, D.C.

Volstad, J.H., W. Richkus, J. Miller, A. Lupine, and J. Dew. 2003. The Delaware River Creel Survey 2002. Pennsylvania Fish and Boat Commission, Versar Inc. Columbia, Maryland.

Wiggins, T.A., T.R. Bender, Jr., V.A. Mudrak, J.A. Coll and J.A. Whittington. 1986. Effect of initial feeding rates of *Artemia* nauplii and dry-diet supplements on the growth and survival of American shad larvae. Progressive Fish-Culturist 48:290-293.

Table 8.1 Number of American shad larvae stocked in the Delaware River Basin, 1985-2005.

Year	Delaware	Schuylkill	Lehigh
1985		251,980	600,000
1986		246,400	549,880
1987		194,575	490,730
1988			340,400
1989		316,810	833,170
1990		285,100	2,087,700
1991		75,000	793,000
1992		3,000	353,000
1993			789,600
1994			642,200
1995			1,044,000
1996			993,000
1997			1,247,000
1998			948,000
1999		410,000	501,000
2000		535,990	447,390
2001		490,901	675,625
2002		2,000	85,025
2003		1,000,448	783,013
2004		421,583	366,414
2005	169,802	545,459	668,792
Total	**169,802**	**4,779,246**	**15,238,939**

Table 8.2 Commercial landings (lbs) of American shad in the Delaware River Basin, 1954-2005.

YEAR	NJ	DE	Total
1954	8,400	-	**8,400**
1955	5,200	-	**5,200**
1956	6,700	-	**6,700**
1957	7,300	-	**7,300**
1958	38,100	-	**38,100**
1959	18,500	-	**18,500**
1960	12,400	-	**12,400**
1961	92,800	-	**92,800**
1962	71,800	-	**71,800**
1963	66,700	-	**66,700**
1964	134,400	-	**134,400**
1965	150,300	-	**150,300**
1966	93,500	-	**93,500**
1967	84,100	-	**84,100**
1968	35,500	-	**35,500**
1969	4,500	-	**4,500**
1970	9,400	-	**9,400**
1971	6,600	-	**6,600**
1972	10,300	-	**10,300**
1973	12,800	-	**12,800**
1974	8,900	-	**8,900**
1975	5,600	-	**5,600**
1976	18,800	-	**18,800**
1977	29,600	-	**29,600**
1978	31,400	-	**31,400**
1979	17,500	-	**17,500**

YEAR	NJ	DE	Total
1980	50,600	-	**50,600**
1981	67,600	-	**67,600**
1982	134,000	-	**134,000**
1983	53,600	-	**53,600**
1984	49,300	-	**49,300**
1985	72,000	168,483	**240,483**
1986	81,600	179,518	**261,118**
1987	129,600	180,582	**310,182**
1988	98,000	229,302	**327,302**
1989	79,300	187,787	**267,087**
1990	253,113	385,072	**638,185**
1991	173,301	364,385	**537,686**
1992	155,800	220,014	**375,814**
1993	142,980	233,449	**376,429**
1994	50,371	196,140	**246,511**
1995	73,432	146,328	**219,760**
1996	18,663	165,474	**184,137**
1997	43,799	116,516	**160,315**
1998	14,255	80,974	**95,229**
1999	88,706	76,184	**164,890**
2000	121,431	53,877	**175,308**
2001	96,138	201,829	**297,967**
2002	48,417	38,710	**87,127**
2003	90,520	62,422	**152,942**
2004	59,470	96,546	**156,016**
2005	87,984	123,610	**211,594**

Table 8.3 Delaware Basin American shad commercial landings (lbs), by area, 1985-2005.

Year	River/Upper Bay	Other Bay	All
1985	52,397	188,086	240,483
1986	46,322	214,796	261,118
1987	30,640	279,542	310,182
1988	41,713	285,589	327,302
1989	29,049	238,038	267,087
1990	56,379	581,806	638,185
1991	34,807	502,879	537,686
1992	51,012	324,802	375,814
1993	32,560	343,869	376,429
1994	23,413	223,098	246,511
1995	26,104	193,656	219,760
1996	11,195	172,942	184,137
1997	17,723	142,592	160,315
1998	8,122	87,107	95,229
1999	7,725	157,165	164,890
2000	50,166	125,142	175,308
2001	72,775	225,197	297,972
2002	35,256	51,871	87,127
2003	88,946	63,996	152,942
2004	95,088	92,463	187,551
2005	47,220	164,374	211,594
Mean	**40,886**	**221,858**	**262,744**

Table 8.4 Sex ratios of New Jersey's commercially caught American shad in the Delaware Basin, 1996-2005.

Year	New Jersey (Bay)		New Jersey (River)	
	% Roe	% Buck	% Roe	% Buck
1996	-	-	-	-
1997	-	-	55.9	44.1
1998	-	-	55.9	44.1
1999	82.6	17.4	67.2	32.8
2000	86.0	14.0	29.8	70.2
2001	83.8	16.2	64.0	36.0
2002	69.4	30.6	72.7	27.3
2003	80.3	19.7	71.5	28.5
2004	77.9	22.1	56.6	43.4
2005	73.9	26.1	49.3	50.7

Table 8.5 CPUE from Delaware Bay and River commercial fisheries, 1989-2005.

Year	DE lb/yd all	DE RIV (lb/yd)	DE Riv lb/yd revised	NJUpper (lbs/sqft)	NJLower (lbs/sqft)	NJALL (lbs/sqft)
1989	0.398	0.350	56.40			
1990	0.395	0.290	30.50			
1991	0.276	0.260	11.10			
1992	0.183	0.280	78.60			
1993	0.280	0.370	53.30			
1994	0.275	0.340	34.90			
1995	0.203	0.310	26.50			
1996	0.272	0.160	15.60	0.014		
1997	0.263	0.220	27.80	0.007		
1998	0.211	0.250	28.60	0.006	0.017	0.016
1999	0.231	0.070	7.30	0.007	0.027	0.020
2000	0.188	0.190	20.80	0.014	0.015	0.019
2001	0.473	0.100	5.80	0.022	0.022	0.015
2002	0.141	0.160	7.70	0.013	0.010	0.020
2003	0.326	0.160	17.00	0.022	0.012	0.023
2004	0.303	0.110	9.57	0.025	0.029	0.019
2005	0.309	0.030	3.92	0.015	0.019	0.019

Table 8.6 CPUE (fish/haul) of American shad caught in the Lewis haul seine fishery, 1925-2005.

Year	# Hauls	# Shad Caught	CPUE (hauls)	Year	# Hauls	# Shad Caught	CPUE (hauls)
1925	458	742	1.62	1966	44	77	1.75
1926	208	661	3.18	1967	65	243	3.74
1927	436	1061	2.43	1968	27	33	1.22
1928	543	2174	4.00	1969	29	90	3.10
1929	616	2706	4.39	1970	25	122	4.88
1930	362	470	1.30	1971	54	664	12.30
1931	501	887	1.77	1972	64	348	5.44
1932	450	1442	3.20	1973	69	496	7.19
1933	420	2325	5.54	1974	49	417	8.51
1934	520	1796	3.45	1975	117	1738	14.85
1935	328	4417	13.47	1976	123	1470	11.95
1936	392	951	2.43	1977	110	1120	10.18
1937	448	4161	9.29	1978	121	1226	10.13
1938	693	3240	4.68	1979	107	2003	18.72
1939	506	4439	8.77	1980	148	1920	12.97
1940	170	611	3.59	1981	118	6392	54.17
1941	162	129	0.80	1982	127	3789	29.83
1942	193	1096	5.68	1983	100	1444	14.44
1943	215	3025	14.07	1984	152	2383	15.68
1944	45	226	5.02	1985	69	2022	29.30
1945	144	295	2.05	1986	99	3036	30.67
1946	118	254	2.15	1987	111	1830	16.49
1947	358	1358	3.79	1988	78	2778	35.62
1948	59	43	0.73	1989	89	4646	52.20
1949	32	3	0.09	1990	92	2332	25.35
1950	51	9	0.18	1991	76	2312	30.42
1951	38	25	0.66	1992	94	4790	50.96
1952	43	27	0.63	1993	33	347	10.52
1953	31	0	0.00	1994	49	387	7.90
1954	26	9	0.35	1995	66	1257	19.05
1955	43	36	0.84	1996	57	209	3.67
1956	32	0	0.00	1997	46	550	11.96
1957	12	10	0.83	1998	49	647	13.20
1958	18	54	3.00	1999	43	198	4.60
1959	24	27	1.13	2000	45	183	4.07
1960	19	6	0.32	2001	32	219	6.84
1961	26	90	3.46	2002	52	200	3.85
1962	18	250	13.89	2003	56	293	5.23
1963	70	3983	56.90	2004	54	220	4.07
1964	90	1646	18.29	2005	36	104	2.89
1965	48	319	6.65				

Table 8.7 Recreational fisheries data from various sources for the Delaware River, 1965-2005.

Year	Catch	Harvest	Effort(#/hr)	Effort(#/trip)	Guide CPUE
1965	5,318			0.10	
1971	25,000			0.50	
1974	43,200			0.60	
1979			0.38		
1980			0.47		
1981	12,767		0.67	2.67	
1982	19,188	10,563			
1983			0.60		
1986		16,099	0.19	0.86	
1986*	56,320	27,471	0.70	2.50	
1989			0.90		
1992	46,780	5,146	1.10	4.60	
1995*	83,141	16,387	0.25	1.05	1.43
1996					2.04
1997					
1998					1.86
1999					1.03
2000			0.77		1.65
2001					1.78
2002*	26,885	4,314	0.25	1.04	1.60
2003					1.03
2004					1.04

* Data from creel survey

Table 8.8 The American shad YOY CPUE (geometric mean) for the upper and lower Delaware River, 1980-2005.

Year	Upper River	Lower River
1980	1.2	0.00
1981	15.8	0.00
1982	40.6	0.00
1983	111.2	0.51
1984	68.9	0.16
1985	76.1	0.13
1986	149.1	0.68
1987	125.4	1.50
1988	63.7	0.54
1989	84.7	8.89
1990	154.7	5.44
1991	49.4	2.54
1992	35.9	6.01

Year	Upper River	Lower River
1993	124.4	5.66
1994	37.8	7.14
1995	70.1	5.19
1996	266	18.21
1997	130.4	3.04
1998	27.5	7.23
1999	71.1	7.07
2000	76.6	9.69
2001	65.5	5.45
2002	18.9	0.92
2003	61.9	9.73
2004	71.3	5.81
2005	123.7	7.90
Mean	**81.6**	**4.59**

Table 8.9 American shad YOY and age-1 trawl CPUE (geometric mean) for the Delaware River, 1990-2005.

Year	YOY	Age-1
1990	0.00	-
1991	0.86	0.05
1992	0.05	0.13
1993	0.15	0.25
1994	0.49	0.11
1995	0.19	0.32
1996	0.30	0.02
1997	0.05	0.17
1998	0.28	0.02
1999	0.00	0.04
2000	0.05	0.07
2001	0.00	0.00
2002	0.19	0.05
2003	0.00	0.00
2004	0.16	0.05
2005	0.00	0.00

Table 8.10 Delaware River American shad population estimates, 1975-2006.

Year*	Peterson Method	Schaffer Method	Hydroacoustic 1 Standard Method	Hydroacoustic 2 Alternate Method
1975	118,700 +/- 93,773			
1976	178,760 +/- 96,150	150,187		
1977	106,202 +/- 65,058	88,415		
1978	233,060 +/- 171,126			
1979	111,839 +/- 32,191	101,249		
1980	181,880 +/- 55,058	137,641		
1981	546,215 +/- 133,590	551,599		
1982	509,201 +/- 176,680	450,200		
1983	249,578 +/- 87,342	212,428		
1986	595,407 +/- 231,060			
1989	831,595 +/- 235,608			
1992	882,648 +/- 197,250	542,865	327,800 +/- 8,600	274,800 +/- 7,200
1995			289,900 +/- 9,600	264,900 +/- 8,800
1996			524,300 +/- 2,800	352,200 +/- 1,900
1998			392,700 +/- 2,500	289,400 +/- 1,700
1999			24,700 +/- 300	22,800 +/- 300
2000			382,200 +/- 2,700	283,600 +/- 2,000
2001			555,500 +/- 2,700	417,300 +/- 2,000
2002				399,200 +/- 1,800
2003				296,600 +/- 1,300
2004				75,500 +/- 500
2005				160,500 +/- 2,100
Mean	**378,757**	**279,323**	**356,729**	**245,900**

*Note: No estimates for 1984, 1985, 1987, 1988, 1990, 1991, 1993, 1994 and 1997.

1) Standard method: Assumes shad are found only in an area from one foot off of bottom to two feet below surface.
2) Alternate method: Assumes shad are found only in an area from one foot off of bottom to six feet above bottom.

Table 8.11 Delaware River American shad index of population (population estimates/1000), 1975-2006.

Year	Peterson	Schaffer	Hydroacoustic 1 Standard Method	Hydroacoustic 2 Alternate Method
1975	118.7			
1976	178.8	150.2		
1977	106.2	88.4		
1978	233.1			
1979	111.8	101.2		
1980	181.9	137.6		
1981	546.2	551.6		
1982	509.2	450.2		
1983	249.6	212.4		
1984				
1985				
1986	595.4			
1987				
1988				
1989	831.6			
1990				
1991				
1992	882.6	542.9	327.8	274.8
1993				
1994				
1995			289.9	264.9
1996			524.3	352.2
1997				
1998			392.7	289.4
1999			24.7	22.8
2000			382.2	283.6
2001			555.5	417.3
2002				399.2
2003				296.6
2004				75.5
2005				160.5
Mean	**378.8**	**279.3**	**356.7**	**257.9**

Table 8.12 Estimates of Delaware River American shad abundance from hydroacoustic monitoring, 1992-2005.

Year	Geo 1	Geo 2	Geo 3	WMUD	CPUE
1992				3.67E-04	
1995				2.75E-04	
1996				2.07E-04	
1998	14.94	14.94	19.41	1.71E-04	72.73
1999	6.75	6.75	11.16	1.50E-05	5.76
2000	10.03	10.03	64.62	1.66E-04	64.57
2001	46.49	47.58	72.43	2.35E-04	86.72
2002	31.12	34.08	43.46	1.97E-04	82.31
2003	73.71	403.69	79.19	1.35E-04	78.09
2004	53.06	91.26	75.87	3.39E-05	15.08
2005	38.43	84.16	46.53	9.14E-05	42.03

Geo 1: Includes all survey days in a given year
Geo 2: Includes only sample days from April and May
Geo 3: Includes only after first arrival to last counted
WMUD: Weighted mean unit density
CPUE: Number shad caught per number of hours

Table 8.13 Estimate of CPUE for the Smithfield Beach (Delaware River) gill net and Easton Dam fish ladder (Lehigh River) as well as fish counts at the Easton Dam.

Year	Easton CPUE	Smithfield Gill Net CPUE	Lehigh # Passed
1995	0.80		873
1996	0.97		1141
1997	1.30		1428
1998	2.52		3293
1999	2.00	31.60	2346
2000	1.57	37.36	2094
2001	3.43	34.51	4740
2002	3.09	23.43	3314
2003	0.51	37.93	375
2004	0.76	24.99	754
2005	0.73	56.28	675

Table 8.14 Mean total length (mm) and sex ratios of American shad during fishery-independent monitoring in the Delaware River, 1996-2005.

Year	Raubsville Electrofishing				Smithfield Beach Gill Net			
	m	f	m:f	all	m	f	m:f	all
1996	-	-	-	-	511.0	547.0		537.0
1997	452.2	516.4	-	467.9	436.0	484.0	1:3.6	474.0
1998	486.0	541.0	1:0.7	508.0	495.0	534.0	1:4.3	527.0
1999	473.0	531.0	1:1.6	509.1	493.0	535.0	1:8.4	530.6
2000	475.9	543.2	1:0.6	500.2	488.9	551.2	1:1.4	525.3
2001	482.2	541.7	1:0.7	508.5	496.1	546.6	1:2.9	533.6
2002	-	-	-	-	512.0	561.8	1:1.6	542.9
2003	-	-	-	-	504.0	569.7	1.2	539.8
2004	-	-	-	-	508.7	560.3	1.7	541.3
2005	-	-	-	-	502.0	560.0		537.0

Table 8.15 Hatchery contribution for adult American shad from Delaware River gill net (rm 218.0) and electrofishing (rm 176.6) catches**.**

Year	Gear	N	Marked	Percent Marked
1997	Gill net	88	0	0.00
1998	Gill net	234	9	3.85
1999	Gill net	208	0	0.00
1999	Electro	150	8	5.33
2000	Gill net	330	10	3.03
2000	Electro	129	14	10.85
2001	Gill net	198	8	4.04
2001	Electro	144	12	8.33
2002	Gill net	378	4	1.06
2003	Gill net	245	19	7.76
2004	Gill net	414	5	1.21
2005	Gill net	776	4	0.52

Table 8.16 American shad tag returns, by year, from fish tagged in Delaware Bay, 1995-2005.

Year	**#Tag**	**Recaptures**											
		1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
1995	107	8	1	1	0	0	0	0	0	0	0	0	10
1996	294		11	2	0	0	1	0	0	0	0	0	14
1997	508			27	6	3	0	0	0	0	0	0	36
1998	554				30	8	0	0	0	0	0	0	38
1999	753					40	2	1	0	1	2	0	46
2000	425						17	4	8	2	1	0	32
2001	663							30	2	1	1	0	34
2002	274								11	2	1	1	15
2003	170									7	0	0	7
2004	51										0	0	0
2005	220											8	8
Total	**4,019**	**8**	**12**	**30**	**36**	**51**	**20**	**35**	**21**	**13**	**5**	**9**	**240**

Figure 8.1 Map of the Delaware River Basin.

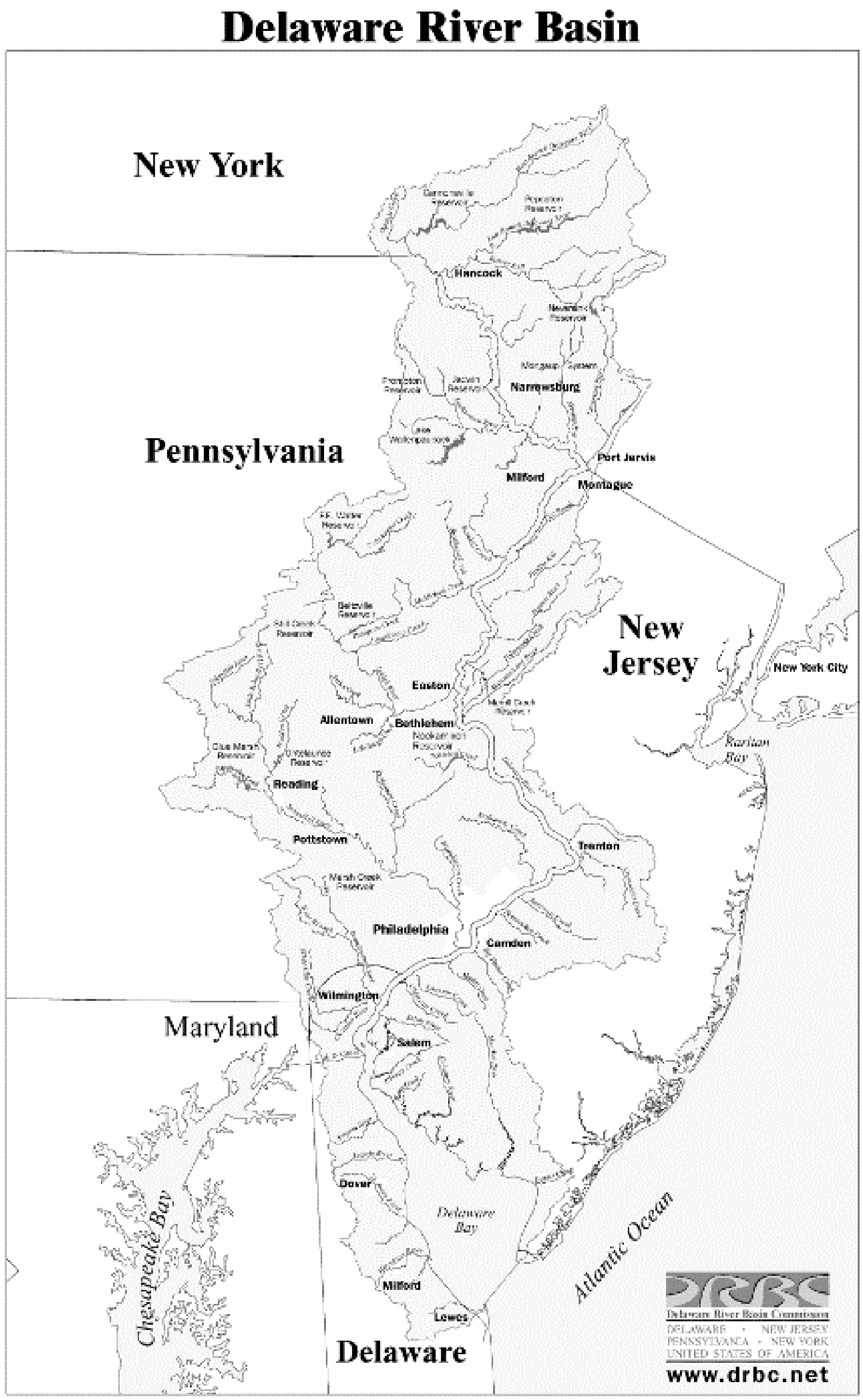


Figure 8.2 Delaware River (includes Upper Delaware Bay) and Lower Delaware Bay commercial landings, 1985-2005.

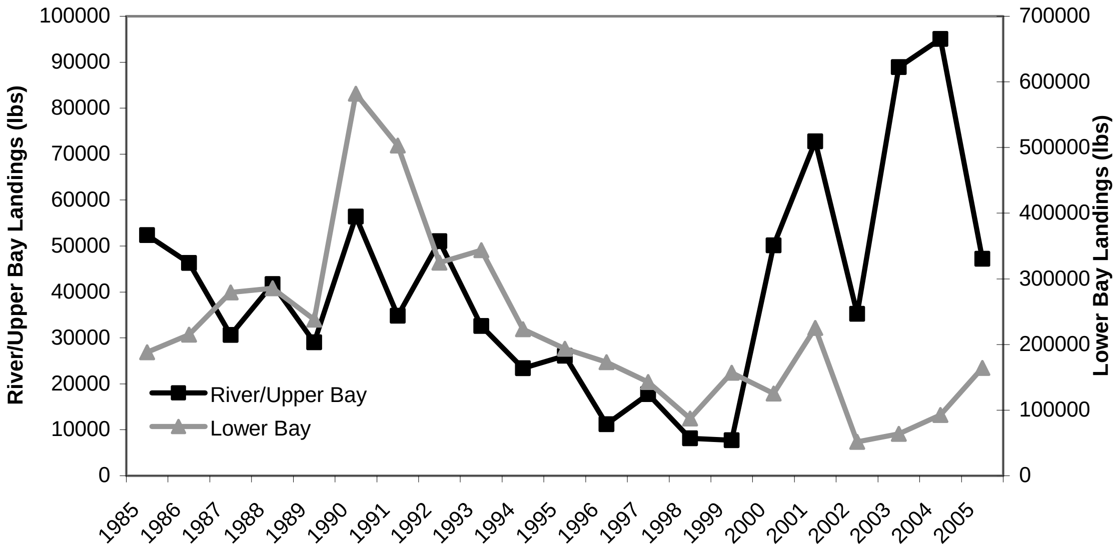


Figure 8.3 Estimates of commercial CPUE in Delaware Bay, including estimates of in-river fishing and the lower Delaware Bay.

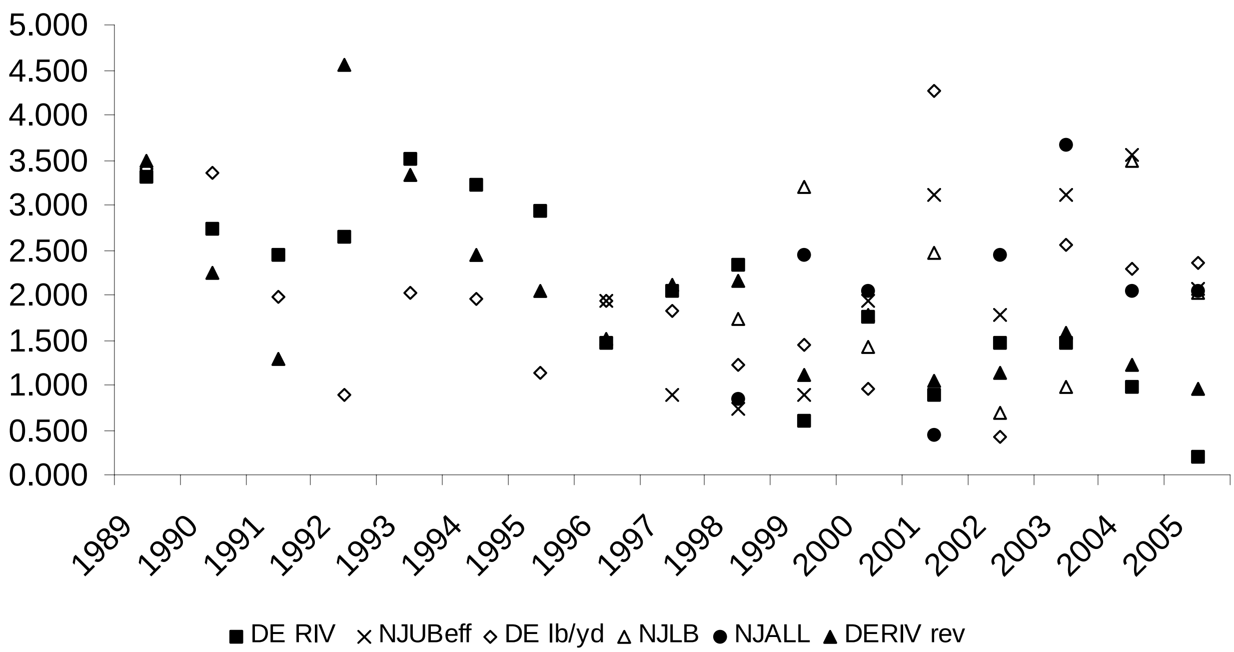


Figure 8.4 CPUE (fish per haul) of American shad caught in the Lewis haul seine fishery, 1925-2005.

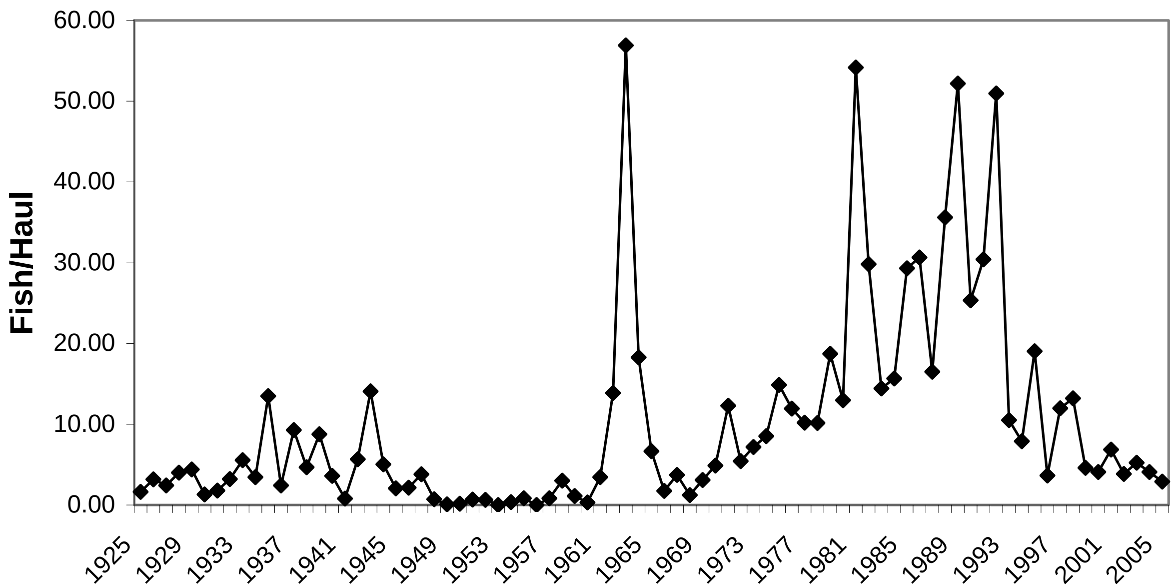


Figure 8.5 Recreational fisheries data from various sources for the Delaware River, 1965-2005.

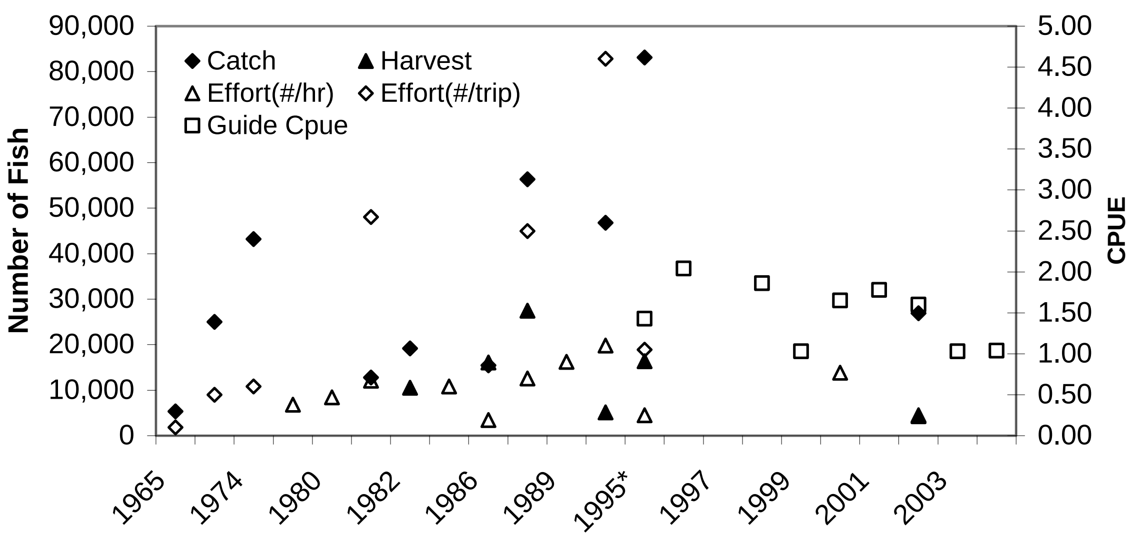


Figure 8.6 Length frequencies (by sex) of American shad harvested in the Delaware River recreational fishery, 2002 (from Versar, Inc. 2003).

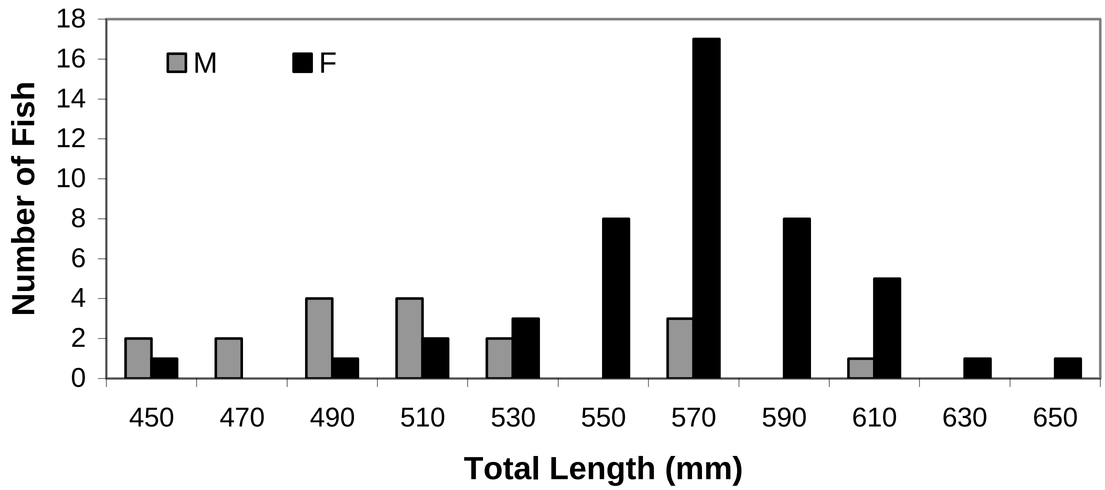


Figure 8.7 The American shad young-of-year (YOY) CPUE for the upper and lower Delaware River, 1980-2005.

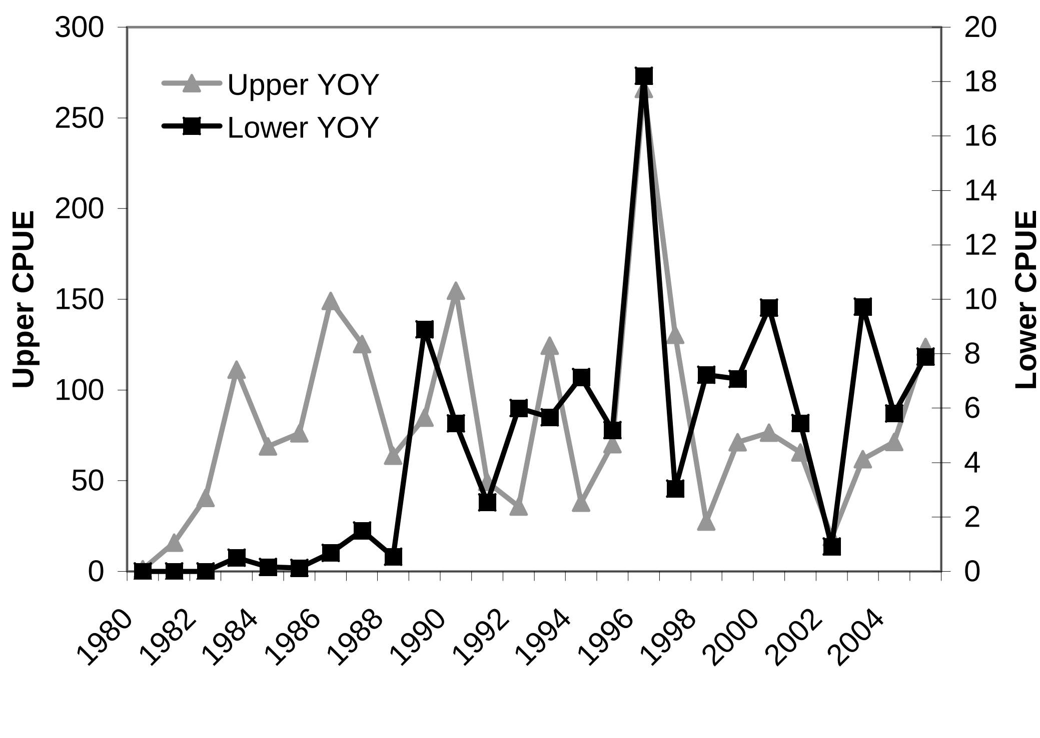


Figure 8.8 Delaware River YOY, upper and lower, 1994-2005.

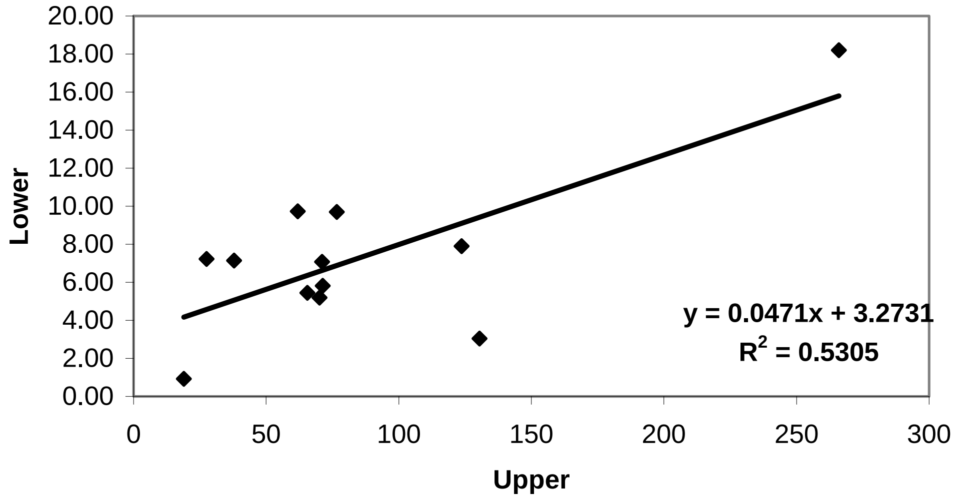


Figure 8.9 Mean fork length (MM) of YOY American shad in the upper Delaware River, 1980-2005.

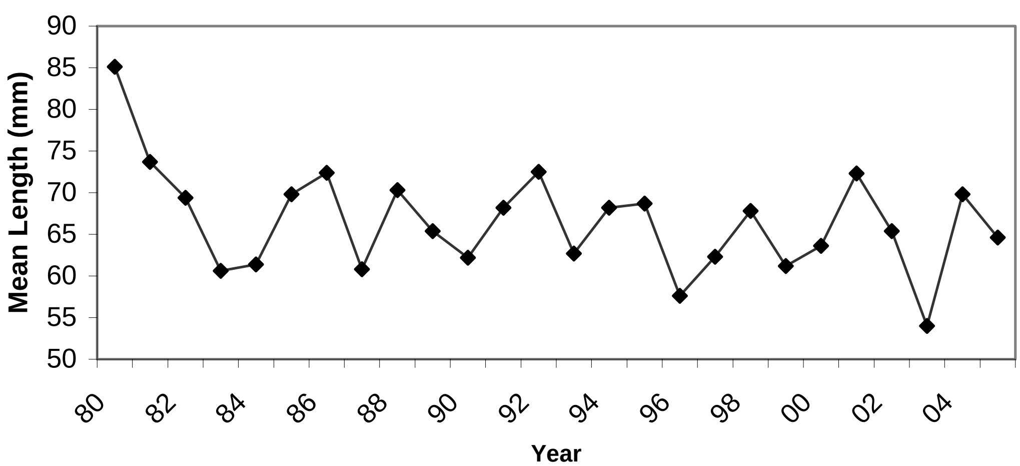


Figure 8.10 Upper Delaware River juvenile abundance index (geometric mean) and YOY length frequency, 1980-2005.

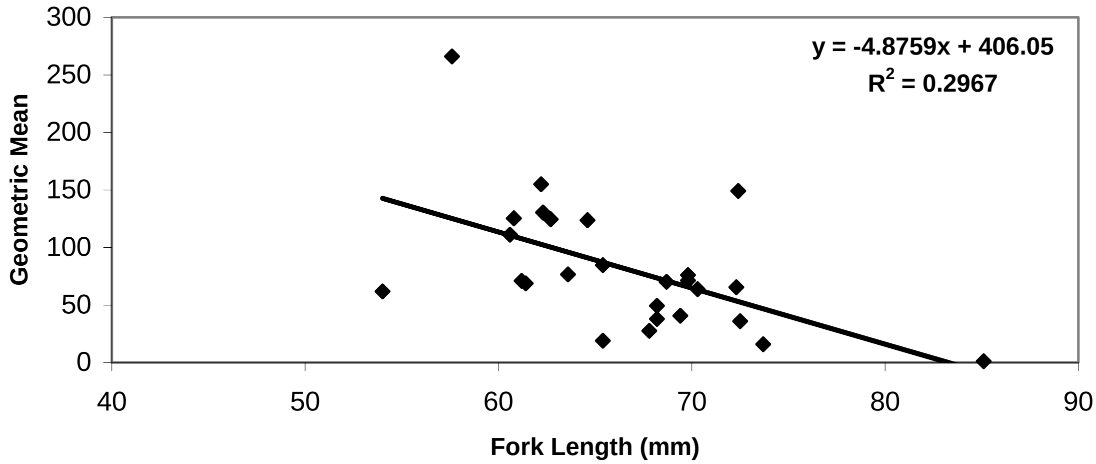


Figure 8.11 Delaware River American shad indices of adult abundance, 1975-2006.

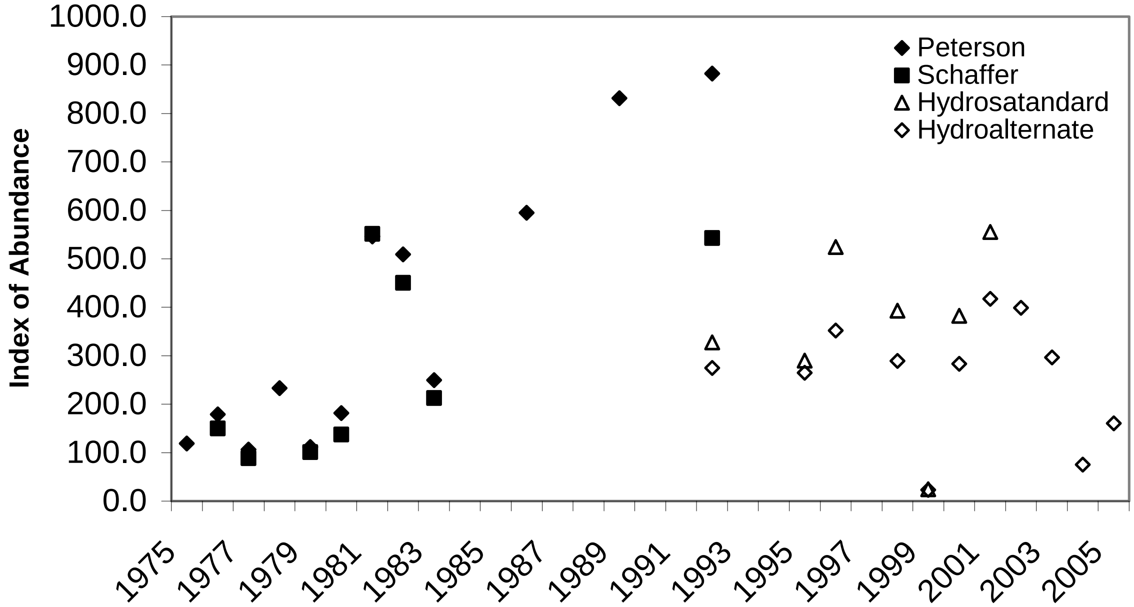


Figure 8.12 Standardized estimates (Z-transformed + 2) of Delaware River American shad abundance from hydroacoustic monitoring, 1992-2005.

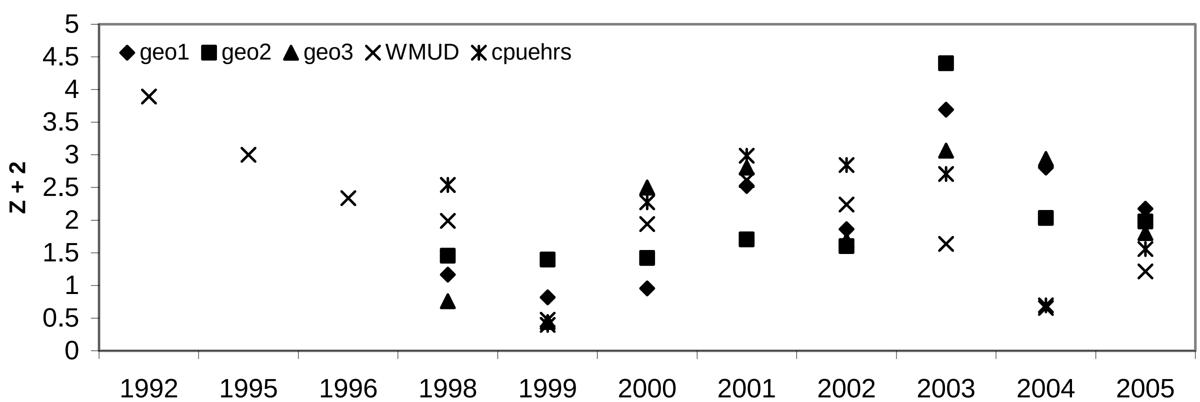


Figure 8.13 Estimate of CPUE for the Smithfield Beach (Delaware River) gill net survey and the Easton Dam fish ladder (Lehigh River).

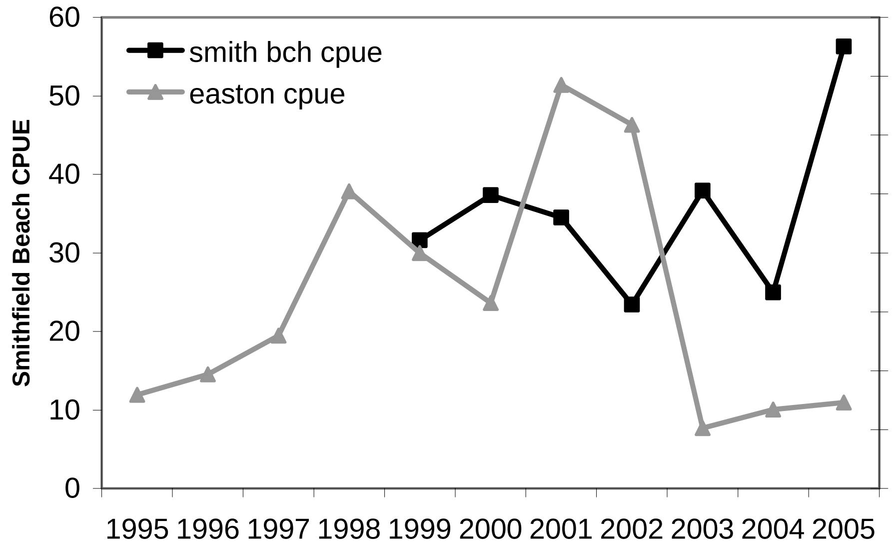


Figure 8.14 Standardized estimates (Z-transformed + 2) of adult American shad abundance , 1975-2005. Point estimates are from the CPUE from the Lewis haul seine fishery and the index of population, while the line represents an average of the two estimates.

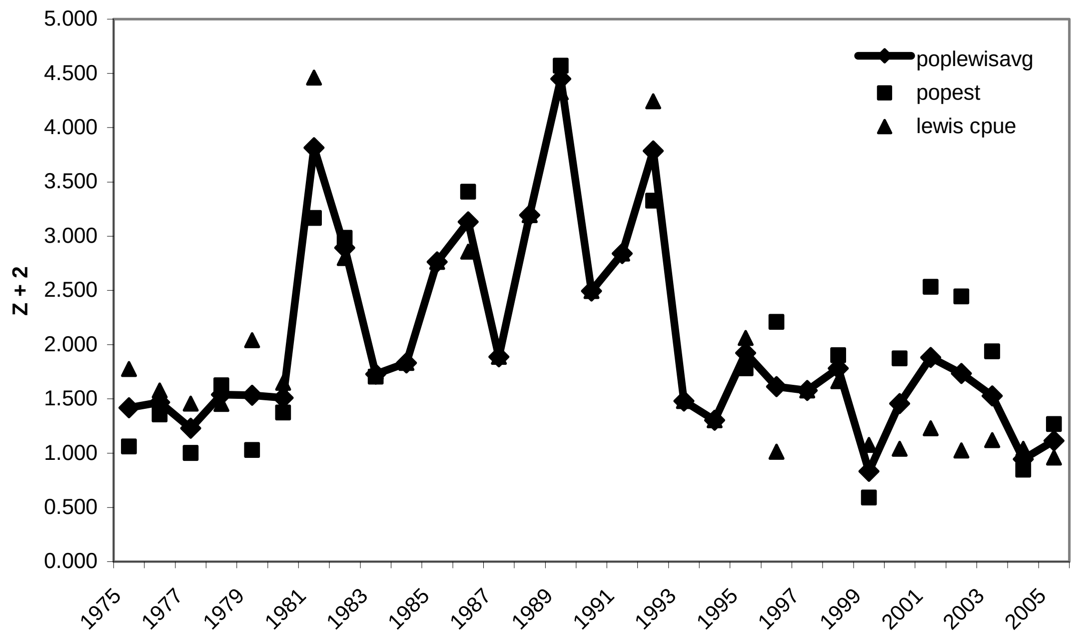


Figure 8.15 Standardized estimates (Z-transformed + 2) of recreational catch-per-hour and Delaware revised estimate of commercial CPUE, 1979-2005.

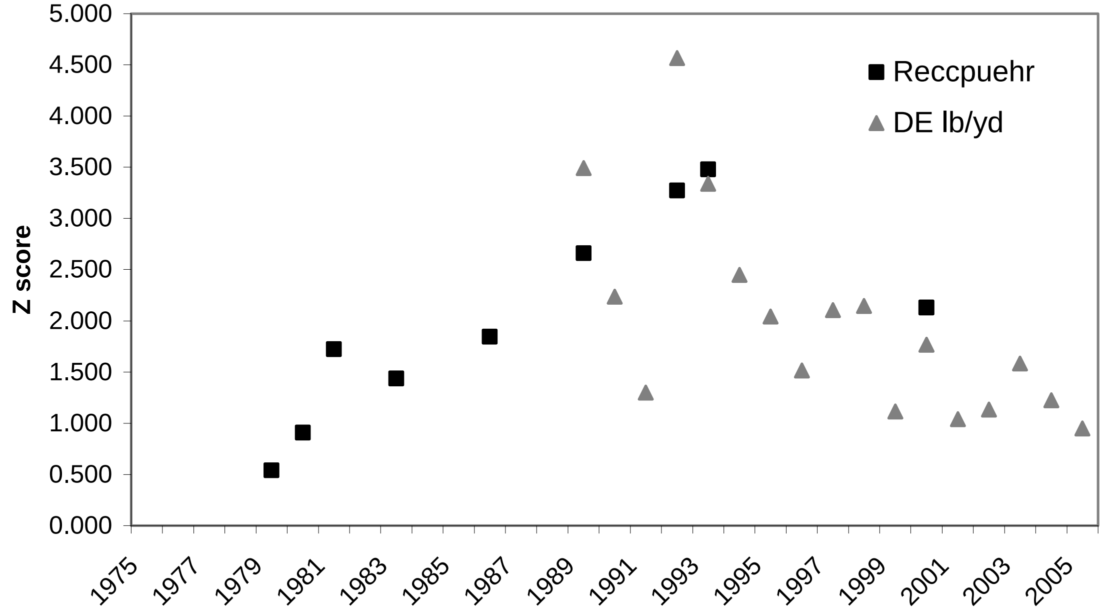


Figure 8.16 Standardized estimate (Z-transformed + 2) of YOY abundance in the Delaware River, 1980-2005. Estimates reflect the mean of the two indices for the upper and lower sections without weighting.

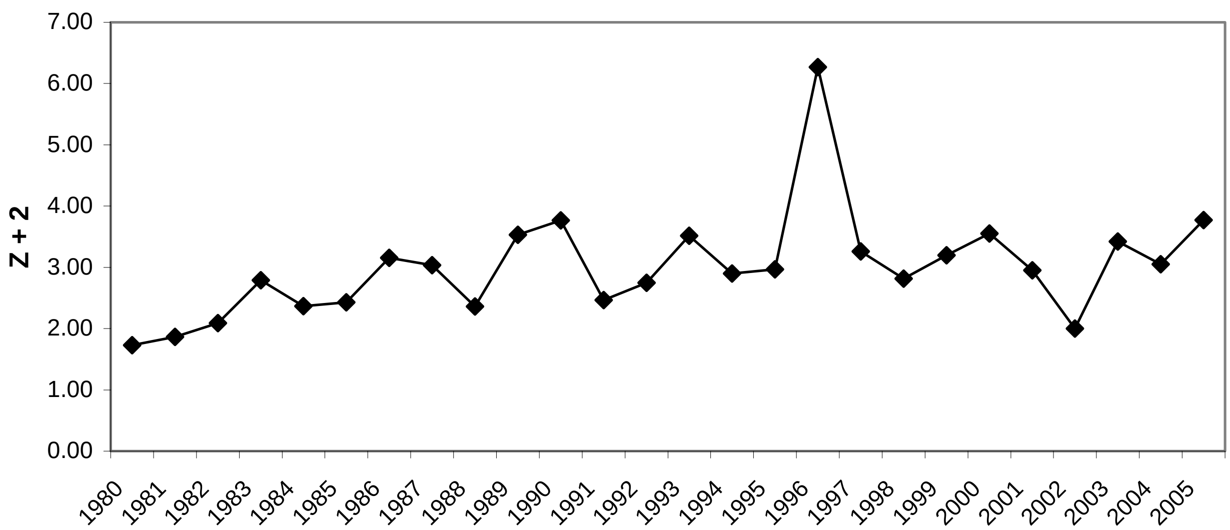


Figure 8.17 Standardized estimate (Z-transformed + 2) of YOY abundance in the Delaware River compared with standardized estimate (Z-transformed = 2) of adult American shad abundance, 1980-2005.

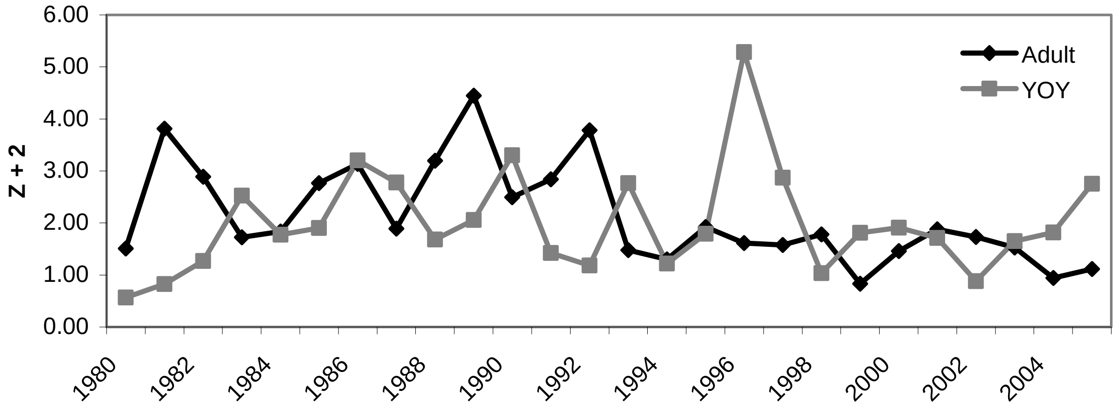


Figure 8.18 Standardized estimate (Z-transformed + 2) of YOY abundance in the Delaware River (1980-2000) lagged and compared with standardized estimate (Z-transformed + 2) of adult American shad abundance (1985-2005).

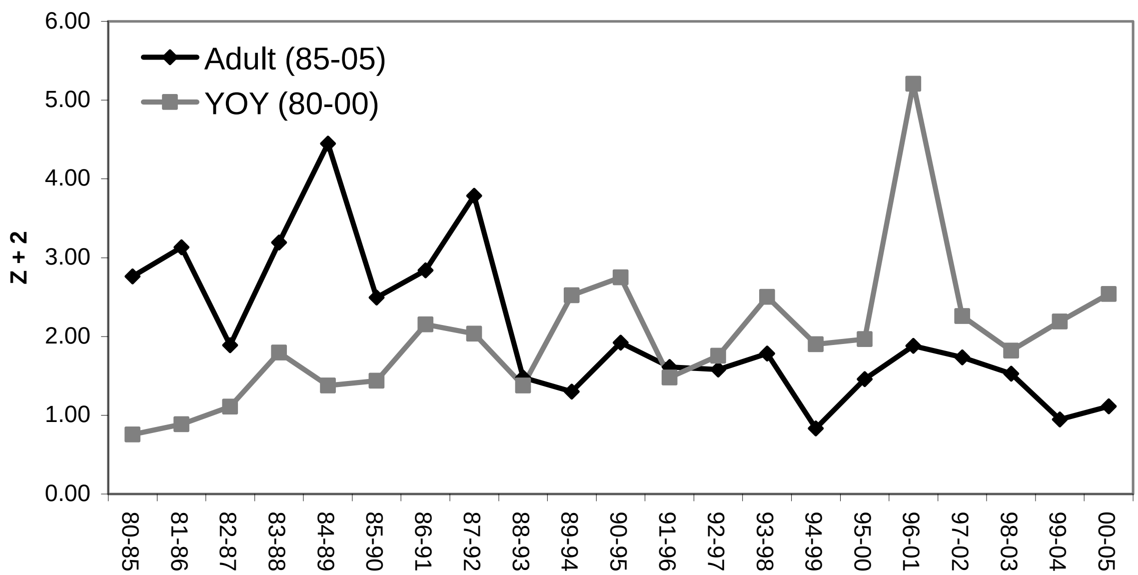


Figure 8.19 Estimates of relative exploitation (river harvest/CPUE) from commercial fishing CPUE estimates in the Delaware Basin. All exploitation estimates were standardized (Z-transformed + 2) for comparison.

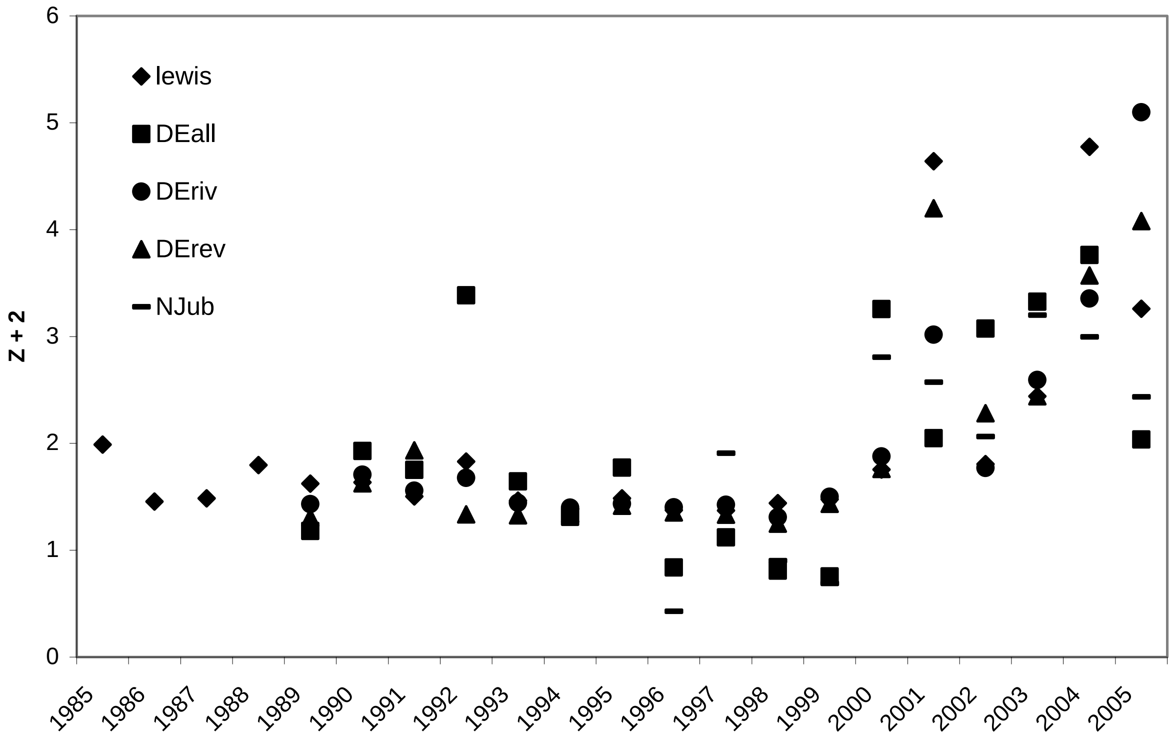


Figure 8.20 Estimates of relative exploitation (harvest/CPUE) based on State of Delaware reported harvest and commercial fishing CPUE in the Delaware Basin. All exploitation estimates were standardized (Z-transformed + 2) for comparison.

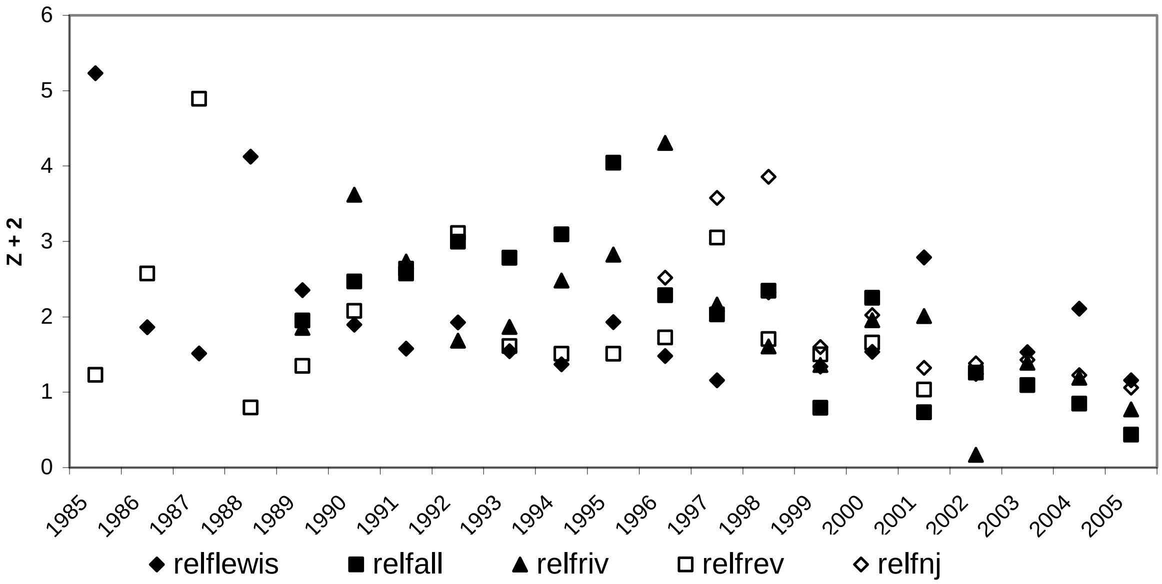


Figure 8.21 Estimates of relative exploitation on American shad from the Lewis haul seine fishery based on estuary harvest (1954-2005) and in-river harvest (1985-2005). Exploitation estimates were standardized (Z-transformed + 2) for comparison.

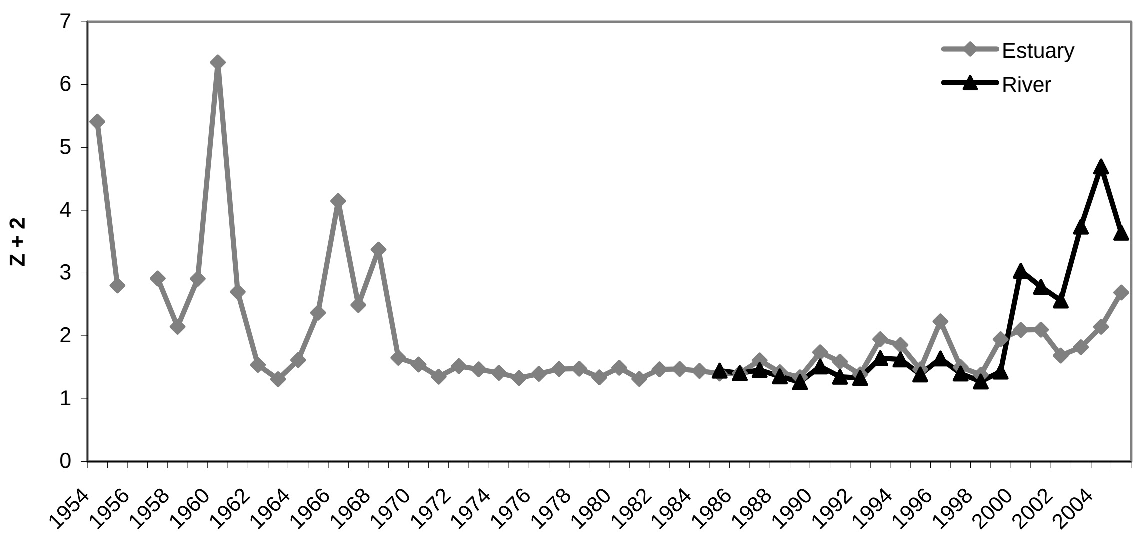


Figure 8.22 Striped bass (ages 2-8) abundance in the Delaware Bay compared with standardized estimate (Z-transformed + 2) of averaged YOY American shad abundance, 1991-2005.

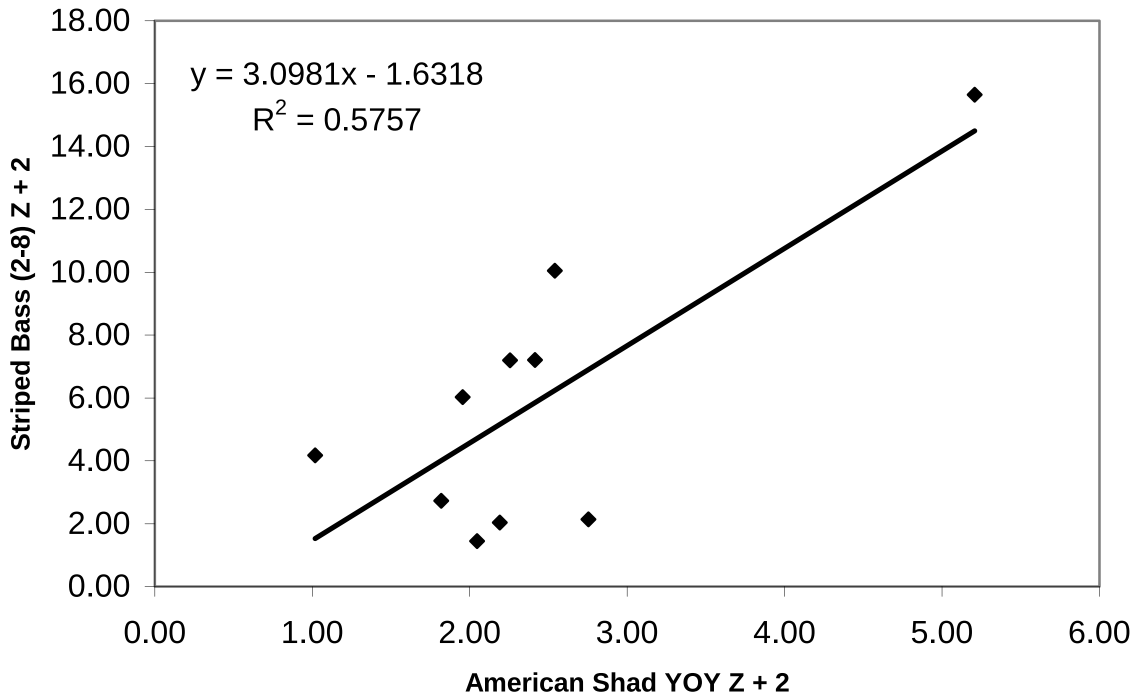


Figure 8.23 Striped bass (ages 2-8) abundance in the Delaware Bay compared with standardized estimate (Z-transformed + 2) of averaged YOY American shad abundance, 1991-2000.

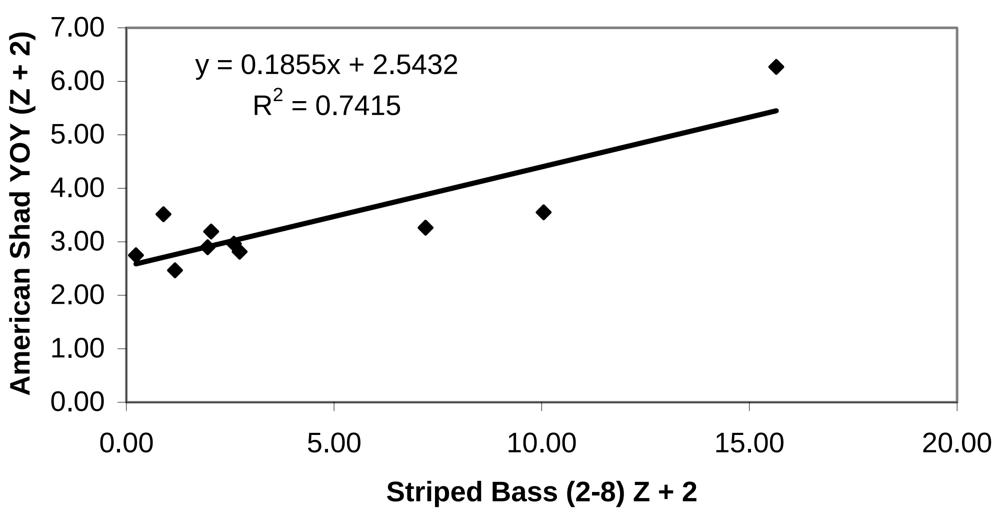


Figure 8.24 Mean total length of male American shad collected in various surveys in the Delaware Basin, 1979-2005.

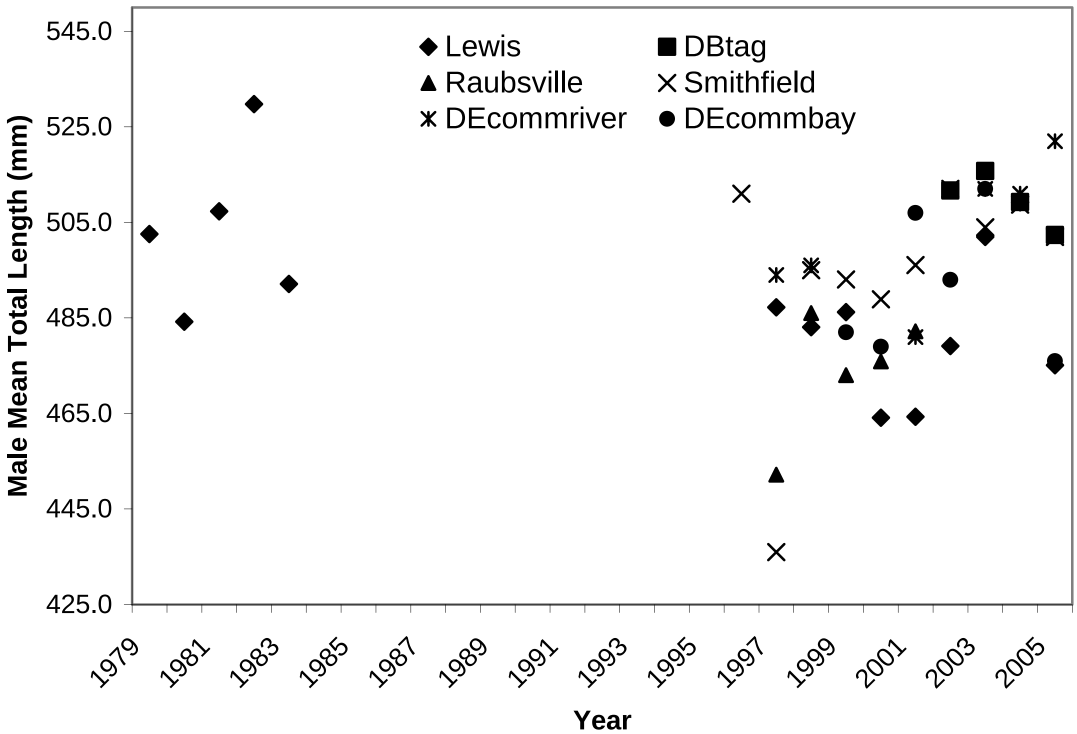
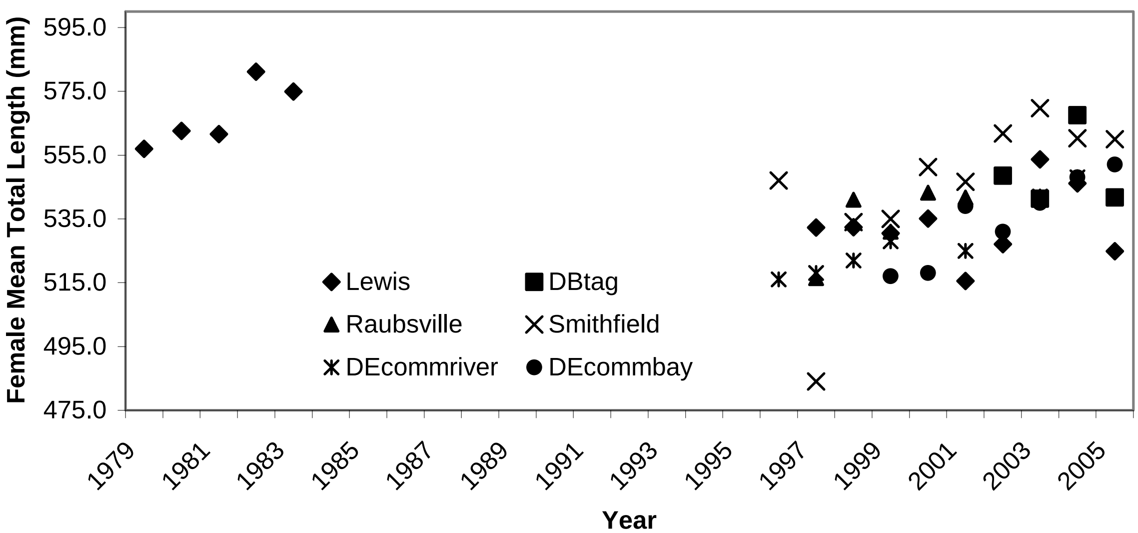


Figure 8.25 Mean total length of female American shad collected in various surveys in the Delaware Basin, 1979-2005.



APPENDIX A: MINORITY REPORT

Stock Assessment of American Shad in Connecticut

by

Victor Crecco, Thomas Savoy and Jacqueline Benway
Connecticut Department of Environmental Protection, Marine Fisheries Division
P.O. Box 719, Old Lyme, Connecticut 06317

EXECTIVE SUMMARY

American shad (*Alosa sapidissima*) landings and run sizes have fallen steadily in the Connecticut River since 1993 despite relatively high and persistent juvenile production since 1990. In this assessment, several analyses are conducted to determine the effects of fishing and predation on the recent stock decline of Connecticut River shad. In addition, ocean recreational shad landings and ocean commercial discards were included in the fishing mortality estimates, and equilibrium and non-steady state overfishing thresholds (F_{msy}, N_{msy}) were re-estimated for Connecticut River shad. Total age aggregate (ages 4+) fishing mortality (FT) estimates on shad, based on the ratio of combined riverine and ocean landings to stock size, were highly variable from 1981 to 1994, ranging from 0.14 to 0.47. Only in 1986 and 1987 did the FT levels slightly exceed the F30% overfishing threshold of 0.43 established for Connecticut River shad from the last peer reviewed stock assessment (ASMFC 1998). After 1995, the FT estimates on ages 4+ shad fell by 40 to 50%, to below 0.20 in most years, culminating in the lowest FT of 0.11 in 2001. All fishing mortality (FT) rates from 1996 to 2005 were 50% below the overfishing threshold (F30% = 0.43). This indicated that the recent drop in shad run size was not due to overfishing. From 1981 to 1993 adult shad run size in the River remained high and relatively stable (> 600,000 fish), but after 1993, shad run size fell steadily thereafter to the historic (since 1965) low level of 226,000 fish in 2005. The 2006 run size of 293,000 adult shad is the second lowest ever recorded since 1965.

Shad juvenile indices monitored annually in the River have varied without trend from 1981 to 1992. Since 1996, juvenile indices have been at or above the long-term median index despite the persistent drop in adult stock size from 1996 to 2005. The sudden and unexpected lack of coherence between recent juvenile indices and subsequent adult recruitment from those year-classes indicated the emergence of a recruitment bottleneck after 1996. Since fishing mortality rates on adult shad have fallen to low levels since 1995, Savoy and Crecco (2004) hypothesized that this recent failure in shad productivity was largely due to a systematic rise in striped bass (*Morone saxatilis*) predation on adult shad in the River. Results from 2005 and 2006 striped bass dietary studies (Davis 2007 in prep) in the River are wholly consistent with the Predation Hypothesis. Davis (2007 in prep) reported that large (> 90 cm) striped bass sampled in the River south of the Holyoke Dam during spring of June, 2005 and 2006 fed extensively on pre-spawned adult shad, whereas smaller stripers (size range: 50-89 cm) consumed large numbers of pre-spawned blueback herring. Some 46% of the diet in weight (gm) of stripers between 90 and 99 cm was composed of adult shad, whereas 82% of the diet (gm) of 100 cm+ stripers was made up of adult shad (Davis 2007 in prep).

An age aggregated Steele and Henderson (S-H) production model was constructed on dada for the Connecticut River stock of American shad. Results indicated that striped bass consumption rates (Mp) on adult shad rose in the River fourfold after 1994 coincident with a steady rise in striped bass abundance. Estimated adult shad consumed annually 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 (FT) 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 (Mp). Statistical and empirical evidence given here strongly suggests 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. The management implications of successful stock rebuilding of Connecticut River shad in the presence of rising predatory mortality are discussed.

1.0 Introduction

The most recent peer-reviewed assessment of American shad (ASMFC 1998) indicated that adult run size in the Connecticut fell steadily from 1992 to 1996. Average aggregated (ages 4+) fishing mortality (FT) estimates on Connecticut River shad, based on the ratio of combined coastal and riverine landings to stock size, varied without trend from 1988 to 1996. Moreover, all FT levels except the 1987 estimate were below the F30% overfishing threshold of 0.43 from the last peer reviewed assessment. Thus the most recent stock assessment (ASMFC 1998) concluded that the recent drop in shad run size in the Connecticut River was not due to overfishing. Although this assessment (ASMFC 1998) clearly demonstrated a pronounced decline in shad abundance after 1992 among several shad stocks along the Atlantic coast, this and all previous assessments have yet to examine the potential impact of non-fishing effects on the recent drop in shad productivity.

Nearly all anadromous finfish assessments, including previous American shad assessments (ASMFC 1988, 1998), assume that natural mortality is constant across all ages (ages 3+) and years. The constant M assumption is thought to be unrealistic under most conditions, particularly for American shad that are susceptible to a wide variety of finfish predators (Savoy and Crecco 2004) and that usually experience very high post-spawning mortality (Leggett et al 2004). Yet the constant M assumption is widely accepted in virtually all stock assessments, because time varying M is often difficult to estimate with confidence and because a constant M assumption greatly reduces the number of parameters to be estimated in conventional VPA models. Although not explicitly stated in most assessments, the constant M assumption implies that predation, inter-specific competition and environmental effects on stock productivity are fixed in time. Thus, the constant M assumption greatly limits our ability to explore the significance of non-fishing effects on the recent failure in stock productivity. Non-fishing effects include enhanced predation that may result in a systematic rise in M (Wahle 2003), as well as temporal shifts in environmental factors that can adversely affect recruitment, somatic growth and maturation. Even subtle shifts in trophic and environmental factors (Link 2002) have been shown to confound stock rebuilding strategies of other depleted fish stocks (Rose et al 2000, Shelton et al 2006).

In this assessment update, several analyses are conducted on Connecticut River shad to determine the effects of fishing and predation on the recent stock decline. Our updated fishing mortality estimates from 1981 to 2005 include shad landings from the ocean recreational fishery, as well as discards from the Atlantic herring (*Clupea harengus*) commercial fishery. Although a thorough test of the Overfishing Hypothesis is our primary goal of this assessment, there is now an increasing body of evidence that suggests that enhanced predation by striped bass in the River has played a major role in the recent drop in shad run size. Savoy and Crecco (2004) recently used empirical and statistical evidence to show that the recent drop in shad population size in the Connecticut River was consistent with enhanced striped bass (*Morone saxatilis*) predation of adult shad. Moreover, Davis (2006 in prep) recently reported that adult shad dominated the diet of large (> 90 cm) striped bass in the River during spring 2005 and 2006. The striped bass is regarded as a voracious finfish predator from the Mid and North Atlantic on menhaden, gizzard shad, American shad and river herring (Walter and Austin 2003; Nelson et al 2005; Rudershausen et al 2005). Moreover, unlike many other marine finfish predators, adult (> 70 cm) striped bass have recently increased in New England waters to record high levels (ASMFC 2005), and have been sampled in large and increasing numbers well above the salt wedge in the Connecticut River since 1993 (Savoy 1995). Therefore, it would be useful to summarize these findings and present an analytical model that merges the population dynamics of American shad with the foraging characteristics of striped bass.

We constructed an age aggregated Steele and Henderson (S-H) production model (Steele and Henderson 1984) to examine the effects of fishing and predation effects on the recent decline of Connecticut River shad. The S-H model has extensive theoretical appeal since it incorporates compensatory stock dynamics of the prey with fishing effects plus a sigmoid Type III foraging response by the predator that may lead to critical depensation at low shad abundance (Spencer and Collie 1997). Since the S-H model can easily accommodate environmental variables (Spencer 1997), this modeling approach represents a modest but straightforward attempt at ecosystem modeling. The S-H model was also used to estimate fixed (equilibrium) and time varying overfishing thresholds (F_{msy}, N_{msy}) for Connecticut River shad under temporal shifts in predation mortality. In addition, more robust and precise estimates of the overfishing thresholds (F_{msy}, N_{msy}) from the S-H model were derived through iterative reweighted least squares regression.

1.1 Management Unit Definition

Connecticut has three major rivers (Connecticut, Housatonic and Thames)(Figure 1) and several 'minor' rivers or large coastal streams. American shad are present in the Connecticut River and this natal stock is our largest and most persistent run. The Thames River is subject to a restoration effort and while several fishways have been constructed with more to follow, run sizes consistently remain below 5,000 fish. Projections of total run size in this system at full restoration are debatable but likely will remain in this order of magnitude. Given limited spawning and rearing habitat in the Thames and Housatonic Rivers below mainstem dams from colonial times until now, annual numbers of adult American shad in these two systems and many of the larger coastal systems in the State could be accounted for by noting that they are likely just strays from the Connecticut River stock.

1.2 Regulatory History

There is a long history of regulations pertaining to American shad in Connecticut with one of the most significant developments being the imposition of 'rest days' in 1922 with prohibition of all commercial fishing except for dip nets. Numbers of rest days per year have varied over time from three to zero (during WWII fishing was encouraged by removal of the rest days) to two which have been in effect since 1948. Other regulations pertaining to fishing areas and gears have also been made (see Commercial Fishery section below).

Fishing for American shad is restricted to the main stem Connecticut River from the Putnam Bridge in Glastonbury/Wethersfield south to the I-95 bridge in Old Saybrook/Old Lyme and in the marine waters of the river south of the I-95 bridge. The open commercial season runs from April 1 through June 15 with nets of mesh size not less than 5 inches stretched mesh. American shad may also be taken commercially in the marine district. The use of a pound net to take American shad in the marine district requires a marine pound net registration. Fewer than three marine pound nets have been licensed/fished in the last twenty years, therefore landings remain confidential by Statute, but overall, American shad are very minimal. American shad are only occasionally taken as bycatch by trawl vessels in Long Island Sound (LIS) and again, landing average less than 250 kg.

The following are prohibited: use of gill nets constructed of single or multiple strand monofilament from sunrise to sunset, monofilament twine thickness greater than 0.28mm (#69), commercial fishing for American shad from sundown Friday to sundown Sunday except by the use of a scoop net, the use of nets with mesh size less than five inches stretched mesh, fishing in other than the main body of the Connecticut River (no coves). The use of pound nets or other fixed or staked nets to take American shad is prohibited, except in the waters of LIS. An annual report of daily fishing activities and catch is required.

1.3 Assessment History

Several stock assessments have been conducted for the Connecticut River stock, with the most recent versions completed in 1988 and 1998 in conjunction with ASMFC (ASMFC 1988, 1998). The 1998 Assessment (ASMFC) indicated that adult run size in the Connecticut River fell steadily from 1992 to 1996. Average aggregated (ages 4+) fishing mortality (F) estimates for Connecticut River American shad—based on the ratio of combined coastal and riverine landings to stock size—varied without trend from 1988 to 1996. Moreover, all F levels except the 1987 estimate were below the F_{30} overfishing threshold of 0.43 developed in the previous peer reviewed assessment (ASMFC 1987). The ASMFC (1998) assessment reported that the majority of evidence presented on the recent decline of American shad in the Connecticut River was directly related to enhanced striped bass predation from below the Holyoke Dam.

2.0 Life History

2.1 Age

The spawning population in the Connecticut River ranges from three to nine years in age, although the majority of fish are between 4 and 6. Very few adult shad have been collected above age seven in the last 25 years and the annual spawning run is heavily dependent (70-90%) upon virgin (first-time) spawners.

2.2 Growth

Data are collected annually on length at annulus from all scales interpreted for age. The resulting age composition and length frequency is extrapolated to the entire population by sex. A systematic decline in mean fork length was apparent over time (Figure 2).

2.3 Reproduction

Annual recruitment success has been monitored annually through weekly collection of juvenile American shad. A long and consistent (1966-2005) time series of juvenile relative abundance indices (mean catch/seine haul) has been established in the Connecticut River (Figure 1). The average annual juvenile abundance indices from 1966 to 2005 were expressed as both the arithmetic and geometric mean catch per seine haul from stations located between Essex, CT (river km 16) and Holyoke, MA (river km 170) (Marcy 1976; Savoy 2002). Further details of the annual juvenile seine survey are contained in Section 5.3.1.1 Fishery-Independent Survey Data, Data Collection Methods, Survey Methods.

The contribution of adult shad recruitment from each year-class (t) was defined as the sum of all virgin (first time spawners) age 4 and 5 spawners from each year-class in the adult shad populations (Savoy 2001). The time series of juvenile shad indices were positively correlated with adult recruitment (Pearson $r = 0.82$, $p < 0.01$) from the 1966-1988 year-classes. However, after 1993, juvenile indices became uninformative (Pearson $r = 0.124$, $P < 0.67$) about subsequent changes in adult recruitment of those year-classes.

2.4 Stock Definitions.

Each of the three major rivers (Connecticut, Housatonic, Thames)(Figure 1) in Connecticut are treated as a separate unit stocks for this assessment. Since stock sizes are very low (<10,000 fish) and limited information are available on the Housatonic River and Thames Rivers, this assessment has focused exclusively on the Connecticut River American shad stock.

A long and consistent (1966-2005) time series of adult shad population estimates in numbers has been established in the Connecticut River (Table 1, Figure 1). Annual Petersen estimates of adult run size have been made from 1965 to 1983 based on annual tag-recapture studies (Leggett 1976; Minta 1980; Crecco 1987; Crecco and Savoy 1987). By 1984, we noticed a strong positive trend (Pearson r = 0.88, P <0.001) between tag-based population estimates from 1970 to 1983 and the average number of adult shad passed annually (mean number/day) during those years at the Holyoke Dam fish lift (river km 170) (Crecco et al 1984). For this reason plus the high labor demands associated with annual tag-recapture studies, the tag-recapture program was discontinued after 1983 in favor of proxy approach based on Holyoke Dam lift data. We believe that informative and more cost effective run size estimates could be derived from 1965 to the present (2006) using annual shad lift rates at the Holyoke Dam that were scaled to units of run size based on the 1970-1983 tag-recapture population estimates. The Holyoke fish passage facility began operation in 1955 and daily counts of American shad lifted have been made annually from 1955 to 2005 (Watson 1970; Moffit et al 1982; Leggett et al 2004). Major technological improvements in the Holyoke lift have been made in 1969, 1975 and 1976 (Henry 1976) which reflect systematic increases in mean annual passage rates (mean number/lift day) of American shad. After 1976 no further improvements in the fish lift were made until 2006, so the time series of fish passage rates from 1976 to 2005 are relatively accurate.

We adjusted the shad passage rates at Holyoke from 1965 to 1976 to reflect technological improvements in the lift by the development of scaling coefficients. These scalars were established by dividing the mean passage rates from 1962-1968 by mean passage rates from 1969-1974, 1975, and from 1976 to 1983 during which improvement in the fish lift took place. The population estimates from 1962 to 2006 were derived in a three-step process (see Crecco and Savoy 1985 for further details). First, to develop the initial lift index, the total number of shad lifted annually at Holyoke was divided by the number of lift days at which 99% of the shad were passed. Second, these mean lift rates (mean shad/day) were adjusted for the weighting coefficient that reflects technological improvements in the fish lift from 1962 to 1976. Finally, the mean adjusted lift rates from 1962 to 2006 were scaled to units of shad population size (thousands of fish) based on the 1970 to 1983 tag-based population estimates. Our analysis was limited to shad population data from 1981 to 2006 in order to match these data to the time series of coast-wide striped bass stock estimates. We considered that the proxy stock estimates from 1981 to 2006 based on catch rates at the Holyoke fishlift to be highly informative about temporal shifts in shad run size. Trends in indirect population estimates of American shad based on the lift from 1981 to 2005 were highly correlated (Pearson r = 0.71, P < 0.0001) to trends in total annual riverine commercial and sport landings in numbers (Figure 2). The resulting shad population estimates from 1981 to 2006 and age structure data were used to monitor changes in age, sex and year-class of each shad run (Leggett 1976; Crecco and Savoy 1987; Savoy and Shake 1993: Savoy 2002: Leggett at al 2004).

2.5 Genetic Information.

No genetic studies have been conducted thus far by the CT DEP on American shad stocks in Connecticut waters, but all previous tagging studies (Leggett 1976; 1977) concluded that recreational and commercial fisheries within Connecticut waters are prosecuted on natal stocks. Brown and Epifano (1995) utilized mitochondrial DNA to determine stock composition in the ocean intercept fishery off Virginia. Connecticut River American shad were estimated to comprise 3 to 6.4% of the catch before that fishery was closed.

2.6 Natural Mortality

It is widely recognized that instantaneous natural mortality (M) for American shad and for other exploited finfishes is difficult to estimate with confidence. In nearly all single species stock assessments, the magnitude of M is chosen indirectly either from the 5% rule (Quinn and Deriso 1999), or from life history models such as the regression of M on maximum age (t_{max}) (Hoenig 1983; Hewitt and Hoenig 2005). In most assessments, once a value of M is chosen, it is assumed to remain fixed across all ages and years. Under the constant M assumption, instantaneous fishing mortality (F) is estimated indirectly over time by subtraction of the fixed M from the annual instantaneous total mortality rate (Z). These ad hoc methods of estimating a fixed M have been applied primarily to marine fisheries, where fishing (F) and natural (M) mortality occur concurrently throughout the year. Applying this approach indiscriminately to shad fisheries can generate substantial bias to the estimates of F and M. Note that annual fisheries differ sharply in the extent and timing of exploitation as compared to most seasonal salmon and American shad fisheries, in which highly variable post-spawning mortality (M) occurs after escapement from a seasonal (spring) fishery. Moreover, there is now a growing body of empirical evidence that natural mortality rates vary by size (Vetter 1988 and in this assessment). M levels can also rise systematically over time due to increased fish passage at dams (Leggett et al. 2004), as well as to enhanced predatory mortality (Shelton et al. 2006 and in this assessment). If M rises systematically over several years, the magnitude and trend in F estimates under an assumed fixed M can be grossly overestimated.

We found that the magnitude of M for Connecticut River shad was not fixed over time by the maximum age, but instead was linked to temporal changes in post-spawning mortality. In the Connecticut River, American shad reach sexual maturity between ages 3 and 6 (Leggett 1976; Crecco and Savoy 1987). The maximum age in annual spawning runs since 1966 seldom exceeded age 6 (Leggett 1976; Leggett et al 2004). The annual mean incidence (%) of repeating spawning has varied greatly since 1966 from 9% to 55%. Recently, Leggett et al. (2004) reported that the incidence of repeat spawning of Connecticut River shad fell steadily by 50% after 1980 coincident with a rise in the number of shad passed annually at the Holyoke Dam fishlift. Since a drop in the incidence of repeat spawning is inversely related to post-spawning mortality rates (M), M rates on post-spawning shad have also risen by about 50% after 1980 due mainly to enhanced fish passage. These findings reveal that the constant M assumption, used to estimate F elsewhere in these assessments, would have been severely violated for Connecticut River shad and undoubtedly for other shad stocks. For this reason, we estimated a time series of age aggregated F values directly based on the log ratio of riverine and ocean landings (sex combined) to total run size assuming a type 1 fishery (seasonal) (refer to page 21 and equations 1 and 2 in this assessment). Before M values could be estimated, a time series of total mortality (Z) rates was estimated (Leggett 1976; Crecco and Savoy 1987) from 1966 to 1986 as a log ratio of repeat spawners in the run during year t+1 to total run size in year t. Having estimates of F and Z, natural mortality (M) rates from 1966 to 1985 were estimated indirectly by subtraction (i. e. M = Z - F). Age aggregated M estimates for post-spawning adult shad in the River since 1966 were highly variable, ranging annually from 0.60 to over 2.00. These M estimates reflect a high incidence of post-spawning mortality due to excessive energy expenditure related to migration (Leggett 1976). These variable M estimates for Connecticut River shad are considerably higher than the fixed annual M estimates (M range: 0.30 to 0.45) reported elsewhere in this stock assessments.

3.0 Fishery Description

3.1 Brief Overview of Fisheries

Commercial Fishery

Connecticut has a commercial gill net fishery for American shad in the inland waters of the Connecticut River. This fishery has been in existence for many years. The State of Connecticut has some data on landings dating back to 1880. More intensive monitoring of shad abundance (numbers and pounds), age structure and spawning history has been conducted annually from 1974 to 2004. The fishery has changed little since the adoption of outboard powered vessels other than the change to drift gill nets from all other gear types (haul seine, fixed gill nets and traps/pound nets). Fishing for American shad is restricted to the mainstem Connecticut River from the Putnam Bridge in Glastonbury/Wethersfield south to the I-95 Bridge in Old Saybrook/Old Lyme and in the marine waters of the river south of the I-95 bridge. The open commercial season runs from April 1 through June 15 with nets of mesh size not less than 5 inches stretched mesh. American shad may also be taken commercially in the marine district. The use of a pound net to take American shad in the marine district requires a marine pound net registration. Shad are only occasionally taken as bycatch in Long Island Sound.

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American shad are the only alosine species harvested by directed fisheries in Connecticut waters.

Recreational Fishery

Angling for American shad is the only legal method of take and may take place during the open season from April 1 through June 30 in rivers and streams open to fishing all year; otherwise, the open season runs from the 3rd Saturday in April through June 30. There is a daily possession limit of 6 American and hickory shad in the aggregate, per person, in both the Inland and Marine Districts. In the Pawcatuck River, the open season for American shad follows Rhode Island regulations and no take is allowed. Fishing licenses are required for anyone 16 years of age or older fishing in the Inland District. Licenses are issued on a calendar basis and expire on December 31st

There have been no changes to Connecticut Statutes or regulations pertaining to shad fishing since March 19, 1999 when the existing 6 fish recreational creel limit was modified to include hickory shad as an aggregate creel limit for the two species.

3.2 Current Status

Commercial: The number of commercial shad fishing licenses (and associated effort) has been systematically declining since peak levels during and after World War II. Commercial license sales have declined to low levels and are expected to stay low or further decrease as fishermen retire and are not replaced (Table 1).

Recreational: The Connecticut River was once the place to go for recreational fishing for American shad and some think this was the birthplace of the sport. Numbers of fishermen, effort, catch and harvest have all varied greatly over time, but similar to commercial fishing, recreational fishing for American shad exhibit a general decrease with time. Anecdotal and creel information gathered in the last ten years indicates that few fishermen have targeted American shad in the traditional shad fishing areas from Hartford to the CT/MA state line in recent years and, the trend is not expected to change much. Anglers that traditionally fished for shad in this area have switched to pursue striped bass, which now provide a quality fishery from Hartford up into Massachusetts. The decrease in fishing levels for shad and particularly in the harvest is also a function of reduction in the number and percentage of the fishing population who know how to bone American shad. Lack of creel surveys of shad after 1996 (Table 1) led to estimating sport landings as 1% of the population size.

4.0 Description

4.1 Brief Overview of Habitat Requirements

The Connecticut River stock of American shad are not known to have any unique habitat requirements. Water temperature is considered to be the major hydrographic variable controlling oocyte maturation and the timing of American shad spawning (Leggett 1969; Watson 1970). Spawning occurs in the Connecticut River mainly from mid-May through mid-June at water temperatures between 14 C and 23 C (Marcy 1976; Crecco and Savoy 1987b), mainly at night or on overcast days (Whitney 1961; Chittenden 1976; Layzer 1974). Female shad release semibuoyant eggs in riffles, shoals near river channels and downstream from the confluence of two rivers (Layzer 1974; Gilmore 1975), but seldom release eggs over silt, mud or bedrock (Scherer 1974). However, when eggs are released, they are subject to transport by prevailing river currents and may be dispersed well downstream of their point of release (Marcy 1972).

Group spawning involving several male and one female shad has been observed during late evening in the Connecticut River (Whitworth and Bennett 1970; Marcy 1972). Those studies reported that spawning fish swim vigorously at the surface forming a closely packed circle, whereby eggs are released into the water and fertilized by several males (Marcy 1972). Fertilized shad eggs roll along the bottom for 3 to 5 km (Stira 1976) which presumably facilitates oxygen uptake and successful development (Blair 1976).

Female American shad are prolific spawners (150,000-500,000 ova/female), with the absolute fecundity increasing with age, length and weight (Leggett 1969). The relatively high fecundity of American shad is crucial for perpetuating the stock since many eggs fail to fertilize (Reed and Russo 1976), and only about one out of every 100,000 eggs survive to become a spawning adult (Leggett 1977b).

Hatchery studies have shown that shad eggs ripen gradually in the ovary, allowing spawning to occur over several days (Mansueti and Kolb 1953; Meade 1976). This batch spawning strategy of American shad and many other fishes may be an evolutionary adaptation to enhance the probability that at least some eggs will be released under low river flow conditions shown to be favorable to egg and larval survival (Crecco and Savoy 1985a).

After spawning, the surviving adult shad leave the Connecticut River by mid-August (Crecco et al. 1984; O'Leary and Booke 1986) and migrate with subadult shad to their summer feeding grounds in the Gulf of Maine (Walburg and Nichols 1967; Dadswell et al. 1983), or within an area south of Nantucket shoals (Neves and Dupres 1979). When ocean temperatures in the Gulf of Maine drop below 12 C in late November, American shad move south to Florida by following the 12-13 C isotherm (Neves and Dupres 1979). Beginning in February, American shad of various stocks commence their spawning migration up the Atlantic coast and return to their respective river of origin to spawn (Leggett and Whitney 1972).

Egg Stage

Newly spawned shad eggs are transparent and about 1.8 mm in diameter, but expand to 2.2-3.5 mm after fertilization due to the absorption of water (Mansueti and Hardy 1967; Chittenden 1969). The rate at which shad eggs develop is inversely related to water temperature during May and June (Marcy 1976). Shad eggs hatch in 8-12d at 13-15 C, 6-8d an 17 C and 3d at 24 C (Watson 1970). This inverse relationship between egg incubation period and water temperature is considered to be an evolutionary adaptation, allowing many larvae to hatch in synchrony with rising water temperatures and falling river flows shown to be favorable to larval growth and survival (Marcy 1976; Crecco and Savoy 1985b, 1987a).

American shad eggs in the Connecticut River experience catastrophic mortality, ranging annually from 24 to 44%/d between 1979 and 1984 (Table 11) (Savoy and Crecco in prep.). As a result, only between 5 and 19% of the fertilized eggs survive to hatching. High mortality of fertilized eggs has been attributed to suffocation, fungal infection, predation and physical damage due to high river flows (Leach 1925; Mansueti and Kolb 1953; Walburg and Nichols 1967). High river flows also reduce river temperatures and prolong the duration of the egg stage, thereby indirectly enhancing egg mortality rates.

Larval Stage

Newly hatched shad larvae (7-10 mm TL) occur during May and June and remain near the river bottom until the yolk sac is nearly absorbed about 3-4 days later (Maxfield 1953; Cave 1978). Following yolk absorption, American shad larvae (10-12 mm TL) are transported by river currents into eddies and backwater areas where current velocities are greatly reduced (Cave 1978; Crecco et al. 1983). Within these areas, first-feeding larvae must consume sufficient numbers of crustacean zooplankton and insects (Crecco and Blake 1983), or death from malnutrition will ensue within five days (Wiggins et al. 1984). Moreover, since first-feeding herring larvae deprived of food grow and swim more slowly than well fed larvae (Hunter 1976b), malnourished larvae are also more susceptible to predator-induced mortality. There is also direct evidence that hydrographic events during and shortly after spawning modulate the rates of larval predation and malnutrition (Sinclair and Tremblay 1984). Intra-annual fluctuations in rainfall and river flow regulate the May-June temperature gradient, thereby affecting the spatial and temporal match or mismatch between larval production, their food supply and their predators (Crecco and Savoy 1987a,b).

American shad larvae in the Connecticut River typically experience high mortality during May and June (Table 11). Mortality rates were highest (17 to 26%/d) among first-feeding larvae then declined steadily throughout larval development (Crecco et al. 1983; Savoy and Crecco 1986) because older shad larvae (>20 days old) grow rapidly and are better able to locate food and avoid predators. Based on the 1979-1984 survivorship data, about 60 to 80% of newly hatched larvae die about 3-7 days after feeding begins. The larval stage for American shad lasts between 4 and 6 weeks, during which the larvae grow fairly rapidly (0.4 mm/d) to about 22-26 mm TL (Savoy and Crecco 1986). Nearly all larvae metamorphose into facultative filter-feeding juveniles by August and resemble the adults in shape and coloration.

Juvenile Stage

Juvenile American shad (40-150 mm TL) are distributed throughout the river from July through November, grazing extensively on aquatic and terrestrial insects, as well as crustacean zooplankton (Levesque and Reed 1972). The wide diversity of prey found in the stomachs of juvenile shad suggests that they are opportunistic feeders whose feeding constraints depend mainly on prey size (Maxfield 1953).

Juvenile shad form dense schools and gradually move downriver during late fall (October-November) when river temperatures drop below 16 C (Watson 1968; Marcy 1976; O'Leary and Kynard 1986). Their movements throughout the nursery area are also influenced by river currents and by their growth rates (Watson 1970). Juvenile shad grow rapidly (0.7 to 1.0 mm/d) in both fresh and saltwater up to about 150 mm in their first summer (Crecco and Savoy 1985b). Juvenile growth rates from 1966 through 1986 were inversely related to their abundance (Rosen 1982; Crecco et al. 1984), suggesting that juvenile growth is limited by inter- and intra-specific competition for food and space. Juvenile shad that grow fastest usually emigrate to the lower river first (Marcy 1976; Crecco et al. 1984). Juvenile mortality rates from 1979 through 1984 (Crecco and Savoy 1987a) were much lower (1.5 to 2.5%/d) than mortality rates on eggs and larvae (Table 11). Since juvenile shad can tolerate food deprivation for long periods (Maxfield 1953), the main causes of juvenile mortality are believed to be predation and turbine-induced mortality at hydroelectric dams (Taylor and Kynard 1985). Juvenile shad descend from the lower Connecticut River (river km 1-20) during November and December (Marcy 1976), grow rapidly in the ocean, and return to the Connecticut River as adults some 3 to 6 years later. Although the mortality rates among subadult shad in the ocean has never been estimated directly, Savoy and Crecco (1988) reported that oceanic mortality ranges between 30 and 40%/yr based on indirect estimates (Pauly 1980).

5.0 Data Sources

5.1 Commercial

5.1.1 Data Collection Methods

5.1.1.1 Survey Methods

5.1.1.2 Sampling Intensity

5.1.1.3 Biases

5.1.1.4 Biological Sampling

Sampling has varied over time. For many years, commercial catches were qualified by sampling at commercial markets using only fishermen's catches who were known not to cull their catch for male shad. Markets and catches were sampled one or two days per week depending upon availability and catch size. In more recent years, CT DEP staff collected biological samples to characterize the fishery with drift gillnets and mesh sizes similar to the commercial fishery and in a similar fashion to that used by commercial operators. Gill nets were fished during daylight hours to avoid interfering with commercial efforts; research nets were shorter in length and drift times were shorter than those employed by commercial netters.

5.1.1.5 Ageing methods

All scale samples collected were separated by sex and stratified into 1 cm length groups. Scale samples were processed by cleaning with an ultrasonic cleaner and pressed onto acetate for aging. Age determinations were made as the consensus of two or more readers of projected images (43x) counting annuli and spawning scars according to the criteria of Cating (1953). Repeat spawners were noted by the presence of spawning scar(s) at the periphery of the scale. The age and repeat spawning frequency were extrapolated to the entire population by direct proportion.

5.1.2 Commercial Landings

Commercial fishermen are required to report daily landings of American shad. Total fishing effort (Net-days) was summed from individual catch reports.

5.1.3 Commercial Discards/Bycatch/Poaching

No poaching or illegal catch of American shad is thought to occur in this fishery. The fishery is somewhat self regulating in that drift gill nets are pre-emptive in nature and licensed commercial fishermen are not likely to allow unlicensed fishers to displace them from preferred fishing reaches. American shad are rarely taken as bycatch in the trawl fishery in Long Island Sound. These catches are minimal with annual reported landings of all commercial license holders combined being less than 250 kilograms.

5.2 Recreational

5.2.1 Data Collection Methods

5.2.1.1 Survey Methods

Recreational shad landings in numbers were estimated annually from 1980-1996 and periodically thereafter by a roving creel census (Savoy 1998). Prior to 1993, there was a thriving recreational fishery for American shad in the Connecticut River from Enfield, CT (river km 99) to the Holyoke Dam, MA (river km 140). Prior to 1990, these sport landings often comprised as much as 60% of the total in-river landings (Table 1). Recreational shad landings began to fall dramatically after 1995 to a point where harvest estimates from creel surveys were unreliable and imprecise as reflected by high (> 80%) proportional standard errors about the mean harvest estimates. Because of low precision due to a scarcity of positive intercepts in the creel survey, recreational harvest estimates from 1999 to 2005 did not differ significantly ($P < 0.05$) from zero. For this reason, recreational harvest estimates from 1999 to 2005 were assumed to be 1% of the population estimate (Table 1).

5.2.1.2 Sampling Intensity

Sampling intensity has varied over time, becoming generally less intensive with time as the fishery got smaller and anglers switched their angling preferences to other species. Two of five weekdays and both weekend, all holidays were sampled in past years compared to one of five weekdays and one of two weekend days sampled. All Holidays were always sampled given higher expected numbers of people available.

5.2.1.3 Biases

All shad caught in the recreational fishery are assumed dead although, it is known that most are released and some survive the catch episode. Hook and release mortality is a function of age, sex and physiological condition of the fish and external factors including water temperature, length of time 'played' by the angler, skill of the angler in handling and releasing the fish and hook type/location.

5.2.1.4 Biological Sampling. No sampling of recreational fishermens' catches was conducted since 1978.

5.2.1.5 Aging methods

Recreational catch is generally not characterized by sex and age since biological samples were not collected.

5.3 Fishery-Independent Survey Data

5.3.1 Data Collection Methods (to include, but not limited to the following)

5.3.1.1 Survey Methods

The adult American shad population estimate, age structure and sex ratio were calculated from samples collected at the Holyoke dam fishlift at Holyoke, MA. Information on the number of fish lifted daily, the number of lift days (days the lift is in operation) and the daily sex ratio at Holyoke were obtained from the Massachusetts Division of Fisheries. The annual sex ratio was calculated by weighting the daily sex ratios by the number of fish lifted that day.

The annual population estimate was derived using daily shad lift rates at the Holyoke dam. The shad population size was determined by dividing the number of American shad lifted by the number of days in which 99% of the total shad were passed. This rate was multiplied by a weighting coefficient (0.10) to adjust for lift improvements since 1976 and then multiplied by 1000 to scale the estimates to the proper magnitude (Crecco and Savoy 1985). Population estimates derived from Holyoke lift data were shown to be positively correlated ($r=0.68$, $P<0.01$) to population estimates derived from mark-recapture studies (1967-1978) and were positively correlated ($r=0.90$, $P<0.001$) to juvenile indices of abundance.

Age structure was derived from scale samples collected at the Holyoke Fishlift in Holyoke MA. and were used to characterize the population. Adult shad were sexed, measured to fork length (mm) and 10-15 scales removed. All scale samples collected were separated by sex and stratified into 1 cm length groups. Scale samples were processed by cleaning with an ultrasonic cleaner and pressed onto acetate for aging. Age determinations were made as the consensus of two or more readers of projected images (43x) counting annuli and spawning scars according to the criteria of Cating (1953). Repeat spawners were noted by the presence of spawning scar(s) at the periphery of the scale. The age and repeat spawning frequency were extrapolated to the entire population by direct proportion.

Juvenile American shad were collected weekly from July 18th through October 16th at seven fixed stations located from Holyoke, MA to Essex, CT in the Connecticut River. Seine haul locations and techniques have remained similar to those employed in past Connecticut River shad investigations (Marcy 1976; Crecco et al. 1981). Sites were previously chosen based on location, physical conditions and accessibility. One seine haul per station was made during daylight hours with a 15.2 m nylon bag seine (4.6 mm mesh, 2.4 m deep, and 2.4 m bag) and 0.5 m lead ropes. Each haul was completed by using a boat to set the net approximately 30 m upstream and offshore of the site. Using the lead ropes, the seine was then towed in a downstream arc to the shore and beached. With small sample sizes (less than 500 fish), all clupeids (*Alosa sapidissima*, *A. aestivalis*, *A. pseudoharengus*, and *Brevoortia tyrannus*) were returned to the laboratory. With large sample sizes, clupeids were subsampled volumetrically and unneeded fish returned to the water. Water temperature, weather conditions, time and tidal stage (when appropriate) were recorded for each station.

In the laboratory, juvenile clupeids were identified to species by the criteria of Lippson and Moran (1974) and counted. Up to 40 juvenile shad per haul were measured (TL mm). Individual seine collections containing greater than 40 shad were randomly subsampled for length measurements. All other clupeids were only counted. The relative abundance of juvenile American shad was calculated as the geometric mean catch per seine haul from all stations and all dates sampled.

5.3.1.2 Sampling Intensity

5.3.1.3 Biases

5.3.1.4 Biological Sampling

There are two biases as a result of sampling location. The Holyoke Dam and Fishlift are located at river kilometer 140. The net result is that all of the commercial fishing (by statute confined to below rkm 75) and most of the recreational fishing has already taken place causing removals. The resultant escapement is thus a function of run minus harvest and discard mortality. The more significant bias is presently unquantifiable and that is what is the percentage of the population that desires to continue upstream passage beyond river kilometer

140. The Connecticut River stock of American shad persisted and produced sustainable runs from time of closure of the Holyoke dam in 1849 to 1975 when effective fish passage began.

5.4 Other

Other losses (fish passage mortality, discarded males, brood stock capture, research losses, etc.). No other losses of American shad are known to occur in Connecticut waters from any of the cited reasons. Transplanting of Connecticut River American shad within and out of basin occurs from the Holyoke Fishlift in Massachusetts.

6.0 Methods

6.1 Models

We conducted several analyses on Connecticut River shad to determine the effects of fishing and predation on the recent stock decline. Our updated fishing mortality estimates from 1981 to 2005 include shad landings from the ocean recreational fishery, as well as discards from the Atlantic herring (*Clupea harengus*) commercial fishery. Although a thorough test of the Overfishing Hypothesis is our primary goal of this assessment, there is now an increasing body of evidence that suggests that enhanced predation by striped bass in the River has played a major role in the recent drop in shad run size. Savoy and Crecco (2004) recently used empirical and statistical evidence to show that the recent drop in shad population size in the Connecticut River was consistent with enhanced striped bass (*Morone saxatilis*) predation of adult shad. Moreover, Davis (2006 in prep) recently reported that adult shad dominated the diet of large (> 90 cm) striped bass in the River during spring 2005 and 2006. The striped bass is regarded as a voracious finfish predator from the Mid and North Atlantic on menhaden, gizzard shad, American shad and river herring (Walter and Austin 2003; Nelson et al 2005; Rudershausen et al 2005). Moreover, unlike many other marine finfish predators, adult (> 70 cm) striped bass have recently increased in New England waters to record high levels (ASMFC 2005), and have been sampled in large and increasing numbers well above the salt wedge in the Connecticut River since 1993 (Savoy 1995). Therefore, it would be useful to summarize these findings and present an analytical model that merges the population dynamics of American shad with the foraging characteristics of striped bass.

An age aggregated Steele and Henderson (S-H) production model (Steele and Henderson 1984) was used to examine the effects of fishing and predation effects on the recent decline of Connecticut River shad. The S-H model has extensive theoretical appeal since it incorporates compensatory stock dynamics of the prey with fishing effects plus a sigmoid Type III foraging response by the predator that may lead to critical depensation at low shad abundance (Spencer and Collie 1997). Since the S-H model can easily accommodate environmental variables (Spencer 1997), this modeling approach represents a modest but straightforward attempt at ecosystem modeling. The S-H model was also used to estimate fixed (equilibrium) and time varying overfishing thresholds (F_{msy}, N_{msy}) for Connecticut River shad under temporal shifts in predation mortality. In addition, more robust and precise estimates of the overfishing thresholds (F_{msy}, N_{msy}) from the S-H model were derived through iterative reweighted least squares regression.

American shad make extensive coastal migrations, so stocks are susceptible to several fisheries, including in-river sport and commercial fisheries, coastal intercept fisheries, ocean recreational fisheries and ocean bycatch fisheries. Statistical support for the Overfishing Hypothesis would be evident if stock declines in the Connecticut River after 1995 coincided with a systematic rise in combined ocean and riverine fishing mortality rates (FT). Support for this Hypothesis would be enhanced if recent FT estimates had risen beyond the overfishing threshold (F30% = 0.43) derived from the last peer-reviewed assessment (ASMFC 1998).

A commercial gill-net fishery and a recreational hook and line fishery have harvested American shad in the Connecticut River since the late 19th century. The commercial shad fishery in the Connecticut River is a spring fishery (April-June) that extends from the river mouth to Glastonbury, CT (river km 62). Commercial shad fishermen are required by law to report their annual gillnet landings and fishing effort (number of days fished) to the State by September. The reported commercial landings (numbers) of American shad are believed to be less than the true landings because certain fishermen underreport their landings for tax purposes (Leggett 1976), and discard male shad due to their low market value. Both Leggett (1976) and Crecco et al. (1986) reported that in-river commercial fishermen may have underreported their landings by 35 to 67% annually from 1966 to 1983 based on the ratio of tag returns to reported commercial landings. Reported commercial landings in the River from 1981 to 2006 were increased by a constant rate of 50% to reflect underreporting and discards (Table 1). American shad are occasionally caught (0-40 pounds) annually in the commercial trawl fishery in eastern Long Island Sound (LIS). These landings are not only very small, but are also suspected of being mis-identified for hickory shad (*Alosa mediocris*). The State of Connecticut also has strict rules of confidentiality regarding the public disclosure of commercial landings reported by less than three fishermen (Greg Wojcik CT DEP pers. comm.). Given the confidentiality issue surrounding the disclosure of these small landings, we decided not to include them in this assessment.

Recreational shad landings in numbers have been estimated annually from 1980-1996 and periodically thereafter by a roving creel census (Savoy 1998). Prior to 1993, there was a thriving recreational fishery for American shad in the Connecticut River from Enfield, CT (river km 99) to the Holyoke Dam, MA (river km 140). Prior to 1990, these sport landings often comprised as much as 60% of the total in-river landings (Table 1). Recreational shad landings began to fall dramatically after 1995 to a point where harvest estimates from creel surveys were unreliable and imprecise as reflected by high (> 80%) proportional standard errors about the mean harvest estimates. Because of low precision due to a scarcity of positive intercepts in the creel survey, recreational harvest estimates from 1999 to 2005 did not differ significantly ($P < 0.05$) from zero. For this reason, recreational harvest estimates from 1999 to 2005 were assumed to be 1% of the annual population. In-river recreational and commercial fisheries combined have harvested between 18,000 to 213,000 fish annually from 1981 to 2005 (Table 1).

A coast-wide intercept fishery for American shad had expanded from 1975 to 1990 (ASMFC 1998), but coast-wide intercept landings (pounds) have fallen steadily thereafter to 12,000 shad in 2005. Recent management action by coastal states under ASMFC has mandated a complete closure of ocean intercept landings after 2005. The coastal intercept fishery has harvested a mixed stock of American shad using drift gillnets during late winter and early spring. This commercial intercept fishery is located mainly between South Carolina and New Jersey and has harvested mostly adult shad (size range: 45 - 60 cm, TL, weighing an average between 1.5 and 2.5 kg) (Krantz et al. 1992). The contribution of Connecticut River shad to the coastal intercept fishery between 1981 and 2005 (Table 1) was based on the total coastal landings from Virginia to Maine and the stock identification data from tagging and mtDNA results (Hattala et. al. 1997; Hattala 2006). Specifically, the coastal landings attributed to the Connecticut River shad stock was the sum of the VA-MD coastal harvest (times the predicted Connecticut River contribution of 0.064 and 0.03), the DE-NJ coastal landings (times 0.188), and the NY-NE coastal landings (times 0.50). The estimated coastal intercept landings (Hattala 2006) in number (assumed average weight = 2.3 kg) for the Connecticut River shad stock (see Table 1) was doubled to reflect the combined effects of underreporting and the discard of male shad. Since the 2005 ocean intercept landings may be incomplete (Hattala 2006), the estimated 2005 ocean landings from the Connecticut River stock was tripled.

In addition to ocean commercial landings, there are also ocean recreational catch estimates of American shad recorded coast-wide from 1981 to 2005 by the Marine Recreational Fishery Statistics Survey (MRFSS). These catch estimates were only recently accessed from the MRFSS web site so that these data have never before been included in the total landings of Connecticut River shad. Since shad recreational catches occur coast-wide across all sub-regions (South, Mid and North Atlantic) and waves (two- month periods), the ocean recreational fishery apparently harvests a mixed stock of American shad. The annual shad catches (fish harvested and released) are usually imprecise with annual proportional errors standard (PSE) that often exceed 80% of the mean catch. Moreover, there are no length (cm) data available at this time on American shad catches in the MRFSS web site so the spawning potential (i. e. adult or subadult) of these catches cannot be determined. Despite the poor precision about most of these mean catch estimates, to fully test the Overfishing Hypothesis, we included a time series (1981-2005) of ocean recreational shad catches from the Connecticut River in this assessment using the following criteria. First, we assumed that all catches were adult shad that would have spawned in that year. Second, we assumed 100% mortality of all shad released in this fishery. Third, since the shad ocean recreational fishery is clearly seasonal and thus regarded as an intercept fishery, we use recreational catch data for only waves 1-3 (January to June) that occur prior to shad spawning. Most (40-80%) of the recreational ocean shad catches each year occurred during wave three (May-June). The effects of recreational catches that occur after spawning (waves 4-6) were assumed to be included in the post-spawning mortality rate. Since the average long-term (1981-2005) contribution of Connecticut River shad in the commercial ocean intercept fishery was around 10%, we assumed that 10% of the coast-wide recreational catches within waves 1-3 each year were Connecticut River fish (Table 1).

There is also the potential for significant bycatch losses of American shad in the Connecticut River and elsewhere associated primarily with the Atlantic herring (*Clupea harengus*) fisheries in the Gulf of Maine. The Atlantic herring fishery lands annually more than 60 million pounds of herring so there is the clear potential for significant bycatch losses to all shad stocks along the Atlantic coast. The NMFS Observer Program has monitored the shad bycatch from a subsample of landings in the Atlantic herring fishery between 1989 and 2005. According to the most recent bycatch data (Lora Lee ASMFC pers. comm.), American shad have comprised on average about 0.23% of the total Atlantic herring landings from 1989 to 2005 (Appendix 1). The highest percentage contribution of American shad bycatch of 2.2% occurred during 1998, whereas no American shad were recorded as bycatch in 1999 and 2000. We assumed that all shad caught as bycatch were adult (> 42 cm) fish, and that all shad in the bycatch experienced 100% mortality. The annual coast-wide bycatch (pounds) from 1989 to 2005 was derived by multiplying the total annual landings (pounds) of Atlantic herring times the estimated fraction of shad found as bycatch. The annual shad bycatch from 1981 to 1988 was estimated indirectly as the product of total Atlantic herring landings for those years and the long-term (1989-2005) average fraction of shad (0.0023) in the bycatch. Since adult American shad weigh on average about 4.5 pounds, the coast-wide bycatch of American shad in numbers was derived from 1981 to 2005 by dividing the coast-wide shad bycatch in pounds by 4.5 pounds. As in the previous analyses, we assumed that 10% of the coast-wide bycatch of American shad were Connecticut River fish (Table 1). Like the ocean recreational shad catches, these discard estimates from the Atlantic herring fishery have never been included in F estimates for Connecticut River shad.

RESULTS

Shad run size (Nt, thousands) in the Connecticut River varied between 588,000 and 1,574,000 fish from 1981 to 1993, but run sizes from 1994 to 2005 fell and never again exceeded 800,000 fish (Table 1, Figure 3). Shad run size dropped further to the historic (since 1965) low level of 226,000 fish in 2005, and the preliminary 2006 run size of 290,000 adult shad is the second lowest ever recorded. Although shad run size has dropped greatly after 2000, juvenile indices in the River have remained at or near the long-term (1981-2005) median after 1999 (Figure 3), indicating the presence compensatory density-dependent mortality.

Commercial and recreational landing (numbers) of Connecticut River shad varied greatly from 1981 to 2005 (Figure 4). Both commercial and recreational inriver landings remained relatively high from 1981 to about 1992 with peak total landings of 227,000 fish occurring in 1983 (Figure 4). Although both commercial and recreational landings in the River fell steadily from 1993 to 2005, recreational landings fell recently at a faster rate. The lowest total riverine landings of 14,000 fish occurred in 1999. The drop in inriver commercial landings after 1990 is consistent with a similar drop in commercial fishing effort (gillnet days) (Table 1).

In most years, the contribution of ocean intercept commercial landings to the Connecticut River stock was generally lower but more stable across years than inriver shad landings (Figure 5). The highest ocean intercept landings of 102,000 fish from the Connecticut River stock occurred in 1987 (Table 1). Prior to 1999, annual ocean landings always exceeded 40 thousand fish. As inriver landings fell quickly after 1993, ocean landings fell more slowly and comprised a greater proportion of the total landings on Connecticut River shad (Table 1, Figure 5). The lowest estimated ocean landings of 12,000 shad occurred in 2005 after a total closure to this fishery was mandated by all coastal states under ASMFC.

The ocean recreational landings of Connecticut River shad were highly variable from 1981 to 2005 ranging from 0 to 14,475 fish (Table 1, Figure 5). Except for the 1987 catch of 14,475 fish, the ocean recreational landings always amounted to less than 10,000 fish per year.

Ocean discard estimates of Connecticut River shad from the Atlantic herring fisheries varied greatly across the time series from a low of zero in 1999 and 2000 and to a high of 88,300 shad in 1998 (Table 1). In most years, ocean discards from the Connecticut River ranged annually between 1,000 and 7,000 fish. Although the 1998 ocean discard estimate of 88,300 shad comprised nearly 50% of the total shad landings in that year, in most years, ocean discards have made up less than 5% of the total shad landings (Figure 5).

Overfishing Thresholds

There is currently a range of overfishing threshold levels reported for Connecticut River shad. In the most recent peer-reviewed stock assessment (ASMFC 1998), the Thompson-Bell YPR model was used to establish regional overfishing definitions on selected shad stocks from Florida to Maine. Since stock-recruitment data were unavailable for most coastal shad stocks, F30% was used as a proxy for F_{msy} in the last assessment. As previously stated, an F30% level of 0.43 was derived for Connecticut River shad and many northern stocks in the last coast-wide assessment (ASMFC 1998). By contrast, Lorda and Crecco (1987) reported a much higher average F_{msy} level of 0.89 for Connecticut River shad based on a Ricker environmental-dependent stock-recruitment model. Lorda and Crecco (1987) noted that the mean F_{msy} of 0.89 was highly sensitive to annual shifts in May and June flows and to the number of female shad that spawned annually above the Holyoke Dam. Since their data set included only five years (1976-1980) of high spawning levels in the Holyoke pool, Lorda and Crecco (1987) concluded that the F_{msy} threshold of 0.89 was probably overestimated from this relatively narrow (1966-1980) data set. Crecco and Savoy (1987) attempted to reduce the uncertainty around F_{msy} with the use of a stochastic simulation model that included a Ricker stock-recruitment function embedded with annual variations in May and June river flows and in fish passage levels. Crecco and Savoy (1987) ran several 500 year simulations with the model and reported a relatively narrow range of long-term average equilibrium F_{msy} levels that fell somewhere between 0.48 and 0.53**.** They also noted that shad spawning stock size (sexes combined) at MSY (N_{msy}) in the simulation model varied somewhere between 408,000 to 544,000 shad.

Fishing Mortality and Surplus Production

In-river instantaneous fishing mortality rates (FR) have been estimated annually from 1981 to 2005 as a log ratio (seasonal fishery) (Ricker 1975) of the sum of riverine commercial (ShadCom) and recreational (ShadRec) landings divided by total run size (Nt) (Table 1):

$$\mathbf{FR = - \log (1-((ShadCom+ShadRec)/Nt)).} \qquad \mathbf{(1)}$$

The coastal commercial and recreational intercept fisheries harvest pre-spawning shad before they enter the River. Thus, the coastal instantaneous fishing mortality rates (FC) on Connecticut River shad were estimated as a log ratio of total ocean landings (Shadoc) to stock size (Nt) with the total ocean landings (ShadOc) being added to the denominator of equation 2:

$$\mathbf{FC = - \log [1 - (ShadOc/(ShadOc + Nt))]\ .} \quad \mathbf{(2)}$$

Note that the total ocean landings (ShadOc) in equation 2 represent the sum of the landings from the ocean intercept fishery (ShadCc), the ocean recreational fishery (ShadOr) and ocean discards (ShadDis) from the Atlantic herring fishery (Table 1).

The total instantaneous fishing mortality (FT) on Connecticut River shad between 1981 and 2005 was estimated as the sum of in-river (FR) and coastal (FC) instantaneous mortality rates (Table 2).

In this assessment, a time series (1981-2005) of shad surplus production (SURPt) in numbers (Table 2) was also derived by subtracting shad stock size in year t (Nt) from stock size in year t+1 (Nt1) followed by the addition of total annual landings (numbers) in year t (ShadTct):

$$\mathbf{SURPt = Nt - Nt{+}1 + ShadTct.} \qquad \mathbf{(3)}$$

The units of surplus production for most long-lived (> 15 age groups) finfish stocks are usually expressed in weight (mt) rather than numbers. However, most Connecticut River shad reach maturity gradually over ages 4-6 and seldom survive beyond age 7 (Leggett 1976) due to high post-spawning mortality. Thus, unlike most long lived marine fishes with variable age structure, the average weight of adult shad in the River has usually remained within 4.0 to 5.0 pounds (Leggett 1976, Savoy 1998). As a result, it is reasonable to express surplus production in numbers for American shad. These surplus production estimates will be used below to derive additional overfishing (F_{msy}) and stock size thresholds (N_{msy}).

Additional Overfishing Thresholds (F_{msy}, N_{msy})

Surplus production estimates have been used to monitor trends in per capita stock productivity for exploited finfish populations and to establish overfishing thresholds (Jacobson et al 2002). Having a time series (1981-2005) of shad surplus production (SURPt) (Table 2) and shad stock size estimates in year t (Nt) (Table 1), additional F_{msy} and N_{msy} thresholds were estimated for Connecticut River shad using the Gompertz external surplus production model (Quinn and Deriso 1999; Jacobson et al 2002). We selected the Gompertz form over the more widely used logistics equation because Yoshimoto and Clarke (1993) reported that under simulation conditions, the Gompertz model produced more realistic (positive) and stable overfishing thresholds than the logistics model. In the asymmetrical Gompertz model, surplus production estimates (SURPt) from 1981-2005 were regressed against shad stock size (Nt) and the product of the log of stock size and stock size (LogNt*Nt) in a two variable linear regression model without a y-axis intercept:

$$\mathbf{SURPt = a*Nt + b * ((LogNt)*Nt),} \qquad \mathbf{(4)}$$

where: K – theoretical carrying capacity (numbers) = exp (a / b);
MSY- maximum sustainable yield (numbers) = -b * Binf /2.72;
N_{msy} – stock size (numbers) at MSY = K / 2.72;
F_{msy} – instantaneous fishing mortality at MSY= MSY / N_{msy};
Fcoll – instantaneous fishing mortality at stock collapse = F_{msy} *2.72.

Since surplus production and stock size estimates are often plagued by moderate measurement errors resulting in outlying observations, the Gompertz model (equation 4) was fitted as a linear robust regression model using the least trimmed squares regression (LTS) objective function as recommended by Rousseeuw and Van Driessen (2000). The parameter estimates (a, b) and resulting reference points (F_{msy}, N_{msy}, Fcoll) from the production model (equation 4) were derived from the ROBUSTREG procedure contained in the Statistical Analysis System (SAS 2002). The parameter estimates (a, b) and their standard errors based on least squares (LS) are highly prone to the presence of outliers. With robust linear regression like LTS, outlying observations are identified and automatically down-weighted, resulting in higher precision and greater overall stability of the parameter estimates.

RESULTS

Total aggregate (ages 4+) fishing mortality (FT) on adult shad, based on the ratio of combined ocean and in-river landings to run size, were highly variable from 1981 to 1995, ranging from 0.14 to 0.47 (Table 2, Figure 4). After 1995, the FT estimates fell steadily in most years by 40% to 70% to below 0.20 from 1996 to 2005 (Figure 6). Except for 1986 (FT = 0.44) and 1987 (FT = 0.47), the total fishing mortality (FT) rates from 1981 to 2005 were consistently below the overfishing threshold (F30% = 0.43) established from the last assessment (ASMFC 1998). Total fishing mortality (FT) rates from 1996 to 2005 were more than 50% below the overfishing threshold of 0.43. The FT estimate of 0.11 in 2001 was the lowest in the time series (Table 2).

The systematic drop in total fishing mortality (FT) levels on Connecticut River shad after 1995 (Figure 4) closely followed the decline in total landings (Pearson r = 0.54, P <0.005), but was independent of shad run size (Pearson r = -0.22, P <0.29) (Table 1). If overfishing was the underlying cause of the stock failure of American shad, total fishing mortality (FT) would have risen significantly (P <0.05) after 1996 when shad run size dropped. Since the trend in FT and run size (Nt) was independent (P <0.29), these findings suggest that the decline of Connecticut River shad after 1996 was not caused by overfishing.

The Gompertz external surplus production model (equation 4) was fitted by robust linear regression methods (LTS) to shad surplus production (Surpt) and shad run sizes (Nt, Nt+1) from 1981 to 2005. The production model provided a relatively good fit (r^2 = 0.58) to the shad abundance data and the a and b parameter estimates from equation 4 differed significantly (P <0.0008) from zero (Table 3). The resulting mean overfishing threshold (F_{msy}) for Connecticut River shad was 0.51 (80% CI: 0.32 to 0.69) which is higher than the F30% level of 0.43 based on northern shad stocks from the last peer reviewed assessment. Note that the estimated total fishing mortality (FT) rates on Connecticut River shad, based on combined ocean and river landings, from 1996 to 2005 (Figure 6) were more than 50% below the mean overfishing threshold of 0.51 based on the Gompertz model. This strongly suggests that overfishing is not the primary cause for the recent drop in shad population size. The F_{msy} level of 0.51 from the Gompertz production model fell within the range of F_{msy} values (0.48-0.53) reported by Crecco and Savoy (1987) based on results from their stochastic simulation model.

The resulting N_{msy} threshold estimate from the Gompertz model was 456,000 shad (80% CI: 287,000 to 619,000 fish) (Table 3). This N_{msy} estimate of 456,000 shad is lower than the mean N_{msy} of 476,000 shad reported by Crecco and Savoy (1987) based on simulation modeling (Table 2). The shad run sizes from 1981 to 1993 always exceeded the mean N_{msy} threshold of 456,000 fish (Figure 7). The 1994 to 2003 run sizes were lower and generally hovered near the mean N_{msy} threshold of 456,000 shad. The 2004 to 2006 run sizes were well below the estimated mean N_{msy} of 456,000 fish, indicating that recent run sizes are severely depleted.

Striped Bass Abundance

Striped bass abundance along the Atlantic coast has recently risen to record high levels coincident with the recent failure in shad productivity (ASMFC 2005). Striped bass grow rapidly to a large size (>90 cm) that can easily prey on adult shad, are highly piscivorous on herring-like prey (Hartman 1993), and are efficient diurnal and nocturnal predators (Nelson et al 2005). If the Predation Hypothesis adequately accounts for the recent drop in shad run size in the Connecticut River, we would expect that: 1) large (> 72 cm) striped bass are present in the River during spring and prey heavily on adult shad; and 2) a large (> 50,000 fish) and growing time series of striped bass abundance have been documented in the upper River from April to June when adult shad are spawning.

We used several time series (1981 to 2005) of coast-wide and inriver striped bass abundance to test the Predation Hypothesis. Coast-wide striped bass abundance estimates (N*1000) of ages 7+ stripers have been derived by the ADAPT VPA between 1982 and 2005 (ASMFC 2005) (Table 4). Another coast-wide time series of ages 7+ stripers has been recently developed (Kahn 2005) from 1981 to 2005 as a ratio between age 7+ landings to the fishing mortality rate (F) based on coast-wide tagging (Table 4). In Connecticut waters, striped bass relative abundance (mean catch/tow) has been monitored in Long Island Sound (LIS) from 1984 to 2005 by the CTDEP multispecies trawl survey (Gottschall and Pacileo 2006) (Table 4). Finally, an abundance index of 72 cm+ stripers (mean catch / electro-fishing day) has been monitored annually in the River near Windsor CT (river km 103) from 1993 to 2004 (Savoy 2005) (Table 4). The abundance trends of all these estimates demonstrate that striped bass abundance from Connecticut waters and elsewhere have recently risen to record high levels since 1993 coincident with the recent failure in shad productivity (Figure 8).

The most recent (2002-2005) striped bass abundance estimates from the VPA are plagued by moderate to severe retrospective bias so that the terminal year stock estimates are underestimated by about 50% (Table 4). As a result, we chose to use the tag-based estimates of ages 7+ stripers from 1981 to 2005 as the best coast-wide stock estimates in all analyses to test the Overfishing Hypothesis. Our choice of the tag-based estimates is somewhat arbitrary, however, given that striped bass indices from the River between 1993 and 2004 were highly correlated (Pearson $r = 0.83$, $P < 0.0003$) with both VPA and the tag-based estimates of striped bass (Figure 8).

Scaling the Striped Bass Estimates

To estimate striped bass population size in the Connecticut River during spring, Savoy (1995) conducted a mark-recapture study in 1994. Striped bass were captured mainly with electrofishing gear from April through June 1994 throughout the lower Connecticut River (Old Saybrook to Windsor, CT). A total of 346 striped bass from the Connecticut River were captured, measured to total length (cm) and tagged with internal anchor tags (Table 5). Since no commercial fishing is permitted for striped bass in Connecticut waters, most tag recoveries were from recreational fishermen. Striped bass population size (N) in the River was estimated by the Petersen equation. Because the vast majority of recaptures (93%) and striped bass catches (C) in the River occur from April through June, the population estimate discussed herein mainly reflected the 1994 spring population abundance of striped bass. The tag reporting rate by the recreational fishery was assumed to be 60% based on tagging studies of striped bass in Chesapeake Bay (Rugolo et al. 1994a). The combined effects of tag loss, tag-induced mortality, and migration of tagged stripers from the river was assumed to be 50%. As a result, the number of tagged stripers (Mk) in this study was reduced by 50% (Savoy 1995).

RESULTS

The results of the tagging study revealed a spring (April -June) 1994 population size in the Connecticut River of 407,300 striped bass (95% CI: 269,400 to 604,100 fish) (Table 5). Striped bass in the River ranged in size (TL) from 18 cm to 118 cm. Since striped bass are known to consume finfish prey up to 60% of their own body length (Manooch (1973), striped bass exceeding 72 cm (28 in.) could theoretically prey on most adult male shad (assuming that the mean length of adult male shad is about 43 cm). Based on the 1994 striped bass length frequency data, about 48% (197,000 fish) exceeded 72 cm and therefore would have been large enough to consume most adult male shad. The estimated 197,000 large (> 72 cm) stripers from the River in spring 1994 comprised about 4.9% of the coast-wide 1994 striper stock size of 72 cm+ fish (4,032,000) based on tagging. In this analysis, we assumed that 72 cm+ stripers were equivalent to ages 7+ fish. To estimate striped bass population size in the Connecticut River from 1981 to 2005 (Striprv), the coast-wide abundance estimates of 72 cm+ stripers from 1981 to 2005 based on tagging (Table 4) were multiplied times 0.049 (Table 4). The trend in these scaled estimates of striped bass abundance (Striprv) from 1981 to 2005 shows that the population size of 72 cm+ striped bass abundance has risen about ten-fold in the River since the early 1980's.

Pre-recruit Mortality of American Shad

One major problem in quantifying predation or other trophic responses on American shad is pinpointing the period in the life history where the highest predation risk takes place. Savoy and Crecco (2004) noted that juvenile shad indices in the Connecticut River for the 1966 to 1988 year-classes were positively correlated with subsequent adult recruitment (Pearson $r = 0.82$, $p < 0.01$) from these year-classes. However, juvenile indices after 1988 became uninformative (Pearson $r = 0.124$, $P < 0.67$) about subsequent changes in adult recruitment of those year-classes, indicating the emergence of a recruitment bottleneck. A temporal shift in predation mortality can occur across many shad ages or may be confined mainly to a single age group. Since age 0 shad rarely exceed 13 cm TL, this early stage is particularly susceptible to a heightened risk of mortality from a vast array of potential finfish predators. Several recent predation studies on finfish and crustacea (Beck 1997; Wahle 2003) have shown that size dependent mortality during the juvenile stage may lead to a demographic bottleneck that can inhibit the flow of recruitment to older ages. If this bottleneck is severe and persists over time, prey abundance will eventually cascade downward, resulting in a stock collapse emanating from the youngest to the oldest ages (i. e. bottom-up effect). In the specific case of American shad, a recent rise in striped bass predation would likely undermine shad surplus production by enhancing natural mortality directly on adult shad or by constricting the flow of age 0 recruitment to the adult stock.

Savoy and Crecco (2004) examined whether or not a demographic bottleneck may have developed for Connecticut River shad between juvenile and adult recruitment due to a recent rise in striped bass predation. They derived a time series of relative mortality (Z0) rates from 1980 to 2001 based on a log ratio between the shad population estimates (N_t) in year t (between 1980 and 2001) and the sum of the juvenile shad indices in years t-4 and t-5 (Shadjvt-4, t-5):

$$Z0 = -\log [Nt / Shadjvt\text{-}4,t\text{-}5] \quad . \qquad (5)$$

Since juvenile shad indices (Figure 3) and adult recruitment estimates (Table 1) are now available through 2005, we extended the time series of pre-recruit mortality estimated (Z0) derived by Savoy and Crecco (2004) to include the 2002 to 2005 data (Table 4).

The Predation Hypothesis was tested by least squares (LS) linear regression between relative mortality (Z0) from1980-2001 and striped bass abundance in the River. Savoy and Crecco (2004) also expanded the Predation Hypothesis to include potential effects from other marine finfish predators. As such, the relative mortality (Z0) estimates from 1984 to 2002 were regressed against bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), and spiny dogfish (*Squalus acanthias*) relative abundance (mean catch/tow) based on trawl surveys from Long Island Sound (Gottschall and Pacileo 2005). If striped bass predation was directly linked to the current shad decline in the Connecticut River, a rise in shad natural mortality (Z0) should have occurred after 1994 (Table 4) coincident with an increase in striped bass abundance in the upper River. Thus statistical support for the Predation Hypothesis for striped bass would be evident if the slope of the linear regression between natural mortality (Z0) and striped bass abundance in the River were positive and statistically significant ($P < 0.05$). The slope values of the regressions based on other candidate finfish predators should be statistically significant ($P < 0.05$).

The ocean intercept fisheries annually harvest American shad before they enter the Connecticut River to spawn. If the total intercept fishing mortality (FC) rose to excessively high levels after 1994, a recruitment bottleneck could have been the result of the intercept fishery alone or in combination with predation. To test the Over-fishing Hypothesis, shad relative mortality rates (Z0) (Table 4) were regressed against the coastal (FC) fishing mortality rates (Table 2) derived for Connecticut River shad from 1981 to 2005. A positive and statistically significant ($P<0.05$) slope for fishing effects would support the Overfishing Hypothesis, suggesting that over-fishing by the intercept fishery played a significant role in the recent development of a recruitment bottleneck.

RESULTS

Statistical evidence in support of the striped bass predation hypothesis was clearly evident by the trends in pre-recruit (Z0) mortality and striped bass abundance. Total pre-recruit mortality rates (Z0) on American shad rose after 1995 (Table 4) and were positively correlated ($r = 0.76$, $P<0.001$) to a systematic rise in striped bass abundance in the River from 1995 to 2005 (Table 4). Conversely, changes in pre-recruit mortality (Z0) rates from 1981 to 2005 were statistically independent of changes in ocean fishing mortality (FC) (Table 2), as well as to changes in bluefish, weakfish and spiny dogfish abundance based on Savoy and Crecco (2004). The strong positive linkage between the rise in Z0 and striped bass abundance (Figure 10) suggests that the rise in shad pre-recruit mortality (Z0) and subsequent drop in adult stock size were strongly coupled with a recent increase in striped bass predation effects in the Connecticut River.

Recent Striped Bass Dietary Studies in the River

There is abundant statistical and empirical evidence in support of the Predation Hypothesis. However, additional empirical support such as dietary studies of striped bass in the River is essential to clearly establish a causal link among striped bass abundance, their consumption of adult shad and the resulting decline in shad run size. We present the data on striped bass food habits studies conducted in the River from April to June, 2005 and 2006 by Mr. Justin Davis as part of his doctoral dissertation at the University of Connecticut (Davis 2007 in prep) simply for consideration. Dietary analyses and subsequent bioenergetic modeling of striped bass predator-prey effects on shad and river herring in the River are not yet complete. Davis allowed us the opportunity to summarize his 2005 and 2006 dietary results in the context of support for the Predation Hypothesis. Davis (2007 in prep) sampled striped bass by electro-fishing and angling weekly from five stations located between Wethersfield, CT (river km 89) and the base of the Holyoke Dam, Holyoke MA (river km 140). A total of 126 bass, ranging in size from 30 to 112 cm, were examined for food habits in 2005 and another 331 bass within the same size range were examined in 2006. His dietary results were expressed as percentage frequency of occurrence of shad and percentage weight (gm) of shad in the stomachs.

RESULTS

Of the 457 striped bass examined thus far for food habits, 234 (51.2%) consumed invertebrates, river herring, American shad and other fishes. River herring were found in the stomachs of 25% of the 103 striped bass that measured between 50 cm and 90 cm. Adult shad were only occasionally (5.5%) found in striped bass less than 80 cm. Of the 28 largest (> 90 mm) striped bass examined thus far for food habits, 19 (68%) were found to have adult American shad in their stomachs. In fact, the larger the bass, the greater the incidence of shad in their diet (Table 6). Since male shad are on average 20-30% smaller than female shad, larger (> 90 cm) striped bass tended to select for the smaller male shad in their diet. These dietary findings are wholly consistent with the Predation Hypothesis, indicating that large (> 90 cm) striped bass sampled from the upper River fed actively on adult shad during their spawning migration. It must be noted that the above noted research was conducted in 2005 and 2006. We presented data that documented heavy losses of adult shad since 1993. Changes in adult shad and striped bass abundance and size distribution should be expected to have occurred in the face of 10 plus years of predation.

Steele-Henderson (S-H) Model

Given that large (> 90 cm) striped bass actively prey on adult shad in the River, it would be useful to develop an analytical model that ties striped bass foraging characteristics to the recent drop in shad run size. The Steele-Henderson (S-H) model incorporates compensatory stock dynamics of the prey with fishing effects plus a sigmoid type III functional response by the predator. The Type III response adds a degree of realism to the model since it may lead to either prey stability at low to intermediate predator abundance, or to critical depensation of the prey at low prey abundance (Spencer and Collie 1997). The age aggregated Steele-Henderson (S-H) production model (Steele and Henderson 1984) was used to estimate equilibrium and time varying overfishing thresholds (F_{msy}, N_{msy}) for Connecticut River shad in the presence of a significant ($P < 0.05$) striped bass predatory response. The S-H model assumes the existence of compensatory density-dependent mortality for finfish populations, a position widely held by most fish population ecologists (Wahle 2003). All of the shad population dynamics processes (somatic growth, natural mortality and recruitment) in the S-H model are subsumed in the intrinsic rate of population increase (r) and to a lesser extent in the carrying capacity (K) parameters. Like all production models, successful fitting (precise and robust parameter estimates) of the S-H model requires a high degree of contrast in the time series (1981-2005) of stock sizes. The S-H model was originally configured as a logistics production model with an added sigmoid function that reflected the foraging response by the predator. Previous simulation studies (Yoshimoto and Clarke (1993) have indicated that the Gompertz asymmetrical model produced more realistic (positive values of F_{msy}) and robust parameter estimates than the logistics model. As a result, the surplus production portion of the S-H model was converted from the logistics to the Gompertz form:

Nt+1=Nt+log(K)*r*Nt*(1-(log(Nt)/log(K)))-catcht-[(c*striprv*(Nt)2)/(A**2+(Nt)**2)] (6)**

where: Nt+1 = shad stock size in year t+1;
Nt = shad stock size in year t;
striprv = abundance of the striped bass in the River during year t;
K = estimated carrying capacity of shad (Nt);
r = intrinsic rate of population increase of shad;
c = per capita consumption rate of striped bass;
A = shad stock size at which striped bass satiation takes place.

All parameter estimates (r, K, c and A) from the S-H model (equation 6) were derived from the NLIN procedure (marquardt algorithm) contained in the Statistical Analysis System (SAS 2002). The S-H model was fitted to shad stock sizes (Nt, Nt+1) (Table 1) and striped bass abundance (Striprv) in the River (Table 4) by nonlinear least squares regression methods.

Given the likely presence of measurement errors in the input data, the S-H models was fitted as a nonlinear robust regression using the iterative reweighted least squares method outlined by Holland and Welsch (1978). The algorithm and rationale for this approach is described in SAS (2002). This re-weighting scheme is designed to detect outliers, thereby allowing the down weighting of data from certain years in the model where model residuals, regardless of direction, exceeded a previously defined threshold level. As indicated by Holland and Welsch (1978), the choice of a threshold is subjective and always represents a trade-off between minimizing the variances around the parameters (r, K, c and A) and at the same time generating globally converged parameter estimates. As suggested by Holland and Welsch (1978), a range of threshold estimates was used initially and the final threshold value was selected that satisfied the trade-off between global convergence of all parameter estimates and parameter estimates with maximum precision and minimum variance. The two-step re-weighting approach always produced converged estimates (global estimates) that were within 10% of the parameter estimates (r, K, c and A) derived by the ordinary least squares approach. However, the standard errors about the estimates based on iterative re-weighting were always 30 to 45% lower, resulting in much narrower confidence limits about the overfishing definitions (F_{msy}, N_{msy}) and the striped bass predation parameters (c, A). Finally, after repeated use of the S-H model, we found that the model always converged to stable and robust parameter estimates more quickly when a lognormal error structure was used rather than the normal error structure. The final estimates (r, K, c and A) were derived from the S-H model with iterative re-weighting and a lognormal error structure as recommended for dynamic production models by Schnute (1989).

Uphoff (2005) noted that if the predation parameter estimates (c, A) from the S-H model are sufficiently robust and precise, then a time series of adult shad consumed (Dt) annually by the striped bass (striprv) in the River can be derived in the form:

$$\mathbf{Dt = [(c*striprv*(Nt)**2) / (A^2 + (Nt)^2]} \qquad \mathbf{(7)}$$

Once (Dt) is estimated via equation (7), the instantaneous consumption rate associated with striped bass predation (Mpt) can be derived annually for a seasonal (Type 1) predator:

$$\mathbf{Mpt = - log [1 – [Dt / (Nt\text{-}SHADCOM+ Dt)]\ ]} \qquad \mathbf{(8)}$$

Most of the evidence indicates that striped bass predation on shad occur mainly in the upper (> river km 70) River (Savoy and Crecco 2004). The vast majority of inriver commercial shad landings take place in the lower River (< river km 30). Thus, to estimate the instantaneous striped bass consumption rate (Mp) in equation (8), it was necessary to subtract the annual inriver commercial landings (SHADCOM) (Table 1) from the annual shad run size (Nt) and then add the Dt levels in the denominator of equation (8). Further empirical support for the Predation Hypothesis is given if striped bass consumption rates (Mpt) rose steadily beyond the overfishing threshold (F_{msy}) after 1995 and if the number of shad recently consumed (Dt) by striped bass greatly exceeded recent shad landings from the commercial and sport fisheries.

In the discrete Gompertz production model without predation, the equilibrium F_{msy} threshold is solely expressed by the intrinsic rate (r) parameter, whereas N_{msy} is expressed by the carrying capacity (K) divided by 2.72 (Quinn and Deriso 1999). Since temporal effects of striped bass predation are absent from discrete models, the overfishing definitions (F_{msy}, N_{msy}) in these models are fixed in time. However, in the non-equilibrium S-H model (equation 6) the ability to identify steady-state conditions is far more challenging. In the non-equilibrium S-H model, shad surplus production and predation-induced mortality from striped bass (Mpt) can vary greatly across years, resulting in time varying F_{msy} and N_{msy} thresholds. The degree of temporal variation in F_{msy} and N_{msy} depends on the magnitude and trend in striped bass abundance, the striped bass consumption exponent (c) and on the prey stock size (A) at which the consumption threshold of striped bass takes place in equation (6). Thus, the annual $F_{msy\ t}$ value from the S-H model is not fixed in time but rather is a function of the fixed intrinsic rate (r) minus the time varying predator consumption rate (Mpt):

$$\boldsymbol{F_{msy\ t} = r * \exp(- Mpt)\ .} \qquad \textbf{(9)}$$

Similarly, the annual stock size threshold (N_{msy}) can vary over time depending on the number of shad consumed annually by striped bass (Dt):

$$\mathbf{N_{msy} = [K - Dt\ ] / 2.72\ .} \qquad \textbf{(10)}$$

Although overfishing thresholds ($F_{msy\ t}$, $N_{msy\ t}$) derived from the S- H model are time varying, equilibrium reference points can be approximated as long-term (1981-2005) mean F_{msy} t and $N_{msy\ t}$ levels.

RESULTS

The full S-H Gompertz production model (equation 6) provided a very good fit ($r^2 = 0.88$, $P < 0.0001$) to the 1981-2005 shad and striped bass abundance data with statistically significant ($P < 0.05$) estimates of r, K, c and A parameter estimates (Table 7). The iterative re-weighting method estimated the four parameters of the S-H model based on 22 of the 25 data points, indicating that the remaining three data points were designated as statistical outliers and thereby down-weighted in the model. In this model configuration, there was little if any systematic residual pattern from the S-H model fitted by iterative re-weighting (Figure 9), indicating the presence of relatively low process error for the S-H model.

The time series (1981-2005) of adult shad consumed by striped bass in the River (Dt) and the instantaneous striped bass consumption rates (Mp) were derived via equations (7) and (8), respectively (Table 8). The consumption rates (Mp) rose in magnitude after 1995 coincident with a steady drop in shad run size and corresponding rise in striped bass abundance in the River (Figure 10). The estimated number of shad consumed (Dt) by striped bass remained below 70,000 adult shad in most years prior to 1996, but Dt levels rose abruptly to over 154,000 adult shad after 2000, and Dt levels as high as 374,000 shad occurred in 2002 (Table 8, Figure 11). Moreover, after 1999, adult shad consumed by striped bass (Dt) were 7 to 15 times higher than the inriver landings for those years (Figure 11). The number of shad consumed (Dt) remained relatively high from 2000 to 2005 despite the fact that shad run size for those years had declined steadily to historic low levels (Figures 8 and 9). Note also that the instantaneous striped bass consumption rate (Mp) rose steadily after 1999 during which shad run size was falling (Figure 10). This inverse relationship between instantaneous consumption (Mp) and shad run size is consistent with the presence of depensatory density-dependent predation mortality that could become highly destabilizing to future stock rebuilding. Finally, when the instantaneous consumption rates (Mp) on adult shad from 1981 to 2005 were summed to the total instantaneous fishing mortality rates (FT) on shad, the resulting fishing and predation mortality rates (FT + Mp) rose well beyond the current overfishing thresholds (F30% = 0.43) after 2000 (Figure 12). These findings strongly suggest that the recent rise in shad pre-recruit mortality (Z0) and the parallel drop in shad run size after 1996 are tied directly to the instantaneous consumption rate (Mp) from striped bass in the River.

Estimates of the striped bass consumption rates (Mp) and the number of adult shad consumed by striped bass (Dt) rose systematically from 1995 to 2005 (Figures 10 and 11). Thus, under time-varying predation, the overfishing definitions (F_{msy}, N_{msy}) for Connecticut River shad based on the S-H model are not fixed in time. The non-equilibrium F_{msy} levels via equation (9) remained relatively stable at about 0.55 from 1981 to 1993 during which total fishing mortality (FT) on shad were the highest (Figure 11). However, when shad run size declined steadily after 1998 and striped bass consumption rates (Mp) rose, annual $F_{\mathrm{msy}\ t}$ thresholds dropped sharply from around 0.39 in 1997 to 0.02 by 2004 in concert with a drop in total fishing mortality (FT) (Figure 11). In contrast, non-equilibrium run size thresholds (N_{msy}) were more robust to rising striped bass consumption rates (Mp) (Figure 12). The N_{msy} thresholds remained fairly stable at around 500,000 fish from 1981 to 1999 (Figure 13). Despite a six-fold rise in Mp levels from 1981 to 2005, annual N_{msy} thresholds fell slightly from about 500,000 shad in the late 1980's to about 400,000 shad after 2000.

Although steady-state overfishing thresholds (F_{msy}, N_{msy}) do not normally apply to non-equilibrium conditions in the S-H model, approximate equilibrium thresholds (F_{msy}, N_{msy}) were expressed as the long-term (1981-2005) average F_{msy} and N_{msy} levels. The resulting average overfishing thresholds (av F_{msy}, av N_{msy}) for Connecticut River shad were 0.39 and 470,000 shad, respectively (Table 7).

9.0 Recommendations and Findings

We conclude, based on the statistical and empirical evidence, that predation by striped bass provides the best explanation for the recent shad stock decline in the Connecticut River. As for the Overfishing Hypothesis, there is no evidence that in-river and coastal commercial fisheries have increased recently to levels that would have resulted in the recent drop of the Connecticut River shad stock. Moreover, despite the recent inclusion of ocean recreational landings and discards from the Atlantic herring fishery to our F estimates, total fishing mortality rates (F_T) on Connecticut River shad have declined steadily after 1994. Recent (1996-2005) F estimates are more than 50% below the current over-fishing definition ($F_{30\%} = 0.43$) for American shad based on the last peer reviewed assessment (ASMFC 1998). By contrast, nearly all of the statistical evidence given herein supports the Predation Hypothesis as the most reasonable explanation for the recent failure in Connecticut River shad. Statistical evidence in support of the Predation Hypothesis consists of a significant positive regression between pre-recruit mortality (Z_0) of American shad and striped bass abundance in the River from 1981 to 2005. In addition, estimated shad consumed by striped bass in the S-H model have more than tripled after 2000, so that the estimated numbers of adult shad consumed by stripers grew to represent more than 5 to 15 times the annual shad landings from 2000 to 2005.

It is widely recognized that statistical evidence (regression and production models) alone does not demonstrate causality, but recent empirical evidence is wholly consistent with the Predation Hypothesis involving striped bass. Due to the success of striped bass management, striped bass abundance has risen steadily to record levels in mid and north Atlantic coastal waters from 1993 to 2005 (Crecco 1994; ASMFC 2005; Kahn 2005). The results of striped bass tagging in the River revealed a spring (April -June) 1994 population size in the Connecticut River of 407,300 striped bass (95% CI: 269,400 to 604,100 fish) (Table 7). Striped bass in the River ranged in size (TL) from 18 cm to 118 cm. Since striped bass are known to consume finfish prey up to 60% of their own body length (Manooch 1973), the 1994 striped bass stock exceeding 72 cm (assuming that the mean length of adult male shad is about 43 cm) was 197,000 fish. Since all striped bass abundance estimates both coast-wide and regional have more than tripled since 1994 (Figure 8), it is reasonable to conclude that bass population size in the Connecticut River and elsewhere has more than tripled from 1994 to 2005. These abundance data from 1994 to 2005 suggest that a sufficient number of large (> 72 cm) striped bass were available in the River during springtime to have caused a measurable reduction in shad run size. Moreover, during the spawning migration, adult shad have an enormous urge to reach their upriver spawning grounds (Leggett et al 2004; Fay et. al 1983). This strong drive to spawn may hamper the predator avoidance capability of adult shad, rendering them more susceptible to predation during the migration and spawning phase of their life history. Lower predation risk perhaps occurs on sub-adult shad in the ocean due to their greater capacity to adopt tactics (i.e. schooling, spatial stratification) which may serve to minimize or impede contact with finfish predators. Finally, striped bass food habits studies recently conducted in the River (Davis 2007 in prep) indicated that large (> 90 cm) striped bass fed almost exclusively on shad. The results from this recent dietary study are consistent with the theoretical expectations of the Predation Hypothesis. The recent decline in the Connecticut River shad run and concomitant rise in pre-recruit mortality (Z_0) is likely due to predation effects by striped bass.

The management implications and long-term prognosis for Connecticut River shad following a major trophic incident are challenging and somewhat ambiguous. On the plus side, shad juvenile production in the River has thus far remained relatively high and stable despite a recent 50% to 80% drop in adult run size. That shad recruitment levels appear to be highly resilient to a sharp drop in egg production is consistent with earlier findings (Leggett 1976; Crecco and Savoy 1987: Lorda and Crecco 1987) that Connecticut River shad, like other alosines, possess a high degree of compensatory reserve. Although predation mortality on adult shad has risen to levels that exceed our F_{msy} thresholds, the recent dietary study of striped bass (Davis 2006 in prep) in the River clearly shows that the highest risk of striper predation is confined to smaller male shad. The clear preference for male shad in the diet of large striped bass (Davis 2007 in prep) suggests that risk of predation is lower on female shad. This selective mortality might serve to preserve future egg production at current levels and allow the shad population to stabilize indefinitely at some lower equilibrium abundance.

Furthermore, since most adult American shad exceed 40 cm in length, only the largest (> 90 cm) and least numerous striped bass in the River are capable of consuming adult shad. In addition, the Type III functional response within the S-H model would force the per capita rate of predation towards an upper limit, allowing the shad population even greater ability to achieve some level of stability.

On the negative side, the strong inverse relationship between estimated striped bass consumption (Mp) rates from the S-H model and adult shad run size is consistent with the presence of depensatory density-dependent mortality brought about by predation. This phenomenon plus the apparent emergence of a pre- recruitment bottleneck between ages 0 and adult recruitment should make stock rebuilding of Connecticut River shad via management measures an exceedingly difficult task. As indicated by Spencer and Collie 1997), fish stocks that are subject to moderate to severe depensatory predatory mortality, often undergo a sudden and persistent drop in stock abundance over time even when fishing mortality rates have remained low for more than a decade. Note that total fishing mortality (FT) rates on Connecticut River shad have remained well below the overfishing threshold (F30%= 0.43) and the Steele-Henderson average F_{msy} level of 0.39 for over a decade. Under severe depensatory predation by striped bass, Connecticut River shad run sized is expected to remain low and unresponsive to favorable climatic events and to further fishery management restrictions. The phenomenon of depensatory mortality, if driven largely by striped bass predation, could lead to a persistent and perhaps irreversible failure in shad productivity unless striped bass abundance reverts back to pre 1994 levels.

There is a prevailing consensus that overfishing has had an adverse effect on many fish stocks throughout the world (Myers et al 1997; Hutchings and Reynolds 2004; Scheffer et al. 2001). However, the catch-at-age models traditionally used to estimate fishing mortality over time have almost always assumed a low and constant (M = 0.20) natural mortality rate. Under low and constant M and rising total mortality (Z), rapid success of stock rebuilding for depleted finfish stock is always predicted over a narrow timetable by sizeable reductions in F. With M low and constant, total mortality (Z) is always dominated by fishing mortality (F). Clearly there are finfish stocks throughout the world where natural mortality (M) approaches 0.20 or can otherwise vary without trend over time. But as shown for Connecticut River shad, a systematic rise in predation mortality on shad coupled with a steady drop in F can either greatly extend the timetable for rebuilding, or can simply eliminate the likelihood of any stock rebuilding even under moratorium conditions.

Results from the S-H model indicated that a systematic rise in predatory mortality led to non-equilibrium conditions, resulting in a time varying overfishing threshold (F_{msy}) for Connecticut River shad. Under non-equilibrium conditions, the most restrictive management measures, such as a river-wide moratorium to harvest, would reduce riverine FR levels on shad to zero, but a moratorium alone would not likely achieve the ultimate goal, which is rapid stock rebuilding back to the pre-1995 levels. After 2005, the ocean intercept fishery for American shad was completely closed to harvest. An additional River-wide moratorium to shad landings in the Connecticut River would only reduce pre-spawning losses by another 10-15%. Since current riverine fishing mortality (FR) levels comprise a very small fraction of Z, a River-wide closure to shad harvest could not reduce the ratio of fishing effects to total mortality (FR/Z ratio) enough to leverage stock rebuilding over a reasonable planning horizon (5-10 years) unless striped bass predation levels in the River drop significantly.

In a sense, the FR/Z ratio is a relative measure of leverage that fishery managers can exert to enhance the future chances of rebuilding depleted stocks. From 1981 to 1993, striped bass predation mortality remained below 0.2, leading to FR/Z ratios that were, in most years, well above 0.60 (see Table 8 for FR/Z ratios). These relatively high FR/Z ratios indicated the presence of relatively high leverage and thus a high probability that future management measures to reduce inriver F, if implemented before 1993, may have led to significant stock rebuilding. As predation mortality increased beyond 0.35 and riverine fishing mortality (FR) fell after 1999, however, the F/Z ratios fell quickly to below 0.10 by 2005, thereby greatly reducing leverage and the likelihood that future management measures would lead to measurable stock rebuilding. A similar case study linking a rise in predation mortality on the lack of stock rebuilding has been recently addressed for Grand Banks cod stocks (Shelton et al 2006). Several cod stocks on the Grand Banks have been under a landings moratorium since 1996, but stock rebuilding of these depleted stocks has, as of 2006, not been realized. Shelton et al (2006) reported that the lack of stock rebuilding of eight cod stocks was attributed to a recent rise in natural mortality from 0.2 prior to 1990 to 0.4 to 0.8 due mainly to enhanced gray seal (*Halichoerus grypus*) predation. In future stock shad assessments made here and elsewhere, the assumption that trophic and environmental effects on adult shad are low and constant over time should be critically examined. The potential impacts of trophic and environmental effects on Atlantic coast shad should also be integrated into fisheries models and rigorously tested as a potential alternative hypothesis to the Overfishing Hypothesis.

LITERATURE CITED

ASMFC (Atlantic States Marine Fisheries Commission). 1988. Stock assessment of American shad from selected rivers. Analyses by M. Gibson, V. Crecco and D. Stang. Atlantic States Marine Fisheries report No. 15, 75 pp.

ASMFC. 1998. Stock assessment of American shad from selected Atlantic coast rivers. Atlantic States Marine Fisheries Commission, Washington, D.C. ASMFC Spec. Rpt.

ASMFC. 2005. Catch-at-age based virtual population analyses for Atlantic coast striped bass. Report prepared by the Striped Bass Stock Assessment Subcommittee, September 14, 2005, 72 pp.

Beck, M.W. 1997. Size-specific limitation in stone crabs, a test of the demographic bottleneck hypothesis. Ecology 76:968-980.

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

Cating, J.P. 1953. Determining age of Atlantic shad from their scales. U.S. Fish and Wildlife Service Fishery Bulletin 54: 187–199.

Cave, J.R. 1978. American shad, Alosa sapidissima, larval distribution, relative abundance and movement in the Holyoke Pool, Connecticut River, Mass. M.S. Thesis. Univ. of Mass., Amherst, MA. pp. 65.

Chittenden, M.E. 1969. Life history and ecology of the American shad, Alosa sapidissima, in the Delaware River. Ph.D. Thesis. Rutgers Univ., New Brunswick, NJ. pp. 459.

Crecco, V.A. 1987. Connecticut River shad studies, a progress report on shad population dynamics. Ct. Dept. Environ. Prot. Marine Fisheries, Progress Report for 1986. 54 pp.

Crecco. V.A. 1994. Alternative regulations for the striped bass recreational fishery along the Atlantic coast consistent with amendment 5. CT Marine Fisheries Division, Old Lyme CT. August 15, 1994, 25 pp.

Crecco, V.A. and M.M. Blake. 1983. Feeding ecology of coexisting larvae of American shad and blueback herring in the Connecticut River. Trans. Amer. Fish. Soc. 112:498-507.

Crecco, V.A., L. Gunn, and T. Savoy. 1981. The Connecticut River shad study, 1980. Final Report. Connecticut Department of Environmental Protection. AFC 12. 87 p.

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

Crecco, V.A., and T.F.Savoy. 1985. Effects of biotic and abiotic factors on growth and relative survival of young American shad (*Alosa sapidissima*) in the Connecticut River. Canadian Journal of Fisheries and Aquatic Sciences 42: 1640–1648.

Crecco, V.A., and T.F. Savoy. 1987. Fishery management plan for American shad in the Connecticut River. Marine Fisheries Office, Department of Environmental Protection , State of Connecticut. 112pp.

Crecco, V.A., and T.F. Savoy. 1987. Review of recruitment mechanisms of the American shad: the critical period and match-mismatch hypotheses reexamined. American Fisheries Society Symposium 1: 455–468.

Crecco, V.A., T. Savoy and W. Whitworth. 1986. Effects of density-dependent and climatic factors on American shad recruitment: a predictive approach. Can. J. Fish. Aquat. Sci.43(2): 457-463.

Dadswell, M.J., G.D. Melvin, and R.S. Gregory. 1983. Effect of turbidity on the temporal and spatial utilization of the inner Bay of Fundy by American shad (Alosa sapidissima) (Pisces: clupeidae) and its relationship to local fisheries. Can. J. Fish. Aquat. Sci. 40(1):322-330.

Davis, Justin. 2007. Food habits of striped bass in the Connecticut River.Unpublished data in preparation for Doctoral Dissertation. University of Connecticut, Storrs, CT

Facey, D.E., and M.J. Van Den Avyle. 1986. American shad species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic). U.S. Fish and Wildlife Service Biological Report 82 (11.45), TR EL-82-4:18.

Fay, C.W., R.J. Neves and G.B. Pardue. 1983. Species profiles: life history and environmental requirements of coastal fisheries and invertebrates (mid-Atlantic) striped bass. U.S. Fish and Wildlife Service Biological Services Program 82-11.9 Washington, D.C.

Garabedian, S.P., J.F. Coles, S.J. Grady, E.C.T. Trench, and M.J. Zimmerman. 1998. Water quality in the Connecticut, Housatonic, and Thames River Basins, Connecticut, Massachusetts, New Hampshire, New York, and Vermont, 1992–1995. U.S. Geological Survey Circular 1155. U.S. Geological Survey, Reston, VA.

Gilmore, K.S. 1975. Spawning areas and egg distribution of American shad, Alosa sapidissima, (Pisces: Clupeidae) in the Connecticut River between Holyoke and Turners Falls, MA. M.S. Thesis, Univ of Mass., Amherst, MA. pp. 53.

Gottschall, K.F. and D.J. Pacileo. 2006. Marine finfish survey: part 1 Long Island Sound trawl survey. Job 2. In A study of marine recreational fisheries in Connecticut. F-54-R-21 Annual Performance Report. Connecticut Department of Environmental Protection: 43-139.

Hartman, K.J. 1993. Striped bass, bluefish, and weakfish in the Chesapeake Bay: energetics, trophic linkages, and bioenergetics model applications. Ph.D. dissertation, University of Maryland, 188 pp.

Hattala, K., R. Allen, N. Lazar, and R. O'Reilly. 1997. Stock contributions for American shad landings in mixed stock fisheries along the Atlantic coast. ASMFC, Washington, D.C.

Hattala, K. 2006. Updated 1980-2005 ocean intercept landings of American shad by river of origin. E-mail requested data provided to Victor Crecco on October 31, 2006.

Henry, S.M. 1976. Development of fish passage facilities for American shad at the Holyoke Dam on the Connecticut River. *In*: Proceedings of a Workshop on American Shad: December 14–16, 1976, Amherst, Massachusetts. pp. 289–304. University of Massachusetts, Amherst. 350 p.

Hewitt, D. A. and J. M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fish. Bull. 103: 433-437.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Holland, B.F., and G.F. Yelverton. 1973. Distribution and biological studies of anadromous fishes offshore North Carolina. N.C. Dep. Nat. Econ. Resour., Div. Commercial and Sports Fish., Spec. Sci. Rep. No. 24. 132 p.

Holland, P.W. and R.E. Welsch. 1978. Robust regression using iterative reweighted leas squares. Communications in Statistics A9 pp 813-827.

Hunter, J.R. [ed.]. 1976. Report on la Colloquium on larval fish mortality studies and their relation to fishery research, Jan. 1975. National Oceanic Atmospheric Administration Technical Report. Natl. Mar. Fish. Ser. Cir-395, pp. 5

Hutchings, J.A. and J.D. Reynolds. 2004. Marine fish population collapses: consequences for recovery and extinction risk. Bioscience 54, 297-309.

Jacobson, L.D., S.X. Cadrin, and J.R. Weinberg. 2002. Tools for estimating surplus production and F_{msy} in any stock assessment model. N. Amer. J. Fish. Manage. 22: 326 338.

Kahn, D. 2005. ASMFC Striped Bass Tagging Subcommittee summary of USFWS Cooperative tagging program results. Report to the ASMFC Striped Bass Tech Committee, September 23, 2005. 44 pages.

Layzer, J.B. 1974. Spawning sites and behavior of American shad, Alosa sapidissima, (Wilson), in the Connecticut River between Holyoke and Turners Falls, MA, 1972. M.S. Thesis. Univ. of Mass., Amherst, MA. pp. 46.

Leggett, W.C. 1969. Studies on the reproductive biology of the American shad (Alosa sapidissima). A comparison of populations from four rivers of the Atlantic seaboard. Ph.D. Thesis. McGill University. pp. 125.

Leggett, W.C. 1976. The American shad *Alosa sapidissima*, with special reference to its migration and population dynamics in the Connecticut River. In:D.Merriman and L.M.Thorpe, eds. The Connecticut River Ecological Study: The Impact of a Nuclear Power Plant. Am.Fish.Soc.Monogr.No.1:169-225.

Leggett, W.C., and J.E. Carscadden. 1978. Latitudinal variation in reproductive characteristics of American shad (*Alosa sapidissima*): evidence for population specific life history strategies in fish. Journal of the Fisheries Research Board of Canada 35: 1469–1478.

Leggett, W.C., T.F. Savoy, and C.A. Tomichek. 2004. The impact of enhancement initiatives on the structure and dynamics of the Connecticut River population of American shad. *In*: P.M. Jacobsen, D.A. Dixon, W.C. Leggett, B.C. Marcy, Jr. and R.R. Massengill (eds), The Connecticut River Ecological Study (1965–1973) Revisited: Ecology of the Lower Connecticut River 1973–2003. pp. 391–405. American Fisheries Society, Monograph 9, Bethesda, Maryland.

Link, J.S. 2002. Ecological considerations in fisheries management: when does it matter? Fisheries 27(4):10-17.

Lippson, A. J., and R. L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River estuary. Power Plant Siting Program, Maryland Department of Natural Resources.

Lorda, E. and V.A. Crecco. 1987. Recruitment variability and compensatory mortality of American shad following the addition of spawning habitat in the Connecticut River. Symp. # 1 On Common Strategies of Anadromous and Catadromous fishes. Trans. Amer. Fish. Soc. Spec. Publ. Bethesda, Maryland.

Mansueti, R.J. and H. Kolb. 1953. A historical review of the shad fisheries of North America. Chesapeake Biol. Lab. Publ. 97. pp. 293.

Mansueti, R.J. and J.D. Hardy, Jr. 1967. Development of fishes of the Chesapeake Bay Region, Part I. An atlas of egg, larval and juvenile stages. pp. 202 In: E.E. Deubler, Jr. [ed] Nat. Resour. Inst., Univ of Maryland.

Marcy, B. 1972. Spawning of the American shad, *Alosa sapidissima*, in the lower Connecticut River. Chesapeake Science 13(2): 116–119.

Marcy, B.C., Jr. 1976. Early life history studies of American shad in the lower Connecticut river and the effects of the Connecticut Yankee Plant. In D.Merriman and L.M.Thorpe, eds. The Connecticut River Ecological Study: The Impace of a Nuclear Power Plant. Am.Fish.Soc.Monogr.No.1:141-168.

Marcy, B. 2004. Early life history studies of American Shad in the lower Connecticut River and the effects of the Connecticut Yankee Plant. *In*: P.M. Jacobsen, D.A. Dixon, W.C. Leggett, B.C. Marcy, Jr. and R.R. Massengill (eds), The Connecticut River Ecological Study (1965–1973) Revisited: Ecology of the Lower Connecticut River 1973–2003. pp. 155–180 American Fisheries Society, Monograph 9, Bethesda, Maryland.

Manooch, C.S. III. 1973. Food habits of yearling and adult striped bass, *Morone saxatilis* (Walbaum), from Albemarle Sound, North Carolina. Ches. Sci. 14(2):73-86.

Maxfield, G.H. 1953. The food habits of hatchery-produced pond-cultured shad Alosa sapidissima, reared to a length of two inches. Chesapeake Bio. Lab. Pub. No. 98. pp. 38.

Meade, J.W. 1976. Experimental intensive rearing of shad at Van Dyke, Pennsylvania. pp. 211-234, In: Process Workshop on American shad. U.S. Natl. Mar. Fish. Ser.

Melvin, G.D., M.J. Dadswell, and J.A. McKenzie. 1992. Usefulness of meristic and morphometric characters in discriminating populations of American Shad (*Alosa sapidissima*) (Osteichthyes: Clupeidae) inhabiting a marine environment. Canadian Journal of Fisheries and Aquatic Sciences 49: 266–280.

Mertz, G. and R.A. Meyers. Influence of errors in natural mortality estimates in cohort analysis. Can. J. Fish Aquat. Sci. 54: 1608-1612.

Minta, P. 1980. Connecticut River shad studies, 1977-1979. Final Report for AFC-11. Federal Aid Project. 88 pages.

Moffit, C.M., B. Kynard, and S.G. Rideout. 1982. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. Fisheries 7(6):2-11.

Myers, R.A., J.A. Hutchings and N.J. Barrowman. 1997. Why do fish stocks collapse? The example of cod in Atlantic Canada. Ecol. Applications: 7(1)-91-106.

Nelson, G.A., B.C. Chase and J. Stockwell. 2005. Food habits of striped bass in coastal Massachusetts. J. Northw. Atl. Fish. Sci. 32: 1-25.

Neves, R.J. and L. Dupres. 1979. The oceanic migration of American shad, Alose sapidissima, along the Atlantic coast. Fish. Bull. 77:199-212.

O'Leary, J. and H.E. Booke. 1986. Connecticut River anadromous fish investigations. Project Performance Report F-45-R-2. Mass. Coop. Fish. Res. Unit. pp. 37.

O'Leary, J. and B. Kynard. 1986. Behavior, length and sex ratio of seaward-migrating juvenile American shad and blueback herring in the Connecticut River. Trans. Amer. Fish. Soc. 115:529-536.

Quinn. T.J. and R.B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. 191 Fish Res. Bd Can., 382 pp.

Rose, G.A., B. DeYoung, D.W. Kulka, S.V. Goddard and G.L. Fletcher. 2000. Distribution shifts and overfishing the northern cod (*Gadus morhua*): a view from the ocean. Can. J. Fish. Aquat. Sci: 57: 644-663.

Rousseeuw, P.J. and K. Van Driessen. 2000. An algorithim for positive breakdown regression based on concentration steps in data analysis.pages 335-346. In Data analysis: Scientific Modeling and Practical Application, 279 pp.

Rudershausen, P.J., J.E. Tuomikoski and J.A. Buckel. 2005. Prey selectivity and diet of striped bass in western Albemarle Sound, North Carolina. Trans. Am. Fish. Soc.134: 1059-1074.

Rugolo, L., P.W. Jones, R.K. Schaefer, K.S. Knotts, H.T. Hornick, and J.L. Markham. 1994b. Estimation of Chesapeake Bay-wide exploitation rate and population abundance for the 1993 striped bass stock. Report to the Atlantic States Marine Fisheries Commission, July14, 1994, 101 pp.

Savoy, T. 1995. Striped bass investigations in Connecticut waters. A report to the Connecticut Fisheries Division, April 20, 1995, 23 pp.

Savoy, T. 1998. Anadromous fish studies in Connecticut Waters. Progress Report AFC-25.Connecticut Department of Environmental Protection. 26pp.

Savoy, T. 2001. Connecticut anadromous fish investigations. Progress Report AFC-25. Connecticut Department of Environmental Protection. 14pp.

Savoy, T. 2002. Anadromous fish studies in Connecticut Waters. Progress Report AFC-24-1.Connecticut Department of Environmental Protection. 24pp.

Savoy, T., and J. Benway. 2004. Connecticut anadromous fish investigations. Connecticut Department of Environmental Protection, AFC 26. 22 p.

Savoy, T.F., and V.A. Crecco. 1988. The timing and significance of density-dependent and density-independent mortality of American shad, *Alosa sapidissima*. Fisheries Bulletin US. 86(3): 467-482.

Savoy, T.F. and V.A. Crecco. 2004. Factors affecting the recent decline of blueback herring and American shad in the Connecticut River. *In* P.M. Jacobsen, D.A. Dixon, W.C. Leggett, B.C. Marcy, Jr. and R.R. Massengill (eds), The Connecticut River Ecological Study (1965–1973) Revisited: Ecology of the Lower Connecticut River 1973–2003. American Fisheries Society, Monograph 9, Bethesda, Maryland. pp. 361-377.

Savoy, T, and D. Shake. 1993. Anadromous fish studies in Connecticut Waters. Progress Report AFC-21-1. Connecticut Department of Environmental Protection. 44pp.

Savoy, T., and D. Shake. 1995. Striped bass investigations in Connecticut Waters. unpublished report. Connecticut Department of Environmental Protection. 32pp.

SAS. 2002. Statistical Analysis System (SAS) Users Guide to Syntax, Procedures and Concepts: Section on Nonlinear Least Squares Regression Methods. 425 pp.

Scheffer, M., S. Carpenter and B. de Young. 2001.Catastrophic shifts in ecosystems. Nature 413:591-596.

Scherer, M.D. 1974. Analysis of factors affecting passage of American shad (Alosa sapidissima; Wilson) at Holyoke Dam, MA, and assessment of juvenile growth and distribution above the dam. Ph.D. Thesis, Univ. of Mass., Amherst, MA. pp. 224.

Schnute, J. 1989. The influence of statistical error on stock assessment: Illustration from Schaefer's model. p 101-109. In R.J. Beamish and G.A. McFarlane [ed] Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Can. Spec. Publ. Fish. Aquat. Sci. 108.

Shelton, P. A., A.F. Sinclair, G.A. Chouinard, R. Mohn and D.E. Duplisea. 2006. Fishing under low productivity conditions is further delaying recovery of Northwest Atlantic cod (*Gadus morhea*). Can. J. Fish. Aquat. Sci. 63: 235-238.

Sinclair, M., and M.J. Tremblay. 1984. Timing of spawning of Atlantic herring (Clupea harengus harengus) populations and the match-mismatch theory. Can. J. Fish. Aquat. Sci. 41:1055-1065.

Spencer, P.D. and J. Collie. 1997. Effect of nonlinear predation rates on rebuilding the Georges Bank haddock (*Melanogrammus aeglefinus*). Can J. Fish Aquat. Sci. 54: 2920-2929.

Spencer, P.D. 1997. Optimal harvesting of fish populations with non-linear rates of predation and autocorrelated environmental variability. C. J. Fish. Aquat. Sci. 54: 59-74.

Steele, J.H. and E.W. Henderson. 1984. Modeling long-term fluctuations in fish stocks. Science 224: 985-987.

Stira, R.J. 1976. Sinking rate and drift distance of eggs of American shad (Alosa sappidissima) in the Connecticut River, MA. M.S. Thesis, Univ. of Mass., Amherst, MA.

Taylor, R. and B. Kynard. 1985. Mortality of juvenile American shad and blueback herring passed through a low-head Kaplan hydroelectric turbine. Trans. Amer. Fish. Soc. 114:430-435.

Uphoff, J. 2005. Does a regime shift underlie the failure of weakfish recovery? Report submitted to the ASMFC Weakfish Stock Assessment and Technical Committees, March 2005, 27 pages.

Vetter, E. F. 1988. Estimation of natural mortality in fish stocks: a review. Fish. Bull. 86: 25-43.

Walburg, C. H., and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries. Atlantic coast of the United States, 1960. U.S. Fish and Wildl. Ser. Special ScientificReport 550.

Waldman, J., K. Nolan, J. Hart, and I. Wircin. 1996. Genetic Differentiation of Three Key Anadromous Fish Populations of the Hudson River. Estuaries 19 (4): 759–768.

Wahle, R.A. 2003. Revealing stock-recruitment relationships in lobsters and crabs: is experimental ecology the key? Fish. Res. 65: 3-32.

Walter, J.F. and H.M. Austin. 2003. Diet composition of large striped bass (*Morone saxatilis).* Fish Bull. 101: 414-423.

Watson, J. F. 1968. The early life history of the American shad, *Alosa sapidissima* (Wilson), in the Connecticut River above Holyoke, Massachusetts. M.S. Thesis, University of Massachusetts, Amherst. 55 p.

Watson, J.F. 1970. Distribution and population dynamics of American shad, *Alosa sapidissima* (Wilson), in the Connecticut River above Holyoke Dam, Massachusetts. Ph.D. Dissertation, University of Massachusetts, Amherst. 105 p.

Whitney, Richard R. 1961. The Susquehanna Fishery Study, 1957-1960. A report of a study on the desirability and feasibility of passing fish at Conowingo Dam. Dep. Res. Educ. Solomons, Maryland, Contrib. 169. 81pp.

Whitworth, W.R., and D.H. Bennett. 1970. A limnological study of the lower Farmington River with special reference to the ability of the river to support American shad. Inst. Water. Res., Univ.of Conn. Rep. 9. pp. 57

Yoshimoto, S.S. and R.P. Clarke. 1993. Comparing dynamic versions of the Schaefer and Fox Production models and their application to lobster fisheries. Can. J. Fish. Aquat. Sci. 50: 181-189.

Table 1. American shad population estimates (N*1000), Connecticut River commercial (CT River Comm) landings data (N*1000), inriver commercial fishing effort (gillnet days), recreational landings (CT River Sport, N*1000), landings from the ocean sport fishery (Ocean Rec, N*1000), landings from the coastal intercept fishery (Ocean Intercept, N*1000), ocean discards (N*1,000) and total landings and discards from 1981-2005.

Year	Population Estimate	CT River Comm	Comm Effort (Days)	CT River Sport	Ocean Rec	Ocean Intercept	Discards	Total Losses
1981	909	98	907	69	0.0	66	6.7	240
1982	939	81	790	44	0.0	85	3.3	214
1983	1574	99	840	99	0.0	53	2.4	254
1984	1231	79	575	71	0.6	70	3.4	224
1985	728	76	590	41	4.9	82	2.7	207
1986	748	108	525	105	1.0	79	3.3	297
1987	588	63	350	93	14.5	84	4.0	259
1988	648	62	450	53	0.1	102	4.2	222
1989	979	61	400	60	0.0	78	0.7	205
1990	816	45	500	38	1.2	79	0.8	171
1991	1196	48	500	85	1.0	77	1.1	217
1992	1628	51	410	120	0.0	50	2.7	224
1993	749	34	400	65	0.9	55	6.4	162
1994	326	32	350	45	0.0	32	2.4	111
1995	304	21	400	14	0.0	46	5.5	88
1996	667	24	300	11	0.0	48	7.9	92
1997	659	32	300	6	4.7	49	7.9	101
1998	651	32	300	7	7.6	61	88.0	196
1999	475	16	225	2	9.5	56	0.0	83
2000	427	35	225	4	2.4	35	0.0	76
2001	773	22	200	2	4.4	53	1.8	84
2002	687	42	250	4	0.8	53	1.6	102
2003	527	40	250	4	2.4	28	1.3	76
2004	351	24	225	2	1.4	25	1.4	54
2005	226	22	200	2	1.7	12	4.8	43

Table 2. Instantaneous riverine fishing mortality estimates on shad from the the in-river sport and commercial fisheries (FR), coastal intercept fishery (FC), combined fishing mortality (FT = FC + FR) and surplus production estimates from 1981 - 2005.

Year	FR	FC	FT	Surplus Prod
1981	0.203	0.078	0.281	270.3
1982	0.143	0.090	0.233	848.6
1983	0.134	0.035	0.169	-89.4
1984	0.130	0.059	0.189	-278.6
1985	0.175	0.116	0.292	226.8
1986	0.335	0.106	0.441	136.6
1987	0.308	0.161	0.470	318.9
1988	0.195	0.152	0.348	552.7
1989	0.132	0.082	0.214	42.0
1990	0.107	0.102	0.209	550.8
1991	0.118	0.068	0.186	649.0
1992	0.111	0.032	0.143	-655.3
1993	0.142	0.081	0.223	-260.8
1994	0.269	0.100	0.369	89.2
1995	0.122	0.160	0.282	450.8
1996	0.054	0.082	0.135	83.7
1997	0.059	0.091	0.151	93.0
1998	0.062	0.216	0.278	19.9
1999	0.038	0.129	0.167	35.1
2000	0.094	0.084	0.178	421.9
2001	0.032	0.074	0.106	-2.5
2002	0.070	0.077	0.147	-58.5
2003	0.087	0.059	0.146	-100.2
2004	0.078	0.076	0.154	-70.9
2005	0.113	0.080	0.193	106.9

Table 3. Parameter estimates and equilibrium overfishing thresholds (F_{msy}, N_{msy}) for Connecticut River shad derived from the Gompertz external production model. The model was fitted to the LTS Robust regression model. The standard error (SE) is given for each parameter estimate (a, b), as well as the coefficient of determination (r^2). Overfishing thresholds (F_{msy}, N_{msy}) are presented with 80% CI.

LTS Robust Regression Model

Parameter	Mean	SE	P
a	3.611	1.00	< 0.0004
b	-0.507	0.144	< 0.0004
r^2	0.58		

Overfishing Thresholds

Threshold	Mean	80% Confidence Limit
F_{msy}	0.51	0.32 – 0.69
Fcoll	1.38	0.87 – 1.88
N_{msy}	456,000 fish	288,000 – 621,000 fish

Table 4. Coastwide striped bass abundance from tagging (Strip*1000), coastwide striped bass abundance from VPA (Strip2*1000), striped bass index from LIS (Stripls), bass index from the river (Stripriv), estimated bass population size in the river (Striprv*1000) and American shad prerecruit mortality (Z_0)- note that all of the above estimates are for 72cm+ striped bass except for the LIS estimates (Stripls).

Year	Strip	Strip2	Stripls	Stripriv	Striprv	Z_0
1981	1300	215			63.70	
1982	1395	218			68.36	
1983	1619	253			79.33	0.102
1984	1734	271	0.02		84.97	0.498
1985	1498	234	0.00		73.40	1.069
1986	1734	271	0.00		84.97	0.392
1987	1210	357	0.05		59.29	0.861
1988	2849	348	0.04		139.60	1.064
1989	3827	501	0.06		187.52	0.597
1990	2075	997	0.16		101.68	0.924
1991	1844	1278	0.15		90.36	1.205
1992	1994	1840	0.22		97.71	1.000
1993	2486	2022	0.27	11	121.81	1.966
1994	4027	2373	0.30	44	197.32	2.998
1995	3486	2832	0.59	13	170.81	2.922
1996	5201	3129	0.63	86	254.85	2.657
1997	4893	3606	0.85	142	239.76	2.866
1998	3877	4120	0.97	110	189.97	3.093
1999	4256	4072	1.10	59	208.54	3.169
2000	8280	4592	0.84	198	405.72	2.331
2001	9907	5960	0.61	126	485.44	2.136
2002	13066	6621	1.30	113	640.23	2.280
2003	13672	6056	0.87	162	669.93	2.501
2004	17099	6712	0.56	203	837.85	2.765
2005	21102	6923	1.17		1034.00	3.110

Table 5. Population estimate and 95% confidence limits (CI) of striped bass in the Connecticut River from April through June, 1994 based on the Petersen mark-recapture method (Savoy 1995). Note that this table was taken from Savoy and Crecco (2004).

Statistic	Estimate or Number
Number Tagged (M)	346 1/
Number Recaptured (R)	26 2/
Recreational Catch in River (C)	30,610 3/
Population Estimate (P)	407,300
95% Confidence Limits	269,400 to 604,100 4/

1/ Marked fish were reduced by 50% (from 692 tagged fish to 346 fish) to reflect a combination of factors including tag loss, tag-induced mortality and migration of tagged fish from the River to LIS.

2/ Number of recaptures increased to reflect a 60% (from 16 recaptures to 26 recaptures) reporting rate.

3/ Striped bass recreational catch in the Connecticut River was taken from the MRFSS and information in the 1994 Volunteer Angler Survey.

4/ 95% confidence limits were based on a Poisson distribution of recaptures (Appendix 2, Ricker 1975).

Table 6. Results of striped bass dietary studies in the Connecticut River during 2005 and 2006 conducted by Mr. Justin Davis as part of his Doctoral dissertation. The dietary data (234 stomach samples) are expressed as the percentage of river herring and shad biomass in the stomachs of striped bass distributed by 10 cm length groups**.**

Striped Bass Size class (cm)	% biomass river herring	% biomass shad
< 30	0	0
30 – 39	0.8	0
40 – 49	1.7	0
50 – 59	2.5	3.7
60 – 69	18.3	5.9
70 – 79	41.1	6.3
80 – 89	34.4	8.3
90 – 99	9.2	45.5
> 100	5.8	82.4

Table 7. Parameter estimates and approximate equilibrium overfishing thresholds for Connecticut River shad derived from the Steele-Henderson production model with predation effects. The Steele-Henderson production model (equation 6) with striped bass predation effects was fitted by least squares iterative re-weighting with lognormal error using data for 1981-2005. The standard error (SE) is given for each parameter such as the intrinsic rate of shad population increase (r), shad carrying capacity (K in numbers), striped bass per capita consumption (c), and shad stock size at which striped bass satiation (A) takes place. The coefficient of determination (r^2) is also shown. Averaged long-term overfishing thresholds (avF_{msy}, avFcoll, avB_{msy}) with 95% CI are also shown below.

Iterative Re-weighting Least Squares

Parameter	Mean	SE
r	0.59	0.09
K	1,396,000 fish	210,611 fish
c	0.88	0.21
A. A	488,000 fish	196,000 fish
r^2	0.88	

Approximate Equilibrium Overfishing Thresholds

Parameter	Mean	95% Confidence Limits
avF_{msy}	0.39	0.23 - 0.55
avFcoll	1.41	1.32 - 1.48
avB_{msy}	470,000 fish	462,000 - 494,000 fish

Table 8. Striped bass consumption rate (Mp), total fishing mortality (FT), annual Fmsy, annual run size at MSY (Nmsy*1000), shad consumed annually by striped bass (Dt), ratio of fishing mortality (FRC) to predation (MP), annual riverine landings (SHADTOTR*1000), ratio of landings to predation loss (FRCC) and sum of fishing + predation mortality (RIVMORT).

YEAR	Mp	FT	F_{MSY}	N_{MSY}	Dt	FRZ	SHADTOTR	FRCC	RIVMORT
1981	0.0523	0.2806	0.5377	497.61	43.52	0.7953	167	0.7933	0.3328
1982	0.0537	0.2330	0.5363	496.19	47.36	0.7267	125	0.7252	0.2868
1983	0.0423	0.1692	0.5477	490.19	63.69	0.7608	198	0.7566	0.2114
1984	0.0546	0.1886	0.5354	489.85	64.62	0.7042	150	0.6989	0.2432
1985	0.0661	0.2915	0.5239	497.22	44.57	0.7260	117	0.7242	0.3576
1986	0.0788	0.4411	0.5112	494.32	52.45	0.8097	213	0.8024	0.5199
1987	0.0572	0.4696	0.5328	502.24	30.90	0.8436	156	0.8347	0.5268
1988	0.1256	0.3478	0.4645	484.78	78.39	0.6088	115	0.5947	0.4734
1989	0.1345	0.2143	0.4555	465.01	132.18	0.4951	121	0.4779	0.3488
1990	0.0820	0.2095	0.5080	489.37	65.90	0.5667	83	0.5574	0.2915
1991	0.0577	0.1858	0.5323	488.54	68.17	0.6715	133	0.6612	0.2435
1992	0.0488	0.1428	0.5412	484.60	78.89	0.6945	171	0.6843	0.1917
1993	0.1001	0.2228	0.4899	485.94	75.25	0.5862	99	0.5681	0.3228
1994	0.1674	0.3692	0.4226	493.90	53.58	0.6168	77	0.5897	0.5366
1995	0.1385	0.2825	0.4516	498.15	42.03	0.4691	35	0.4544	0.4209
1996	0.2047	0.1355	0.3853	459.90	146.08	0.2084	35	0.1933	0.3402
1997	0.1967	0.1507	0.3933	463.51	136.26	0.2320	38	0.2181	0.3474
1998	0.1595	0.2777	0.4305	474.25	107.03	0.2792	39	0.2671	0.4372
1999	0.1777	0.1669	0.4123	480.78	89.28	0.1752	17.6	0.1647	0.3447
2000	0.3329	0.1785	0.2571	456.68	154.82	0.2211	38.5	0.1992	0.5113
2001	0.3413	0.1057	0.2487	401.30	305.45	0.0853	24.2	0.0734	0.4470
2002	0.4578	0.1470	0.1322	375.93	374.46	0.1320	46.2	0.1098	0.6048
2003	0.5018	0.1458	0.0882	396.92	317.39	0.1480	44	0.1218	0.6476
2004	0.5703	0.1542	0.0197	421.18	251.39	0.1206	26.4	0.0950	0.7244
2005	0.5809	0.1928	0.0091	454.53	160.69	0.1632	24.2	0.1309	0.7737

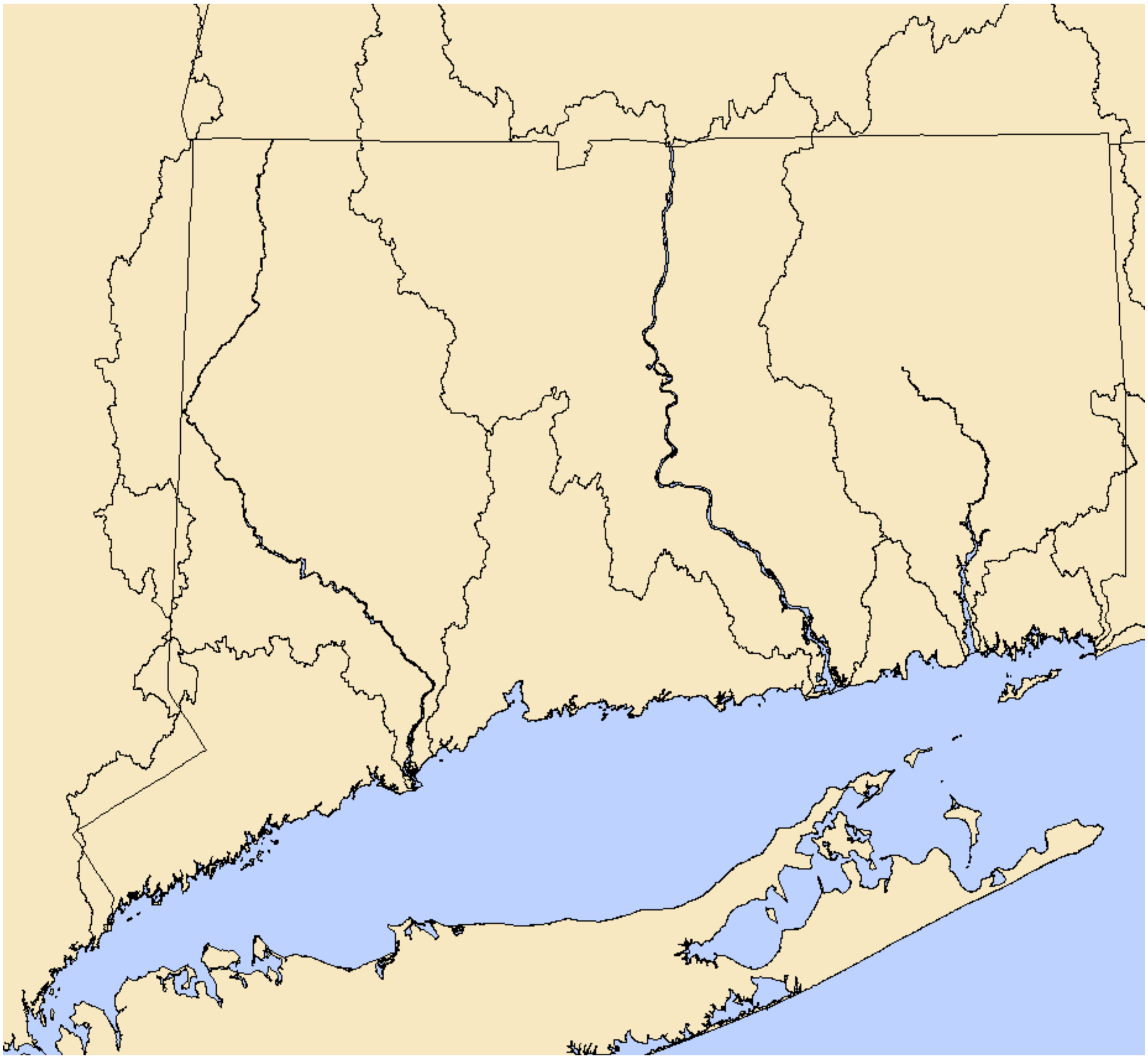

Figure 1. Map of Connecticut with Connecticut, Thames and Housatonic Rivers.

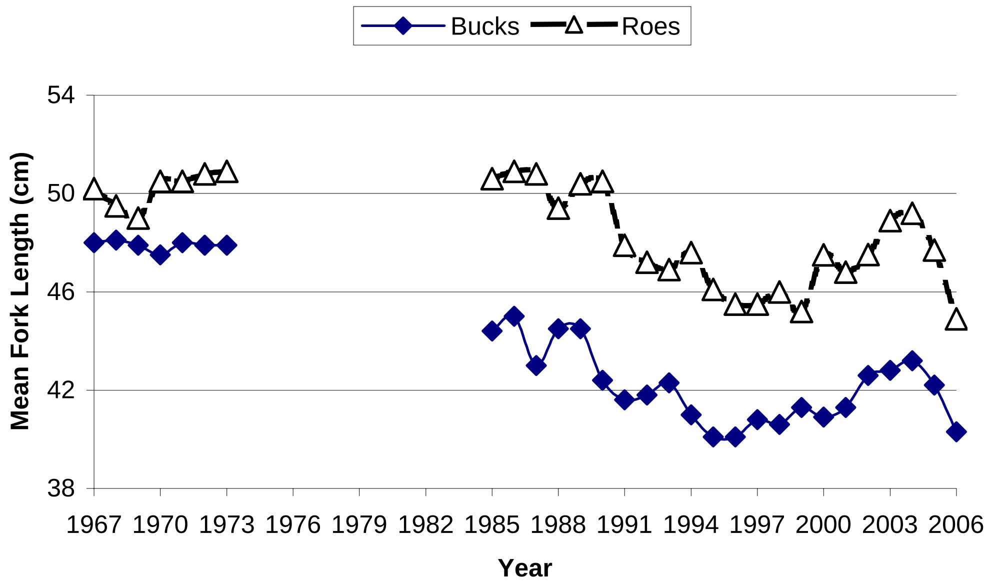

Figure 2. Mean Fork Length (cm) of male and female American shad in the Connecticut River from 1966 through 2006

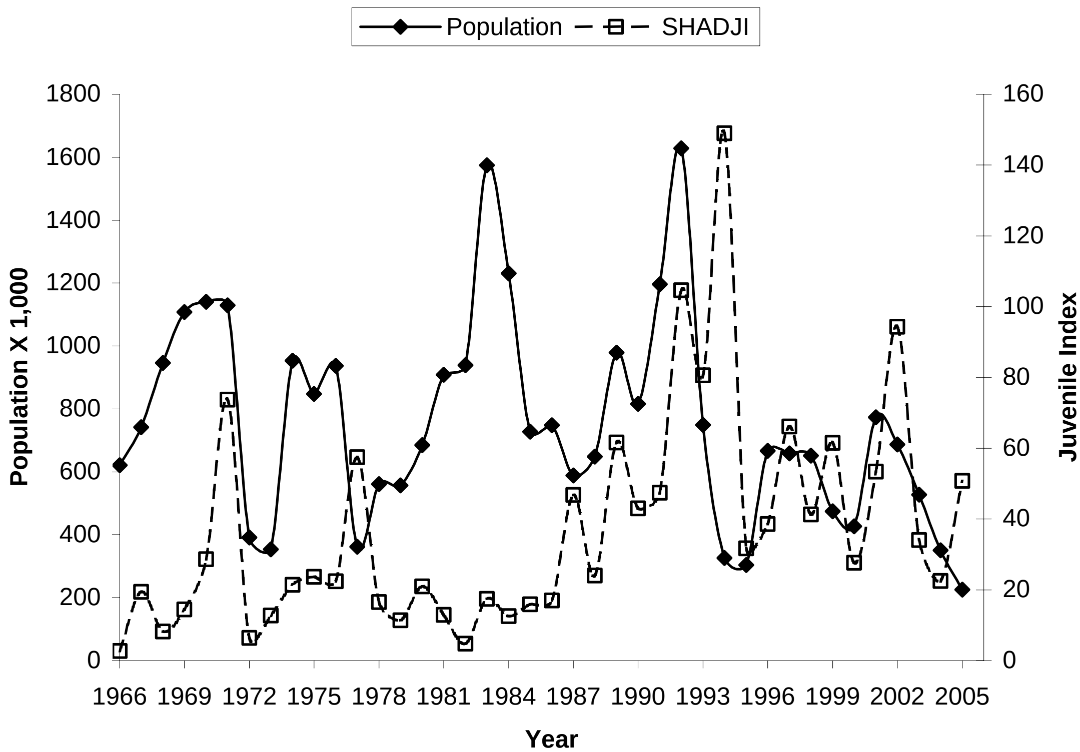

Figure 3. Relationship between shad run size and juvenile indices from 1966-2005.

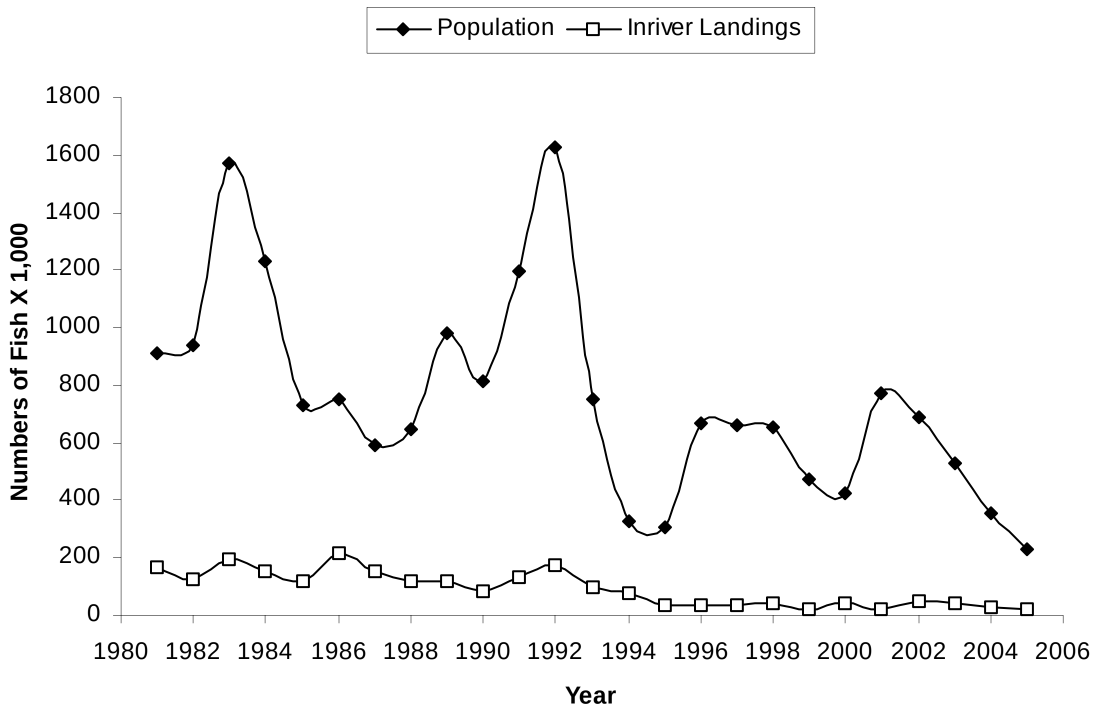

Figure 4. Relationship between shad run size and total inriver commercial and recreational landings (n*1,000).

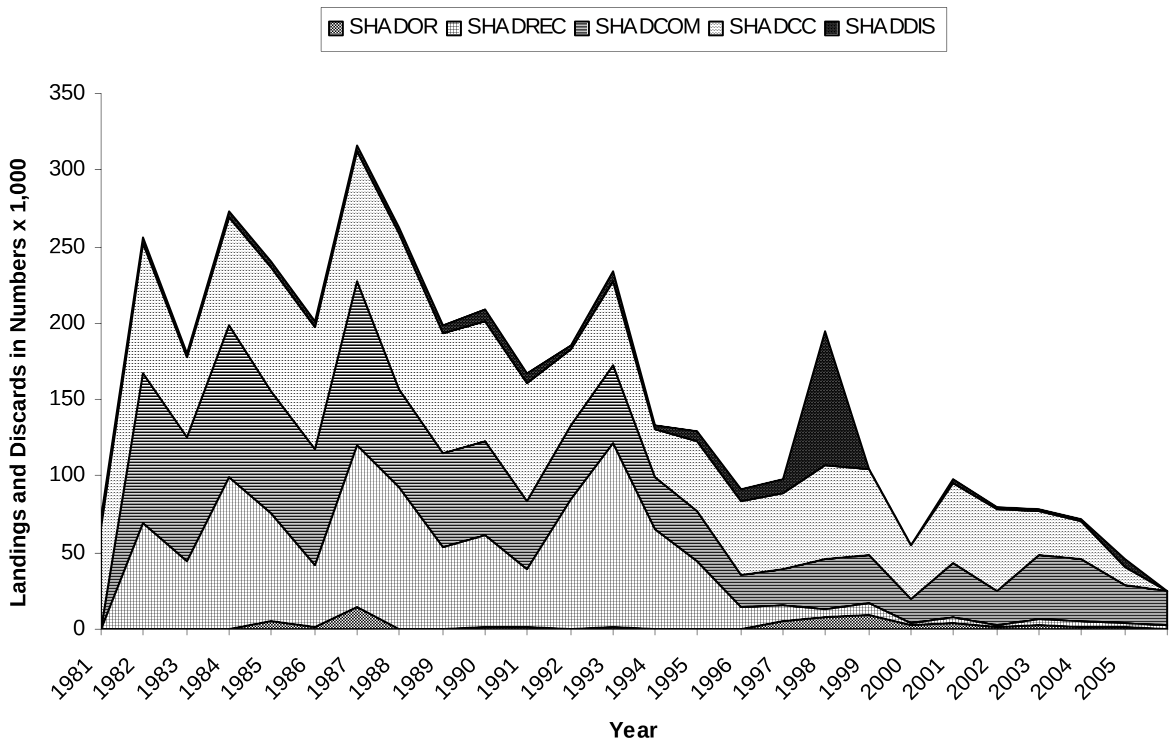

Figure 5. Stacked plot showing contribution of inriver commercial landings (SHADCOM), inriver recreational landings (SHADREC), ocean recreational landings (SHADOR), ocean commercial intercept landings (SHADCC) and ocean discards (SHADDIS) of Connecticut River shad. Landings and dicards are all expressed as numbers of shad.

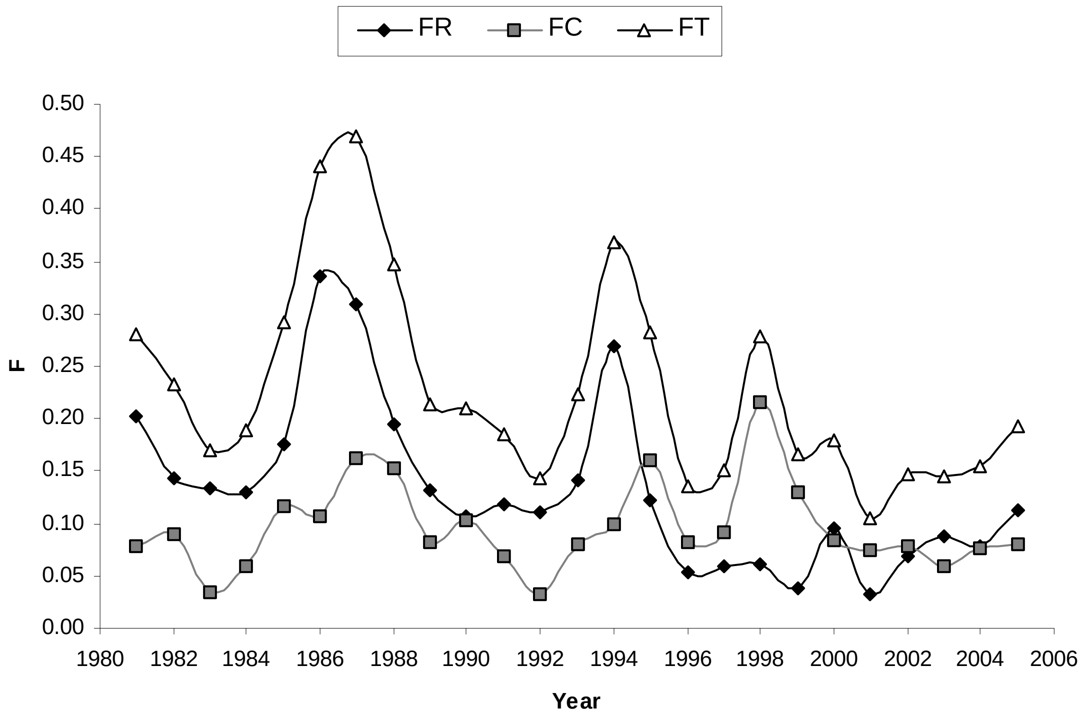

Figure 6. Relationship among inriver fishing mortality (FR), ocean fishing mortality (FC) and total fishing mortality (FT) of Connecticut River shad.

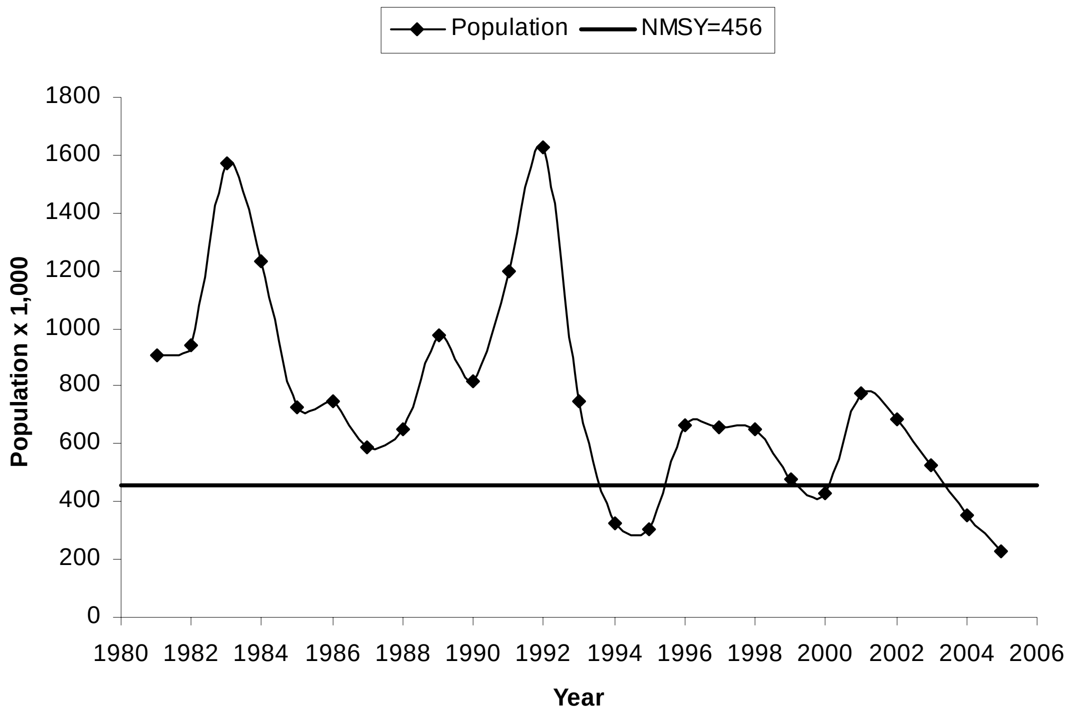

Figure 7. Relationship between shad run size (SHADPOP) and the overfishing threshold (NMSY) based on the Gompertz external production model.

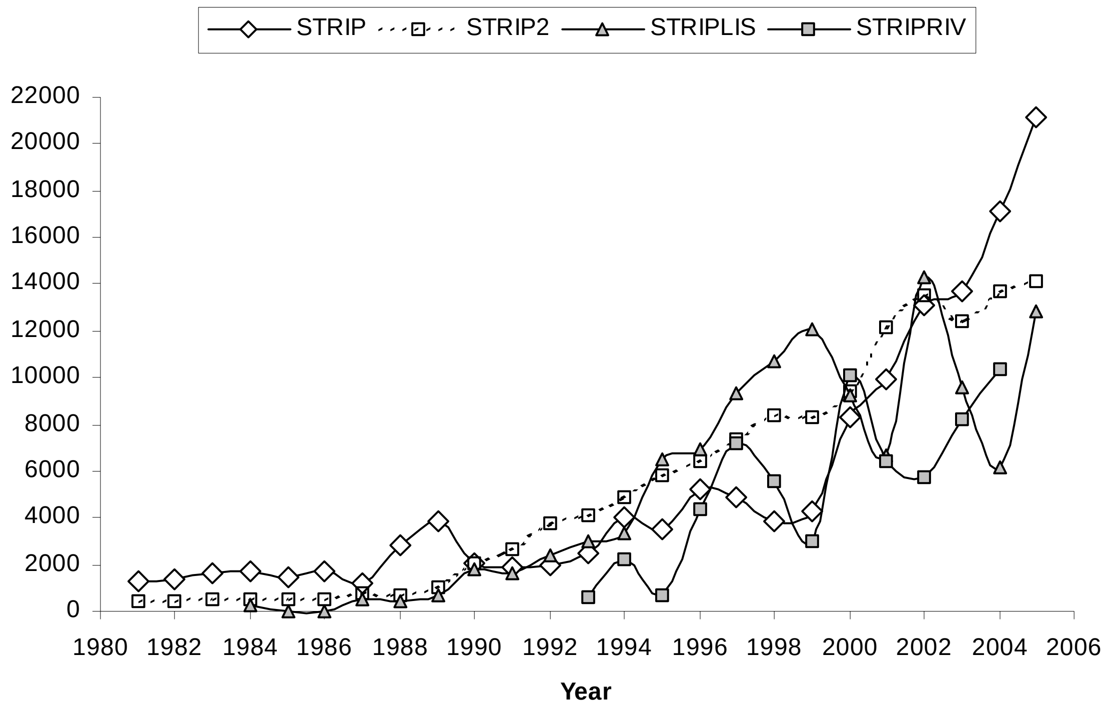

Figure 8. Relationship among the various striped bass abundance estimates that were scaled to the same units. STRIP=tag based abundance of ages 7+ stripers, STRIP2=VPA based striped bass abundance of ages 7+ fish, STRIP LIS= Long Island Sound indices of striped bass, and STRIPRIV=electrofishing indices of age 7+ striped bass in the river.

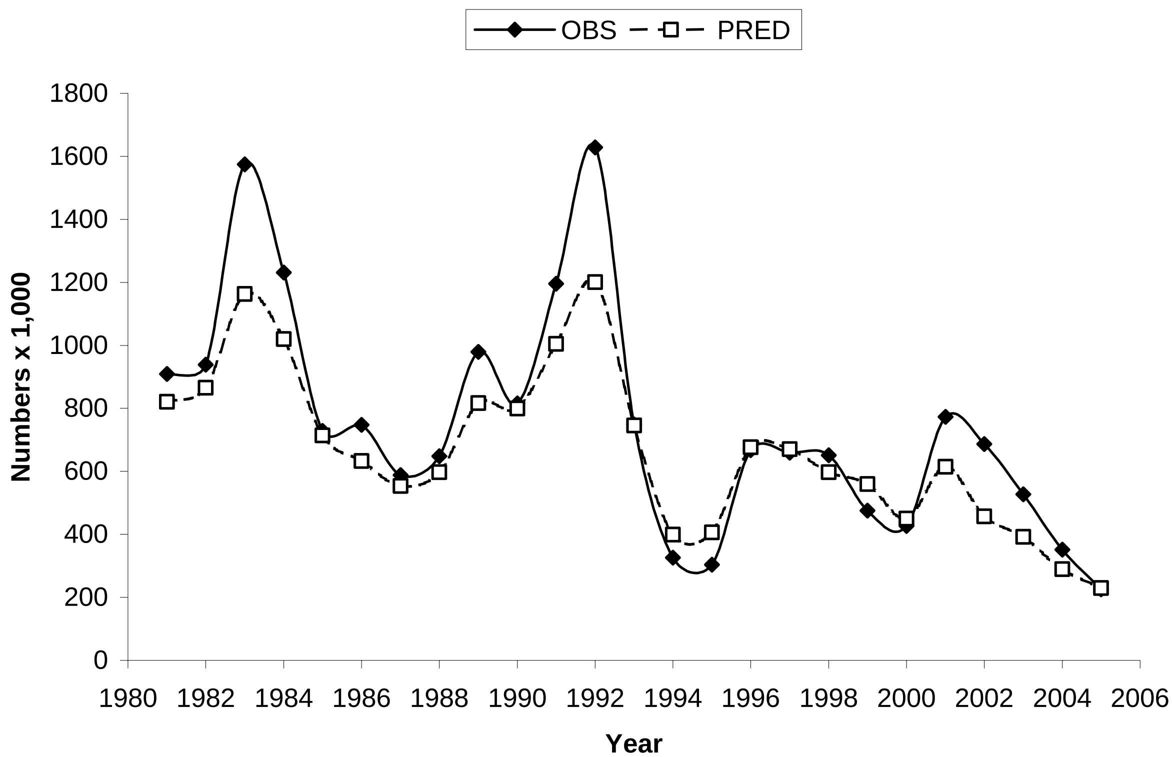

Figure 9. Observed and predicted shad run size (N*1000) based on the Steele-Henderson surplus production model with lognormal error.

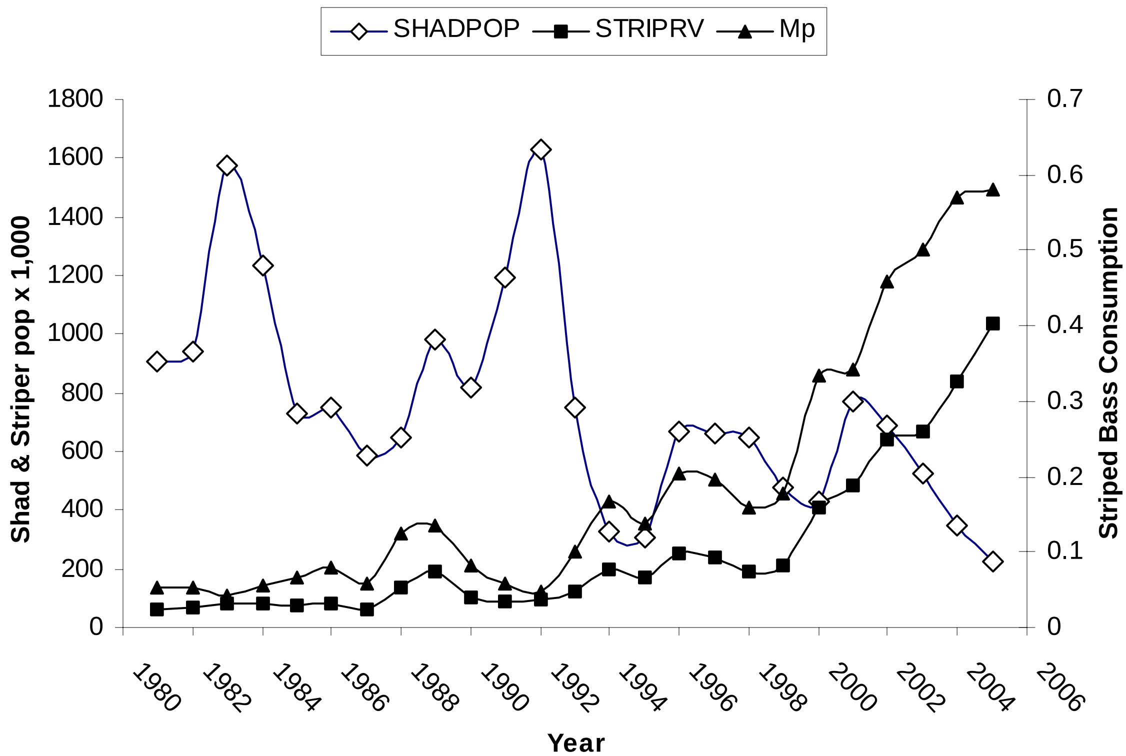

Figure 10. Relationship among shad run size (SHADPOP), ages 7+ striped bass abundance in the river (STRIPRV) and the instantaneous consumption rate (Mp) of striped bass on American shad based on the Steele-Henderson model.

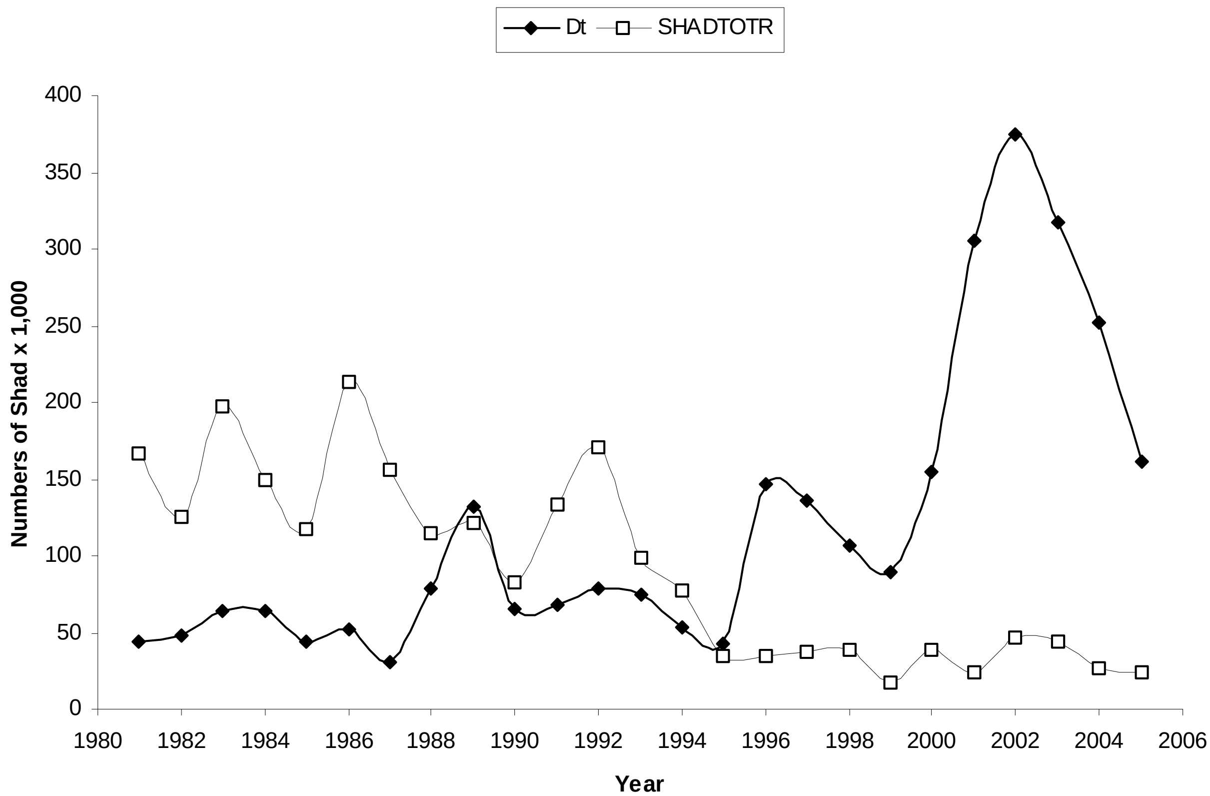

Figure 11. Plot of inriver landings (commercial + recreational) and the estimated number of adult shad consumed by striped bass (N * 1,000) based on the Steele-Henderson model.

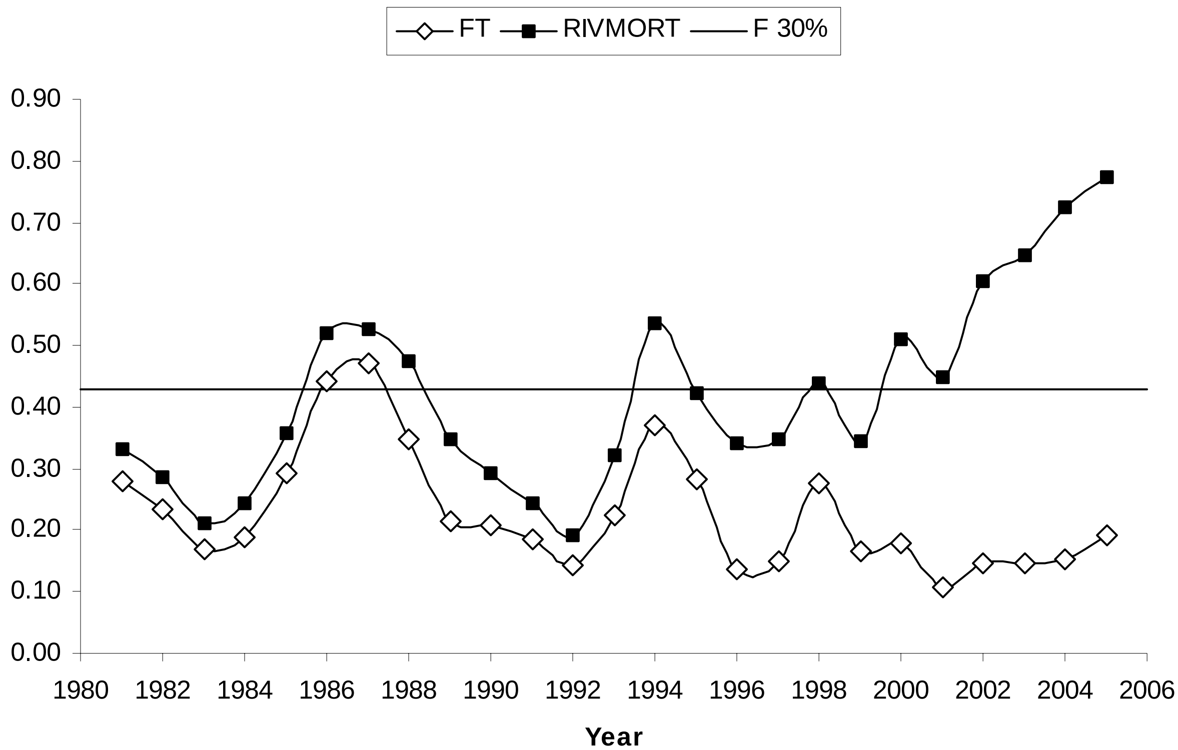

Figure 12. Plot of total fishing mortality (FT), the total inriver mortality (Rivmort) and the estimated F30% level of 0.43. Note that total inriver mortality consists of the inriver fishing mortality (FR) and the striped bass consumption rate (MP).

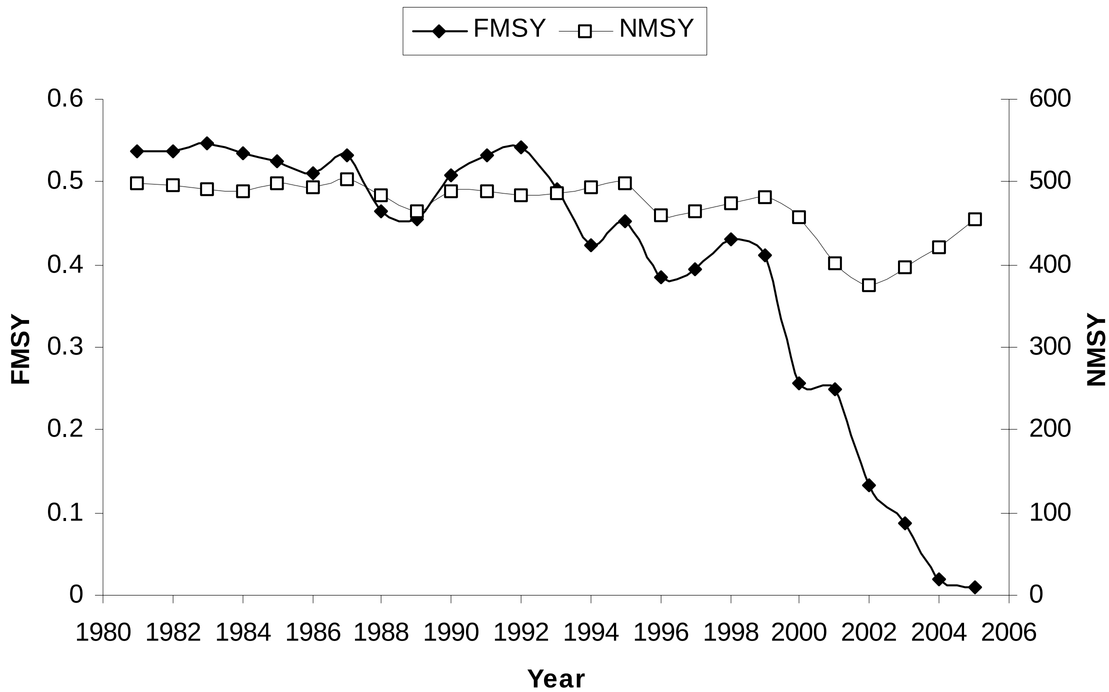

Figure 13. Plot of non-equilibrium overfishing thresholds (F_{msy}, N_{msy}) based on the Steele-Henderson model from 1981-2005.

Appendix 1. Annual Atlantic herring (ATH) landings (pounds*1000), pounds of catch subsampled for bycatch, number of shad in subsampled catch, fraction of shad in subsample, coast-wide shad discards (ATH*fraction of shad)/4.5lbs(ave weight per shad) (N*1000) and shad bycatch from the Connecticut River (10% of coast-wide discards) (N*1000).

Year	ATH Landings	Subsample	Shad in Catch	Fraction	Total Coast Shad	Shad CT River
1981	143,502	-	-	0.002	67	6.7
1982	71,260	-	-	0.002	33	3.3
1983	51,265	-	-	0.002	24	2.4
1984	74,030	-	-	0.002	34	3.4
1985	57,129	-	-	0.002	27	2.7
1986	70,540	-	-	0.002	33	3.3
1987	86,952	-	-	0.002	40	4.0
1988	90,396	-	-	0.002	42	4.2
1989	89,761	160,209	56	0.0003	7	0.7
1990	113,854	225,682	74	0.0003	8	0.8
1991	107,547	807,248	382	0.0005	11	1.1
1992	122,998	887,273	892	0.001	27	2.7
1993	109,679	425,592	1,114	0.003	64	6.4
1994	100,989	133,388	114	0.001	24	2.4
1995	152,014	164,965	267	0.002	55	5.5
1996	195,554	637,762	1,157	0.002	79	7.9
1997	210,305	546,961	919	0.002	79	7.9
1998	180,612	111,601	2,442	0.02	880	88.0
1999	175,005	75,289	0	0	0	0
2000	155,829	766,321	0	0	0	0
2001	208,964	1,343,279	510	0.0004	18	1.8
2002	135,775	2,018,652	1,085	0.0005	16	1.6
2003	211,800	447,639	123	0.0003	13	1.3
2004	188,347	2,518,596	822	0.0003	14	1.4
2005	188,347	9,810,557	11,364	0.001	48	4.8