Abstract

Christopher F. Batsavage. **LIFE HISTORY ASPECTS OF THE HICKORY SHAD (*ALOSA MEDIOCRIS*) IN THE ALBEMARLE SOUND/ROANOKE RIVER WATERSHED, NORTH CAROLINA**. (Under the direction of Roger A. Rulifson). Department of Biology, East Carolina University, December 1997.

The hickory shad (*Alosa mediocris*), which supports commercial and recreational fisheries in the Roanoke River and Albemarle Sound, North Carolina, is an anadromous species closely related to the American shad (*A. sapidissima*). The Albemarle Sound population has exhibited a surge in numbers since 1989, but the cause is unexplained. Little is known about the life history of this species, which now supports a fast-growing sport fishery on the Roanoke River near Weldon, NC, and increased commercial catches in Albemarle Sound. The goal of this study was to characterize key life history aspects of hickory shad in the Albemarle Sound/Roanoke River watershed including the age, size, and sex compositions of the population, the sexual maturity schedule (age to maturity), potential fecundity of adults, and identification of the nursery grounds. Fish examined in this study were captured in 1996 from the Albemarle Sound and Roanoke River. The sex ratio (males:females) of adult fish sampled from Albemarle Sound and the Roanoke River at Weldon was statistically similar (0.73:1 and 0.76:1, respectively). A 57% agreement was found between aging fish with scales and otoliths; scales overestimated younger-aged fish and underestimated older-aged fish. Most males were age 3 and most females were age 4; few fish were older than age 4 and the maximum age was 7. Males were generally smaller than females; overlapping lengths and weights at age make estimates of size at age difficult. Some fish were mature by age 2, and essentially all were mature at age 3.

Fecundity estimates ranged from 80,290 to 478,944 eggs with most fish spawning two or three times before leaving the population (from harvest or natural mortality). Reduced visceral fat of fish in the Roanoke River indicated use of stored lipid reserves during migration. Juvenile hickory shad apparently do not utilize Albemarle Sound as a nursery ground in the same manner as American shad and river herring, but they may use coastal ocean waters. A short life span and low fecundity makes this population vulnerable to overharvest.

LIFE HISTORY ASPECTS OF THE HICKORY SHAD (*ALOSA MEDIOCRIS*) IN THE ALBEMARLE SOUND/ROANOKE RIVER WATERSHED, NORTH CAROLINA

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Christopher F. Batsavage

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LIFE HISTORY ASPECTS OF THE HICKORY SHAD (*ALOSA MEDIOCRIS*) IN THE

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by
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Introduction

The hickory shad (*Alosa mediocris*) is one of four anadromous *Alosa* species native to North Carolina. It ranges from Cape Cod, Massachusetts to the Saint John's River, Florida (Robins et al. 1986), although there does not appear to be any spawning populations north of Maryland (Richkus and DiNardo 1984). Hickory shad is intermediate in size between the larger American shad (*A. sapidissima*) and the smaller alewife (*A. pseudoharengus*) and blueback herring (*A. aestivalis*). The largest hickory shad reported was 60 cm total length (TL) (Robins et al. 1986); however, adults are typically 30-45 cm fork length (FL) and weigh 0.5-1.0 kg (Figure 1).

The hickory shad has a low commercial value when compared to American shad, alewife, and blueback herring (the latter two marketed together as river herring) (Marshall 1977). Typically it is a bycatch species in the American shad gill net fishery in Albemarle Sound and the Atlantic Ocean. It also is caught in pound nets, haul seines, drift gill nets used for river herring, and in the offshore winter trawl fishery for striped bass (*Morone saxatilis*) (Street et al. 1975). The mesh sizes (102-140 mm) used in the gill net fishery only catch the larger hickory shad. The females are marketed together with American shad, while the males are often sold as crab bait (Richkus and DiNardo 1984). Hickory shad along the southern part of the range has a higher commercial value in the winter before the other alosid species commence their spawning migrations (Bigelow et al. 1963; Godwin 1968; Richkus and DiNardo 1984).

Figure 1. Illustration of a hickory shad (top) and an American shad (bottom) (from Manooch 1984).

The statewide commercial catch of hickory shad has been increasing over the past several years, from 26,170 kg in 1994, and 30,699 kg in 1995 to 85,399 kg in 1996 (North Carolina Division of Marine Fisheries (NCDMF) 1997a) even in spite of a 1994 moratorium on the sale of commericial fishing licenses in North Carolina (North Carolina Moratorium Steering Committee 1996). In 1995 the northern coastal district, which includes Albemarle Sound and its tributaries, contributed the largest proportion (81.5%) of the statewide commercial catch with 25,028 kg. These increases in the commercial catch reflect a noticeable growth in the hickory shad population in the Albemarle Sound region, and the rest of North Carolina. Consequently, the stock status of hickory shad is classified as "stressed recovering" by NCDMF (NCDMF 1997b).

A sport fishery for hickory shad, which is rich in tradition, has thrived for many years on the Neuse River, North Carolina (Hawkins 1980; Manooch 1984). This sport fishery has expanded in recent years in the coastal rivers of northeastern North Carolina during the spawning migration in late winter and early spring. In the northern district, fishing typically is centered near the hypothesized spawning locations on the Roanoke River near Weldon, North Carolina and on the Cashie River near Windsor, North Carolina (Pete Kornegay, North Carolina Wildlife Resources Commission (NCWRC), personal communication). Hickory shad are caught on a variety of baitfish-imitating lures such as small spoons, shad darts, spinners and jigs (Manooch 1984). They are relatively easy to catch and exhibit a sporting fight when hooked, which are two attributes that make them popular with anglers. Also, since they ascend rivers in the Albemarle Sound region before the other alosids, striped bass, and white perch (*Morone americana*), they offer the first major fishing opportunity of the year for many anglers in eastern North Carolina.

The increase in the North Carolina hickory shad population, suggested by increasing recreational and commercial catches, has resulted in a much improved sport fishery. It is common for anglers to harvest 50-100 fish in a day. The recreational harvest of hickory shad in the Roanoke River for 1996 was an estimated 58,621 fish (P. Kornegay, NCWRC, personal communication). In contrast, a creel survey conducted by the NCWRC in 1968 estimated only 143 hickory shad harvested by sport anglers in the Roanoke River and another 2,377 fish caught by special devices such as gill nets and dip nets (Baker 1968). Hickory shad was declared a gamefish species in inland waters of North Carolina in July 1996; however, there are no size or creel limits at the present time.

Little is known about life history aspects of hickory shad. The most comprehensive studies on hickory shad were done in the 1950s on the Patuxent River, Maryland (Mansueti 1962), the late 1960s on the Neuse River, North Carolina (Pate 1972) and the Altamaha River, Georgia (Street 1970). Life history aspects examined included egg and larvae development, fecundity, time and duration of spawning, spawning habitats, nursery areas, food habits, and age and growth. The importance of hickory shad and other *Alosa* species to the Native Americans up to the present was reviewed by Heath (1997).

The status of hickory shad spawning populations is unknown in many states. It is assumed that hickory shad return to natal streams to spawn, but this aspect has not been documented. A 1992 survey of east coast fisheries agencies indicated that the current status of hickory shad spawning populations was unknown in 50% of the rivers; North Carolina agencies could not offer any responses to this portion of the survey because hickory shad information for North Carolina was lacking (Rulifson 1994).

Understanding key life history aspects as well as the status of individual populations are critical to the management of the species in this state. Currently, the

Atlantic States Marine Fisheries Commission (ASMFC) is updating its interstate fishery management plan for shad and river herring (ASMFC 1995). Information on life history aspects of hickory shad was identified as a priority for future research by the ASMFC (Richkus and DiNardo 1984). Key life history aspects include: population structure (age, size, and sex distributions), the sexual maturity schedule (age to maturity), fecundity, spawning habitats, and nursery grounds.

The goal of this study was to characterize key life history aspects of hickory shad in the Albemarle Sound/Roanoke River watershed because of the increased commercial and recreational harvest in this system. Objectives to accomplish the goal were: 1) to describe the age, size, and sex composition of prespawning adults in the spring staging areas of Albemarle Sound; 2) to describe the age, size, and sex composition of hickory shad during the spawning migration near the (hypothesized) spawning sites in the Roanoke River; 3) to identify possible nursery grounds; and 4) to determine relative abundance of juveniles at selected sites.

The Roanoke River flows in a northwest to southeast direction and enters Albemarle Sound at its western end. The headwaters are located in the Appalachian Mountains of southwest Virginia. It flows 220.5 km from the last dam at Roanoke Rapids Reservoir to Albemarle Sound (Figure 2) (Street et al. 1975; Rulifson and Manooch 1990). Much of the channel is greater than 4 m with holes in excess of 15 m in depth (Street et al. 1975). The coastal plain portion of the watershed below the last dam has an extensive floodplain consisting of hardwood forest, backwater swamps, oxbow lakes, and small creeks (Zincone and Rulifson 1991) which are connected to the river by natural and anthropogenic openings in the natural river levee.

Most of the river is freshwater with the lower part of the river subject to both wind and lunar tides. However, the section of river between Plymouth, North Carolina and

Albemarle Sound occasionally becomes slightly brackish as a result of salt wedges from the sound (Zincone and Rulifson 1992). The natural river flow has been altered by several reservoirs located upstream. A flow regime for the lower Roanoke River from 1 April to 30 June was established by the Roanoke River Water Flow Committee to ensure favorable conditions during the striped bass spawning migration (Rulifson and Manooch 1991). The hydroelectric dams on the Roanoke River are undergoing relicensing through the Federal Energy Regulatory Commission (FERC) with fish passage and lower river habitat utilization by anadromous fish as research priorities (Virginia Power and Foster Wheeler Environmental Corporation 1996).

Albemarle Sound is an extensive estuary in northeast North Carolina measuring 88.5 km long (west to east) and 4.8 to 22.5 km wide (north to south) (Figure 3) (Street et al. 1975). The Roanoke, Cashie, and Chowan rivers are tributaries of Albemarle Sound that have spawning populations of hickory shad (Street et al. 1975). Its central basin ranges from 5.5 to 7.6 m deep. The shoreline consists mostly of cypress swamps and small sand beaches. It is essentially freshwater through the western and central portions and brackish in the eastern sound. Closest access of Albemarle Sound to the Atlantic Ocean is at Oregon Inlet, which is located between Bodie Island and Hatteras Island. Albemarle Sound is not significantly influenced by lunar tides; instead, wind tides prevail.

Figure 2. Map of the Roanoke River watershed, North Carolina showing the sampling sites for the independent gill net survey in the Roanoke River National Wildlife Refuge (RRNWR) and for the sport fishery in Weldon, North Carolina.

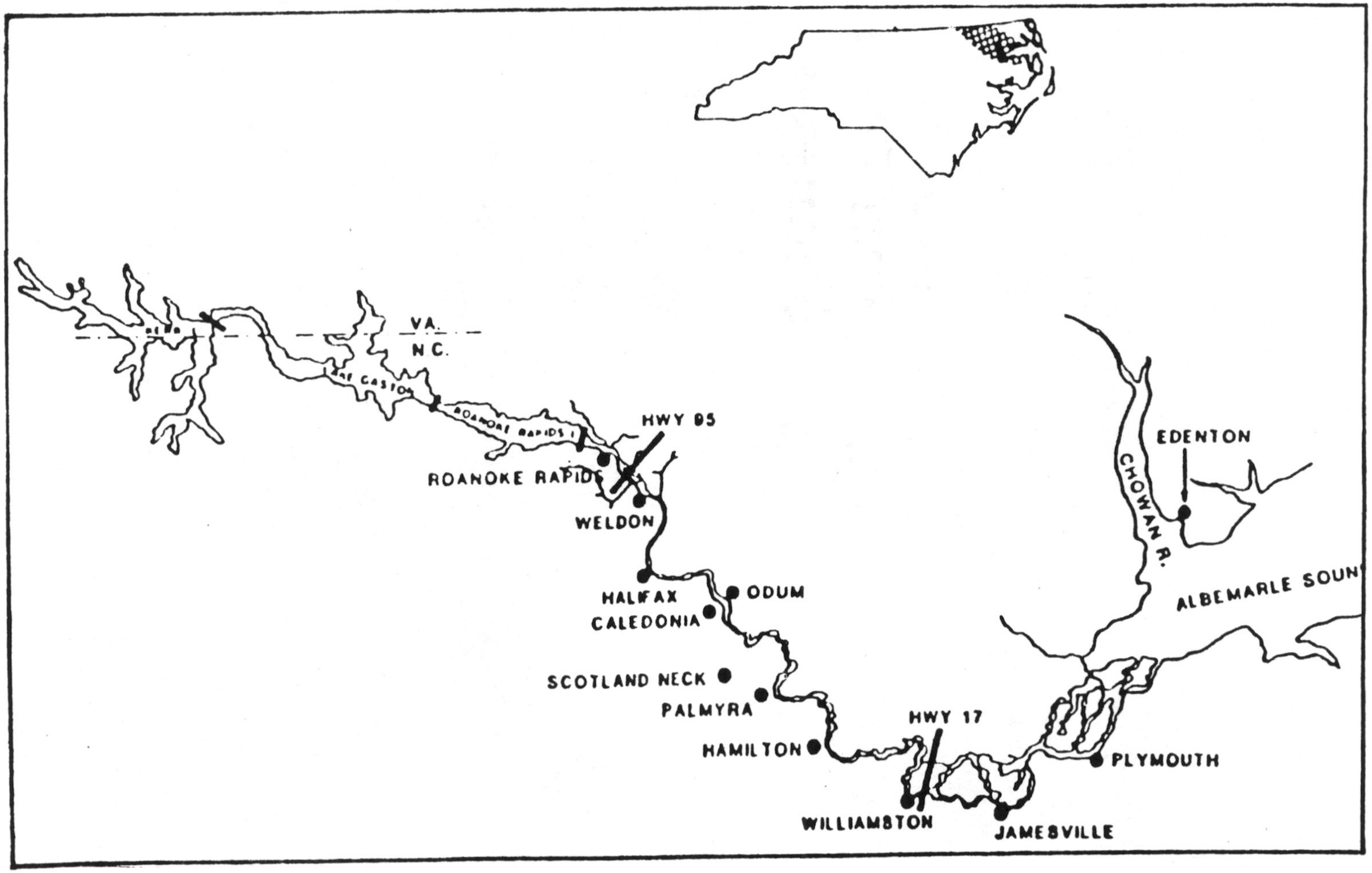
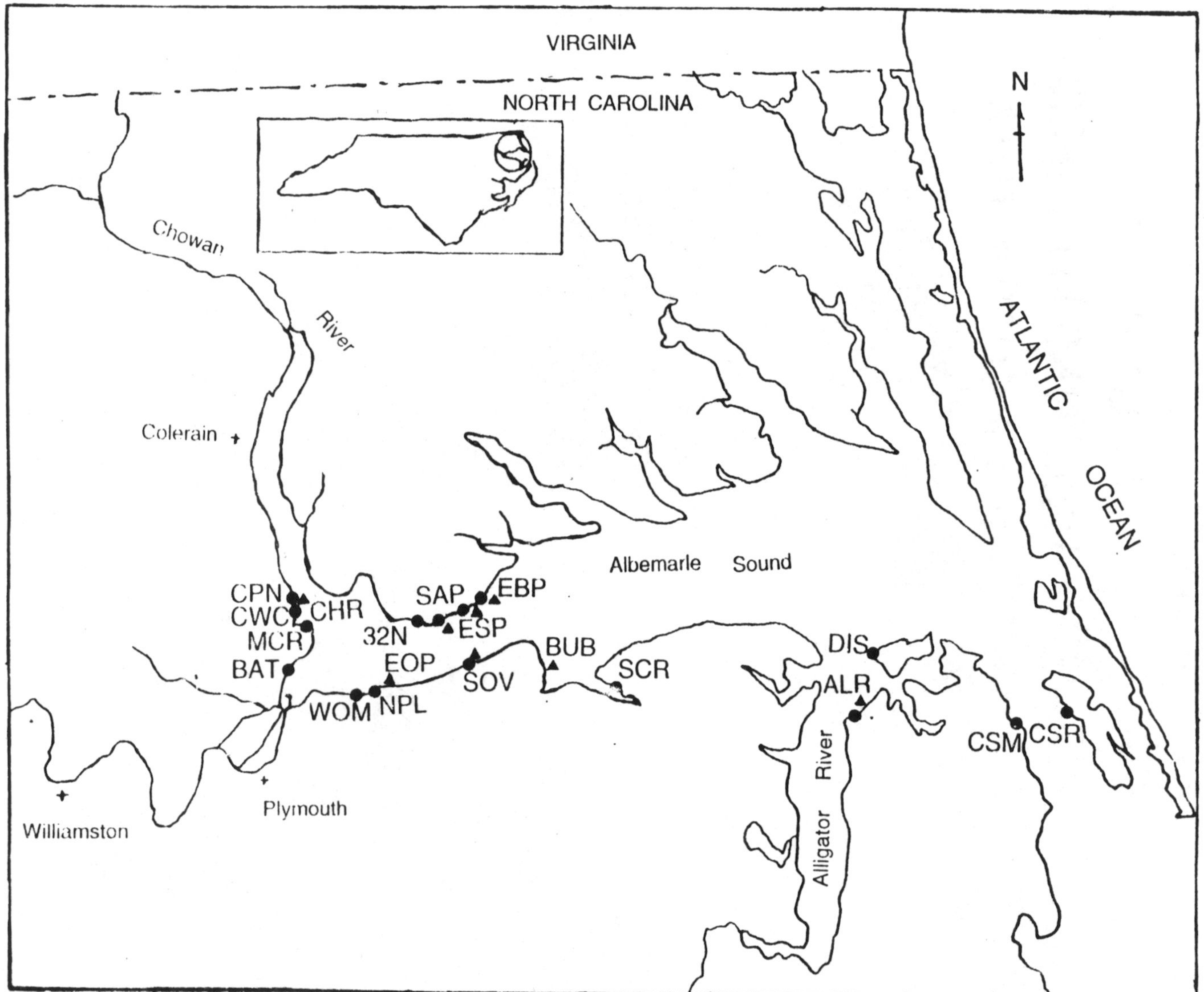

VA.
N.C.
HWY 95
ROANOKE RAPIDS
WELDON
HALIFAX
ODUM
CALEDONIA
SCOTLAND NECK
PALMYRA
HAMILTON
HWY 17
WILLIAMSTON
JAMESVILLE
PLYMOUTH
EDENTON
CHOWAN R.
ALBEMARLE SOUN

Figure 3. Map of Albemarle Sound and its tributaries showing the seine (circles) and trawl (triangles) sampling sites for the juvenile hickory shad survey.


VIRGINIA
NORTH CAROLINA
N
Chowan
River
Colerain
ATLANTIC
OCEAN
Albemarle Sound
CPN
CWC
CHR
MCR
BAT
SAP
EBP
32N
ESP
BUB
EOP
SOV
SCR
WOM
NPL
DIS
ALR
CSM
CSR
Alligator River
Plymouth
Williamston

Materials and Methods

Adult Collection

Specimens of adult hickory shad were collected by the NCDMF independent gill net survey in Albemarle Sound and its tributaries from 20 February to 1 May 1996; the Roanoke River National Wildlife Refuge (RRNWR) independent gill net survey, which was conducted by National Marine Fisheries Service (NMFS) and RRNWR personnel from 30 March to 17 April 1996; and from the sport fishery on the Roanoke River at Weldon from 16 March to 17 April 1996 (Figure 2). The NCDMF study used single mesh gill nets 9.15 m long with mesh sizes from 64 to 102 mm stretch mesh (Winslow 1989). The RRNWR independent gill net survey employed single mesh gill nets ranging from 3.6 m long x 1.5 m deep to 12.2 m long x 2.3 m deep; gill net mesh sizes ranged from 63 mm to 76 mm stretch mesh (Settle et al. 1996). Fish from the Weldon sport fishery were examined fresh at the access points, while gill-netted hickory shad were received frozen and examined at East Carolina University (ECU). Data recorded included fork length (mm), total length (mm), body depth (mm), body weight (g), and gonad weight (g). Ovaries of all females were preserved in 10% buffered formalin for fecundity estimates, and the viscera of all specimens were also preserved in 10% buffered formalin for mesentery fat and gut content analysis. Chi square analyses were performed to test for significant differences in adult sex compositions between the three collection sites (Albemarle Sound, RRNWR, and Roanoke River at Weldon, North Carolina). Regression analyses were performed for log-transformed fork length to weight, and for total length to fork length.

Scale and Otolith Aging

Ten to 20 scales were removed with a scalpel from the left side of the fish above the lateral line and below the dorsal fin, and were stored in scale envelopes. Scales were soaked in soapy water for at least six hours to remove dirt, mucous, and residual pigment. They were dried and individually viewed under a dissecting scope to determine which scales were suitable for aging. These scales were mounted between two microscope slides and read using a microfiche reader equipped with a 24x lens.

Otoliths were removed by using a hacksaw to make a diagonal cut behind the eye, which bisected the brain cavity. The labyrinth with the otoliths attached was removed with a pair of forceps. Excess tissue was removed from the otoliths by rubbing them between the thumb and forefinger. Otoliths were stored dry in 20-ml scintillation vials. Whole otoliths were aged by placing each in a watch glass containing distilled water and viewed under a dissecting scope at 30x magnification. The otoliths were not sectioned before aging because the short life span of the fish and the thin nature of the otoliths allowed the rings to be visible on the external portion of the structure (Charles Manooch and Jennifer Potts, NMFS, Beaufort Laboratory, personal communication).

Both scales and otoliths were aged independently three times. Age analyses used those scales and otoliths whose ages agreed on two readings; samples that had no age agreement were not used for age analyses. Scale aging techniques followed criteria used by Cating (1953), Judy (1961), Street and Adams (1969), and Pate (1972). Otolith aging techniques followed criteria used by Kornegay (1977) and Libby (1985). Fish that had both scale and otolith ages were used to analyze the percent agreement between these ages. Regression analyses were performed to determine the relationships of age to fork length and age to weight for both sexes.

Spawning History

Spawning history for both sexes was determined by counting the number of spawning marks on the scales. These marks are formed by the erosion of the scale margin from lack of feeding during the spawning migration and are counted as annuli.

Spawning marks are thicker and more visible than the winter annuli formed before fish are sexually mature. Presence or absence of these marks on scales indicates the percentage of the population spawning for the first time.

Mortality Estimates

Total instantaneous mortality estimates of fish within the River were obtained by taking the age and sex composition of fish collected from the Roanoke River at Weldon, and then applying it to the NCWRC recreational harvest estimate in the Roanoke River. This procedure was necessary because the creel survey used to obtain the harvest estimate did not record the age or sex of the fish (P. Kornegay, NCWRC, personal communication). This provided a sufficient number of males and females in each age class to estimate mortality from a catch curve (Van Den Avyle 1993).

Total instantaneous mortality (Z) was estimated for ages where recruitment was greater than 95% complete (Males; ages 3-5; Females; ages 4-6; Sexes combined; ages 3-6) to eliminate age classes not fully recruited to the population. Total instantaneous mortality was calculated by estimating the slope of the line from a catch curve from a single season. The equation is as follows:

$$\log_n(N_t) = \log_n(N_0) - Z(t)$$

where N_t = number alive at time t,

N_0 = number alive initally (at time t_0),

Z = instantaneous mortality rate, and

t = time elapsed since t_0 (Van Den Avyle 1993).

Annual total mortality (A) was estimated by taking the inverse natural log of -Z and subtracting it from one:

$$A = 1 - e^{-Z} \text{ (Ricker 1975).}$$

Natural mortality (M) was estimated by using von Bertalanffy parameters (L_∞ and K) and mean water temperature (T, °C) for the spawning habitat (Pauly 1979 as discussed in Manooch et al. 1997). The equation is as follows:

$$\log_{10}M = 0.0066 - 0.279 \log_{10}L_\infty + 0.6543 \log_{10}K + 0.4634 \log_{10}T.$$

The mean water temperature of 20 °C used in this equation was estimated by combining the mean of the spawning temperature range for hickory shad found in Table 22 and the mean of the water temperature range of Albemarle Sound in Table 21. Fishing mortality (F) can be estimated by F = Z - M.

Annual rates of fishing and natural mortality were calculated for a Type 2 fishery, in which fishing and natural mortality operate together (Ricker 1975). Annual fishing mortality (u) was calculated with the following equation:

$$u = FA/Z,$$

where, F = instantaneous fishing mortality rate,

A = annual total mortality rate, and

Z = instantaneous total mortality rate.

Annual natural mortality (v) was calculated with the following equation:

$$v = MA/Z$$

where, M = instantaneous natural mortality rate, A = annual total mortality rate, and

Z = instantaneous total mortality rate (Ricker 1975).

Scale and Otolith Back Calculations

Scales and otoliths used for back calculations were those in which the ages were the same. For each fish, the largest scale with legible annuli was selected for taking measurements of the scale image projected on the screen of a microfiche reader. Scale measurements were taken diagonally from the focus to the anterior margin. Otoliths from 75 fish were measured in order to determine the otolith radius to fork length relationship. All specimens < 250 mm FL and > 350 mm FL were examined (otoliths from eight fish > 350 mm FL were unreadable). The dominant length classes, 250 to 300 mm FL and 300 to 350 mm FL, were subsampled to minimize the bias associated with dominant size classes affecting the linear regression calculations. Otolith images were measured using a video screen connected to a dissecting scope magnified at 16x. Otolith annuli were measured vertically from the nucleus to the ventral margin with a millimeter ruler.

Fork length back calculations were estimated from the von Bertalanffy growth equation (Cailliet et al. 1986). The mean back calculated fork lengths at age (sexes combined) for otolith-measured fish were used to calculate this equation. The von Bertalanffy equation is expressed as:

$$L_t = L_\infty (1 - e^{-K(t - t0)})$$

where L_t = predicted length at time t,

L_∞ = maximum length predicted by the equation,

e = base of the natural log,

t = time,

t_0 = the size at which the fish would have been age 0, and

K = the growth coefficient (instantaneous rate).

Back calculations were also computed by the direct proportion method (DeVries and Frie 1996) using the following equation:

$$L_i = [S_i / S_c] \, L_c$$

where L_i = back calculated length of the fish when the ith increment was formed,

L_c = fork length (mm) at capture,

S_c = radius of otolith at capture, and

S_i = radius of the otolith at the ith increment.

Fecundity

A subsample of ovaries was examined for fecundity estimates. The formalin was decanted from the specimen bag and the whole ovaries were blotted with a paper towel, then weighed to the nearest 0.01 g. Three subsamples, each weighing at least 0.50 g, were taken from each ovary: one from the anterior region, one from the medial region, and one from the posterior region. Eggs were counted in each subsample and extrapolated to estimate the number of eggs/g. The mean number of eggs/g from the three subsamples was multiplied by the ovary weight to estimate the number of eggs in that ovary. The sum of the two ovaries provided the estimate of potential fecundity. The gonadosomatic index (GSI) was estimated for these fish by dividing the gonad weight by the body weight and multiplying the quotient by 100. Monthly differences in mean GSI by age were analyzed. Paired t-tests were used to detect significant differences in weight and potential fecundity between left and right ovaries. An analysis of variance (ANOVA) was used to see if signicant differences in the number of mean eggs/g occurred between anterior, median, and posterior sections of the ovaries. Regression analyses between potential fecundity and fork length, somatic weight, age and GSI were used to see which variable was the best predictor of potential fecundity.

Mesentery Fat and Gut Content Analysis

The few literature references indicate that other hickory shad populations do not feed during the spring spawning migration (White and Curtis 1969; Curtis 1970; Perkins and Dahlberg 1971; Pate 1972). However, hickory shad in the Roanoke River have been observed with full stomachs (unpublished data, Manooch, personal communication; Batsavage, present study), and they commonly strike at baitfish-imitating lures. I hypothesized that hickory shad feed in the ocean waters before the spawning migration, and they use mesentery fat as an energy source during the migration instead of feeding, so mesentery fat content of the body cavity and stomach contents were examined to confirm if significant feeding occurs in this watershed. Mesentery fat was removed from the viscera and weighed to the nearest 0.01 g. Food items removed from the stomach and intestine were identified to the lowest practical taxon, enumerated, and weighed to the nearest 0.01 g. T-tests were used to test for significant differences in mesentery fat between males and females and between fish collected in Albemarle Sound and fish collected in the Roanoke River.

Nursery Grounds

The juvenile hickory shad survey began after the conclusion of the adult spawning season. It was conducted twice a month during daylight hours from May to October 1996 in the Albemarle Sound and selected tributaries (Figure 3). Two gear types were used: a semi-balloon trawl (i.e., Hassler trawl) with a 5.5 m headrope, and a 18.2 m x 1.8 m beach seine with 6.35 mm ace mesh that contained a 1.8 m x 1.8 m tailbag (Rulifson et al. 1993). The trawl was towed behind a 6.7 m fiberglass boat equipped with a 150 hp outboard motor. Two 5 min tows at 1200 rpm were made at each site. The seine was deployed in the water approximately 1 m in depth parallel to the shoreline and then pulled into shore. The distance pulled through the water varied with each site because of differences in water depth; however, all samples at a single site were collected in the same manner. Therefore, each seine haul was considered one unit of effort. Air temperature (^{O}C), water temperature (^{O}C), dissolved oxygen (mg/L), conductivity (mS), secchi visibility (cm), wind direction and velocity (miles/hour), weather conditions, and time of day were recorded at each site. Dissolved oxygen (DO) was measured with a YSI_{TM} Model 52B DO meter. Conductivity was measured with a total dissolved solids (TDS) tester. Samples were preserved in 10% buffered formalin and returned to ECU for enumeration to lowest practical taxon.

The Albemarle Sound sampling locations (Figure 3) and their abbreviations are listed in Table 1. Seine sites SAP and SOV were established on 14 May. Seine sites CPN, CWC, MCR, BAT, NPL, and WOM were established on 27 May . Trawl sites BUB, ALR, CHR, and seine sites SCR, ALR, and DIS, were established on 10 June. Seine sites 32N, ESP, EBP, CSM, and, CSR were established on 22 July. Trawl sites EBP, EOP, ESP, SAP, and SOV were established on 22 August. Unfavorable weather conditions sometimes prevented sampling of certain sites on every sampling trip. Logistical problems involving boat availability and unfavorable weather precluded us from sampling trawl sites on a regular basis.

Seine sites were divided into five regions: northwest (BAT, CPN, CWC, MCR), north-central (EBP, ESP, SAP, 32N), southwest (NPL, WOM), south-central (SCR, SOV), and southeast (ALR, CSM, CSR, DIS). There were no seine sites in the northeast section of Albemarle Sound. Species composition and catch per unit effort (CPUE) for the four juvenile *Alosa* were examined and calculated for each region.

At the same time, the NCDMF conducted a juvenile alosid survey and a juvenile striped bass survey in Albemarle Sound. Both surveys employed a seine with the same dimensions as the juvenile hickory shad survey (Steve Trowell, NCDMF, Elizabeth City, personal communication; Winslow 1989). The juvenile striped bass survey was conducted in the western sound with nine sites sampled weekly from 4 June to 8 July 1996 (Figure 4). The juvenile alosid survey was conducted from June to October 1996 with 23 sites located throughout Albemarle Sound (Figure 4). Eleven of these sites were sampled monthly, and 12 of the sites were sampled once in September.

Figure 4. Map of Albemarle Sound and its tributaries showing the sampling sites for the juvenile striped bass (circles) and juvenile alosid (triangles) surveys conducted by the North Carolina Division of Marine Fisheries (NCDMF).

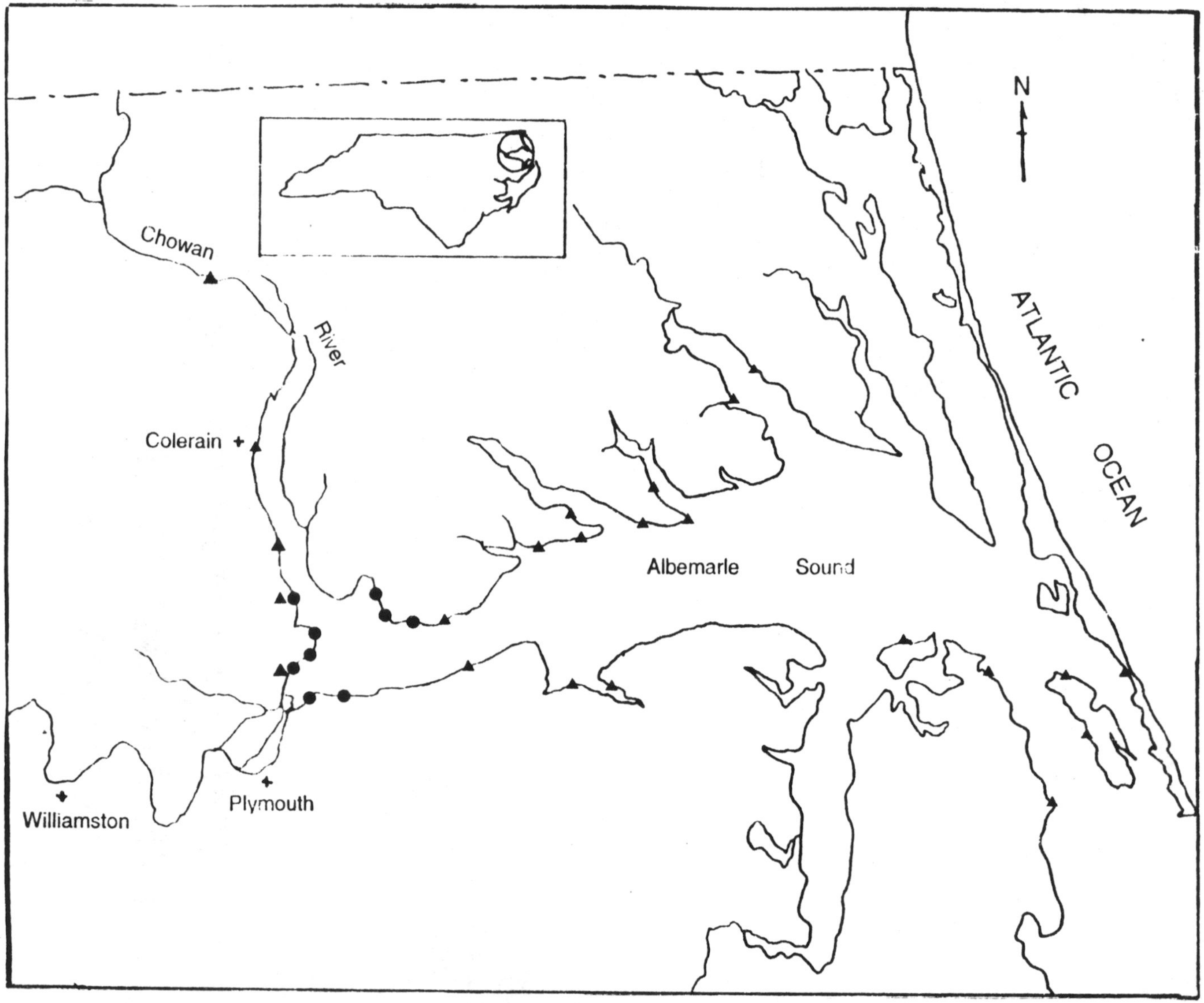

N
Chowan
River
Colerain
ATLANTIC
OCEAN
Albemarle
Sound
Williamston
Plymouth

Table 1. Description of beach seine and trawl sampling sites in Albemarle Sound and selected tributaries for the juvenile hickory shad survey.

Code	Site name	Coordinates	Description
Juvenile Hickory Shad Seine Survey (HSS)			
North shore			
MCR	Mouth of Chowan River	36.00° N, 76.41°W	west shore of Chowan River mouth, north shore western Albemarle Sound
CPN	Chowan River, between the pound nets	36.02° N, 76.42° W	west shore of Chowan River south of Rt. 17 bridge north shore of western Albemarle Sound
CWC	Chowan River, west shore cliffs	36.01° N, 76.42° W	west shore south of Rt. 17 bridge at base of bluffed shoreline north shore of western Albemarle Sound
BAT	Batchelor Bay	35.58° N, 76.42° W	western Albemarle Sound between Cashie River Mouth and Black Walnut Point
32N	Rt. 32 Bridge, North Shore	36.00° N, 76.30° W	central Albemarle Sound north shore just west of Rt. 32 bridge
SAP	Sandy Point Beach	36.00° N, 76.30° W	central Albemarle Sound, north shore just east of Rt. 32 bridge
ESP	East of Sandy Point	36.00° N, 76.29° W	central Albemarle Sound north shore, east of Sandy Point
EBP	East of Bluff Point	36.01° N, 76.27° W	central AlbemarleSound north shore, east of Bluff Point

Table 1, cont.

Code	Site name	Coordinates	Description
South Shore			
WOM	West of Mackey's Creek	35.56°N, 76.36°W	western AlbemarleSound, south shore west of NC power lines
NPL	Near Powerlines	35.56° N, 76.36° W	western Albemarle Sound, south shore, next to old barge
SOV	Soundview	35.57° N, 76.29° W	western Albemarle Sound, south shore just east of Rt. 32 bridge
SCR	Scuppernong River	35.56° N, 76.18° W	eastern shore of Scuppernong River, south shore of central Albemarle Sound
ALR	Alligator River	35.53° N, 75.58° W	east shore of Alligator River between Rt. 64 bridge and NCWRC boat ramp, south shore of eastern Albemarle Sound
DIS	Durant Island	35.57° N, 75.56°W	eastern Albemarle Sound east of Alligator River mouth
CSM	Croatan Sound at Mann's Harbor	35.55° N, 75.43° W	west shore of Croatan Sound north of Rt. 64 bridge, eastern Albemarle Sound
CSR	Croatan Sound on Roanoke Island	35.55° N, 75.43° W	east shore of Croatan Sound north of Rt. 64 bridge, eastern Albemarle Sound
Juvenile Hickory Shad Trawl Survey (HTS)			
ALR	Alligator River	35.54° N, 75.57° W	western shore of Alligator River, south shore of eastern Albemarle Sound

Table 1, cont.

Code	Site name	Coordinates	Description
BUB	Bull Bay	35.56^{o} N, 76.20^{o} W	central Albemarle Sound, south shore at Colonial Beach
CHR	Chowan River	36.00^{o} N, 76.41^{o} W	west shore of Chowan River between Rt. 17 bridge and Salmon Creek mouth, north shore of western Albemarle Sound
EBP	East of Bluff Point	36.01^{o} N, 76.27^{o} W	central Albemarle Sound north shore, east of Bluff Point
EOP	East of Powerlines	35.56^{o} N, 76.33^{o} W	western Alb. Sound south shore east of NC power lines
ESP	East of Sandy Point	36.00^{o} N, 76.29^{o} W	central Albemarle Sound north shore, east of Sandy Point
SAP	Sandy Point Beach	36.00^{o} N, 76.30^{o} W	central Albemarle Sound, north shore just east of Rt. 32 bridge
SOV	Soundview	35.57^{o} N, 76.29^{o} W	western Albemarle Sound, south shore just east of Rt. 32 bridge

Results

Results of this study are divided into the following components: adult sex ratios, adult size distributions, age analysis, mortality, age back calculations, fecundity analysis, and the juvenile nursery ground survey. Since adult hickory shad came from three sources (NCDMF independent gill net survey in Albemarle Sound, RRNWR independent gill net survey, and the recreational sport fishery at Weldon, NC), portions of the results analyze these three groups individually.

Adult Sex Ratios

Of the 643 adult hickory shad examined, the majority (83%) were from Albemarle Sound and the Roanoke River at Weldon, which were similar in the male:female ratios. A total of 266 specimens were from the Albemarle Sound area, 111 from the Roanoke River National Wildlife Refuge (RRNWR), and 266 from the Roanoke River at Weldon. A two-way chi-square analysis indicated that the male:female ratios for Albemarle Sound (0.73:1) and the Roanoke River at Weldon (0.76:1) were statistically similar (X^2 = 0.064, n = 532, df = 1, P> 0.05) (Table 2). The independent gill net survey in the RRNWR had a male to female ratio of 4.29:1 (Table 2), a value significantly different from Albemarle Sound and Weldon, NC (X^2 = 54.28, n = 643, df = 2, P< 0.001). However, interpretation of this three-way comparison should be made with caution because of the small gill net mesh sizes used in the refuge survey, which likely selected for the smaller male fish.

Table 2. Chi square analysis of male to female ratios for Albemarle Sound, RRNWR, and Weldon, NC. O = observed E = expected.

Location	Male	Female	Total examined	Male to female ratio
Two-way comparison				
Albemarle Sound	O = 112 E = 113.50	O = 154 E = 152.50	266	0.73:1
Weldon, NC	O = 115 E = 113.50	O = 151 E = 152.50	266	0.76:1
Total (observed)	227	305		
N = 532 $X^2 = 0.064$ $P > 0.05$				
Three-way comparison				
Albemarle Sound	O = 112 E = 131.14	O = 154 E = 134.86	266	0.73:1
Weldon, NC	O = 115 E = 131.14	O = 151 E = 134.86	266	0.76:1
RRNWR	O = 90 E = 54.72	O = 21 E = 56.28	111	4.29:1
Total (examined)	317	326		
N = 643 $X^2 = 54.28$ $P < 0.001$				

Adult Size Distributions

Most males were between 270-330 mm FL, while most females were 290-360 mm long (Figure 5). Male hickory shad ranged from 257 mm to 376 mm FL, and female hickory shad ranged from 280 mm to 402 mm FL. Dominant sizes of males (47.3%) were in the 280 mm and 290 mm size classes, while females (41.5%) were in the 330 mm and 340 mm size classes (Figure 6).

Log transformed body weight (Log_n BWT) plotted against log transformed fork length (Log_n FL) indicated that body weight generally increased with fork length for both males ($r^2 = 0.78$, Figure 7) and females ($r^2 = 0.73$, Figure 8). The equations for these relationships were:

Males: Log_n BWT (g) = 3.09 (Log_n FL (mm)) -11.75, and

Females: Log_n BWT (g) = 2.94 (Log_n FL (mm)) -10.78.

Since variations in gonad weight of both sexes varied considerably, these data were analyzed using log-transformed somatic weight (Log_n SWT) (total body weight - gonad weight); results showed a similar trend (males: r^2= 0.81; females: r^2= 0.76) (Figures 9 and 10). The equations for these relationships were:

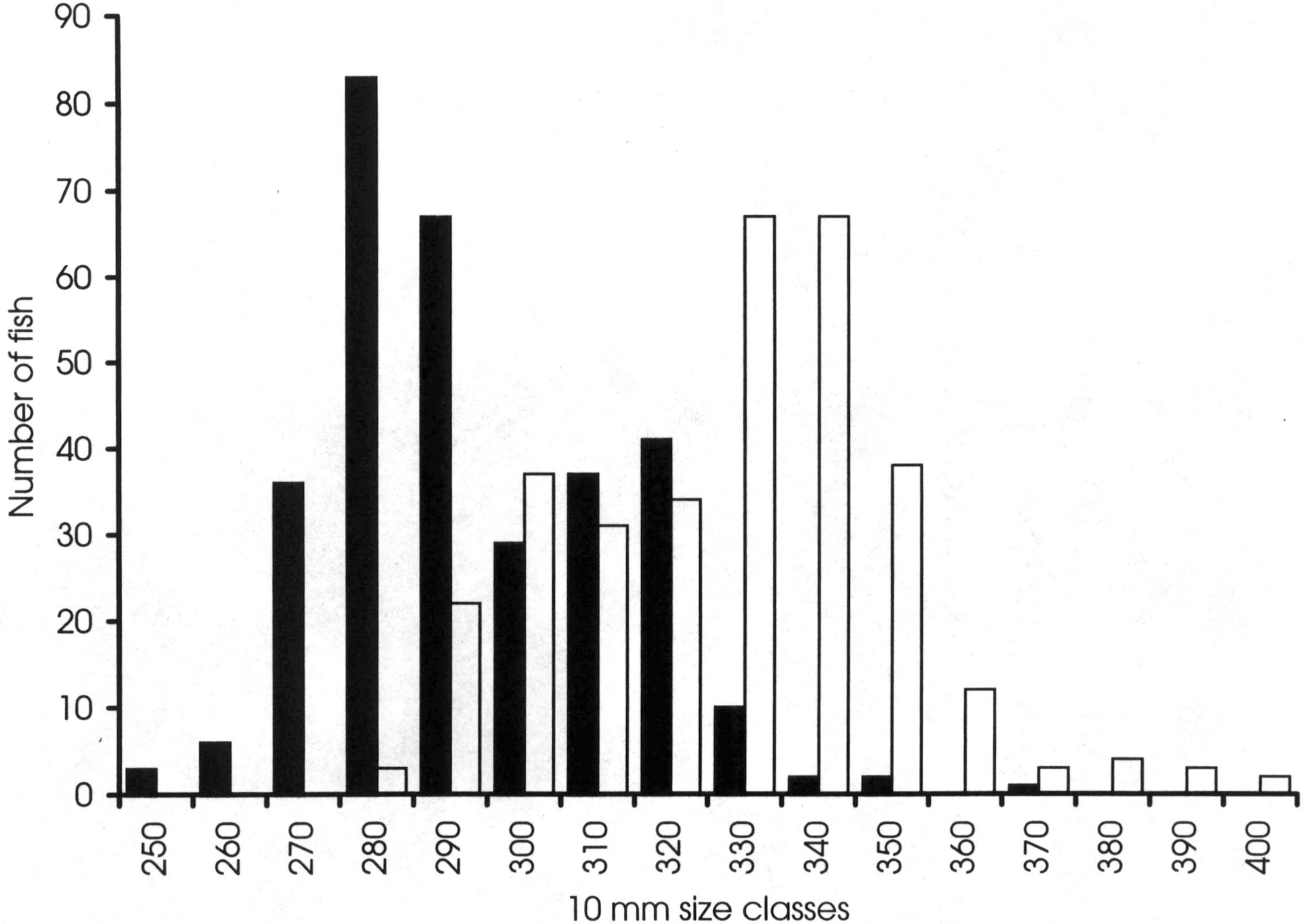
Males: Log_n SWT (g) = 3.01 (Log_n FL (mm)) -11.34, and

Females: Log_n SWT (g) = 2.77 (Log_n FL (mm)) -9.96.

Total length plotted against fork length showed a strong relationship (r^2= 0.98, Figure 11). The equation for this relationship was:

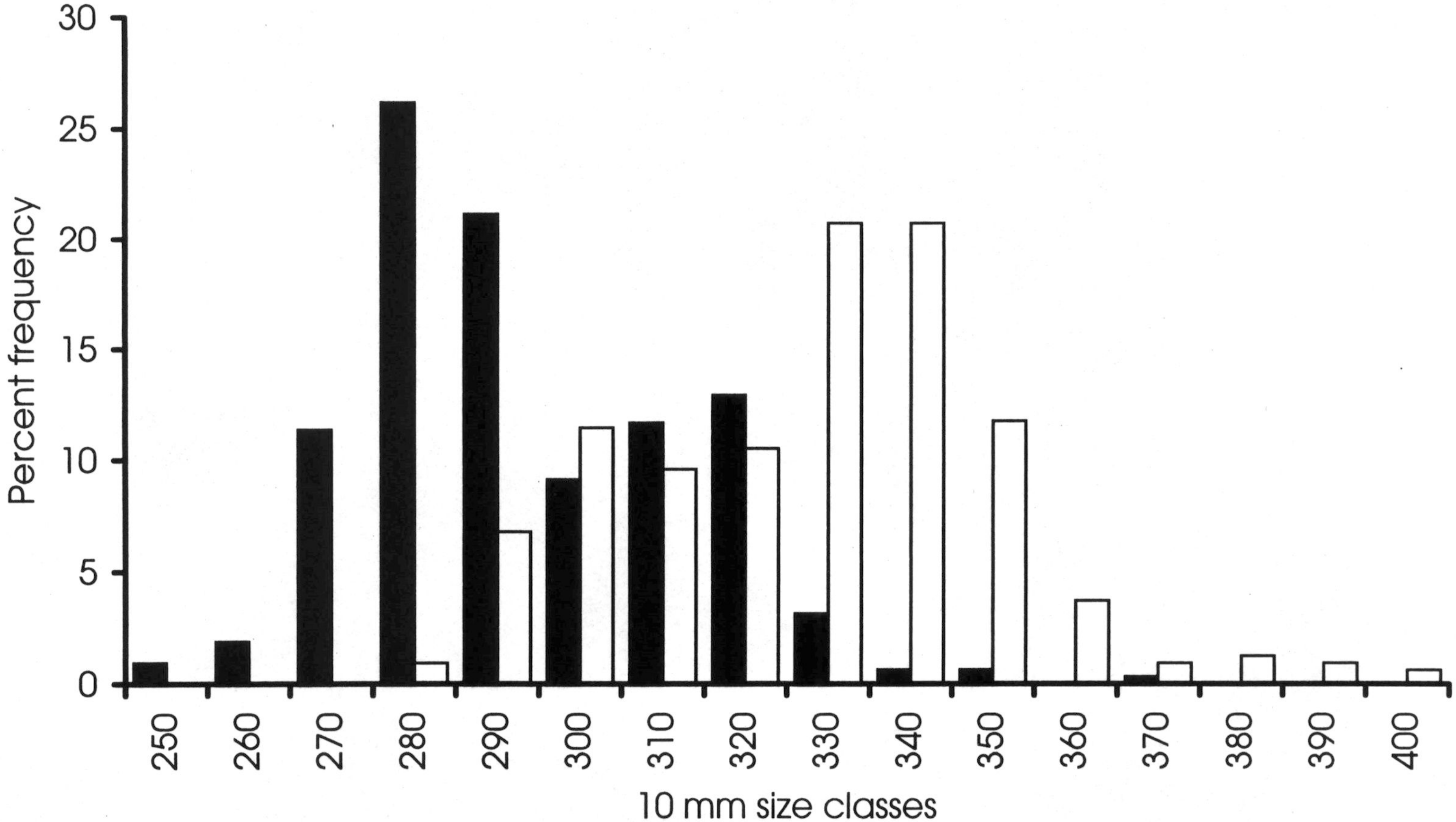
TL (mm) = 1.15 (FL (mm)) + 4.06.

Figure 5. Length frequencies of adult hickory shad into 10 mm size classes, by sex.
Males: black bars. Females: white bars.



Number of fish
90
80
70
60
50
40
30
20
10
0
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
10 mm size classes

Figure 6. Percent frequencies of adult hickory shad into 10 mm size classes, by sex.
Males: black bars. Females: white bars.



Percent frequency
0
5
10
15
20
25
30
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
10 mm size classes

Figure 7. Log-transformed body weight (g) to log-transformed fork length (mm) relationship for adult male hickory shad.

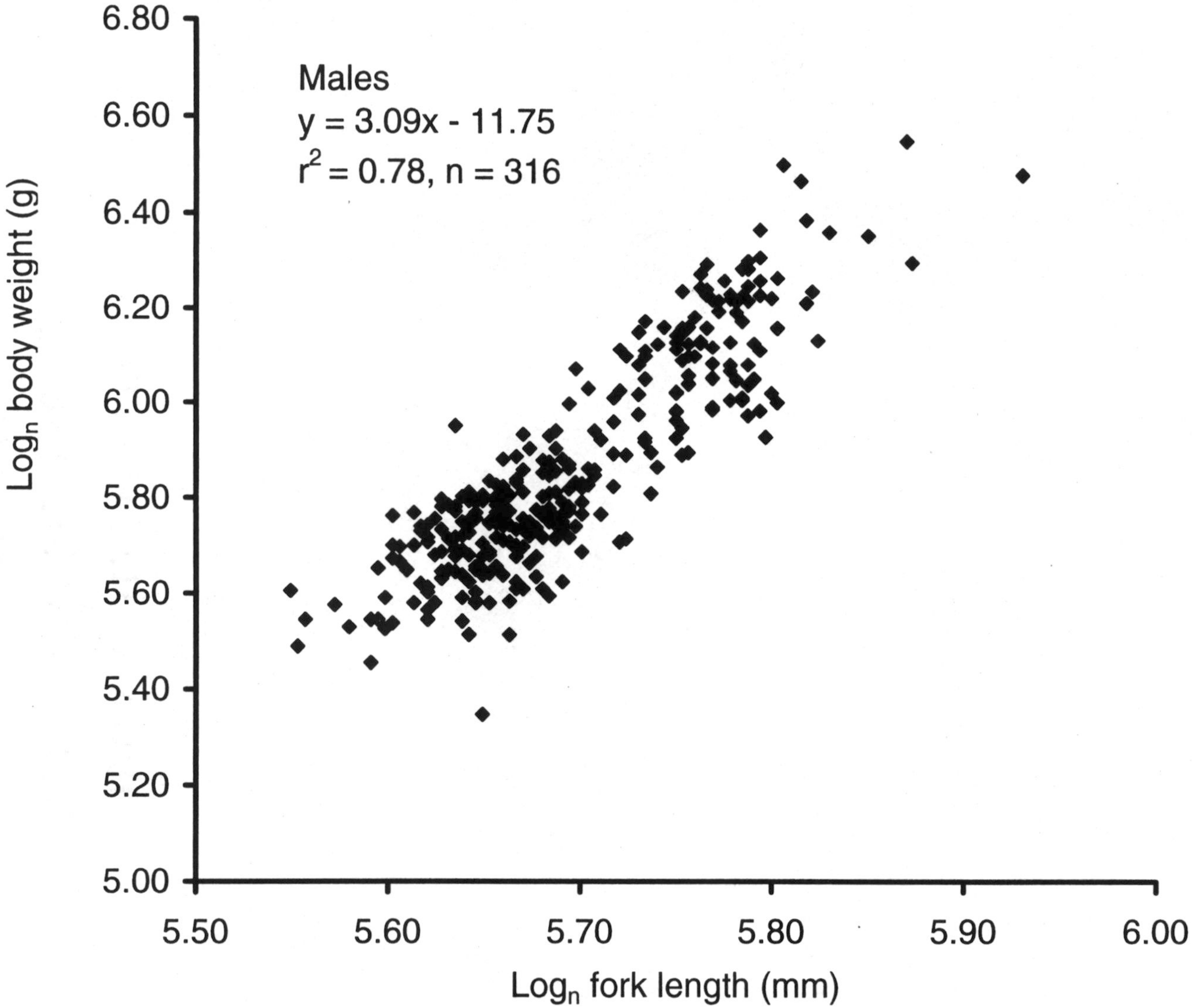
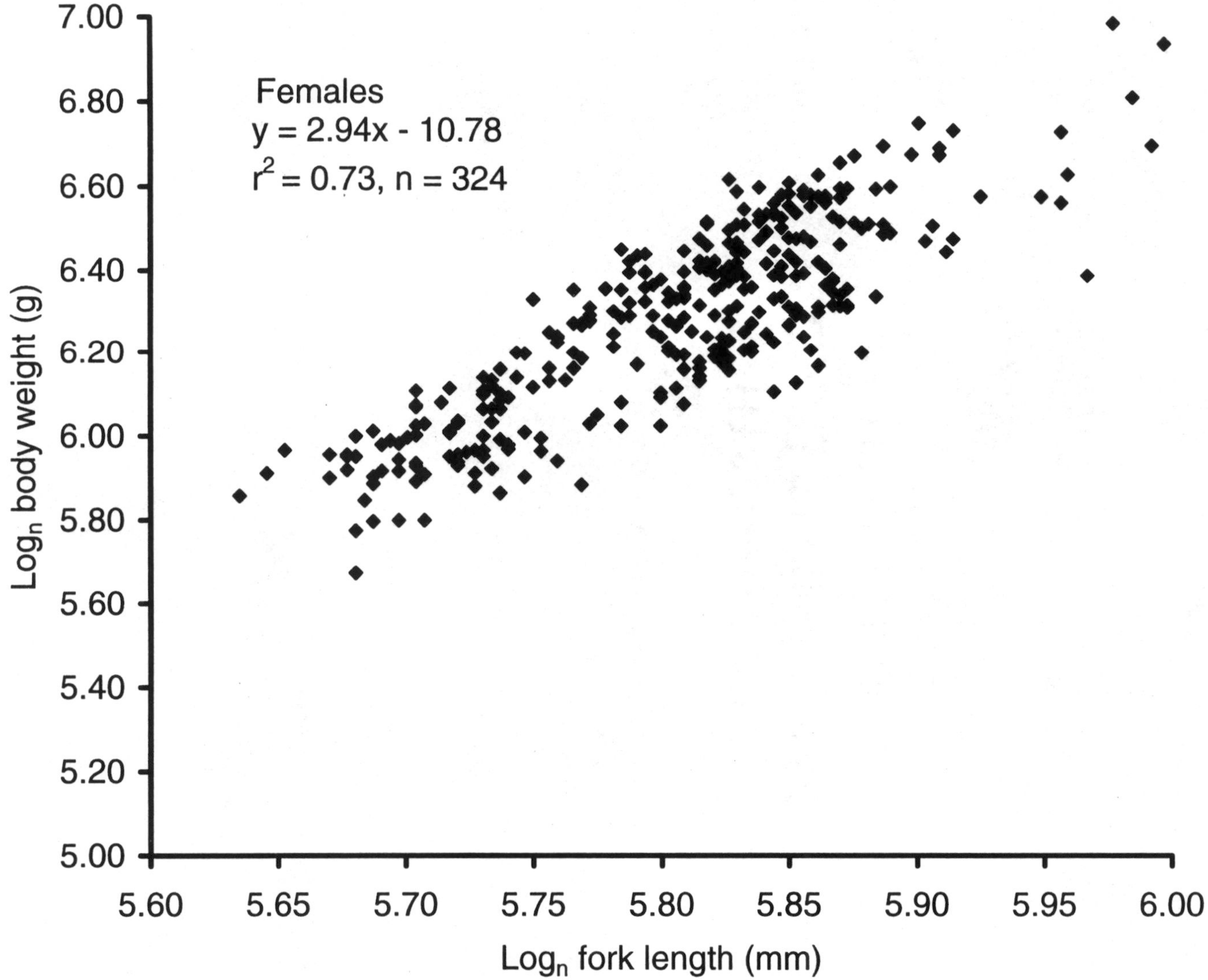
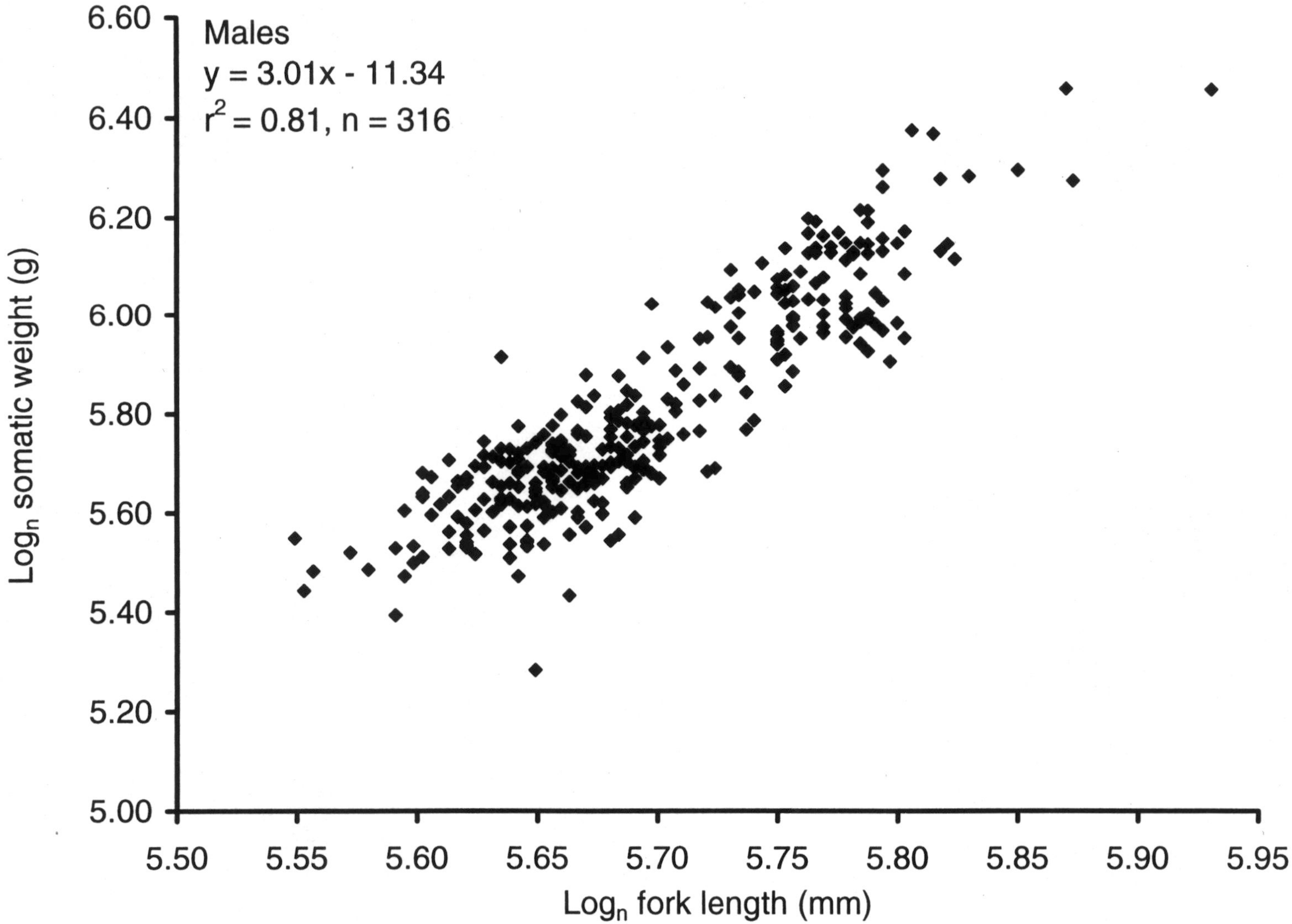

Males
y = 3.09x - 11.75
r² = 0.78, n = 316
6.80
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
Log_n body weight (g)
5.50
5.60
5.70
5.80
5.90
6.00
Log_n fork length (mm)

Figure 8. Log-transformed body weight (g) to log-transformed fork length (mm) relationship for adult female hickory shad.



Females
y = 2.94x - 10.78
r2 = 0.73, n = 324
7.00
6.80
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
Logn body weight (g)
5.60
5.65
5.70
5.75
5.80
5.85
5.90
5.95
6.00
Logn fork length (mm)

Figure 9. Log-transformed somatic weight (g) to log-transformed fork length (mm) relationship for adult male hickory shad.



Males
y = 3.01x - 11.34
r2 = 0.81, n = 316
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
Logn somatic weight (g)
5.50
5.55
5.60
5.65
5.70
5.75
5.80
5.85
5.90
5.95
Logn fork length (mm)

Figure 10. Log-transformed somatic weight (g) to log-transformed fork length (mm) relationship for adult female hickory shad.

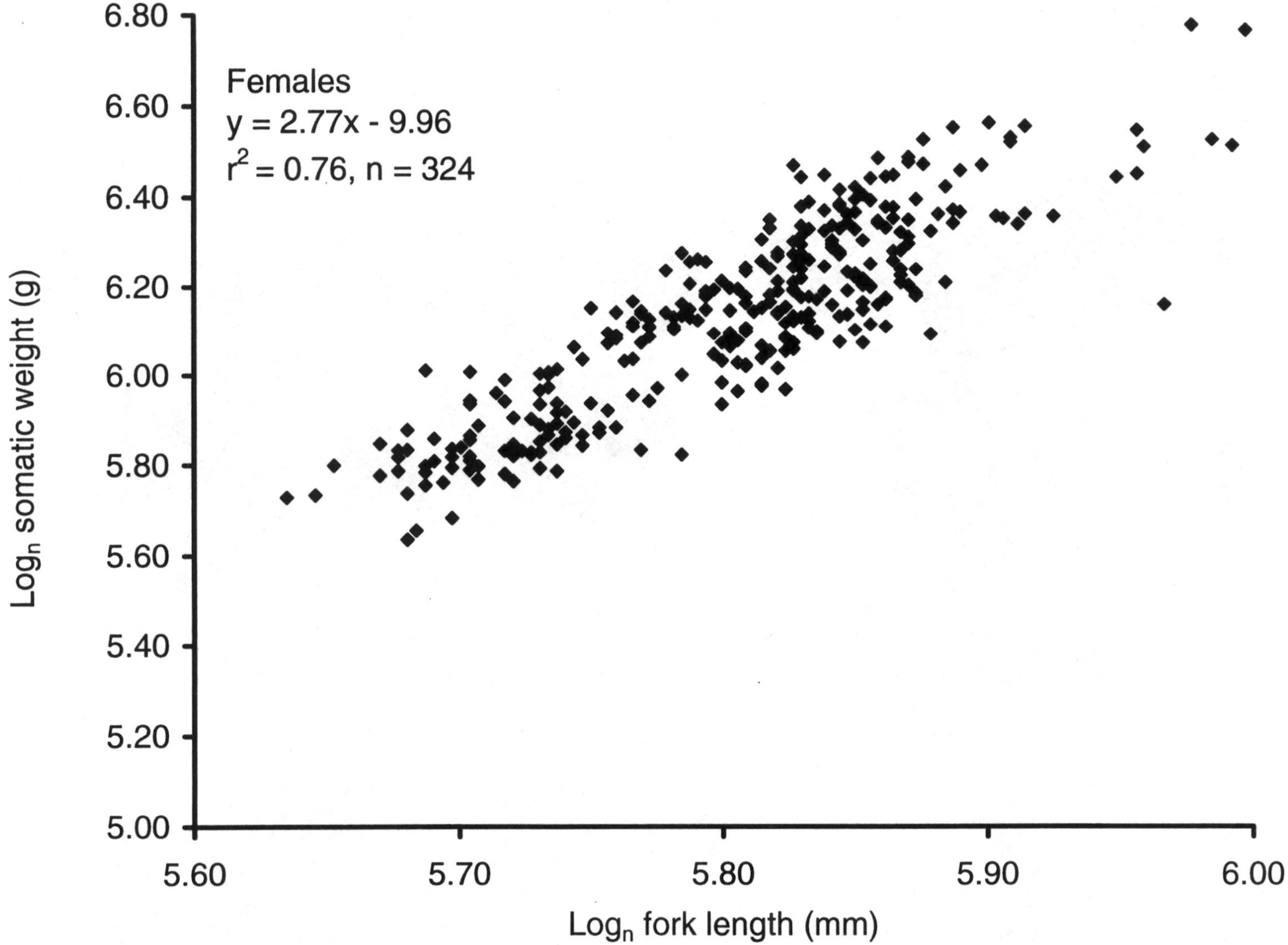
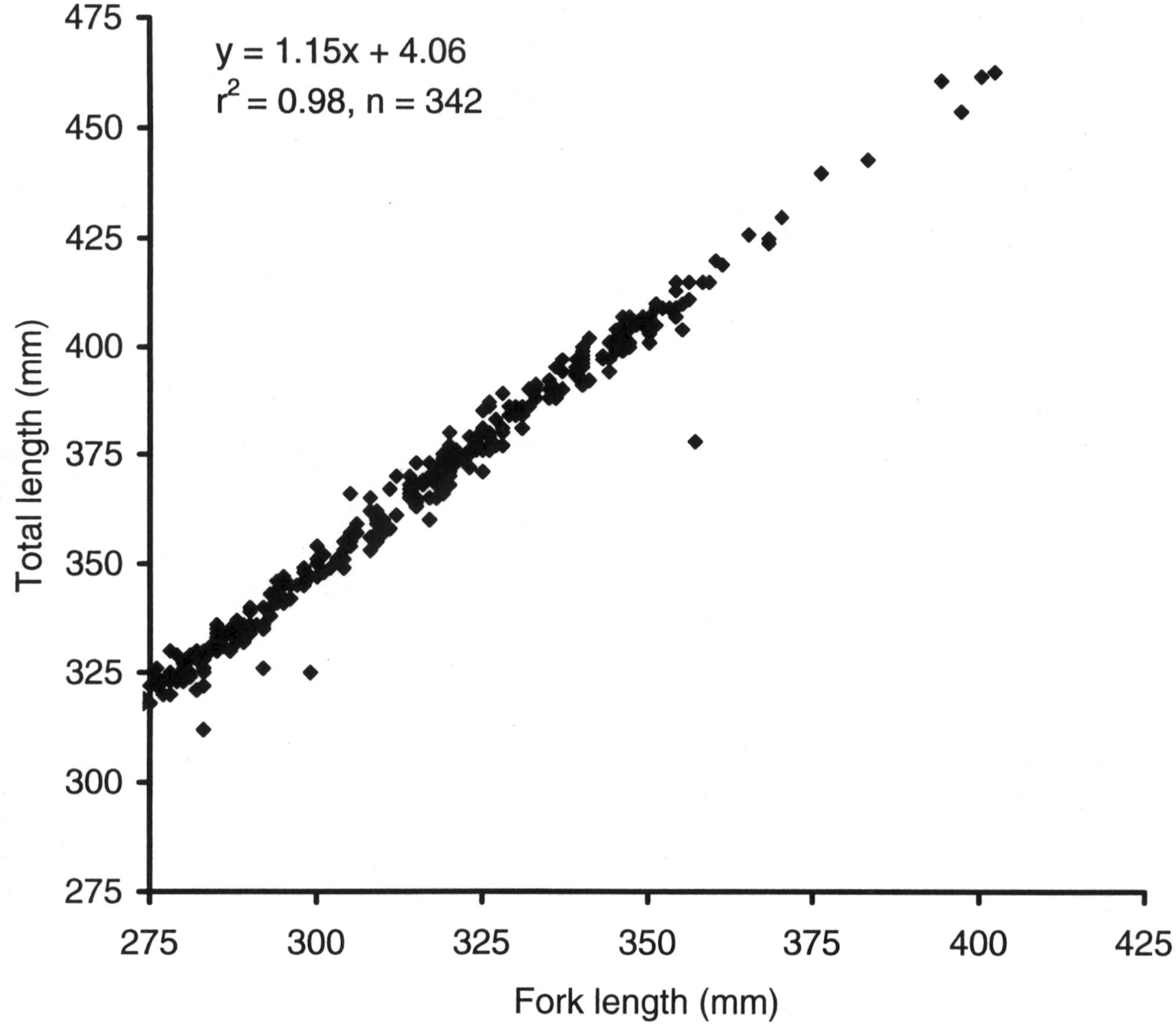

Females
y = 2.77x - 9.96
r2 = 0.76, n = 324
6.80
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
Logn somatic weight (g)
5.60
5.70
5.80
5.90
6.00
Logn fork length (mm)

Figure 11. Total length (mm) to fork length (mm) relationship for adult hickory shad.


y = 1.15x + 4.06
r2 = 0.98, n = 342
Total length (mm)
475
450
425
400
375
350
325
300
275
275
300
325
350
375
400
425
Fork length (mm)

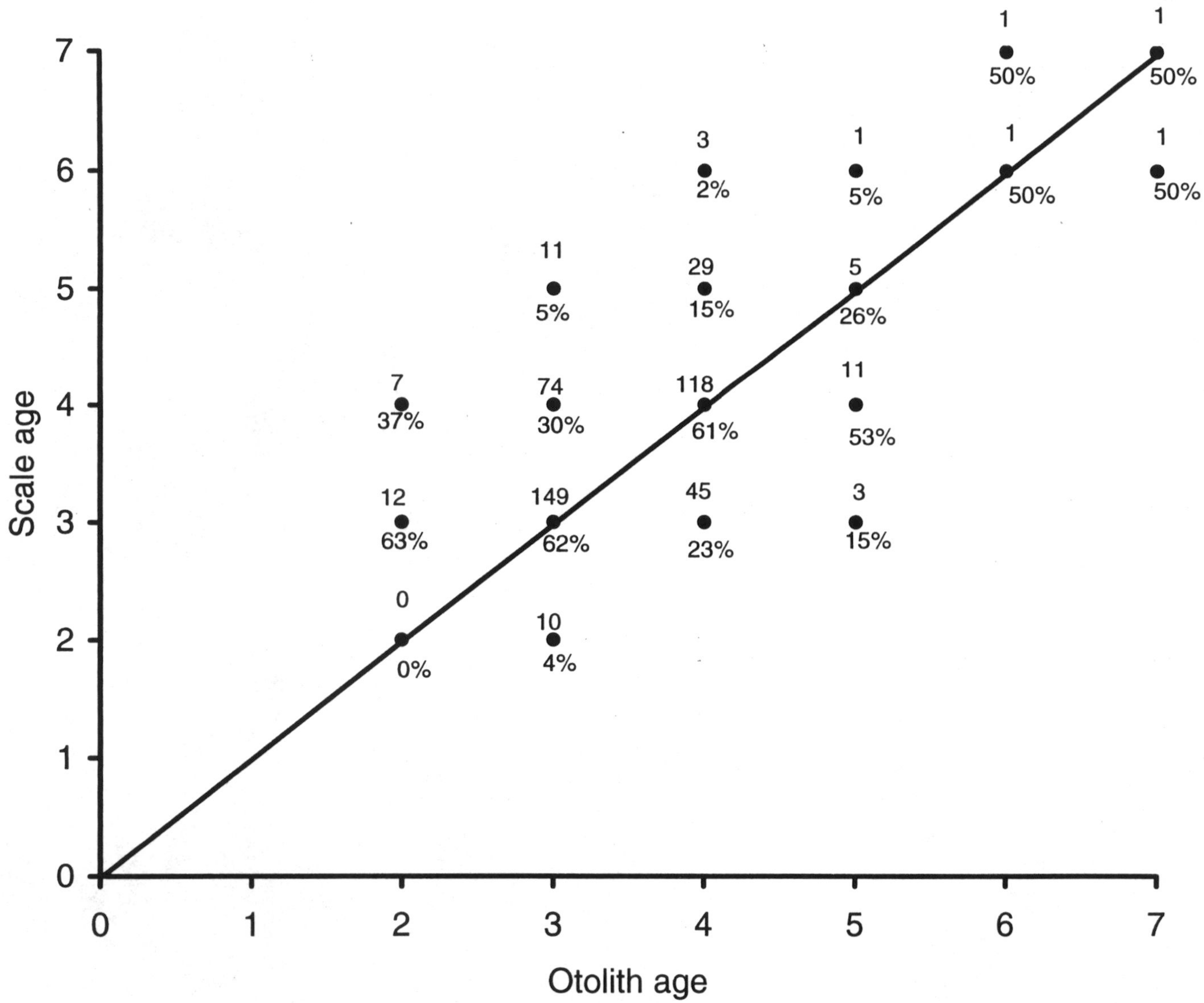
Age Analysis

Age comparison analysis between scales and otoliths of 480 fish showed 57% agreement, with scales overestimating younger-aged fish and underestimating older-aged fish (Figure 12). The scale age never deviated more than ± 2 years from the otolith ages; most scale ages deviated ± 1 year (Figure 12). For example, 61% of otolith age 3 fish were correctly assigned using scales (149 of 242), but 34% were mis-assigned by one year (scale age 2 or 4), and 4% were mis-assigned by two years (scale age 5). There was no agreement between age 2 scales and otoliths, and age 4 scales and otoliths had 61% agreement. Only 26% of age 5 scales and otoliths agreed. Otolith age data were used in all further age analysis because otoliths are considered to be more reliable than scales for aging (DeVries and Frie 1996).

Most (90%) of the 509 hickory shad examined were ages 3 and 4; the majority of males (66%) was age 3 and most females (55%) were age 4 (Table 3; Figure 13). The number of fish ages 2 through 4 (483) was considerably more than the number of fish ages 5 through 7 (26).

Mean fork length and body weight for both sexes generally increased with age, but size ranges and weights at age for males (Table 4, Figures 14-15), females (Table 5, Figures 16-17), and combined sexes (Table 6) show a large degree of overlap. Females were larger at age than males. However, the overlap of size ranges at age for both sexes causes difficulty in estimating the age using fork length measurements.

Figure 12. Age comparison analysis between scales and otoliths.

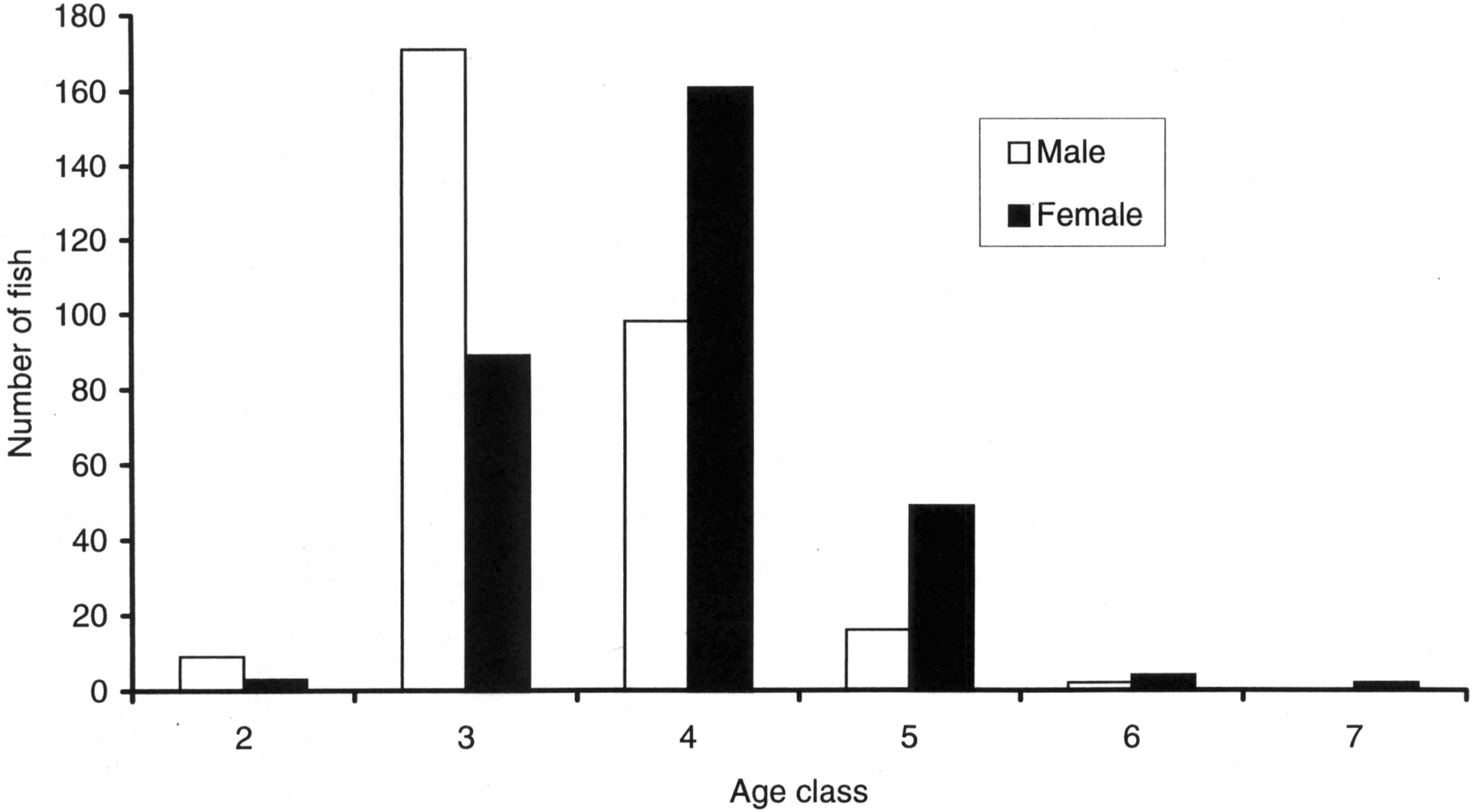


Scale age
Otolith age
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
0
0%
12
63%
7
37%
10
4%
149
62%
74
30%
11
5%
45
23%
118
61%
29
15%
3
2%
3
15%
11
53%
5
26%
1
5%
1
50%
1
50%
1
50%
1
50%

Table 3. Scale and otolith age class distributions of Albemarle Sound/Roanoke River hickory shad by sex, 1996.

Scale	Male		Female	
Age class	Number	Percent	Number	Percent
2	9	3.0	3	1.0
3	171	57.8	90	29.1
4	98	33.1	161	52.1
5	16	5.4	49	15.9
6	2	0.7	4	1.3
7	0	0.0	2	0.6
Total	296	100.0	309	100.0
Otolith Age class				
2	16	6.0	8	3.3
3	177	66.2	80	33.1
4	69	25.8	135	55.8
5	4	1.5	18	7.4
6	1	0.4	1	0.4
7	0	0.0	2	0.8
Total	267	100.0	242	100.0

Figure 13. Age class distributions of male (black bars) and female (white bars) hickory shad.



180
160
140
120
100
80
60
40
20
0
Number of fish
Male
Female
2
3
4
5
6
7
Age class

Table 4. Observed mean values of fork length (mm), body weight (g), and somatic weight (g) at age of male hickory shad collected from the Roanoke River near Weldon, North Carolina, the Roanoke River National Wildlife Refuge, and Albemarle Sound during spring 1996. SD = standard deviation.

		Fork length (mm)		Body weight (g)		Somatic weight (g)	
Age	n	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
2	16	293 ± 9.3	278-314	330 ± 41.7	273-411	310 ± 35.8	256-388
3	177	288 ± 12.9	257-328	319 ± 54.1	210-548	300 ± 57.8	197-525
4	69	319 ± 11.9	283-354	451 ± 70.2	316-698	422 ± 59.8	297-640
5	4	332 ± 16.4	318-355	452 ± 65.2	403-542	430 ± 69.6	385-532
6	1	376		651		638	

Figure 14. Age class to fork length (mm) relationship for male hickory shad.

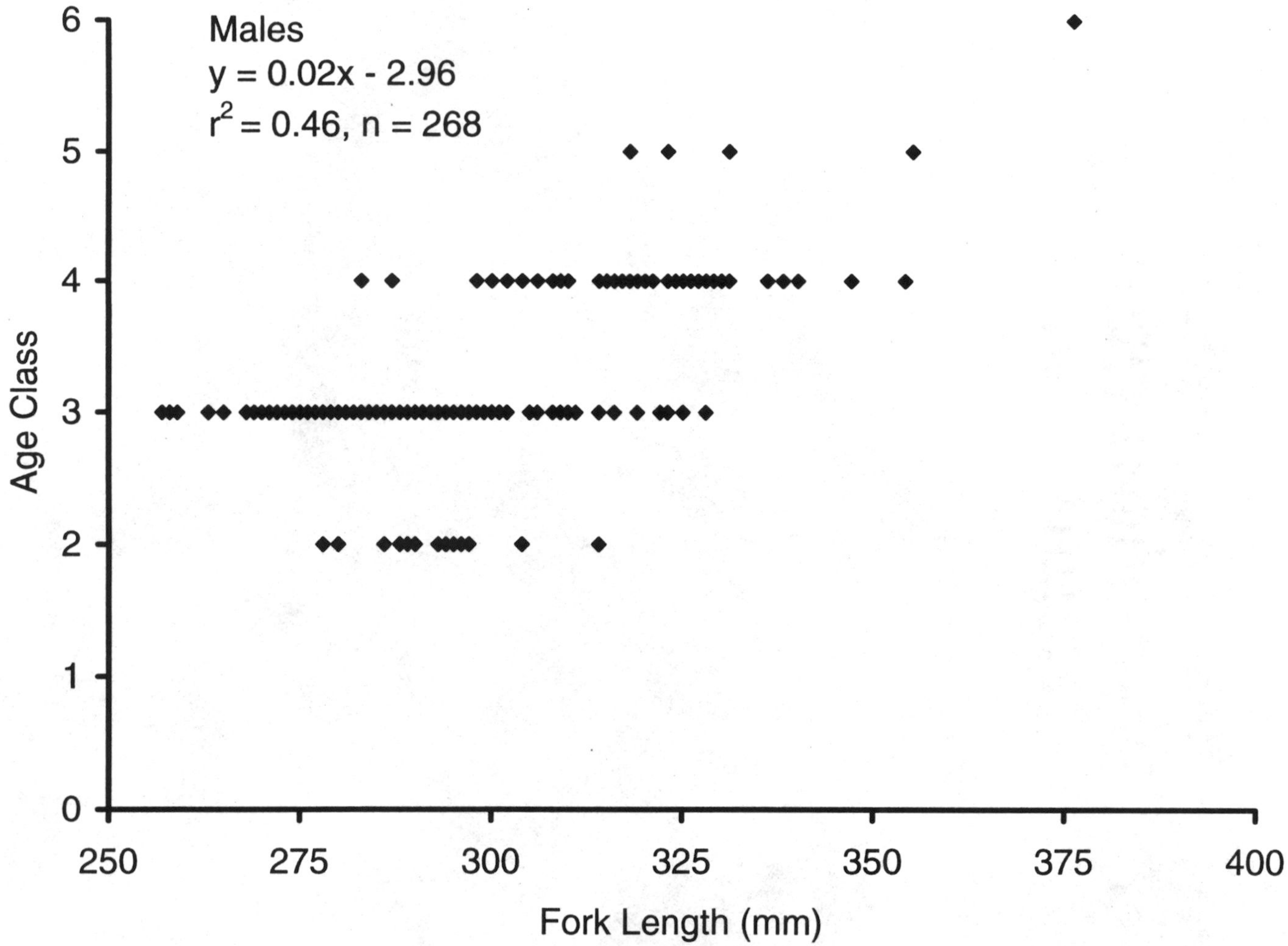
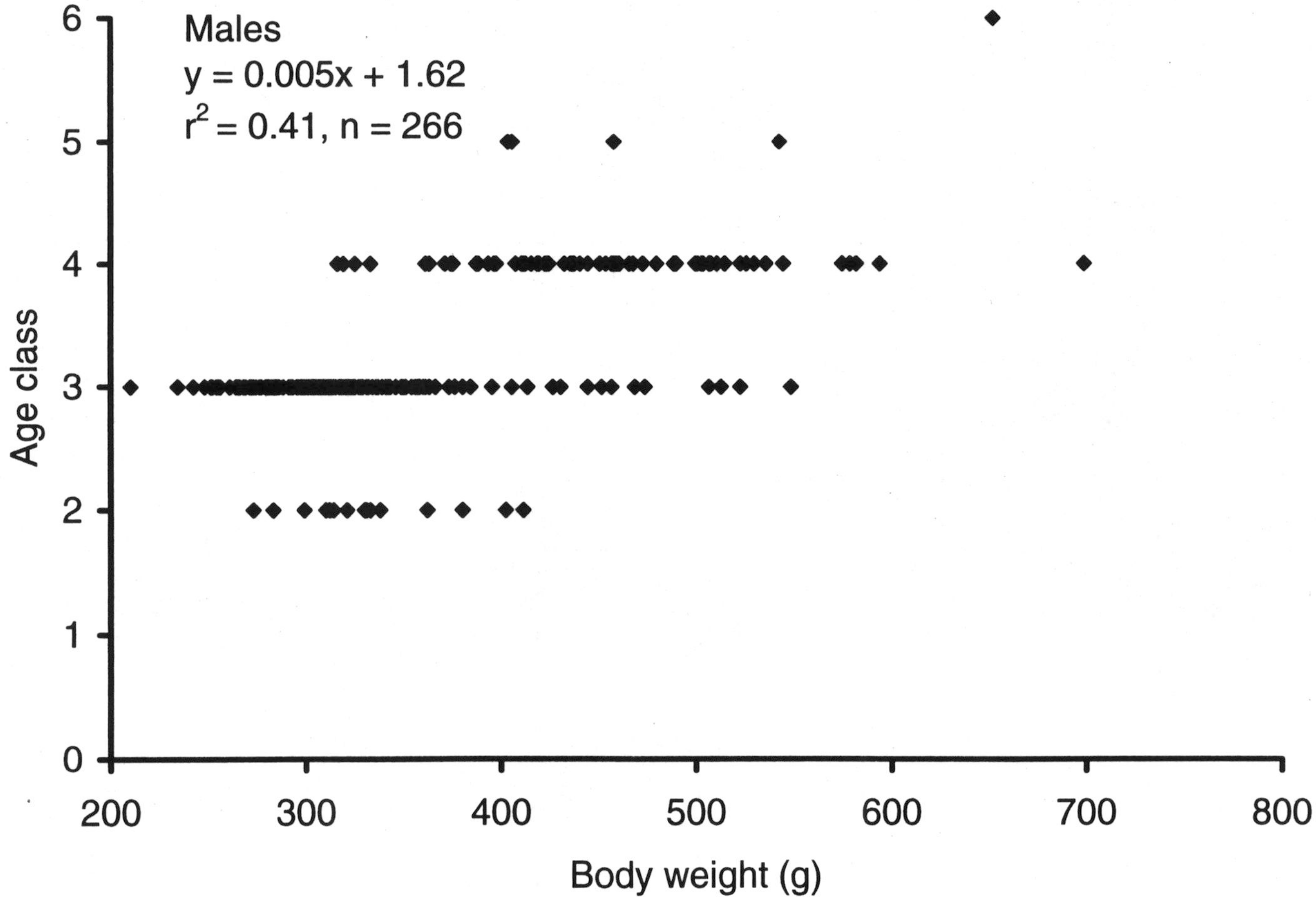

Males
y = 0.02x - 2.96
r2 = 0.46, n = 268
Age Class
0
1
2
3
4
5
6
250
275
300
325
350
375
400
Fork Length (mm)

Figure 15. Age class to body weight (g) relationship for male hickory shad.

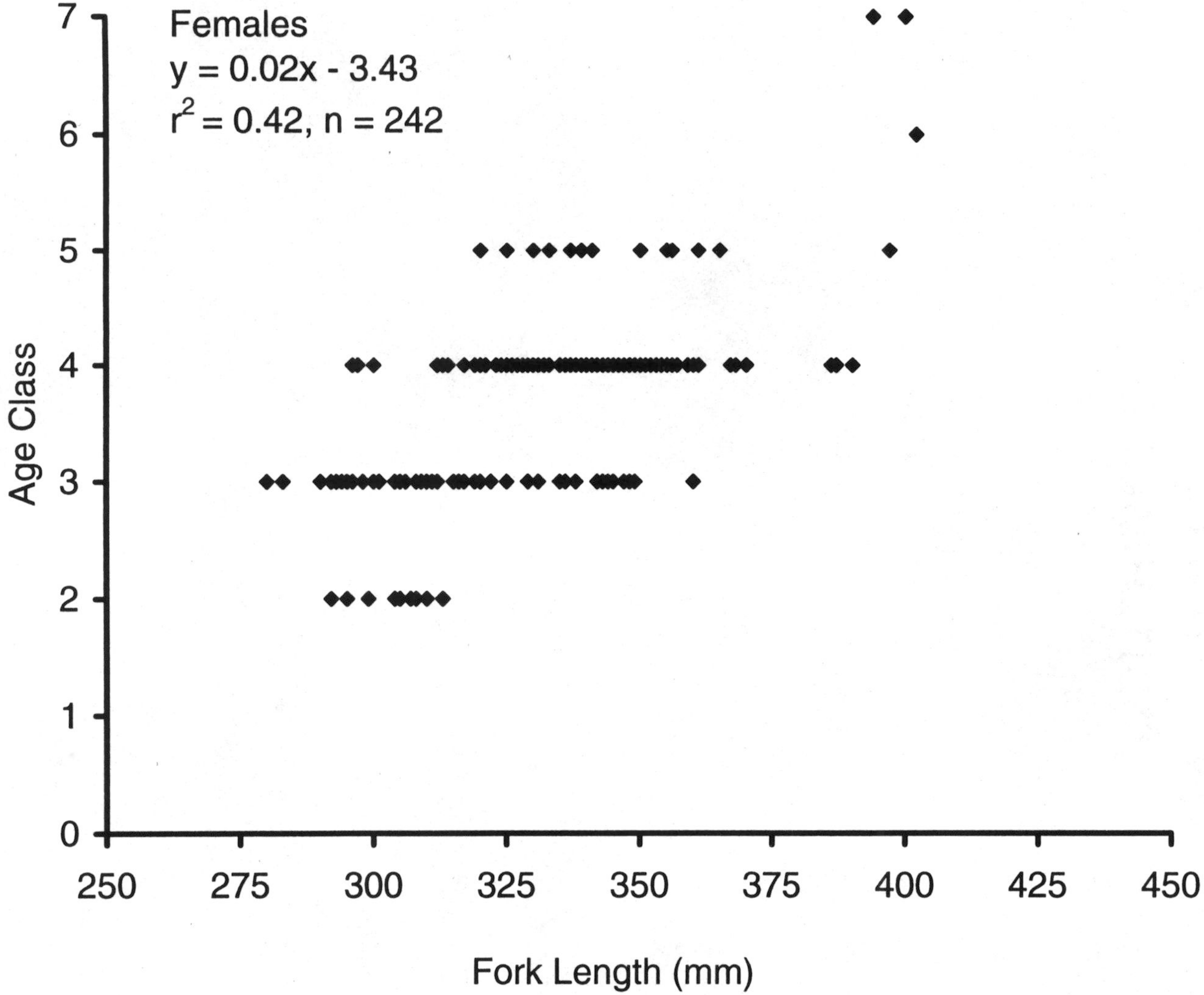


Males
y = 0.005x + 1.62
r2 = 0.41, n = 266
Age class
0
1
2
3
4
5
6
200
300
400
500
600
700
800
Body weight (g)

Table 5. Observed mean values of fork length (mm), body weight (g), somatic weight (g) and potential fecundity at age of female hickory shad collected from the Roanoke River near Weldon, North Carolina, the Roanoke River National Wildlife Refuge, and Albemarle Sound during spring 1996. SD = standard deviation.

		Fork length (mm)		Body weight (g)		Somatic weight (g)		Potential fecundity		
Age	n	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	n	Mean ± SD	Range
2	8	304 ± 7.0	292-313	391 ± 27.3	358-446	343 ± 15.8	325-379	1	85,803	
3	80	313 ± 18.4	280-360	440 ± 85.4	291-839	390 ± 71.1	280-612	14	137,523 ± 33,573	80,290-230,645
4	135	339 ± 15.3	296-390	591 ± 101.1	359-839	505 ± 83.2	318-705	19	223,576 ± 6,067	113,661-334,126
5	16	343 ± 18.8	320-397	639 ± 113.9	447-908	542 ± 84.6	417-710	3	294,798 ± 156,362	179,505-472,769
6	1	402		1,031		871		1	478,944	
7	2	397 ± 4.2	394-400	946 ± 192.0	810-1,082	779 ± 145.4	676-881	2	350,918 ± 92,205	285,719-416,116

Figure 16. Age class to fork length (mm) relationship for female hickory shad.



Females
y = 0.02x - 3.43
r2 = 0.42, n = 242
Age Class
Fork Length (mm)
0
1
2
3
4
5
6
7
250
275
300
325
350
375
400
425
450

Figure 17. Age class to body weight (g) relationship for female hickory shad.

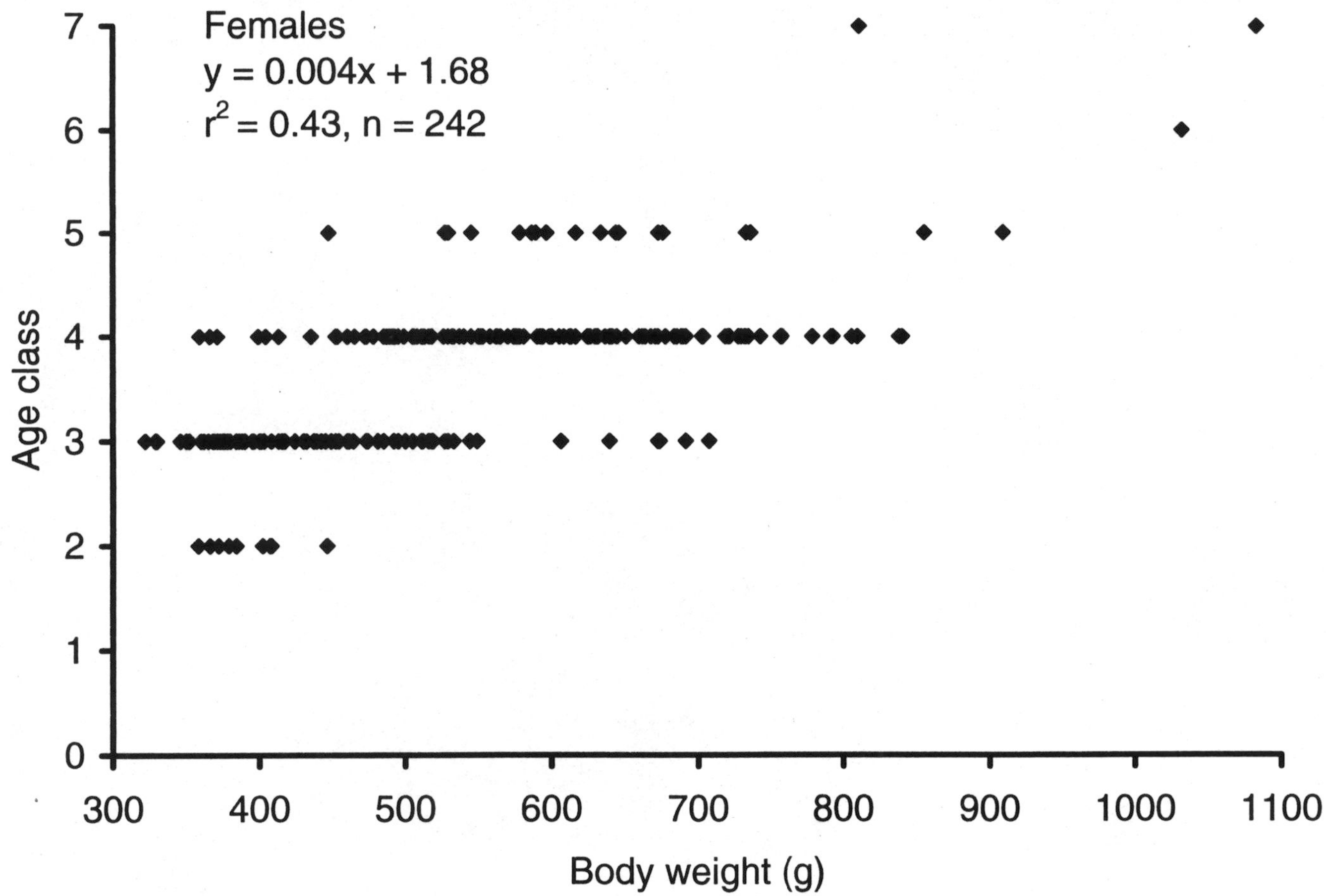

Females
y = 0.004x + 1.68
r2 = 0.43, n = 242
Age class
Body weight (g)
0
1
2
3
4
5
6
7
300
400
500
600
700
800
900
1000
1100

Table 6. Observed mean values of fork length (mm), body weight (g), and somatic weight (g) at age of hickory shad sexes combined collected from the Roanoke River near Weldon, North Carolina, the Roanoke River National Wildlife Refuge, and Albemarle Sound during spring 1996. SD = standard deviation. *= females only.

		Fork length (mm)		Body weight (g)		Somatic weight (g)	
Age	n	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
2	24	297 ± 10.0	278-314	352 ± 47.5	273-446	322 ± 33.7	256-388
3	257	296 ± 18.8	257-360	343 ± 88.1	210-707	329 ± 69.5	197-612
4	204	332 ± 17.1	283-390	543 ± 112.8	316-839	477 ± 85.2	297-705
5	20	341 ± 18.6	318-397	605 ± 128.9	403-908	522 ± 91.9	385-710
6	2	389 ± 18.4	376-402	841 ± 268.7	651-1,031	755 ± 164.4	638-871
7*	2	397 ± 4.2	394-400	946 ± 192.3	810-1,082	779 ± 145.4	676-882

Spawning History

Essentially all males and females were sexually mature by age 3, and all were mature by age 5 (Table 7). Some individuals of both sexes were mature by age 2. Virgin fish comprised nearly half of the male population compared to about one-fourth of the female population. An additional 45.5% of the males spawned only once before, and 7.7% had spawned previously two or more times. No males exhibited more than three spawning marks (Table 8). Only 24.9% of the females examined (233) were virgin fish (Table 9). A total of 45.5% of the females had spawned once before with few showing evidence of spawning more than twice. One age 7 female had four spawning marks.

Mortality Estimates

Total mortality (Z) for males was 1.43 (ages 3-5), 1.76 for females (ages 4-6), and 1.40 for both sexes combined. Natural mortality (M) for both sexes was 0.29, and fishing mortality (F) was approximately 1.11. Annual total mortality for males and females combined was 0.75; the annual rate of total mortality was calculated for the sexes combined because the natural and fishing mortality rates are also based on both sexes together. The annual natural mortality rate was 0.16 while the annual rate of fishing mortality was 0.59. Annual mortality rates for hickory shad for previous Albemarle Sound studies ranged from 0.40 to 0.65; however, annual mortality was calculated by the Robson and Chapman method which computes survival from a catch curve from a single season (Street et al. 1975; Johnson et al. 1978). Fishing mortality rates for hickory shad in the Altamaha River, Georgia were about 0.30 for females and 0.13 for males (Godwin 1968; Richkus and DiNardo 1984). By comparison, fishing mortality rates for American

Table 7. Age at maturity percent of male and female hickory shad in the Albemarle Sound/Roanoke River watershed, 1996. Numbers of fish mature by each age in parenthesis.

		Otolith age			
	n	2	3	4	5
Male	233	36.1 (84)	97.9 (228)	99.6 (232)	100.0 (233)
Female	213	38.5 (82)	93.9 (200)	98.6 (210)	100.0 (213)
Sexes combined	446	37.2 (166)	96.0 (428)	99.1 (442)	100.0 (446)

Table 8. Number of spawning marks for male hickory shad from the Albemarle Sound/Roanoke River watershed, 1996, by age class.

Otolith age	Spawning marks 0	1	2	3	4	Total
2	12					12
3	92	56				148
4	4	50	14			68
5	1	0	1	2		4
6	0	0	0	1		1
Total	109	106	15	3		233
Percent of total population	46.8	45.5	6.4	1.3		

Table 9. Number of spawning marks for female hickory shad from the Albemarle Sound/Roanoke River watershed, 1996, by age class.

Otolith age	Spawning marks 0	1	2	3	4	Total
2	7					7
3	38	24				62
4	6	69	48			123
5	2	4	9	3		18
6	0	0	0	1		1
7	0	0	1	0	1	2
Total	53	97	58	4	1	213
Percent of total population	24.9	45.5	27.2	1.9	0.5	

shad in the natal streams when the stocks were stable were estimate at less than 0.40; this rate assumes a constant non-natal stream fishing mortality rate of 0.15 (ASMFC 1985).

Scale and Otolith Back Calculations

A strong relationship was established between otolith radius and fork length (males: r^2= 0.95; females: r^2= 0.92; sexes combined: r^2= 0.93) (Figures 18-20) but not between scale radius and fork length (males: r^2= 0.15; females: r^2= 0.26) (Table 10). A second regression analysis was performed on just virgin fish to minimize any variation in scale radius caused by spawning mark erosion, but this relationship also was weak (males: r^2= 0.08; females: r^2= 0.10) (Figures 21-22). The regression equations for the otolith radius to fork length relationship were:

Males: FL = 8.3 (Otolith radius (16x)) -62.3,

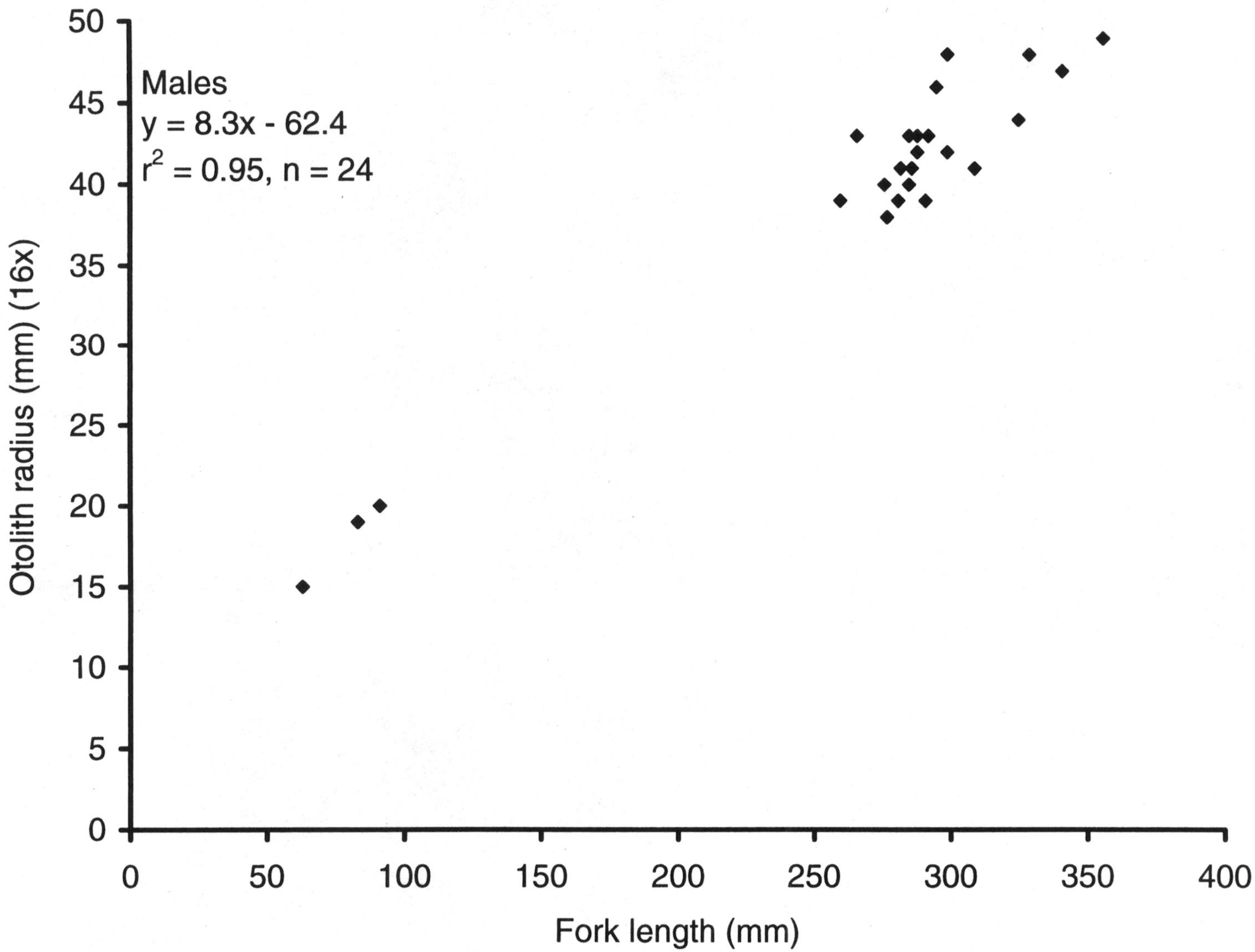
Females: FL = 7.3 (Otolith radius (16x)) -31.2, and

Sexes combined: FL = 7.3 (Otolith radius (16x)) -29.2.

The von Bertalanffy growth equation was $L_t = 460\ (1 - e^{-0.24(t + 1.63)})$.

Mean back calculated fork lengths using the proportional method for male hickory shad ages 2 through 4 were less than the observed mean fork lengths, while the mean back calculated fork length for age 5 males was greater than the observed mean fork length (Table 11). Mean back calculated fork lengths using the proportional method for female hickory shad ages 2, 3, and 7 were less than the observed mean fork lengths, while the mean back calculated fork lengths for age 4 and 5 females was greater than the observed mean fork length (Table11). The predicted fork lengths from the von Bertalanffy growth

Figure 18. Otolith radius (mm) (16x) to fork length (mm) relationship for male hickory shad.



Males
y = 8.3x - 62.4
r2 = 0.95, n = 24
Otolith radius (mm) (16x)
Fork length (mm)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350
400

Figure 19. Otolith radius (mm) (16x) to fork length (mm) relationship for female hickory shad.

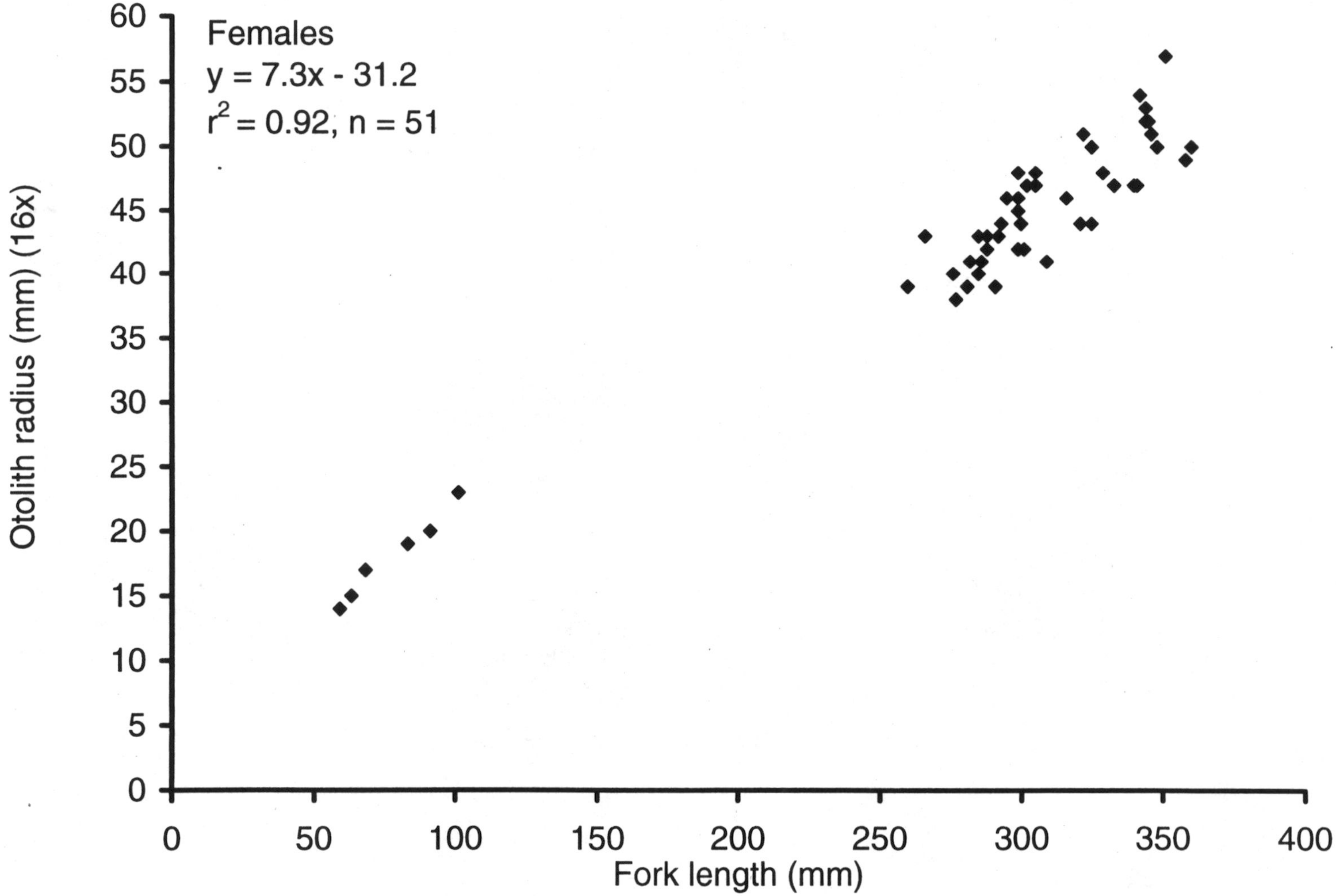

Females
y = 7.3x - 31.2
r2 = 0.92, n = 51
Otolith radius (mm) (16x)
Fork length (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
0
50
100
150
200
250
300
350
400

Figure 20. Otolith radius (mm) (16x) to fork length (mm) relationship for both sexes of hickory shad.

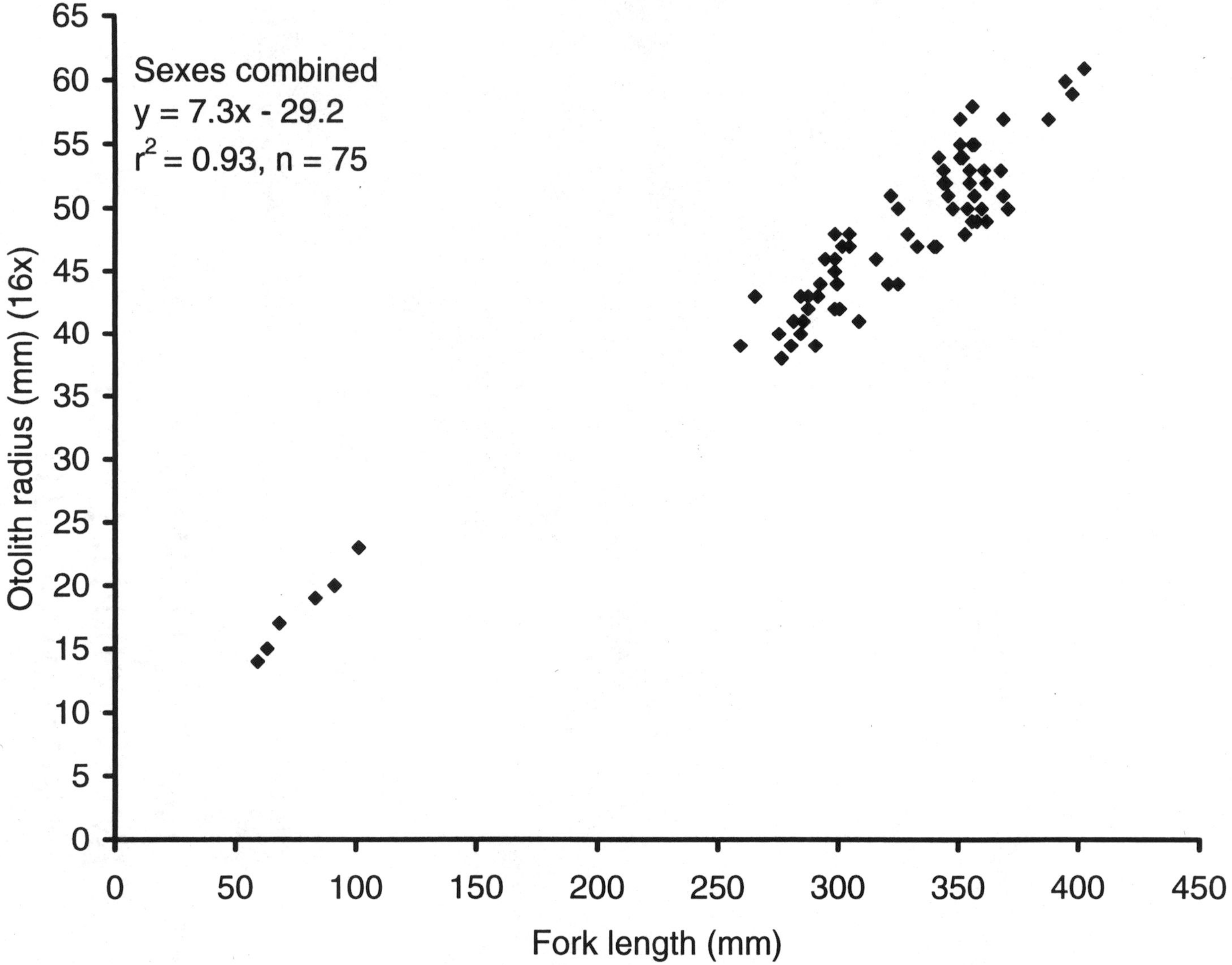
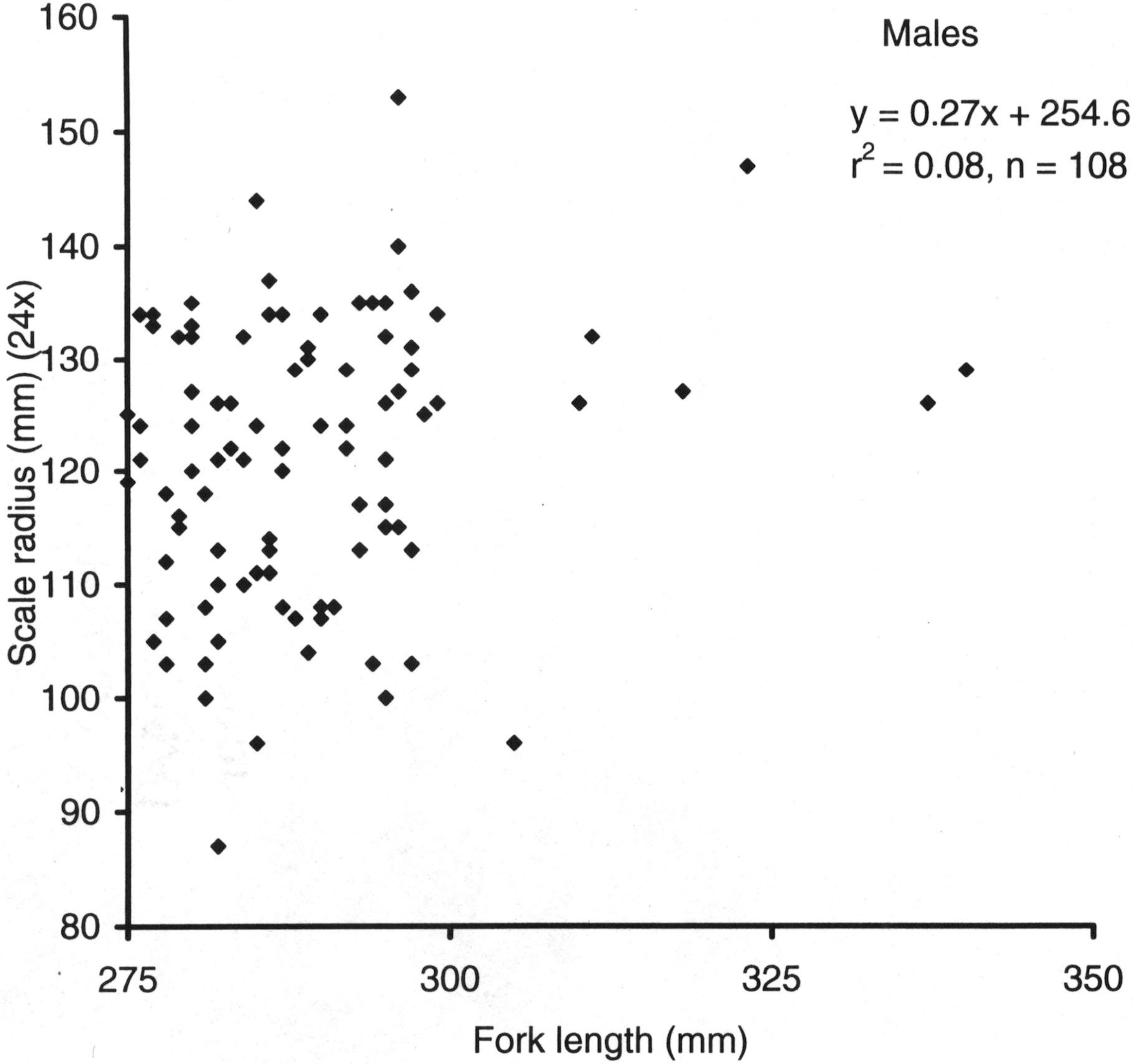

Sexes combined
y = 7.3x - 29.2
r2 = 0.93, n = 75
Otolith radius (mm) (16x)
Fork length (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0
50
100
150
200
250
300
350
400
450

Table 10. Results of linear regressions describing the relationships among fork length (FL, mm), scale radius, and otolith radius for male and female hickory shad.

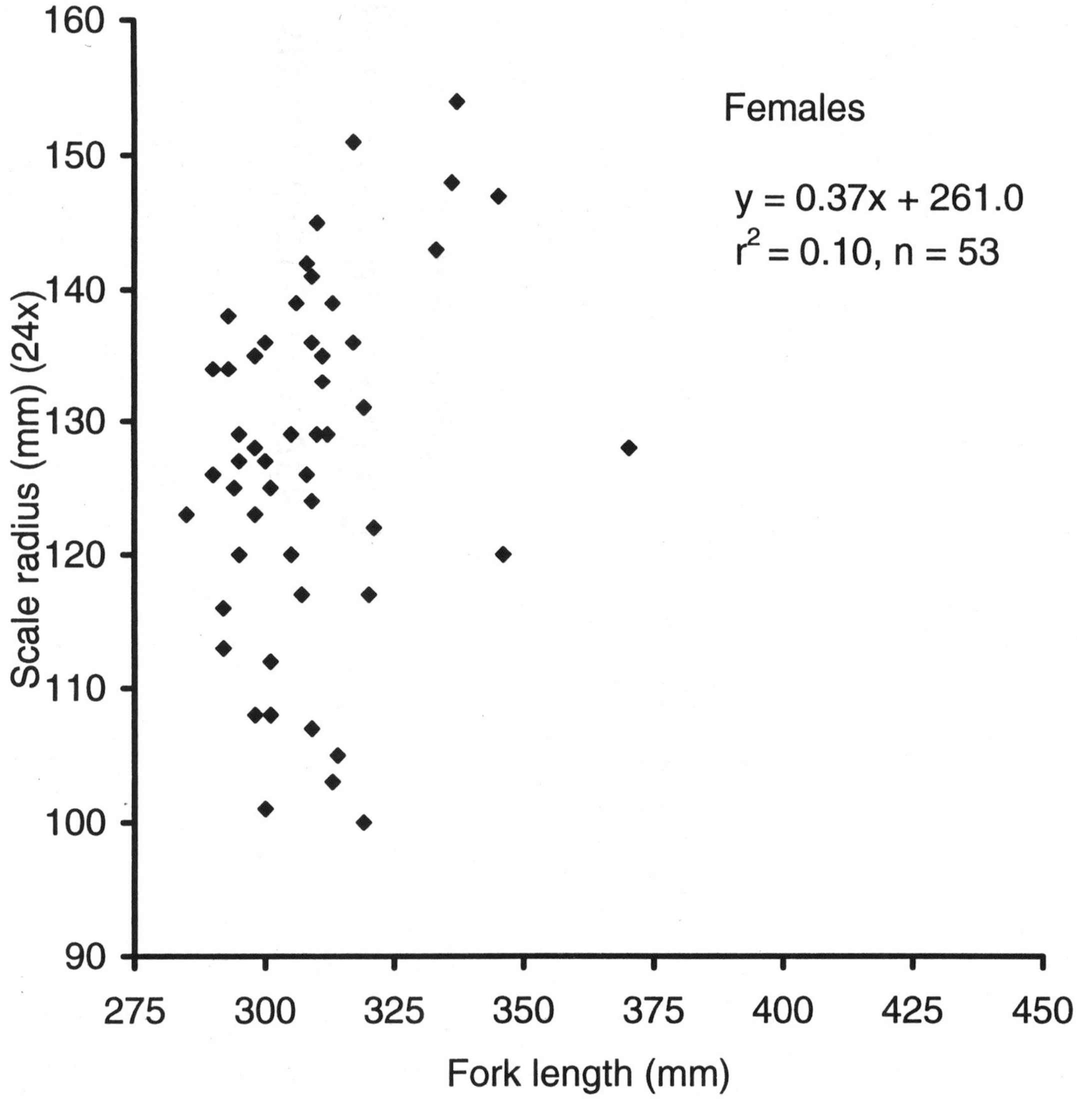
Independent variable	Dependent variable	n	Intercept	Slope	SE of slope	r^2
FL (all males)	Scale radius	128	199.4	19.0	4.0	0.15
FL (all females)	Scale radius	147	202.1	23.3	3.3	0.26
FL (virgin males)	Scale radius	108	254.6	0.3	0.1	0.08
FL (virgin females)	Scale radius	53	261.0	0.4	0.2	0.10
FL (males)	Otolith radius	24	-62.4	8.3	0.4	0.95
FL (females)	Otolith radius	51	-31.2	7.3	0.3	0.92
Fl (sexes combined)	Otolith radius	75	-29.2	7.3	0.2	0.93

Figure 21. Scale radius (mm) (24x) to fork length (mm) relationship for virgin male hickory shad.



Males
y = 0.27x + 254.6
r2 = 0.08, n = 108
Scale radius (mm) (24x)
160
150
140
130
120
110
100
90
80
275
300
325
350
Fork length (mm)

Figure 22. Scale radius (mm) (24x) to fork length (mm) relationship for virgin female hickory shad.



Females
y = 0.37x + 261.0
r2 = 0.10, n = 53
Scale radius (mm) (24x)
160
150
140
130
120
110
100
90
275
300
325
350
375
400
425
450
Fork length (mm)

Table 11. Comparison of mean fork lengths at ages from observed data and back calculated data for males and females, and from von Bertalanffy growth equation data for sexes combined.

	Males		Females		Sexes combined
Age	Mean FL (observed)	Mean FL (back calculated)	Mean FL (observed)	Mean FL (back calculated)	Mean FL (von Bertalanffy)
1		206		212	215
2	293	247	304	263	268
3	288	287	313	306	309
4	319	293	339	345	341
5	332	355	343	363	366
6	376		402	402	386
7			397	394	402

while the predicted fork lengths for age 5 to 7 fish were greater than the observed fork lengths; the predicted fork lengths for age 3 and 4 fish fell between the mean observed fork lengths for males and females (Table 11).

Back calculated fork lengths for ages 1-2 decreased in older fish (Table 12). Age 2 hickory shad had back calculated fork lengths of 226 mm at age 1 and 304 mm at age 2 while age 7 fish had back calculated fork lengths of 197 mm at age 1 and 243 mm at age 2. These differences in fork lengths at age provide some evidence for Lee's phenomenon, which states that larger fish in a year class often have a higher mortality rate than smaller individuals (Cailliet et al. 1986).

Table 12. Calculated fork length at age for adult hickory shad (sexes combined).

			Back calculated fork lengths at age						
Age	N	Mean FL at capture	1	2	3	4	5	6	7
2	3	304 ± 4.5	226	304					
3	22	299 ± 27.4	209	255	299				
4	37	341 ± 24.7	209	242	299	341			
5	5	363 ± 19.4	214	268	309	339	363		
6	1	402	231	277	310	356	376	402	
7	1	394	197	243	282	315	341	368	394

Reproductive Analysis

Seasonal pattern in the GSI was not related to age, but mean GSI for age 3 and 4 hickory shad from Albemarle Sound, RRNWR, and Weldon increased from February to March before decreasing in April (Table 13). Prespawn females caught in Albemarle Sound during February had the lowest mean GSI of any month (age 3 = 8.93; age 4 = 10.98). Water temperatures in the Sound during this month were approximately 6-7°C. Spawning temperatures on the Roanoke River at Weldon from 16 March to 17 April 1996 ranged from 8°C to 12°C. Mean GSI decreased from March to April as more postspawn females were captured from the three locations (Table 13). GSI increases as the oocytes mature prior to spawning but sharply decreases after the fish spawns and the ovarian tissue is resorbed.

Potential fecundity estimates for 47 prespawn females ranged from 80,290 eggs to 478,944 eggs; fecundity generally increased with fork length, body weight, and age (Table 5). Several post spawn hickory shad still had some eggs in the spent ovaries, suggesting that not all eggs are spawned during the season. Potential fecundity increased with fork length (Figure 23) and somatic weight (Figure 24). Somatic weight was used instead of total weight because larger, heavier ovaries will naturally have more eggs and would therefore influence the relationship. Potential fecundity generally increased with age (Figure 25) and GSI (Figure 26), however, some variation existed. These variations were likely the result of the overlapping ranges of fork lengths found at each age class and the variations in fecundity at a given GSI.

Table 13. Mean and range (in parenthesis) of GSI values for ages 3 and 4 female hickory shad from Albemarle Sound, RRNWR, and Weldon by month.

	Age 3			Age 4		
Month	Albemarle Sound n= 27	RRNWR n= 14	Weldon n= 36	Albemarle Sound n= 76	RRNWR n= 2	Weldon n= 57
February	8.93 ± 6.39 (4.41-13.41)			10.98 ± 3.39 (7.97-16.65)		
March	12.11 ± 2.73 (7.87-15.75)		13.45 ± 4.25 (5.36-18.91)	14.89 ± 2.67 (4.45-21.49)		16.49 ± 3.62 (8.47-20.61)
April	8.96 ± 3.72 (2.99-13.56)	11.40 ± 4.12 (3.69-19.58)	13.39 ± 4.36 (5.53-21.77)	11.13 ± 4.10 (4.4.32-15.27)	7.61 ± 3.93 (4.82-10.39)	14.11 ± 4.38 (5.06-24.33)

Figure 23. Potential fecundity to fork length (mm) relationship for female hickory shad.

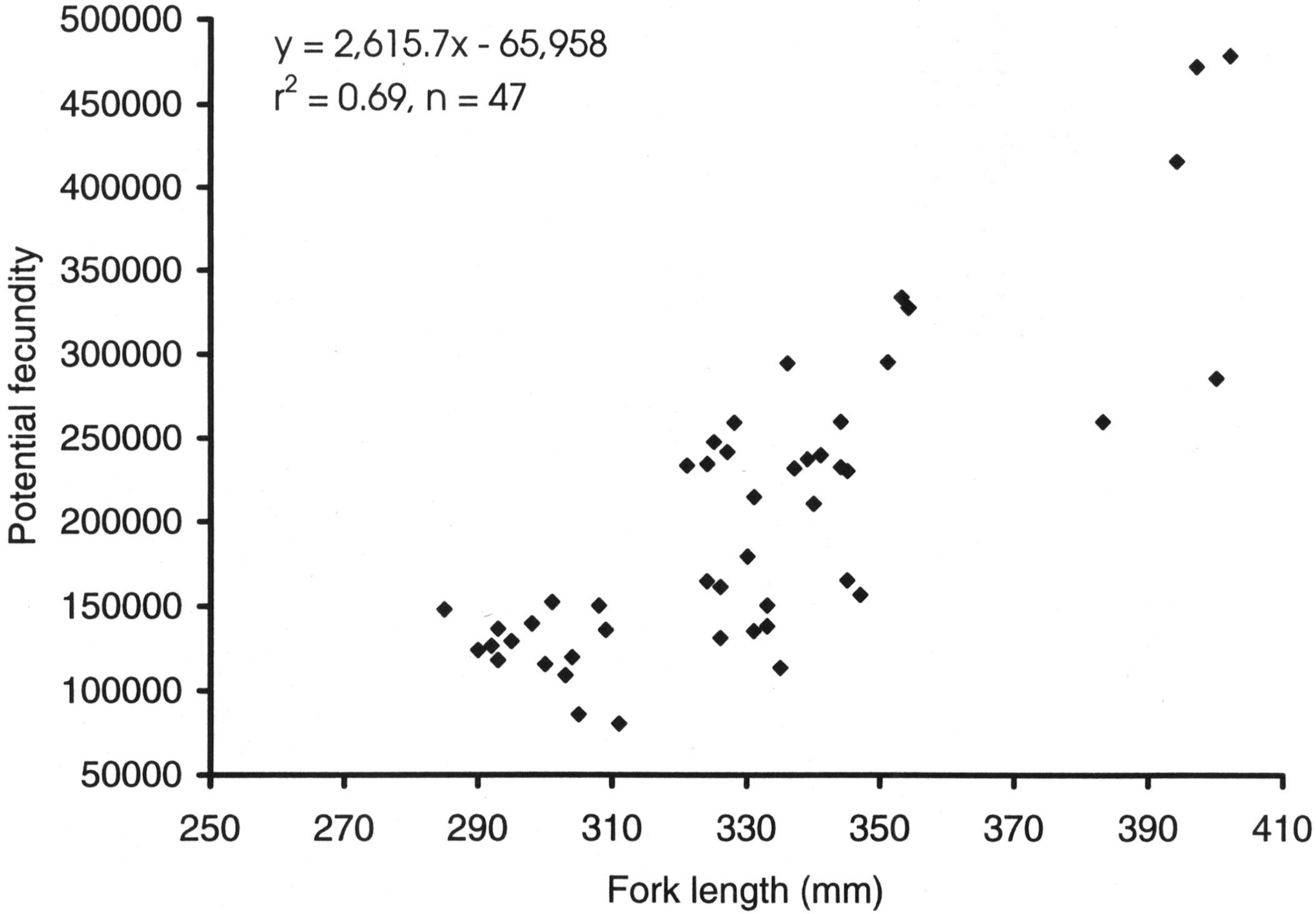

y = 2,615.7x - 65,958
r2 = 0.69, n = 47
Potential fecundity
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
250
270
290
310
330
350
370
390
410
Fork length (mm)

Figure 24. Potential fecundity to somatic weight (g) relationship for female hickory shad.

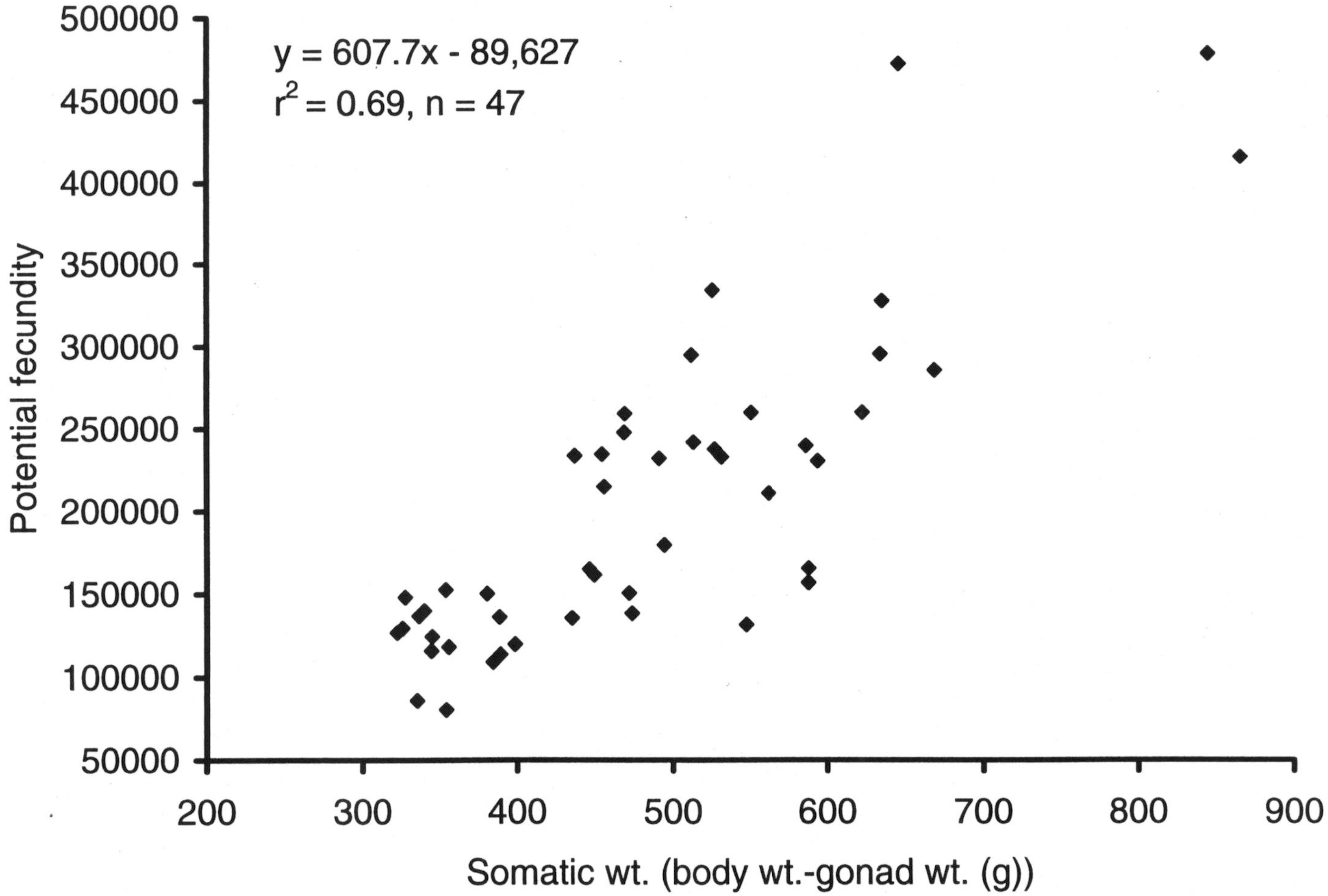
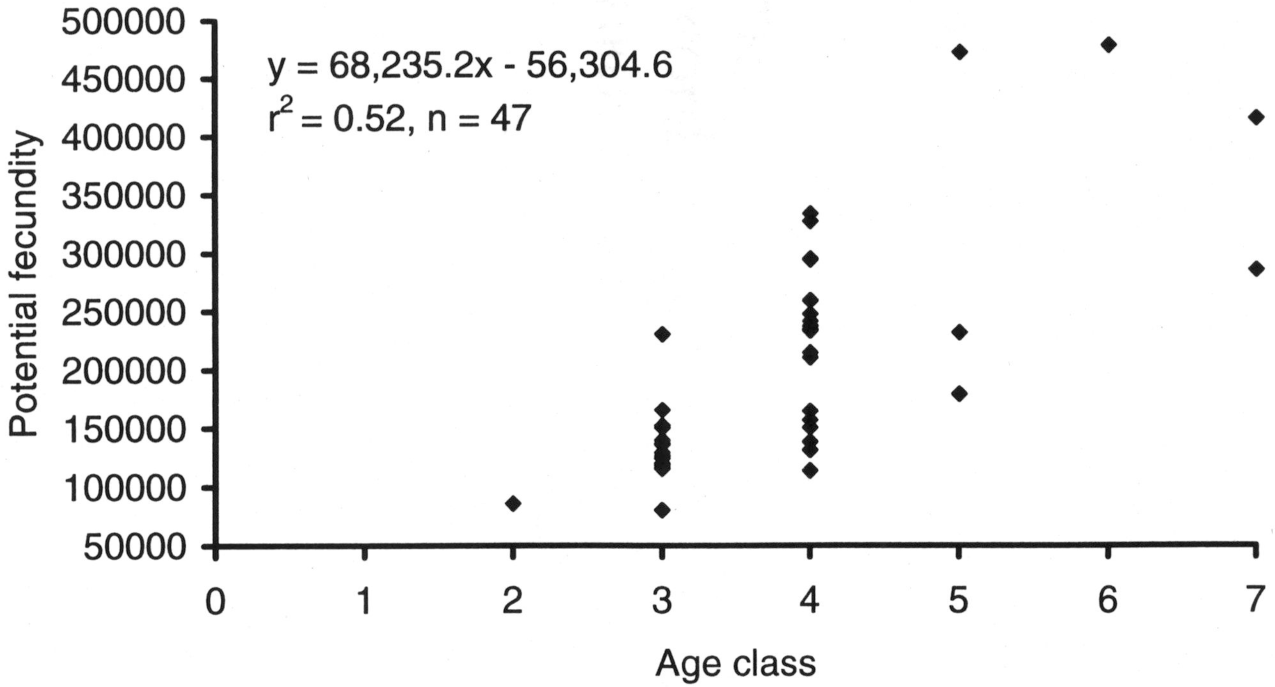
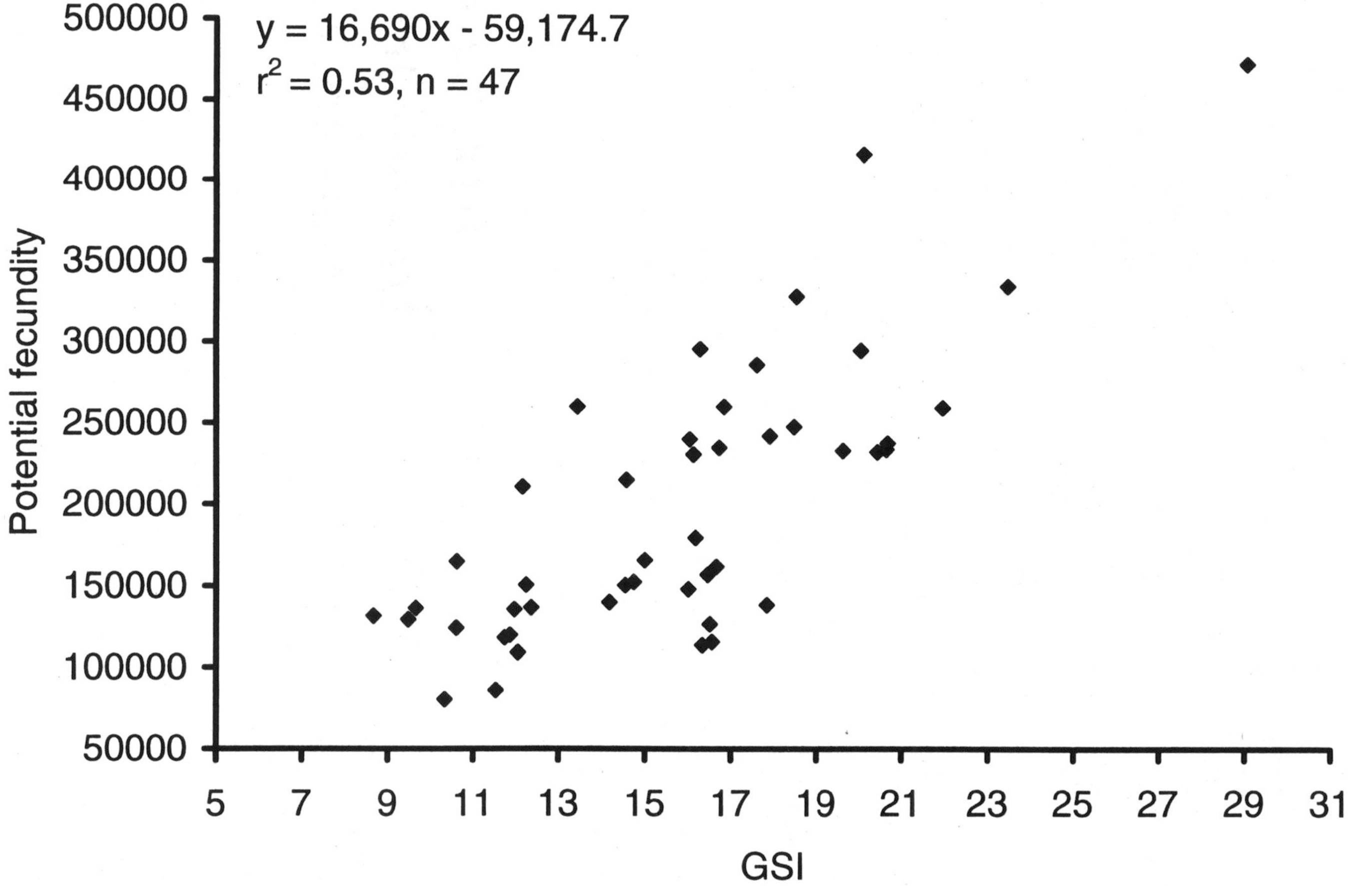

y = 607.7x - 89,627
r2 = 0.69, n = 47
Potential fecundity
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
200
300
400
500
600
700
800
900
Somatic wt. (body wt.-gonad wt. (g))

Figure 25. Potential fecundity to age class relationship for female hickory shad.



y = 68,235.2x - 56,304.6
r2 = 0.52, n = 47
Potential fecundity
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1
2
3
4
5
6
7
Age class

Figure 26. Potential fecundity to gonadosomatic index (GSI) relationship for female hickory shad.



y = 16,690x - 59,174.7
r2 = 0.53, n = 47
Potential fecundity
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
5 7 9 11 13 15 17 19 21 23 25 27 29 31
GSI

Fecundity estimates derived from the regression equations for fecundity as a function of age class, fork length, body weight, and somatic weight at each age were compared to the mean gravimetric fecundity estimates for each age. Age was the closest predictor of fecundity for age 2 and age 5 fish, body weight was the closest predictor of fecundity for age 3 fish, and fork length was the closest predictor of fecundity for age 4 fish (Table 14). Fork length, body weight, and somatic weight equations overestimated fecundity for age 6 and 7 females within 10% of the gravimetric estimate, while age overestimated fecundity for age 6 and 7 females by 17%.

The mean number of eggs per gram of ovarian weight ranged from over 1,500 eggs/g to under 4,000 eggs/g. The anterior portion of both ovaries tended to have a higher number of eggs/g than the posterior region; this relationship was significant for the left ovary ($n= 47$; $F= 4.68$; $P = 0.011$) but not the right ovary ($n= 47$; $F= 1.21$; $P = 0.303$).

The left ovary was significantly greater in weight and mean fecundity compared to the right ovary. Mean left ovary weight was 51.53 g, while the mean right ovary weight was 44.03 g. A paired t-test found these means to be significantly different ($n= 47$; $t= 4.48$; $P < 0.0001$). Mean fecundity of the left ovary was 111,037 eggs, while the right ovary contained an average of 93,630 eggs. These means also were significantly different ($n= 47$; $t= 4.71$; $P < 0.0001$).

Table 14. Potential fecundity of female hickory shad calculated gravimetrically and estimated from regressions developed for age class, fork length (FL, mm), body weight (g), and somatic weight (g).

Age	n	Gravimetric fecundity	Fecundity estimated by age	Fecundity estimated by FL	Fecundity estimated by body wt.	Fecundity estimated by somatic wt.
2	1	85,803	80,165	135,215	111,663	118,814
3	14	137,523	148,400	158,756	135,791	147,376
4	19	223,576	216,635	226,764	210,143	217,262
5	3	294,798	284,870	237,227	314,635	239,746
6	1	478,944	353,105	391,533	426,799	439,680
7	2	350,918	421,340	378,475	384,945	383,771

Mesentery Fat and Gut Content Analysis

Reduced mesentery fat of Roanoke River fish indicated use of stored lipid reserves as fish migrated from Albemarle Sound upstream. Mesentery fat weight was significantly greater in both sexes from Albemarle Sound than from both sexes from the Roanoke River (males: t= -3.05, P= 0.005; females: t= -4.54, P< 0.0001). Mesentery fat for Roanoke River males was significantly less than Roanoke River females (t= -2.14, P= 0.03). There was no significant difference in mesentery fat for males and females from Albemarle Sound (t= -1.57, P= 0.12), suggesting that both sexes fed extensively in ocean waters prior to entering Albemarle Sound for the spawning migration. The relationship between somatic weight and mesentery fat for both sexes was linear but weak (Table 15).

Of the 212 stomachs examined for gut analysis, 26% (n = 62) of the fish from Albemarle Sound and 28% (n = 110) of the fish from the Roanoke River contained identifiable items. Five of the six items (83%) present in the stomachs were found in both Albemarle Sound and Roanoke River fish. These items were fish (family Clupeidae), parasites, seeds, wood, and plastic. Insects were found only in the stomachs of Roanoke River fish.

Nursery Grounds

A total of 47 finfish species, including all four *Alosa* species, was collected from the 16 seine sites (130 samples) and 8 trawl sites (11 samples). Thirteen species were found in both seine and trawl samples; no alosids were found in trawls. Every species collected in trawls also was found in seines. Many of the species caught were in the juvenile stage. In the seine samples, the top 10 species in order of abundance were

Table 15. Results of linear regressions describing the relationship between somatic weight (g) and mesentery fat weight (g) for male and female hickory shad from Albemarle Sound (A.S.) and the Roanoke River (R.R.).

Independent variable	Dependent variable	n	Intercept	Slope	SE of slope	r^2
Somatic weight (R.R. males)	Mesentery fat weight	34	270.3	111.0	48.9	0.14
Somatic weight (R.R. females)	Mesentery fat weight	64	371.2	90.0	31.2	0.12
Somatic weight (A.S. males)	Mesentery fat weight	28	362.5	32.6	18.0	0.11
Somatic weight (A.S. females)	Mesentery fat weight	46	451.6	43.2	27.4	0.13

Atlantic menhaden (*Brevoortia tyrannus*) (11,758), blueback herring (6,140), white perch (5,443), spottail shiner (*Notropis hudsonius*) (1,157), striped bass (1,033), eastern silvery minnow (*Hybognathus regius*) (662), yellow perch (*Perca flavescens*) (588), inland silverside (*Menidia beryllina*) (523), bay anchovy (*Anchoa mitchilli*) (384), and alewife (232) (Table 16). The frequency of occurence in seine samples, by species, was white perch (64% of all samples), striped bass (64%), inland silverside (48%), spottail shiner (34%), yellow perch (33%), alewife (32%), spot (*Leistomous xanthurus*) (29%), blueback herring (24%), Atlantic menhaden (18%), sunfish species (*Lepomis spp.*) (18%), and Atlantic needlefish (*Strongylura marina*) (18%) (Table 16).

Blueback herring was the most abundant juvenile alosid found in Albemarle Sound seine samples (6,140), followed by alewife (232), American shad (38), and hickory shad (10) (Table 17). Juvenile alosids were found in all five regions; alewife was the only one found in every region (Table 17). Blueback herring abundance was the highest in the southwest region while alewife abundance was highest in the south-central region. Most of the 38 juvenile American shad and 10 juvenile hickory shad were collected in the north-central region. CWC, CPN, EBP, SAP, and ALR were the only sites where hickory shad were collected. No conclusions should be made about the distribution of either species in the Albemarle Sound area since such small numbers were collected.

The NCDMF juvenile striped bass survey collected a total of 35 hickory shad for a catch per unit effort (CPUE) of 0.6 (Table18), while the NCDMF juvenile alosid survey collected only 22 hickory shad for a CPUE of 0.32 (Steve Trowell, NCDMF, personal communication). Hickory shad were collected at three NCDMF sites during the month of

Table 16. Species compositions from the juvenile hickory shad survey seine and trawl samples in the Albemarle Sound and selected tributaries, 1996.

		Seine samples (n = 130)			Trawl samples (n = 11)		
Scientific name	Common name	Percent presence in samples	Total catch	Percent of total catch	Percent presence in samples	Total catch	Percent of total catch
Brevoortia tyrannus	Atlantic menhaden	18	11,758	40.2	0	0	0.0
Alosa aestivalis	Blueback herring	24	6,140	21.0	0	0	0.0
Morone americana	White perch	64	5,443	18.6	73	113	10.9
Notropis hudsonius	Spottail shiner	34	1,157	4.0	9	11	1.1
Morone saxatilis	Striped bass	64	1,033	3.5	100	378	36.5
Hybognathus regius	Eastern silvery minnow	15	662	2.3	0	0	0.0
Perca flavescens	Yellow perch	33	558	2.0	18	11	1.1
Menidia beryllina	Inland silverside	48	523	1.8	9	1	0.1
Anchoa mitchilli	Bay anchovy	17	384	1.1	27	163	15.7
Alosa pseudoharengus	Alewife	32	232	0.8	0	0	0.0
Leiostomus xanthurus	Spot	29	222	0.8	73	279	26.9
Strongylura marina	Atlantic needlefish	18	169	0.6	0	0	0.0
Bairdiella chrysoura	Silver perch	8	143	0.5	0	0	0.0
Dorosoma cepedianum	Gizzard shad	14	130	0.4	0	0	0.0
Lepomis spp.	Sunfish species	18	100	0.3	9	2	0.2
Micropogonius undulatus	Atlantic croaker	17	98	0.3	36	58	5.6
Menidia menidia	Atlantic silverside	9	63	0.2	0	0	0.0
Fundulus spp.	Killifish species	14	60	0.2	0	0	0.0
Notomegonus crysoleucas	Golden shiner	6	56	0.2	0	0	0.0
Ameiurus catus	White catfish	8	49	0.2	0	0	0.0
Micropterus salmoides	Largemouth bass	12	40	0.1	0	0	0.0
Alosa sapidissima	American shad	13	38	0.1	0	0	0.0
Anchoa hepsetus	Striped anchovy	5	23	0.1	0	0	0.0
Ictalurus punctatus	Channel catfish	3	23	0.1	9	4	0.4
Ethostoma olmstedi	Tesselated darter	5	21	0.1	0	0	0.0
Mugil cephalus	Striped mullet	7	14	< 0.1	0	0	0.0
Lagodon rhomboides	Pinfish	4	12	< 0.1	0	0	0.0
Trachinotus carolinus	Florida pompano	2	12	< 0.1	0	0	0.0
Alosa mediocris	Hickory shad	5	10	< 0.1	0	0	0.0

Table 16, continued.

Scientific name	Common name	Seine samples (n = 130)			Trawl samples (n = 11)		
		Percent presence in samples	Total catch	Percent of total catch	Percent presence in samples	Total catch	Percent of total catch
Anguilla rostrata	American eel	5	10	< 0.1	0	0	0.0
Ameiurus natalis	Yellow bullhead	5	8	< 0.1	0	0	0.0
Cynoscion nebulosus	Spotted seatrout	2	6	< 0.1	0	0	0.0
Trinectes maculatus	Hogchoker	3	6	< 0.1	27	11	1.1
Moxostoma erythrurum	Golden redhorse	2	5	< 0.1	0	0	0.0
Dorosoma pretense	Threadfin shad	3	4	< 0.1	0	0	0.0
Paralichthys dentatus	Summer flounder	3	4	< 0.1	18	4	0.4
Syngathus spp.	Pipefish species	3	4	< 0.1	0	0	0.0
Ameiurus spp.	Bullhead species	1	2	< 0.1	0	0	0.0
Caranx hippos	Crevalle Jack	1	2	< 0.1	0	0	0.0
Pomatomus saltatrix	Bluefish	1	1	< 0.1	0	0	0.0
Pomoxis nigromaculatus	Black crappie	2	2	< 0.1	0	0	0.0
Archosargus probatocephalus	Sheepshead	1	1	< 0.1	0	0	0.0
Cyprinus carpio	Common carp	1	1	< 0.1	9	1	0.1
Elops saurus	Ladyfish	1	1	< 0.1	0	0	0.0
Opsanus tau	Oyster toadfish	1	1	< 0.1	0	0	0.0
Orthopristis chrysoptera	Pigfish	1	1	< 0.1	0	0	0.0
Raja spp.	Skate species	1	1	< 0.1	0	0	0.0

Table 17. Catch per unit effort (CPUE) of the four juvenile *Alosa* species by region in beach seines in Albemarle Sound and selected tributaries. Number of samples in parenthesis.

	CPUE by region				
Species	Northwest (n= 39)	North-central (n= 27)	Southwest (n= 15)	South-central (n= 20)	Southeast (n= 26)
Hickory shad (n= 10)	0.1	0.2	0	0	0.1
American shad (n= 38)	0.2	1.0	0.1	0.1	0
Alewife (n= 232)	1.1	3.1	0.7	4.0	0.5
Blueback herring (n= 6,140)	1.8	19.2	366.9	2.4	0

Table 18. Species abundance for each sample week of the NCDMF juvenile striped bass survey (Unpublished data, NCDMF, Elizabeth City, NC).

	Species					
Date	Striped bass	White perch	Blueback herring	Alewife	Hickory shad	American shad
960604	332	133	45	0	5	29
960613	277	898	100	147	10	27
960618	440	904	0	42	3	0
960625	266	880	61	19	10	0
960703	227	2,620	2	92	3	0
960708	643	8,350	186	54	4	0
Total	2,135	13,785	394	354	35	56
CPUE	39.5	255.3	7.3	6.6	0.6	1.0

August in the juvenile alosid survey (Table 19). The small number of hickory shad collected precluded any detailed analysis of distribution patterns in Albemarle Sound.

Twenty different species were present at least once in the seven seine samples that contained juvenile hickory shad, but alewife was the only species present in all seven samples (Table 20). American shad and blueback herring were present with hickory shad in one sample each, while white perch and striped bass, the species most commonly found in seine samples, were present in five of the seven seine samples.

Water temperatures among juvenile hickory shad sites were similar with a range from 22.6 °C to 28.0 °C, but other water quality parameters showed significant differences among sites (Table 21). Mean conductivity was highest in sites located in the eastern sound with CSR having the highest mean conductivity (8.3 mS). BAT, which is located in the western sound near the mouths of the Roanoke and Cashie Rivers, and WOM, which is on the south shore of western Albemarle Sound, had the lowest mean conductivity (0.1 mS). Mean dissolved oxygen values at most of the sites ranged from 6.6 mg/L to 7.6 mg/L. SCR, which is located on the east shore of the Scuppernong River, had the lowest mean DO (4.7 mg/L), and CPN, located near the mouth of the Chowan River on the west shore, had the highest mean DO (8.0 mg/L) among the sites. Mean secchi visibility values were lowest in sites located in the eastern sound with CSR (Croatan Sound at Roanoke Island) having the lowest mean secchi visibility (33.6 cm).

Table 19. Juvenile hickory shad collected during the NCDMF juvenile striped bass and juvenile alosid seine surveys (Unpublished data, NCDMF, Elizabeth City, NC).

Date	Survey	Area	N	Mean TL (mm)	Min TL (mm)	Max TL (mm)
960604	Striped bass	Edenton Bay	2	35.0 ± 2.8	33.0	37.0
960604	Striped bass	Avoca Farm	3	29.3 ± 5.9	25.0	36.0
960613	Striped bass	US 17 Bridge	1	35.0		
960613	Striped bass	W. of Mackeys	3	31.7 ± 3.2	28.0	34.0
960613	Striped bass	Old Bayliner Plant	4	37.3 ± 13.5	28.0	53.0
960613	Striped bass	Edenton Bay	2	34.5 ± 2.1	33.0	36.0
960618	Striped bass	Cape Colony	3	55.3 ± 4.5	51.0	60.0
960625	Striped bass	Old Bayliner Plant	2	61.0 ± 2.8	59.0	63.0
960625	Striped bass	Batchelor Bay	8	56.9 ± 5.2	47.0	64.0
960703	Striped bass	US 17 Bridge	3	53.7 ± 6.7	48.0	61.0
970708	Striped bass	Cape Colony	4	54.0 ± 0.8	53.0	55.0
970813	Alosid	Sandy Point	12	70.5	64.0	80.0
970813	Alosid	Arrowhead Beach	8	58.6	54.0	68.0
970815	Alosid	Colonial Beach	2	72.0	54.0	73.0

Table 20. Fish species associated with juvenile hickory shad.

Scientific name	Common name	Total catch in samples with hickory shad	Number present in in samples with hickory shad
Alosa pseudoharengus	Alewife	28	7
Menidia beryllina	Inland silverside	30	5
Morone saxatilis	Striped bass	64	5
Morone americana	White perch	71	5
Strongylura marina	Atlantic needlefish	5	3
Brevoortia tyrannus	Atlantic menhaden	1,158	3
Lepomis spp.	Sunfish species	2	2
Notomigonus crysoleucas	Golden shiner	15	2
Perca flavescens	Yellow perch	26	2
Leiostomous xanthurus	Spot	28	2
Notropis hudsonius	Spottail shiner	39	2
Ethostoma olmstedi	Tessellated darter	1	1
Fundulus spp.	Killifish species	1	1
Mugil cephalus	Striped mullet	1	1
Pomoxis nigromaculatus	Black crappie	1	1
Alosa sapidissima	American shad	2	1
Hybognathus regius	Eastern silvery minnow	7	1
Anchoa mitchilli	Bay anchovy	11	1
Alosa aestivalis	Blueback herring	38	1

Table 21. Water quality parameters for the 16 seine sites in Albemarle Sound and selected tributaries for the period May to October 1996. SD= standard deviation.

		Water temperature (°C)		Dissolved oxygen (mg/L)		Secchi visibility (cm)		Conductivity (mS)	
Site	n	mean ± SD	range	mean ± SD	range	mean ± SD	range	mean ± SD	range
Northwest									
BAT	10	26.4 ± 4.6	18.0-31.0	7.1 ± 1.7	4.0-9.8	70.0 ± 15.8	45.0-90.0	0.1	0.1-0.1
CPN	9	25.9 ± 3.9	18.0-29.0	8.0 ± 1.3	5.6-10.0	60.6 ± 21.3	30.0-85.0	0.3± 0.4	0.1-1.2
CWC	10	26.2 ± 3.6	21.0-30.0	7.6 ± 1.0	5.8-8.7	68.0 ± 21.1	30.0-90.0	0.3 ± 0.5	0.0-1.4
MCR	10	26.0 ± 4.2	18.0-31.0	7.1 ± 1.2	4.7-8.6	77.0 ± 21.8	40.0-100.0	0.4 ± 0.6	0.1-1.8
North-central									
EBP	5	24.1 ± 5.1	16.0-28.0	7.5 ± 0.7	6.9-8.6	63.8 ± 25.0	30.0-90.0	1.0 ± 1.0	0.2-2.8
ESP	6	22.6 ± 5.5	15.0-27.5	7.2 ± 1.3	5.9-9.6	60.8 ± 25.0	20.0-90.0	1.0 ± 0.9	0.2-2.6
SAP	11	25.4 ± 4.3	18.0-30.5	7.6 ± 1.3	5.4-9.8	75.0 ± 20.4	40.0-100.0	0.5 ± 0.7	0.1-2.6
32N	6	24.8 ± 3.4	19.0-28.0	7.3 ± 0.6	6.7-8.4	83.3 ± 16.3	60.0-100.0	0.8 ± 1.1	0.1-2.8
Southwest									
NPL	10	22.7 ± 5.8	12.0-30.0	6.6 ± 2.1	3.2-9.3	58.5 ± 27.5	10.0-90.0	0.3 ± 0.5	0.1-1.8
WOM	7	25.7 ± 4.3	15.0-31.0	6.8 ± 2.1	3.1-8.5	67.9 ± 18.2	40.0-95.0	0.1 ± 0.1	0.1-0.3

Table 21, continued

Site	n	Water temperature (°C)		Dissolved oxygen (mg/L)		Secchi visibility (cm)		Conductivity (mS)	
		mean ± SD	range	mean ± SD	range	mean ± SD	range	mean ± SD	range
South-central									
SCR	8	28.0± 2.6	24.0-31.0	4.7± 2.3	1.5-8.0	59.4± 26.1	15.0-90.0	1.2± 0.6	0.2-1.9
SOV	12	25.0 ± 4.9	15.0-31.0	7.5 ± 1.2	5.2-8.6	59.2 ± 25.1	15.0-90.0	0.3 ± 0.4	0.1-1.6
Southeast									
ALR	7	25.0 ± 3.9	17.0-25.0	7.0 ± 1.0	5.8-8.8	46.4 ± 19.7	30.0-85.0	4.3 ± 0.3	3.9-4.9
CSM	5	26.3 ± 2.9	23.5-29.5	6.6 ± 0.8	5.7-7.8	34.0 ± 12.9	15.0-50.0	6.7 ± 2.3	4.3-10.4
CSR	7	24.0 ± 4.1	18.0-29.5	6.9 ± 1.5	4.0-8.2	33.6 ± 13.1	20.0-50.0	8.3 ± 2.0	5.0-10.9
DIS	7	25.0 ± 3.6	18.0-29.0	7.4 ± 0.9	6.4-8.6	47.1 ± 10.7	35.0-60.0	4.5 ± 0.3	4.2-5.2

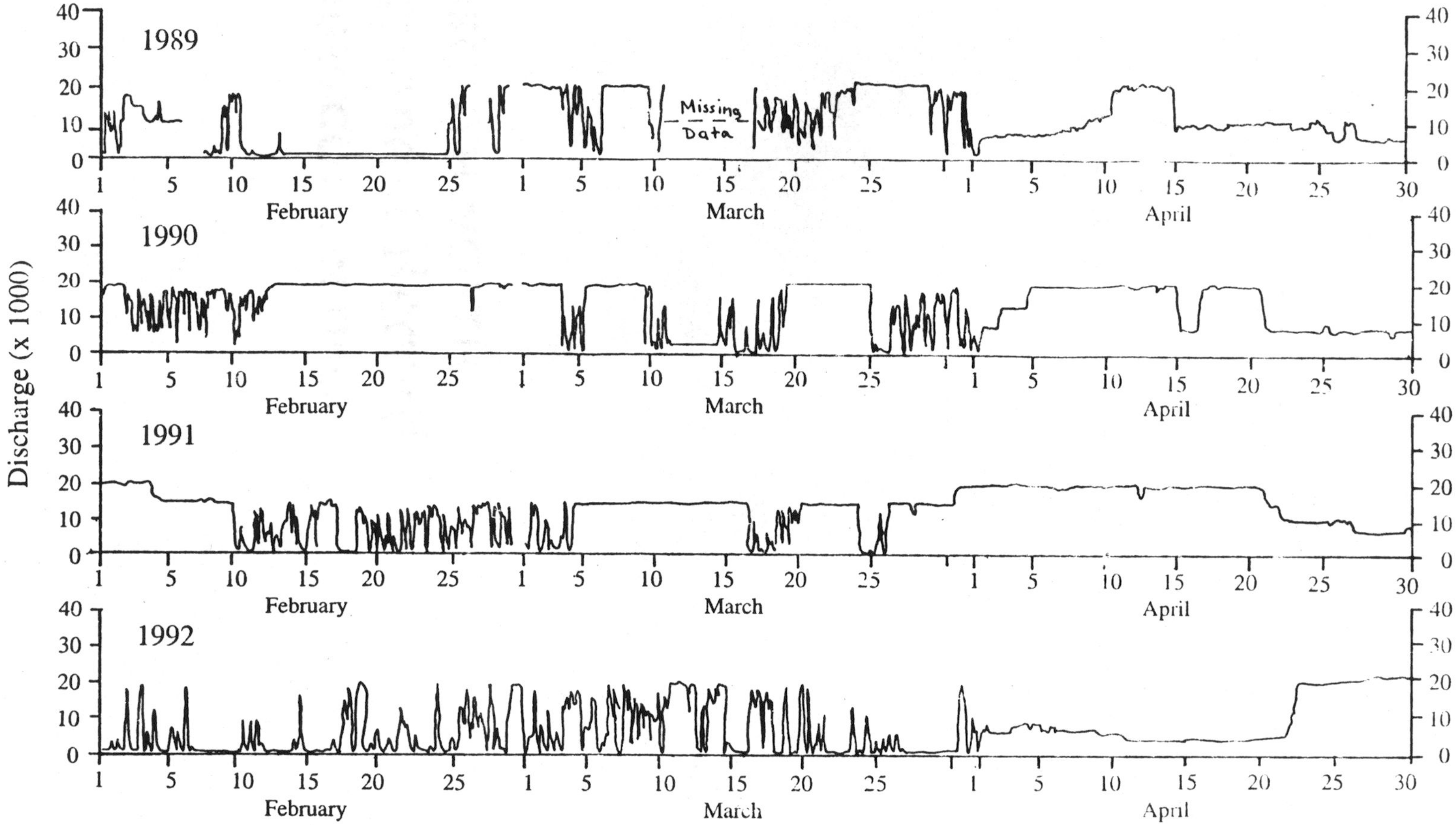
River Flow and Year Class Abundance

It is not clear why the abundance of hickory shad has increased since the 1980s in the Albemarle Sound/Roanoke River watershed, so patterns of river discharge (flow) downstream of Roanoke Rapids Dam during the spawning migration (February through April) were visually examined for possible correlations of year class abundance with river flow from 1989 to 1996 (Figure 27-28).

Hickory shad in 1996 first appeared in the Roanoke River at Weldon in February and were abundant from mid-March through mid-April. The entire month of February had steady flows > 35,000 cubic feet per second (cfs), which was associated with snow melt from winter storms in the upper watershed (Figure 28). The first half of March had significant fluctuations in flow, but the latter part of March experienced steadier flows between 25,000 and 35,000 cfs. A sudden drop in flow occurred at the end of March before returning to steady flows between 20,000 and 30,000 cfs in April.

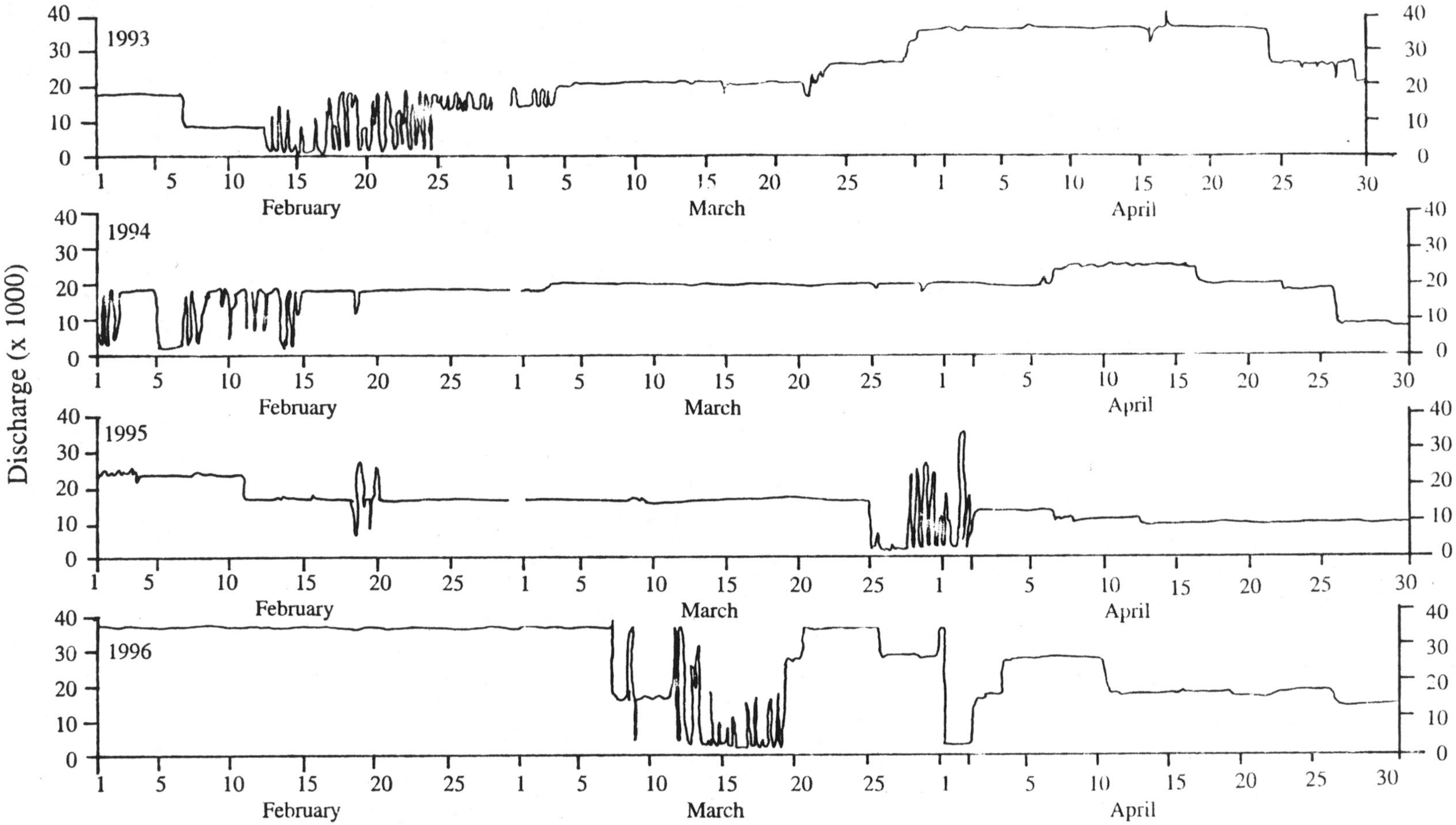
The age 3 hickory shad were born in 1993 during a relatively steady river flow > 20,000 cfs during March and a flow > 30,000 cfs during April as a result of a winter storm in mid-March (Figure 28). The age 4 hickory shad were born in 1992 during significant fluctuations in river flow from 2,000 to 20,000 cfs for February and March, a relatively steady flow around 9,000 cfs for the first three weeks of April, and a sudden increase in flow to about 20,000 cfs on 23 April (Figure 27). The spring seasons from 1989 to 1991 had fluctuations in flow from February through April with periods of steady flows around 20,000 cfs (Figure 27), while 1994 had a stable river flow around 20,000 cfs from mid-February to early April (Figure 28). An average discharge of 8,500 cfs in the spring mimics the preimpoundment river flow that would inundate the floodplain (Rulifson and Manooch 1991), which is the spawning habitat utilized by hickory shad (Street 1970; Pate 1972; Settle 1996).

Figure 27. River flow patterns in the Roanoke River downstream of Roanoke Rapids dam during the hickory shad spawning season (February-April), 1989-1992.



Discharge (x 1000)
1989
Missing Data
1990
1991
1992
February
March
April

Figure 28. River flow patterns in the Roanoke River downstream of Roanoke Rapids dam during the hickory shad spawning season (February-April), 1993-1996.



Discharge (x 1000)
1993
1994
1995
1996
40
30
20
10
0
1
5
10
15
20
25
30
February
March
April

Discussion

Adult Sex Compositions of the Catch

The male to female ratios from Albemarle Sound (0.73:1) and the Roanoke River at Weldon (0.76:1) do not indicate a significant sex selective harvest of female hickory shad in 1996. This can be an important indicator of harvest practices since in some fisheries, females are targeted by the fishery (e.g., hickory shad, American shad, sturgeon (*Ascipenser spp.*)) (Rulifson et al. 1982). In earlier investigations, the sex ratios of hickory shad and American shad were difficult to ascertain because the gill net mesh sizes selected for the larger fish, in this case, the females (Street et al. 1975; Winslow 1989, 1990). Pound net gear is non-selective; sex ratios for alewife and blueback herring for many studies are considered to be unbiased (Winslow 1989; Klauda et al. 1991b). In some cases males are more abundant than females, likely related to a greater proportion of males reaching maturity at an earlier age, and the differential arrival of males and females on the spawning grounds. Such is the case of alewife and blueback herring in the Chesapeake Bay (Klauda et al. 1991b). Pate (1972) found the male to female ratio of hickory shad sampled by a non-selective haul seine in the Neuse River, NC to be 4:1. This ratio could have been the result of a large proportion of virgin males recruited to the spawning population (47.3% of the males were age 2).

The present study, however, found the male to female ratio of hickory shad from Albemarle Sound in 1996 to be 0.73:1, which contrasts the findings of Pate (1972). We believe that the ratio was a good representation of the sex composition for the Albemarle population because the fishery-independent gill net survey which collected these fish employed several gill net mesh sizes to minimize size and sex-selective biases (Table 2). A similar sex ratio was obtained by sampling catches of sport fishermen at Weldon during 1996 (0.76:1), indicating that females in both locations did slightly out number the males. The small gill net mesh sizes used in the RRNWR independent gill net fishery in 1996 appeared to select for males and small females, which may explain why the male to female ratio was significantly different than the ratios from Albemarle Sound and Weldon (4.29:1) (Table 2).

Scale Age/Otolith Age Agreement

The 57% agreement between scale and otolith ages for this study is the same agreement level Kornegay (1977) found with alewife from Albemarle Sound; however, the agreement level he found with blueback herring was approximately 68%. The alewife scale ages never deviated more than ± two years from the otolith age, but two blueback herring scale ages deviated ± three years from the otolith age (Kornegay 1977).

Scale ages differing by one or two years from the otolith age is a relatively large deviation for a fish with a longevity of only seven years. Likewise, the 57% agreement level between scales and otoliths is low. *Alosa* scales are commonly regenerated, spawning marks sometimes obscure annuli near the scale margin, the first annulus is sometimes confused with the freshwater zone (a false annulus formed when juvenile *Alosa* first enter the marine environment), and the first annulus is not always visible on the scale (Cating 1953; Judy 1961; Kornegay 1977). In addition hickory shad scales are considered the most difficult *Alosa* scales to age (Richkus and DiNardo 1984). Therefore, otoliths should be used whenever possible for aging hickory shad.

Age to Maturity

The short life span of hickory shad, combined with an early age to maturity and an anadromous migration pattern, suggests that most fish in the population could be subjected to recreational and commercial harvest in inland waters for only one or two seasons before being removed by exploitation or natural mortality. Approximately 37% of both sexes of hickory shad are sexually mature as early as age 2; 96% of the population is mature by age 3, and 100% of the population is mature by age 5 (Table 9). One or two spawning marks on the scales are common; three or more are rare.

Based on age to maturity and spawning patterns, hickory shad and American shad are exploited similarly in the Albemarle Sound region, but the amount of exploitation on these species differs south of Cape Hatteras. American shad in Albemarle Sound usually reach sexual maturity by age 3 to 4 for males and age 4 to 5 for females; both sexes spawn up to three times (Winslow 1989, 1990). American shad show a latitudinal gradient between semelparity and iteroparity through the species range (Leggett and Carscadden 1978). Populations south of Cape Hatteras seldom spawn more than once, while populations in New York and Connecticut spawn up to five times (Table 22). Hickory shad appear to be iteroparous south of Cape Hatteras as indicated by repeat spawners in the Neuse River, North Carolina (Pate 1972; Hawkins 1980) and in the Altamaha River, Georgia (Street 1970).

Fecundity

Since hickory shad spawn only one to three times with a relatively low fecundity (80,000 to 475,000 in Albemarle Sound), the population could decline from

Table 22. A comparison of life history aspects of American shad, hickory shad, alewife, and blueback herring.

Life history aspect		American shad		Hickory shad		Alewife		Blueback herring	
Distribution		Nova Scotia to Florida [a]		Massachusetts to Florida [b]		Nova Scotia to South Carolina [c]		Nova Scotia to Florida[b]	
Size (TL, mm)		up to 750 mm, usually 500 mm [d]		up to 600 mm, usually 300-400 mm[d]		up to 400 mm, usually 200-300 mm [d]		up to 400 mm, usually 200-300 mm [d]	
Juvenile habitat estuaries		tidal freshwater estuaries migrate to saltwater in fall [b]		poorly documented, saltwater estuaries, migrate to ocean ocean in summer [b,e]		tidal freshwater estuaries migrate to saltwater in fall, some overwinter in estuary [b]		tidal freshwater migrate to SW in fall, some overwinter in estuary [b]	
Juvenile growth (TL, mm)		80-110 mm in fall [b]		119-189 mm in fall [e]		75-110 mm in fall [a]		50-70 mm in fall [a]	
Mean size at age (FL, mm):		M [c]	F [c]	M [a]	F [a]	M [a]	F [a]	M [a]	F [a]
	1	192.6	209.2						
	2	306.0	321.9	295.6	315.0				
	3	380.8	404.2	321.2	337.1	233.0		235.4	247.5
	4	414.0	435.0	341.1	350.7	239.5	248.2	240.0	246.2
	5	440.0	463.8	360.0	376.6	251.0	265.8	248.9	257.7
	6	448.1	478.0	381.6	402.5	261.2	270.3	258.9	267.3
	7	464.8	499.6	372.7	411.0	263.5	274.5	253.5	273.8
	8	482.8	511.3	397.0	411.0	266.0	286.5	262.0	276.5
Longevity		up to age 11-12 [b]		up to age 7-8 [b]		up to age 9-10 [a]		up to age 9 [a]	
Age to maturity		males: age 3-5 females: age 4-6 [a,b]		males: age 2-3 females: age 2-4 [f]		males: age 2-4 females: age 3-5 [b]		combined: age 3-6 [b]	
Fecundity		100,000-600,000 higher in southern latitudes [a,b]		43,000-730,000 [a] 80,000-475,000 [h]		100,000-467,000 [b]		120,000-440,000 [a]	

Table 22, continued

	American shad.	Hickory shad	Alewife	Blueback herring
Spawning season Albemarle Sound	April [a]	mid March- mid May [g] mid March- late April [h]	mid March- early May [g]	mid March- early May[g]
Spawning temperatures	12-20 °C [a]	9.5-22 °C [a]	10-18 °C [a]	13-26 °C [a]
Spawning duration	~ 1 month [f]	2-2.5 months [g]	~2 months [g]	~ 2 months [g]
Spawning habitat	main channel [a]	swamps, small creeks, ponds, main channel [b]	swamps, small creeks, ponds [b]	swamps, small creeks, ponds, ricefields [a]
Spawning frequency	once, S of Cape Hatteras 1-2 times in North Carolina 1-4 times in Maryland and Virginia up to 5 times in New York and Connecticut [c]	mostly 1-3 times [f] mostly 1-2 times, up to 4 times [h]	up to 5-6 times [c]	up to 4-5 times [c]
Ocean migration range	long distance-- American shad from all states and provinces found in Bay of Fundy during summer [i]	unknown--hickory shad have been found off Long Island, NY and New England during summer [j,k]	shorter distance--alewives found in Bay of Fundy during summer are mostly regional or local in origin [l]	long distance--mixed stocks in Bay of Fundy from as far away as North Carolina [l]

a. Rulifson et al. 1982 b. Klauda et al. 1991 c. Richkus and DiNardo 1984 d. Robins et al. 1986 e. Street 1970 f. Pate 1972

g. Street et al. 1975 h. Batsavage present study i. Melvin et al. 1986 j. Bigelow et al. 1963 k. Schaefer 1967

l. Rulifson et al. 1987

overharvest. Other commercially-important, long-lived iteroparous fish such as striped bass can produce from 1,000,000 to 5,000,000 eggs in a single spawning season (Olsen and Rulifson 1992). American shad fecundity is slightly greater than hickory shad with higher fecundity estimates seen in the semelparous, southern populations (Table 22). Because large female hickory shad make up the greatest proportion of hickory shad bycatch in the American shad gill net fishery, and since potential fecundity increases with fork length (Figure 23), the most fecund females are subject to more commercial exploitation than smaller individuals (Richkus and DiNardo 1984).

Fork Length at Age

Difficulty in determining age from fork length compounds the effectiveness of size limit regulations (Tables 4-6). Size limit regulations also are inappropriate because they are used to protect size classes having the greatest potential for rapid growth before harvest (i.e., to prevent growth overfishing) (Richkus and DiNardo 1984). The period of rapid growth for both species appears to be during the immature life stage and would not be exploited by commercial and recreational fisheries targeting the spawning population. Size limits for hickory shad would only have an impact in terms of mortality by sex since the males are smaller than females of equal age (Richkus and DiNardo 1984). Creel limits and commercial quotas would be better management strategies because they would allocate the harvest among commercial and recreational fishers while limiting the total harvest. Since hickory shad are a short lived species with only a few year classes exploited, unrestricted harvest could result in stock overfishing instead of growth overfishing. So instead of a decrease in the potential biomass by harvesting fish too early in the growth period, stock overharvesting may become evident in subsequent precipitous declines of the spawning stock (Richkus and DiNardo 1984).

Mean fork lengths at age of both sexes from age 3 on are smaller than those reported from earlier investigations (Table 23). This could be a function of capture methods in which the hickory shad were collected in large gill net mesh sizes set for American shad (Street et al. 1975; Hawkins 1980). However, Pate (1972) examined hickory shad captured in a non-selective haul seine. It is possible that the larger individuals in each age class are being harvested disproportionately to the smaller fish (i.e., Lee's phenomenon), the evidence for this which is depicted in Table 23.

Scale and Otolith Back Calculations

The weak scale radius to fork length relationship occurred because two age classes dominated the sample and because of the large overlap in size ranges for each age class. Also, between-scale variations in scale radius on the same fish made choosing a representative scale difficult. Since the majority of total growth for hickory shad is reached by age 2, no age 0 or age 1 fish would have a considerable effect on back calculations and the von Bertalanffy growth curve (Pate 1972). A better otolith radius to fork length relationship occurred because otoliths have less size variation than scales, otoliths were available from age 0 fish, and a subsample of the dominant size classes were taken to reduce the influence these size classes had on the relationship.

Table 23. A comparison of fork lengths at age from this study to previous hickory shad studies.

		Age class							
Study	Sex	1	2	3	4	5	6	7	8
Batsavage (1997)	M		293	288	318	332	376		
	F		304	313	339	343	402	397	
Pate (1972)	M		294	332	346	356	357	369	
	F		311	354	376	395	409	379	420
Street et al. (1975)	M		289	325	350	371	360	365	
	F		341	341	355	387	384	390	
Hawkins (1980)	M		295	318	342	353	374	384	397
	F		302	337	350	373	393	413	410

Spawning Habitat

Although this study did not survey spawning habitat of hickory shad in the Roanoke River, both ripe and spent adults were collected from tributaries of the Roanoke River in the RRNWR. Spawning activity of hickory shad in the Neuse River, North Carolina and the Altamaha River, GA was confined to flooded bottomlands and tributaries away from the mainstem of the river (Street 1970; Pate 1972). Mansueti (1962) found hickory shad spawning in the mainstem of the Patuxent River, Maryland, upstream of American shad spawning sites. Hickory shad have been found to spawn in both the mainstem and tributaries of rivers in Virginia (Klauda et al. 1991a). This study collected hickory shad running ripe from the mainstem of the Roanoke River near Weldon, North Carolina, but no spent fish were collected.

The historic range of anadromous *Alosa* spawning migrations on the Roanoke River before the dam blocked further migration at Roanoke Rapids, North Carolina was near Salem, Virginia (Hightower et al. 1996). However, only American shad, alewife, and blueback herring were documented as spawning in the Piedmont region of the Roanoke River. It is possible that hickory shad also utilized the Piedmont stretches of the river since they are commonly misidentified as American shad (Richkus and DiNardo 1984). However, because hickory shad are found to utilize flooded swamps and tributaries on the Coastal Plain as spawning habitat, and because of the lack of evidence that hickory shad ever migrated into the Piedmont region of the Roanoke River, it is difficult to conclude that fish passages installed on the hydroelectric dams of the Roanoke River would provide more spawning habitat for hickory shad.

Juvenile Distributions

Development of state and interstate fishery management plans for hickory shad are difficult without knowledge of nursery grounds and migration patterns of the young-of-year, and the habitats and migration patterns of adults at times other than during the spawning migration (Richkus and DiNardo 1984). Hickory shad have a seasonally early and prolonged spawning period that occurs before the other *Alosa* species in the Albemarle Sound region, which puts the juveniles into the system before the other young-of-year anadromous species (Table 22). Based on the large adult population in the Albemarle Sound region, there should be good young-of-year recruitment during some years, which this study and the NCDMF surveys failed to document in 1996.

I believe that the majority of juvenile hickory shad do not use Albemarle Sound as a nursery ground during the same time period as the other juvenile *Alosa*. The majority of juvenile hickory shad may have migrated to the ocean before the survey was completely underway. Street (1970) found juvenile hickory shad in nearshore ocean waters off the coast of Georgia. This scenario may explain why hickory shad exhibit high growth in the first year compared to other juvenile *Alosa* that utilize estuaries during the first year of life (Table 22).

Comparison of Hickory Shad to Alabama Shad

Although many life history aspects of hickory shad differ from the other anadromous *Alosa* on the East Coast of the U.S., it has some similarities to the Alabama shad (*Alosa alabamae*), a Gulf Coast anadromous alosid. Alabama shad is a short lived species with a longevity of only four to six years (Pattillo et al. 1997). They mature early in life with some males mature by age 1 and both sexes mature by age 2. Juvenile Alabama shad, like the juvenile hickory shad, are fast growing with some as large as 140 mm FL (Mills 1972, cited in Rulifson et al. 1982). However, juvenile Alabama shad tend to stay in freshwater longer than juvenile hickory shad with young of year Alabama shad collected as late as November in natal rivers (Mills 1972, cited in Rulifson et al. 1982).

River Flow and Year Class Abundance

Higher river flows in the late winter and early spring contribute to the initiation of the spawning migrations of anadromous fish. Additionally, steady river flows > 20,000 cfs inundate the floodplain by water from the main channel overtopping natural levees, passing through openings in the levees, and back flooding through creek mouths (Rulifson and Manooch 1991), which could potentially increase the amount of spawning habitat for hickory shad, alewife, and blueback herring. Higher river flows also could reduce catchability of adults, which would allow more fish to spawn. It is not clear if a particular flow regime is more favorable for year class abundance. Variations in year class abundance are more pronounced in short-lived species and for species with brief spawning periods, or for those that spawn in variable, unpredictable environments (Van Den Avyle 1993). Other studies have found age 3 and 4 hickory shad to be the dominant age classes as well (Street et al. 1975; Johnson et al. 1978; Hawkins 1980) so this might be a normal characteristic for hickory shad populations. But since hickory shad are short-lived and spawn in unpredictable habitats, river flow patterns and/or other environmental factors may have a large effect on year class abundance.

Conclusions

Based on the results of my study and review of the hickory shad literature, the following conclusions can be made:

1. The male to female ratios from Albemarle Sound (0.73: 1) and Weldon (0.76.1) do not indicate a significant sex selective harvest of female hickory shad in 1996.
2. The short life span, combined with a young age to maturity, results in individuals subjected to one or two seasons of commercial and recreational harvest before they leave the population (from exploitation or from natural mortality).
3. The low fecundity combined with repeat spawning only one or two times makes hickory shad and other anadromous *Alosa* susceptible to overharvest; harvest of the larger, more fecund females by the American shad gill net fishery could increase the likelihood of population decline.
4. Overlapping fork lengths at age, and size differences between males and females at age, make size limit regulations inappropriate.
5. Juvenile hickory shad do not appear to utilize Albemarle Sound as a nursery ground like the other three *Alosa* species.

<u>Management Recommendations</u>

Based on the conclusions listed above, the following management recommendations are offered:

1. Impose a creel limit of hickory shad and American shad in aggregate on anglers fishing near the spawning grounds. Many anglers cannot distinguish American shad from hickory shad, so identical regulations for both species would minimize

confusion by anglers. A daily creel limit would allow anglers to harvest a reasonable number of fish and at the same time reduce potential for overharvest on the spawning grounds.

2. Modify seasonal limits on the American shad gill net fishery to prevent the excessive bycatch of female hickory shad. Since hickory shad commences its spawning migration before American shad, the opening of the American shad gill net fishery could be delayed to allow hickory shad to enter the rivers to spawn before they become susceptible to commercial harvest.

Research Recommendations

Based on the life history aspects of hickory shad that are not yet understood, the following areas of research are recommended:

1. Initiate a tagging study to characterize the ocean migration patterns, to estimate the population size of spawning stocks, to estimate the exploitation rate, and to quantify the sources of exploitation for hickory shad.
2. Characterize the primary nursery grounds of juvenile hickory through the species range by sampling the estuaries earlier in the spring and by sampling nearshore ocean waters from late spring to fall.
3. Characterize the spawning habitats and the locations of these habitats for hickory shad in the Roanoke River.
4. Expand results of the mesentery fat and gut analysis study by examining fish in the ocean prior to spawning, in the prespawing staging areas of the esturaries and near the spawning grounds just prior to spawning. The analysis should examine both

mesentery and intramuscular fat along with gut analysis to determine what the primary energy source for hickory shad is during the spawning migration and if the energy source changes during the migration.

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