An Assessment of the 1996 American Shad Spawning Run in the Annapolis River, Nova Scotia

1996 Final Report

to

Nova Scotia Power Inc.

prepared by

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EXECUTIVE SUMMARY

The Annapolis Tidal Generating Station and the causeway across the Annapolis Estuary provide an obstacle for migrating anadromous fish which spawn in the Annapolis River. The obstacle potentially affects both adults moving towards spawning grounds upriver, and adults and juveniles leaving the estuary and returning to sea. American shad, striped bass and Atlantic salmon are three of the species that may thus be affected. Assessments of the American shad stock in 1981 and 1982 prior to the generating station coming on-line, described it as an older, slow-growing population (Melvin *et al* 1985). The stock size was estimated to be in the range 100,000 to 130,000 individuals. Studies of the stock in 1989, 1990 (1st generation adults) and 1995 (2nd generation adults), after the generating station came on-line, suggest that the population was at that time dominated by smaller, fast growing, virgin shad. This change was attributed to the virtual absence of the larger, older shad once prevalent in the population, but variation in sampling methodologies between pre- and post operational assessments may have precluded valid comparisons.

Fork lengths of American shad captured during this assessment (males = 414 mm, females = 460 mm) were slightly larger than those captured in 1995, but averaged about 27 mm smaller than for those captured during the 1989 and 1990 post-operational studies. Given that the mean gillnet mesh size fished in 1996 was larger than that of the 1989 or 1990 assessments, this difference may have been underestimated.

Maximum ages observed in 1996 (males = 8 yr., females = 10 yr.) were similar to maximum ages observed in 1995 (males = 9 yr., females = 10 yr.) but represent a marked decrease from the pre-operational assessments of about 12 yr. for males and 13 yr. for females. In 1982, 35 % of the males and 20 % of the females were as old or older than the oldest fish encountered during 1996, indicating a substantial shift in the age structure of the population.

While sampling selectivity may invalidate rigorous comparisons, a number of trends consistent with post-spawning adult turbine mortality appear to be present. These include decreases in mean and maximum lengths, mean and maximum ages, percent repeat spawners and theoretical maximum lengths, and increases in age at first spawning, growth coefficients and instantaneous mortality rates. Other trends, such as the apparent decrease in size-at-age, as suggested by the decrease in mean fork length without a corresponding decrease in mean age between the 1st generation and 2nd generation post-operational assessments, may be consistent with turbine mortality but are more likely indicative that other factors are also causing changes within this stock.

ACKNOWLEDGEMENTS

This project would not have been possible without the hard work of a number of people. The field crew consisted of two full time members, Keir Daborn and Greg McLearn and part time assistance in the field was provided by Sean Gillis and Ken Meade of Nova Scotia Power Inc., and Nicole Humble and John MacMillan, from Acadia University. Mike Chapman, Keir Daborn and Nicole Humble assisted with reading the scales. Mike Dadswell helped with interpretation of the data.

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1.0 INTRODUCTION

The Annapolis River and Estuary in Nova Scotia support a large population of American shad (*Alosa sapidissima*). While this stock is one of few which is not fished commercially by selective gear in its natal river (Melvin et al. 1985), it does support a sport fishery utilizing hook and line (Dadswell and Themelis 1990a). In 1960, a dam and causeway were built across the estuary near Annapolis Royal, limiting the tidal exchange upstream of the dam. The Annapolis Tidal Generating Station was constructed at this location during 1980 - 84, which, together with the causeway, provides an obstacle for migrating anadromous fish spawning in the river. The obstacle potentially affects both adults moving towards spawning grounds upriver, and adults and juveniles leaving the estuary and returning to the sea. At the present time, three routes of passage through the causeway exist: through either of two fishways or through the turbine tube.

Attempts to assess the impact of the Annapolis Tidal Generating Station on migrating alosines include direct measurement of turbine mortality (Stokesbury and Dadswell 1991, Hogans and Melvin 1986, Hogans 1987), fish passage and fishway utilization studies (Stokesbury 1987, McKinley and Patrick 1988, Ruggles and Stokesbury 1990, Gibson and Daborn 1993, Gibson and Daborn 1995a) and fish diversion studies (McKinley and Patrick 1988, McKinley and Kowalyk 1989). These works are reviewed by Andrews and McKee (1991) and Gibson (1996).

Because compensatory responses during other portions of the fishes' life cycle may offset the effects of mortality associated with passage at the causeway, measurements of direct mortality are unable to provide information about the effects of the generating station at the population level. For this reason, impacts are being assessed through comparisons of stock characteristics prior to the Annapolis Tidal Generating Station coming on-line in 1985, with characteristics of the stock since that time. The framework for interpreting these comparisons was first laid out by Melvin et al. (1985) while reporting the results of pre-operational stock assessments conducted in 1981 and 1982. Melvin characterized the stock as an older, slow-growing stock with an annual spawning run of about 100,000 -130,000 individuals. The mean age of males was older than that of any other river studied to that date, while the mean age of females was similar to that of other northern populations. Similarly, the percent repeat spawners was higher and the growth coefficient and total instantaneous mortality were lower than for populations previously examined. Stock assessments in 1989 (Dadswell and Themelis 1990a), 1990 (Dadswell and Themelis 1990b), indicated that a trend towards younger, smaller fish may have been developing in the population, and that the older individuals (10+ years), once prevalent in the population, may have been absent at that time. Mean and maximum ages, mean and maximum lengths and theoretical maximum lengths had apparently decreased since the pre-operational assessments, while total instantaneous mortality rates and growth coefficients had increased since those years. These changes were interpreted as consistent with a moderate to high level of turbine mortality spread over the year-classes in such a way that older shad were being removed. Stock sizes were not estimated as part of those assessments.

A population estimate was attempted during an assessment in 1995 (Gibson and Daborn 1995b), but a wide confidence interval precluded comparisons with pre-operational studies. It did appear, however, that the trends identified in the 1989 and 1990 assessments may have been continuing, as the mean length of both male and female shad were smaller than those encountered in the previous studies. Theoretical maximum lengths had also decreased, with a corresponding increase in the growth coefficients. The percentage of repeat spawners had apparently dropped to nearly 50 %, as compared to 70 to 90 % in pre-operational years.

A problem identified during the 1995 study was that biases associated with the sampling methods in different years may partially or completely invalidate comparisons between the various studies. These biases include gear selectivity (trapnets vs. an assortment of various gillnets) and variability in relative soak times for different mesh sizes when sampling with gillnets. Attempts to quantify the degree of gillnet selectivity during 1995 were not as successful as hoped and it was recommended that these biases should be addressed in future studies.

This project, therefore, was aimed at providing information about the 1996 spawning run of American shad in the Annapolis River. This information was to be pooled with existing data about this stock and used for comparing the 1996 spawning run with runs which were studied in previous years. Objectives of the study were:

1. To estimate the population size of adult American shad spawning in the Annapolis River during 1996 (if obtainable),

2. To obtain information on 1996 stock characteristics for the American shad, specifically: mean length, mean weight, mean age, maximum length, maximum age, percent repeat spawners, reproductive life span, instantaneous mortality rates, asymptotic length and growth coefficients,

3. To develop gillnet selectivity curves which could be used to standardize the

existing data, so that more valid between year comparisons could be made, and

4. To compare the stock characteristics of the 1996 spawning run with those determined for the 1981, 1982, 1989.1990, and 1995 spawning runs to obtain information about the year to year variability inherent within this population and to assess whether identifiable trends had developed since the Annapolis Tidal Generating Station came on-line.

As conducted in 1995, the field portion of the study was to be carried out in two parts. The first phase would involve marking as many shad as possible prior to the fish reaching the spawning areas, while at the same time collecting the scale samples and measurements required to characterize the population. Bridgetown was considered as being downstream of the spawning areas and therefore was used as the upstream limit of the marking area. While capturing shad for marking, a variety of different mesh sizes would be utilized in order to assess the biases associated with using gillnets to collect fish. After a sufficient length of time had passed for the shad to move upstream to the spawning areas, these areas would be surveyed using gillnets to determine the ratio of unmarked to marked fish in the population, thus allowing the size of the population to be estimated using the Peterson's method (Ricker 1975).

In 1995, 509 shad were marked and released after 13 days in the field, and 317 were subsequently examined for marks. The resulting confidence interval was about 100% the population estimate. To avoid a similar scenario this year, we proposed that after a given number of days in the field, a decision should be made about whether to undertake the recapture portion of the project based on the number of fish marked by that time. If the number of fish marked was not large enough to obtain a reasonable population estimate, then the recapture portion of the project would not be undertaken.

2.0 METHODOLOGY

2.1 Field Work

During the marking phase of the project, the intention was to capture, mark and release as many American shad as possible in the estuary before they reached the spawning grounds. Shad were captured using 50 m long monofilament gillnets (10.1, 11.4, 12.7, 14.0, 15.2 cm stretched mesh) that were continually monitored to minimize the length of time that a fish remained in the net. Soak time, mesh sizes and water temperature were recorded for each sampling night. Fishing efforts were concentrated near Bridgetown.

With the exception of a sample of fish retained for laboratory analysis, captured shad were processed in the field and released back into the estuary. Processing included marking the fish, measuring its fork length, determining its sex and collecting a scale sample. Fish were marked using a subcutaneous injection of a small quantity (app. 0.1 *ul*) of an elastopolymer containing fluorescent dye. Marks were applied in the adipose tissue just behind the fishes' right eye, with a 3/8 inch, 26 gauge tuberculin needle. Length was recorded to the nearest 5 mm. In the interests of low-impact environmental research, shad which did not survive capture and processing were used for laboratory analysis. While this practice may introduce a bias to this sample, these fish were used only as a control for our aging method, and were not used for separate morphometric analysis, so the degree of this bias is probably small. We consider the benefit of not unnecessarily sacrificing additional shad to outweigh this bias.

During the first part of the recapture phase, the river between Kingston and Lawrencetown was surveyed with gillnets to determine the ratio of marked to unmarked fish in the population. Nets were fished at more or less randomly chosen locations for about 0.5 hours each time. Captured fish were removed from the net, measured, examined for marks, marked with a color distinct from those used during the initial marking phase, and released back into the river. During the second part of the recapture phase, shad were captured during their seaward exodus in the vicinity of Bridgetown. These fish were examined for marks and released.

In order to allow marked fish the opportunity to mix within the population, only shad marked and recaptured during different parts of the project were considered valid recaptures to be used for estimating the stock size.

2.2 Laboratory Analysis

American shad retained for laboratory analysis were measured and their sex determined in the field. Fish were stored frozen prior to dissection to verify the sex as determinated in the field and to remove the otolith for verifying its age as determined by reading scales.

Age and age at first spawning were determined from the scales using the criteria of Cating (1953) and Judy (1961) for determining spawning marks and annuli. Scales were cleaned with water, mounted on glass slides and projected on Bristol board with a projecting microscope prior to reading. Ages were determined from otoliths by counting annuli using a dissecting microscope after allowing the otolith to clear in 90% ethanol.

2.3 Statistical Analysis

Because body depth varies between pre- and post-spawning American shad (a factor which would influence gillnet selectivity), only data from shad captured during the marking portion of the study were used for determining stock characteristics and gillnet selectivity. All statistical analysis was done using SYSTAT version 7.02. Stock characteristics were calculated using the raw data and after the data had been corrected for gillnet selectivity and for the relative fishing efforts with the different mesh size nets. These manipulations are outlined below:

2.3.1 Gillnet selectivity

Gillnet selectivity was calculated using an indirect method that combines some features of the computational method of Regier and Robson (1966), and the nonlinear, iterative least squares approach of Helser *et al* (1991). Indirect methods of estimating gillnet selectivity require the assumptions that the probability of encounter of fish of a single size class is equal with respect to the different meshes and that each mesh size captures the same proportion of fish in the size-class for which that mesh is most efficient (assumption of equal catchability). Based on these assumptions, the selectivity of a particular mesh for a particular size class can be estimated by fitting any one of several mathematical models over the different mesh sizes for fixed size classes. Separate selectivity curves were developed for males and females, as pre-spawning females appeared to have a wider, deeper body profile than pre-spawning males. Data for each sex were treated as follows:

1. List of symbols:

n_{ij} = number of fish in size class j captured in mesh i
p_{ij} = proportion of fish in size class j captured in mesh i
s_{ij} = selectivity of mesh i to fish in size class j
m_j = size of mesh i
m_0 = estimated mean (optimal) mesh size for capturing fish in size class j
σ = estimated standard deviation of m_0

2. The fork length range encountered was partitioned into size classes of 2.0 cm length and each fish was assigned to a size class based on its length.

3. n_{ij} was calculated as the total number of fish in size class j captured by mesh i. To meet the assumption of equal probability of encounter, n_{ij} was then standardized by the total soak time of each mesh size in this study.

4. The relative number of fish in size class j captured by mesh i was calculated as:

$$p_{ij} = n_{ij} \Big/ \sum_i n_{ij}$$

5. For each size class j, normal probability density distributions were used to describe the functional relationship between p_{ij} and various mesh sizes. Moments of each distribution, m_0 and σ, a were estimated by iteratively seeking a least squares solution to the following model:

$$p_{ij} = \frac{1}{\sigma\sqrt{2\pi}} e^{-(m_i - m_0)^2/2\sigma^2}$$

6. The relationships between m_0 and σ and size class j were estimated using a least squares linear regression model weighted by the square root of number of fish of each sex in each size class. Final estimates of m_0 and σ were obtained from these relationships and were inserted into the model to calculate estimates of s_{ij} for all combinations of size classes and mesh sizes.

7. To meet the assumption of equal catchability at peak efficiency, the ordinates s_{ij} were standardized by multiplying each ordinate by a factor of $1/\max_i(s_{ij})$, where $\max_i(s_{ij})$ is the ordinate at the mean of each probability distribution.

8. Weighting factors were calculated by adjusting each s_{ij} for the total soak time of the corresponding mesh size i during this study. Each fish captured was assigned the appropriate weighting factor. This factor adjusts for the selectivity of the nets and for the fact that the different mesh sizes were not fished for equal amounts of time during the study.

9. To correct for sampling selectivity, each fish was assigned the value of the weighting factor corresponding to its sex, size class and the mesh in which it was captured. For example, if a shad was assigned a weighting factor of 3, it would count as the equivalent of 3 shad with weighting factors of 1.

2.3.2 Stock characteristics

Mean length, maximum observed length, mean age, maximum observed age, mean age at maturity, sex ratios, percent repeat spawners, Von Bertalanffy's growth coefficient and theoretical maximum length (asymptotic length), and instantaneous mortality were calculated for males and females in order to describe the stock. Where applicable, these characteristics are calculated both directly from the untransformed data and after correcting for gillnet selectivity and the variation in total soak time between meshes.

Population growth rates, expressed as Von Bertalanffy's growth coefficient and theoretical maximum age, were estimated by iteratively seeking a least squares solution to the Von Bertalanffy growth equation (Ricker 1975):

$$l_t = L_\infty(1 - e^{-K(t-t_0)})$$

where:

l_t = length at age t
L_∞ = theoretical maximum length
K = growth coefficient
and
t_0 = theoretical age when length = 0.

Mean fork length at age data, collected during the marking portion of the study, were used in these calculations for fish 4 years of age and older. Mean back-calculated lengths from the 1981 and 1982 spawning runs were used in these calculations for ages 1 - 3 years, as fish in these age classes were not encountered during this study. This approach is similar to that of the 1989, 1990 and 1995 assessments.

Instantaneous mortality (Z) was estimated as the slope of the line:

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

where:

N_t = size of the age class at age t

N_0 = theoretical size of the age 0 class

t = age in years

and

Z = instantaneous rate of mortality

Prior to fitting this line, the sizes of the age 4, 5 and 6 classes were adjusted by the percent mature in each age class to account for immature fish unrepresented in the spawning run.

3.0 RESULTS

Field activities for this project commenced on May 2, 1996 and concluded on June 22, 1996. The time, location, nets used and the number and fate of American shad captured on each sampling day are summarized in Appendix 1. During the marking portion of the study, 831 American shad were captured during 12 trips to the field. During the first part of the recapture phase, 484 American shad were captured during 8 field days, and 228 were captured over 4 days while they were migrating downstream. Eighty-seven of these fish did not survive capture and processing, and were used for subsequent laboratory analysis. The remainder were released alive back into the river.

3.1 Gillnet Selectivity

Mesh size and fork length information recorded for 826 American shad captured during the marking phase were used to develop gillnet selectivity curves. Of these fish, 32.3 % were captured in the 10.1 cm mesh, 37.9 % in the 11.4 cm mesh, 23.2 % in the 12.7 cm mesh, 3.8 % in the 14.0 cm mesh, and 2.8 % in the 15.2 cm mesh. Each shad was assigned to a size class based on it's fork length. Normal probability density distributions were then fitted to the proportion of shad of each sex in each size class captured by each mesh size after standardizing the proportion by the soak time of each net. The relationships between the means and standard deviations of these distributions appeared to be more or less linearly correlated with size class (Figure 1), and weighted least squares linear regression models (the square root of the number of fish of each sex in each size class were used as weights to decrease the influence of outliers resulting from small size classes) were used to obtain final estimates of the means and variances describing the normal distributions relating capture probability to mesh size for each size class for both sexes. The resulting probability distributions were standardized to a constant height and used to predict the probability of an American shad of a given size and sex being captured by each of the meshes (Figure 2). Final weighting factors determined for each sex, size class and mesh size, intended to compensate for gillnet selectivity and differences in soak time for each mesh are shown in Figure 3.

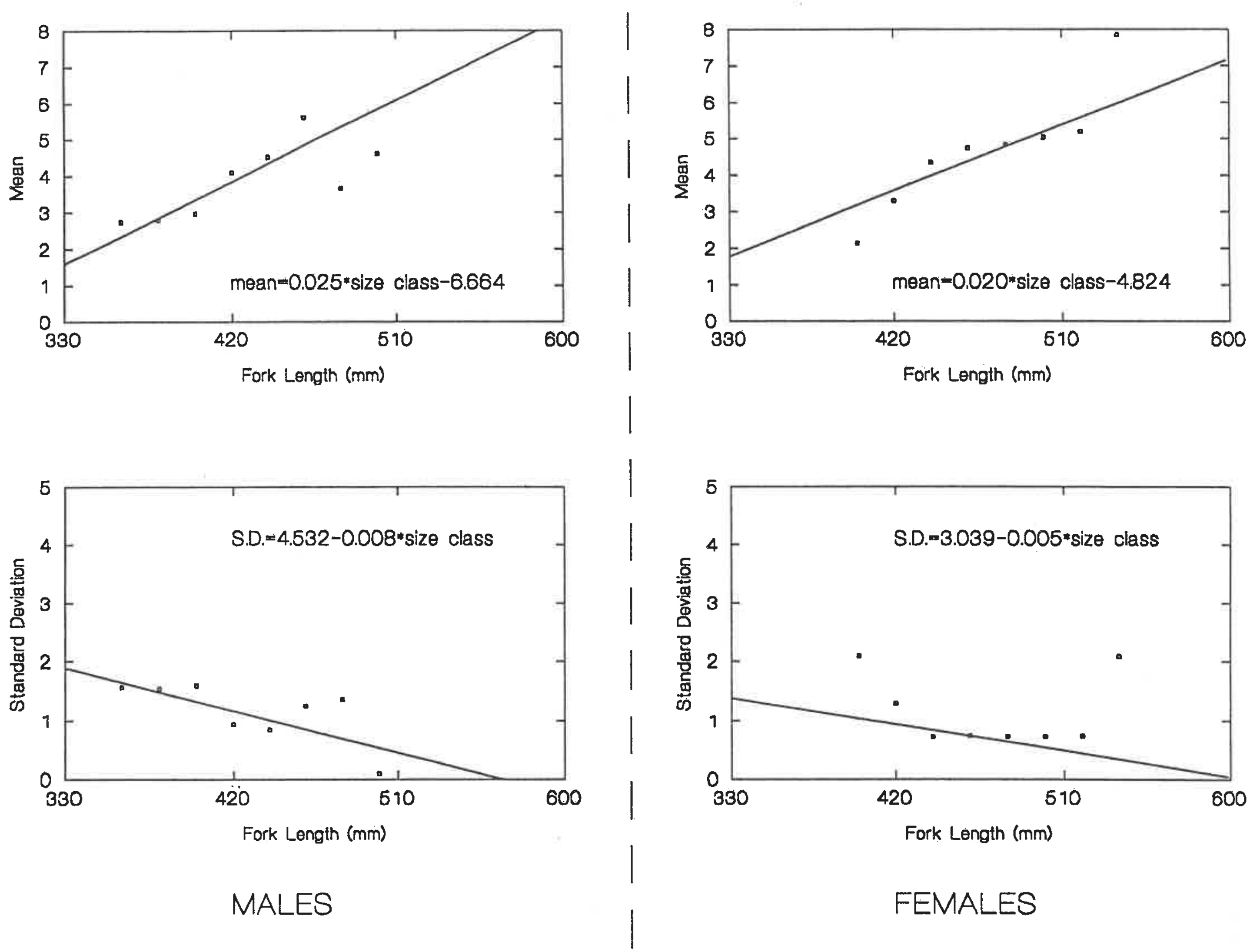


Figure 1. Means and standard deviations estimated by fitting normal probability distributions to the proportion of shad of each sex in each size class captured in each mesh. Weighted least squares linear regression was used to relate these parameters to fork length and the resulting equations were used to obtain the final estimates of the means and standard deviations.

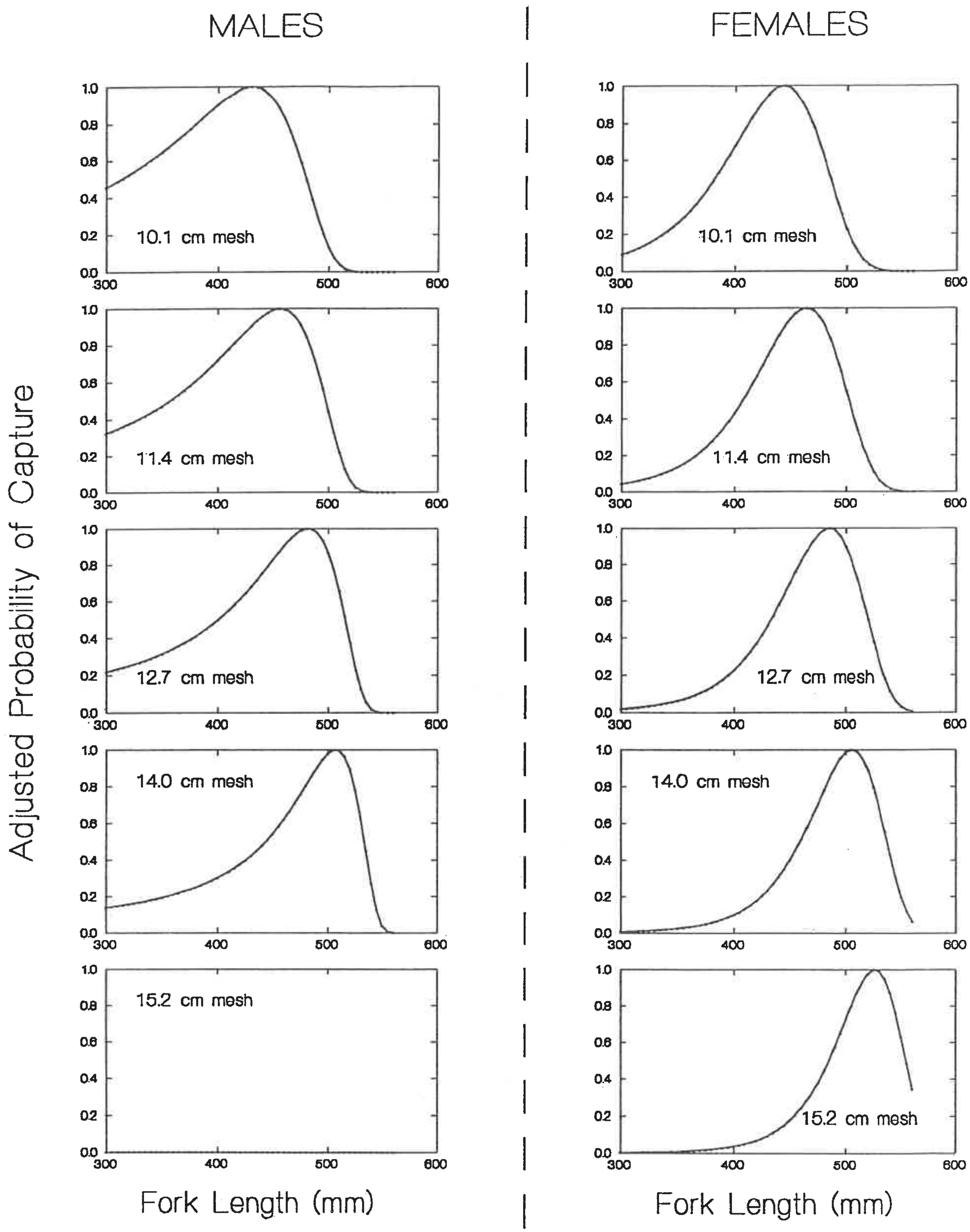


Figure 2. Selectivity curves as estimated for the gillnets used during this survey.

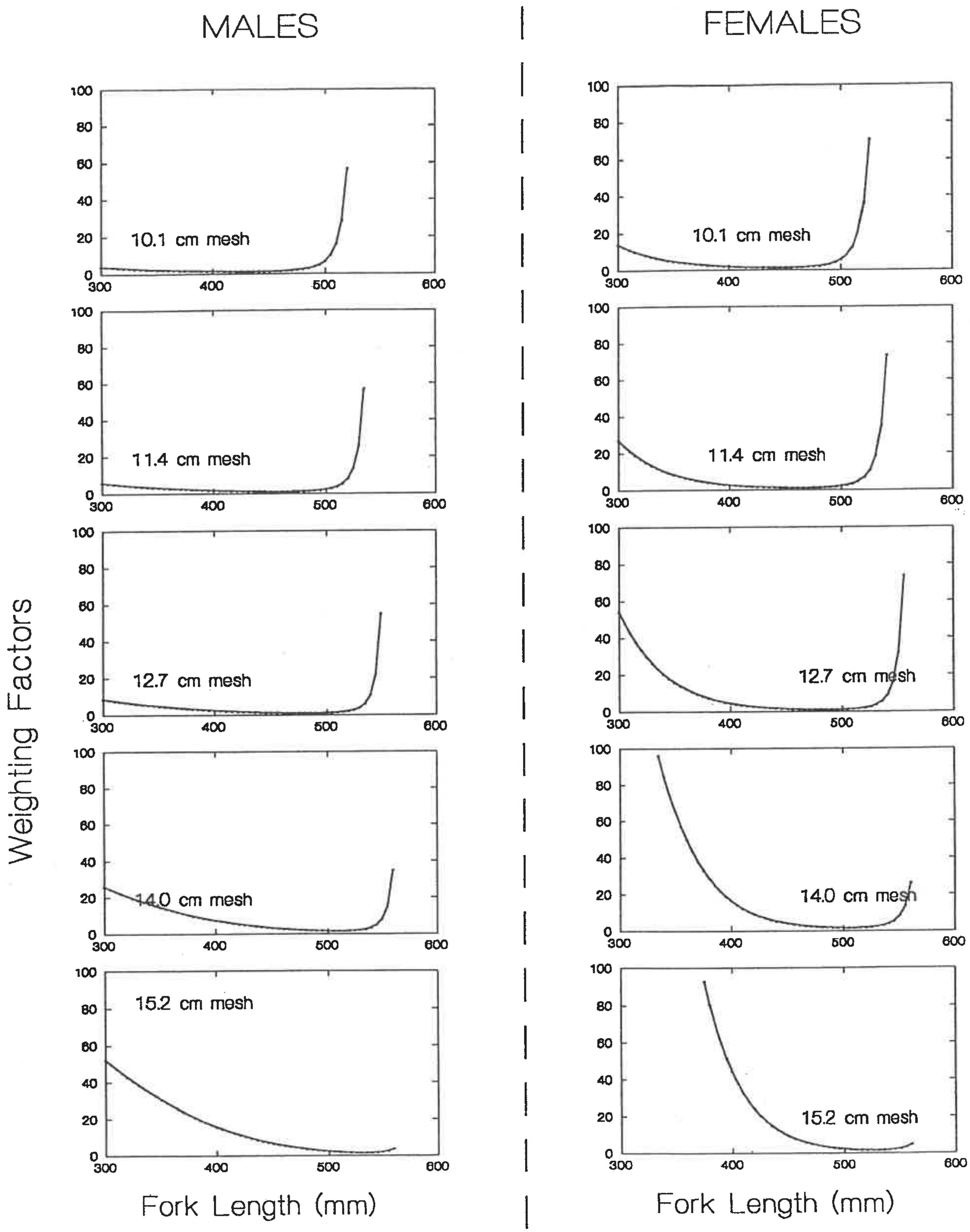


Figure 3. Weighting factors used to correct for the probability of capture for each fish based on its length, sex, the mesh in which it was captured, and the soak time of that particular mesh.

3.2 Population Size Estimate

Our attempts to estimate the size of the 1996 American shad spawning run were unsuccessful. During the initial marking phase, 774 shad were marked and released into the river. During the first portion of the recapture phase, 484 shad were examined for marks, of which 472 were marked and released back into the river. None of the fish examined had been marked during the initial marking phase. During the second portion of the recapture phase, 228 shad were examined for marks, resulting in one valid recapture. While the numbers of shad marked and examined for marks are considerably lower than hoped for during the planning stage of this project (and are not adequate for estimating the stock size), recapturing only one marked fish is not an unrealistic scenario given these numbers. Treating the number of recaptures as a random variable with a Poisson distribution allows the calculation of the probability of a given number of recaptures assuming a given stock size. Given a stock size similar to that of the 1981 spawning run of about 125,000 individuals (Melvin et al 1985) and repeating the above sampling scenario a number of times, the number of valid recaptures during the first part of recapture phase would average only 3.0 and would be one or less about 20 % of the time. During the second part of the recapture phase the number of valid recaptures would average 2.3 and would be one or less about 34 % of the time.

Table 1. The expected number of recaptures (r) and the probability that r would be less than or equal to one if the stock size was similar to the 1981 stock and the numbers of shad marked and examined for marks were similar to this assessment.

Phase	1981 stock size	1996 number of marked fish at large	1996 number of fish examined for marks	Expected number of recaptures	Probability that $r \leq 1$
1st part of recapture phase	±125,000	774	484	3.0	0.199
2nd part of recapture phase	±125,000	1246	228	2.3	0.336

3.3 Stock Characteristics

Stock characteristics are based on data collected during the marking portion of the assessment and are presented both uncorrected and corrected for the sampling methodology.

3.3.1 Fork length

Length frequency distributions for males and females are shown in Figures 4 and 5 respectively. The largest American shad captured during this assessment was a female with a fork length of 540 mm. The largest male captured was 510 mm in length. Means and standard deviations of the fork lengths of both sexes are presented in Table 2. These estimates are based on samples of 426 females and 401 males.

Table 2. Mean fork lengths and standard deviations for the 1995 Annapolis River American shad spawning run.

	Mean Fork Length (mm) ± Standard Deviation	
estimate based on:	Males	Females
uncorrected data	414.3±28.7	459.8±30.4
corrected data	416.9±36.0	462.2±34.8

3.3.2 Sex Ratio

The sex ratio of the samples varied during the sampling period, as shown in Table 3. Overall, during this portion of the study, females outnumbered males by a ratio of about 1.40 : 1. The ratio of females to males during the recapture phase of the study was 1.60 : 1.

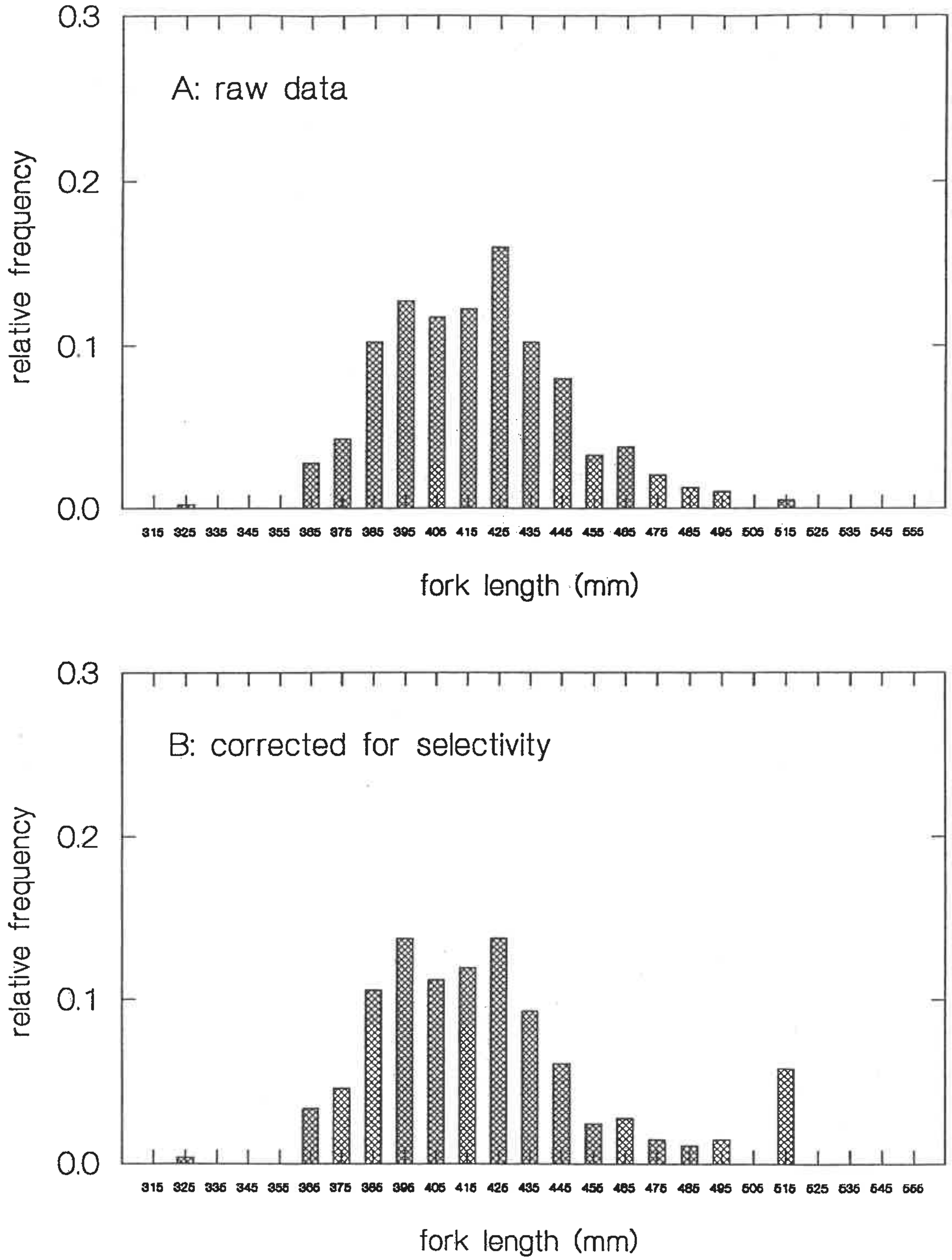


Figure 4. Fork length frequency distributions as estimated for male American shad in the 1996 Annapolis River spawning run, both before (a) and after (b) correcting for gillnet and sampling selectivity.

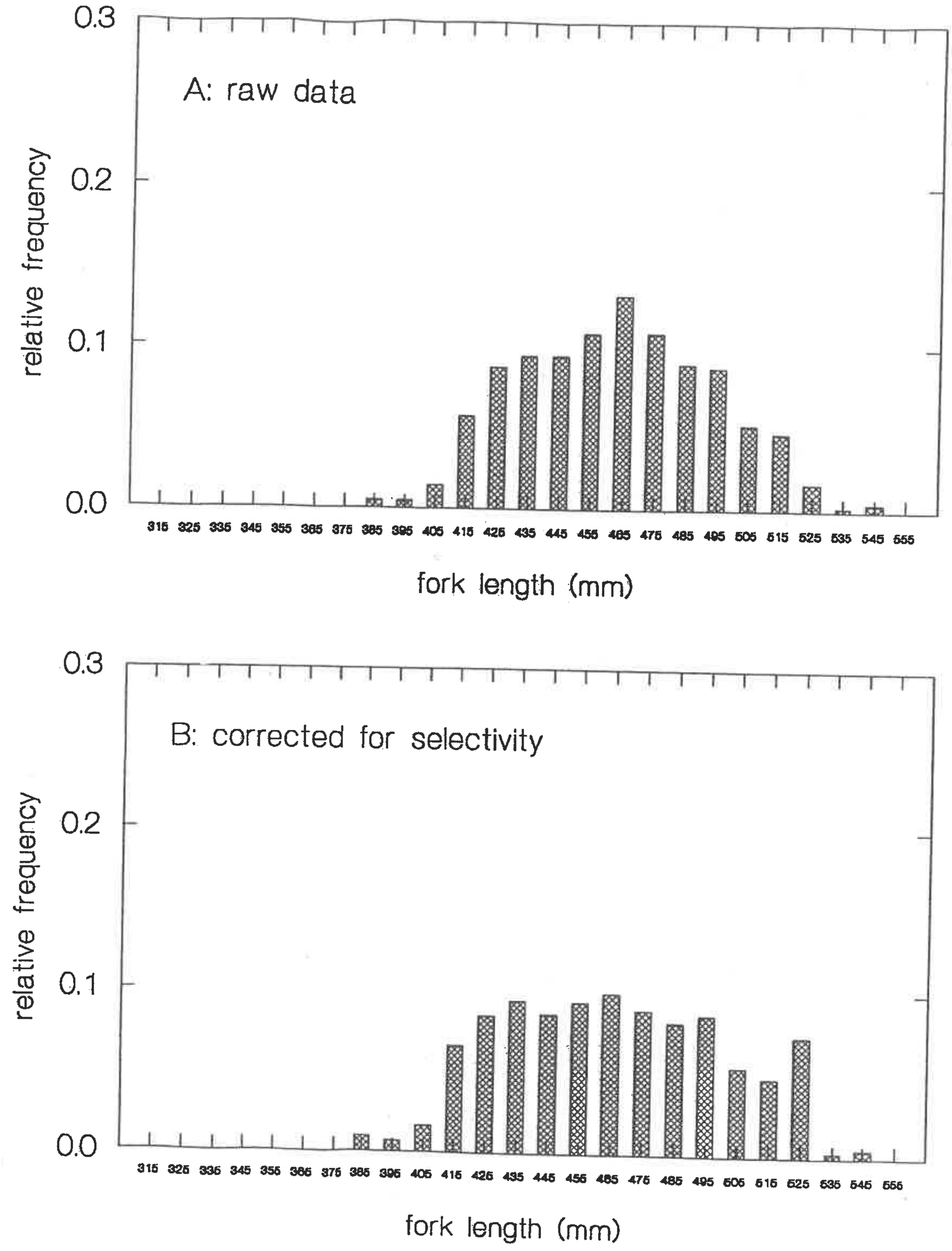


Figure 5. Fork length frequency distributions as estimated for female American shad in the 1996 Annapolis River spawning run, both before (a) and after (b) correcting for gillnet and sampling selectivity.

Table 3. Sex ratio of American shad captured during the marking portion of the study.

Date	Location	Total Catch	Sex Ratio (uncorrected) Female:Male	Sex Ratio (corrected for sampling selectivity) Female:Male
May 4-5	Bridgetown	116	0.26:1	0.32:1
May 6 7	Bridgetown	93	1.32:1	1.23:1
May 7-8	Bridgetown	37	0.61:1	1.11:1
May 9	Bridgetown	83	0.66:1	0.69:1
May 12	Bridgetown	151	1.19:1	1.18:1
May 14	Bridgetown	111	3.44:1	2.86:1
May 16	Bridgetown	104	1.12:1	1.12:1
May 17	Bridgetown	25	1.08:1	0.55:1
May 18	Bridgetown	20	4.00:1	4.28:1
May 20	Bridgetown	36	2.60:1	2.30:1
May 23	Bridgetown	41	0.89:1	1.81:1
	TOTAL	817	1.40:1	1.37:1

3.3.3 Age and Maturity

Ages ranged from 4 to 8 years for males, and from 4 to 10 years for females, as shown by the age frequency distributions in Figures 6 and 7. These distributions are based on ages determined from scales collected from 226 females and 208 males. The oldest American shad captured during this assessment was a 10 year old female. The oldest male encountered was 8 years old. Means and standard deviations of the ages of both sexes are presented in Table 4.

Otoliths collected from 66 shad were used for validating the ages derived from the reading of scales. The mean difference in age between the methods was 0.045 years, a difference which is not statistically significant (paired t-test: $p = 0.67$). The data used for this comparison are depicted in Figure 8.

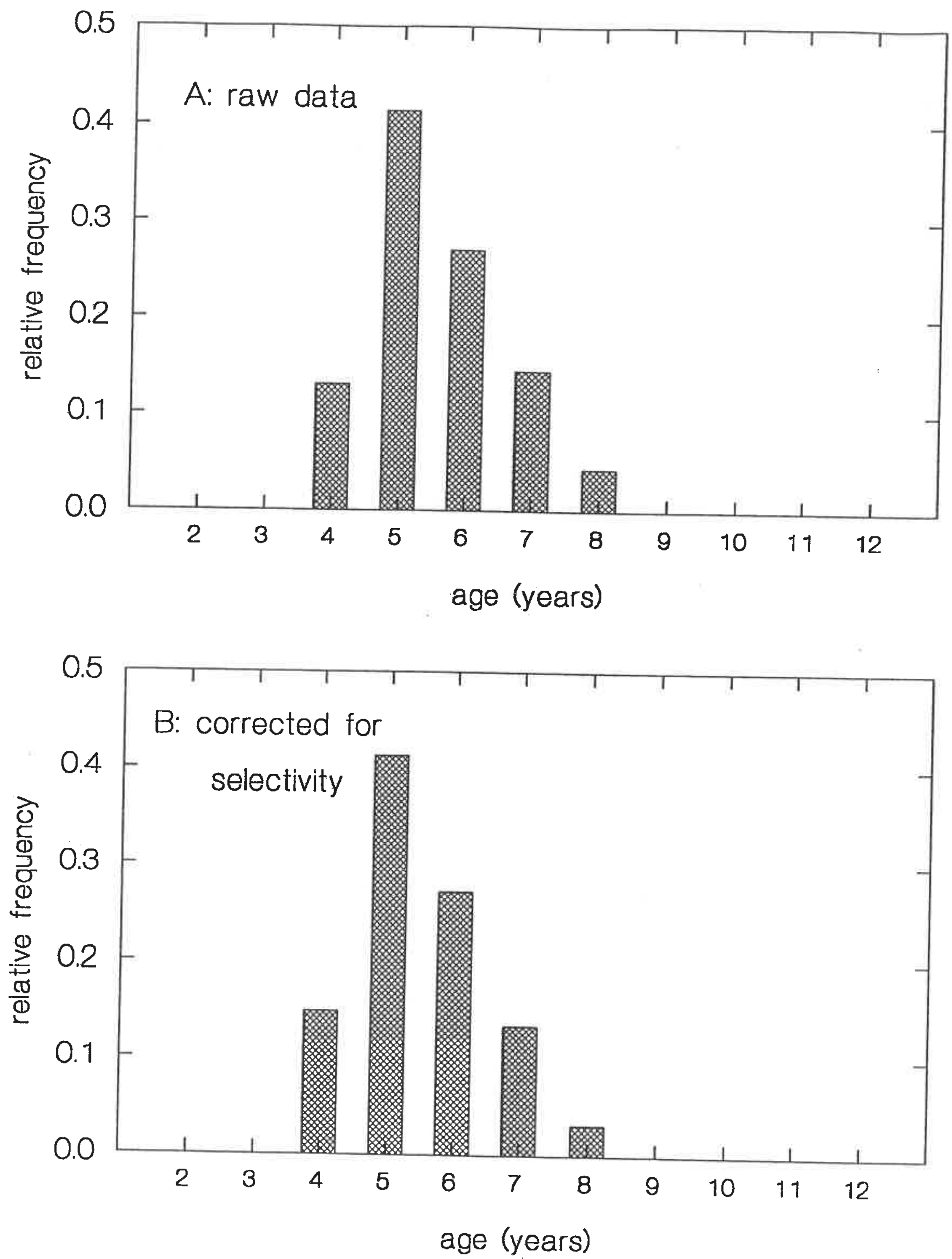


Figure 6. Age frequency distributions as estimated for male American shad in the 1996 Annapolis River spawning run, both before (a) and after (b) correcting for gillnet and sampling selectivity

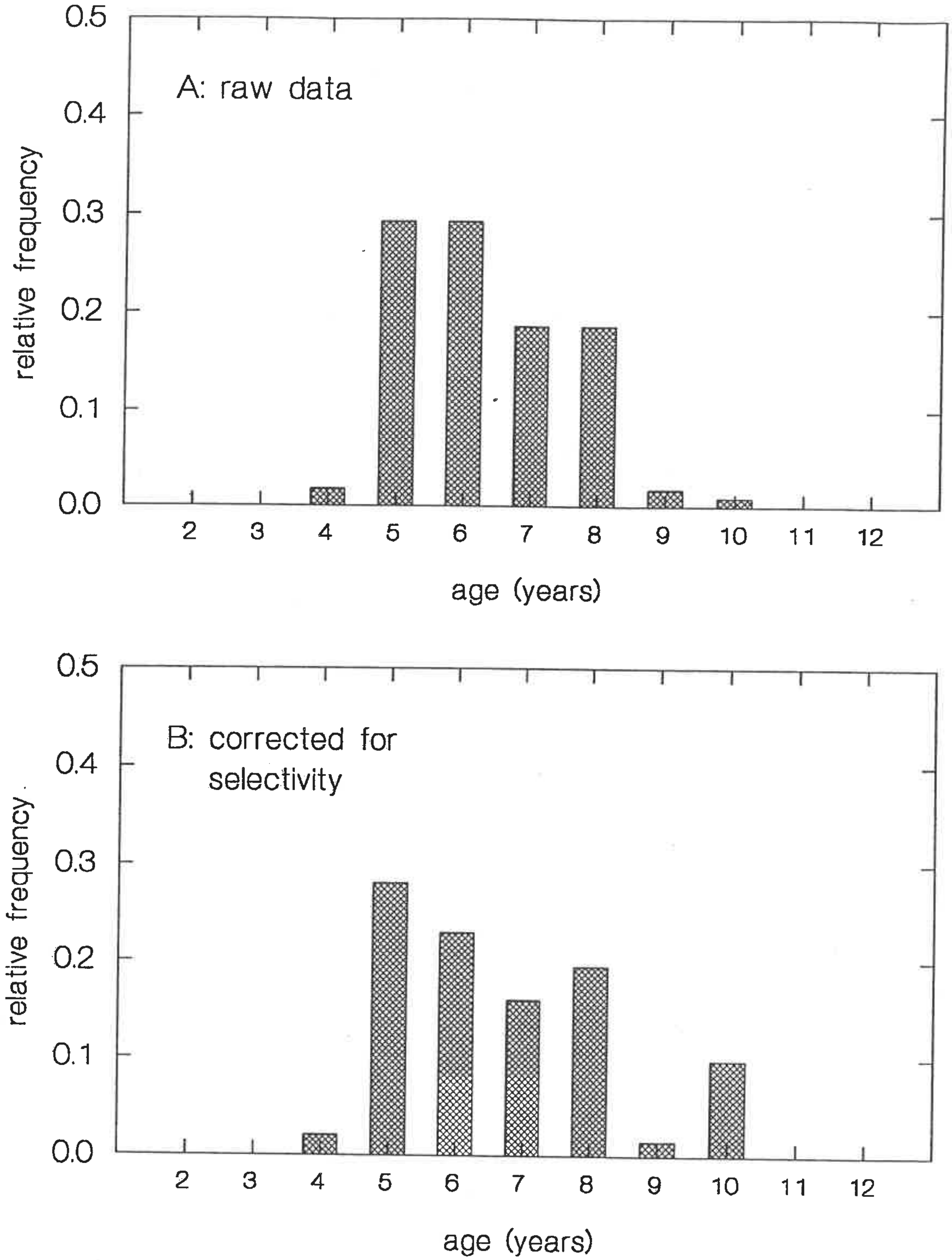


Figure 7. Age frequency distributions as estimated for female American shad in the 1996 Annapolis River spawning run, both before (a) and after (b) correcting for gillnet and sampling selectivity

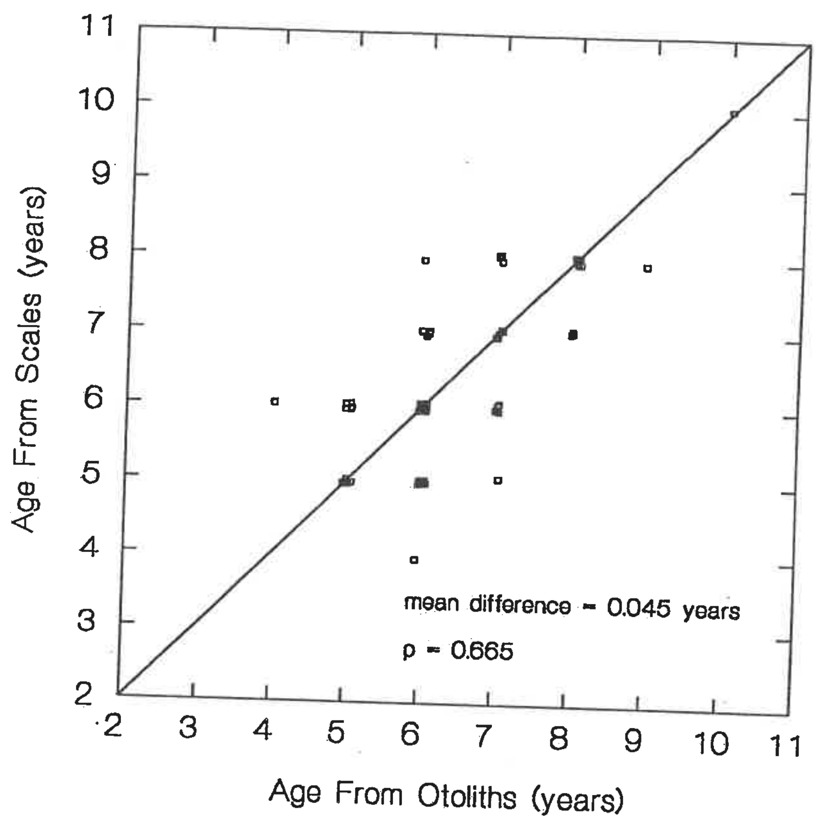


Figure 8. Comparison of ages determined by reading otoliths with ages determined by reading scales from the same fish. Points are jittered so as not to overlap.

Table 5. Mean age and standard deviations for the 1995 Annapolis River American shad spawning run.

estimate based on:	Mean Age (yr.) ± Standard Deviation Males	Females
uncorrected data	5.56 ± 1.03	6.32 ± 1.22
corrected data	5.49 ± 1.01	6.67 ± 1.61

Age at first maturity ranged from 3 to 6 years for males and 4 to 8 years for females (Figure 9). Mean age at first maturity was 4.66 (s.d. = 0.60) for males and 5.27 (s.d. = 0.67) for females. Just over half of the fish were repeat spawners (55.3 % for males, 53.1% for females).

3.3.4 Growth

The Von Bertalanffy growth curves (Figure 10) were derived for both sexes of American shad captured during this assessment. The theoretical maximum length for the males was estimated as 454.8 mm and for the females as 530.6 mm. Growth coefficients were estimated as 0.48 and 0.29 for the males and females respectively.

3.3.5 Mortality

Total instantaneous mortality rates were estimated as 0.52 (corrected for gillnet selectivity), and 0.61 (not corrected for gillnet selectivity) for males and similarly as 0.49 and 0.16 for females. These relationships, fitted to the adjusted size of each age class, are shown in Figure 11.

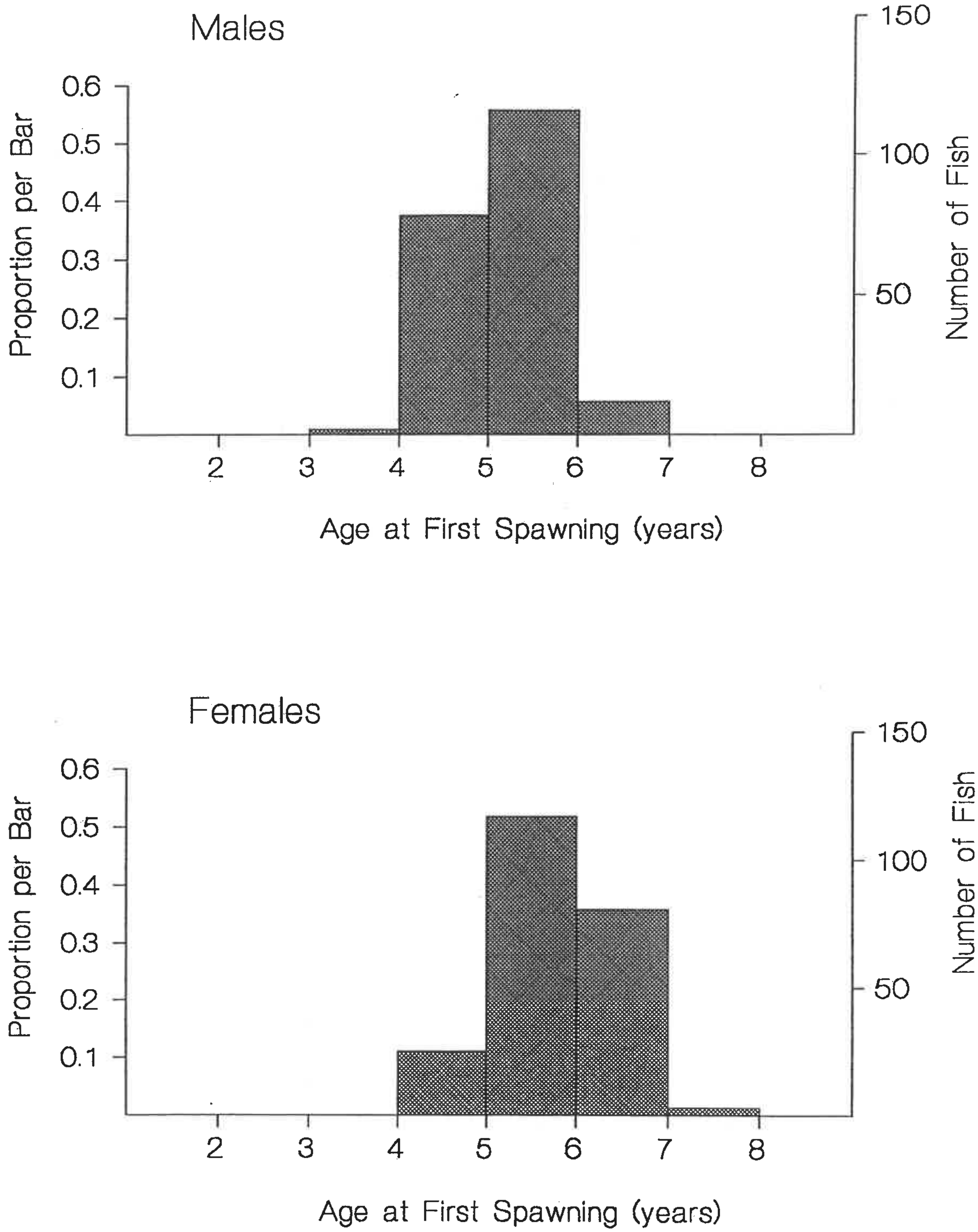
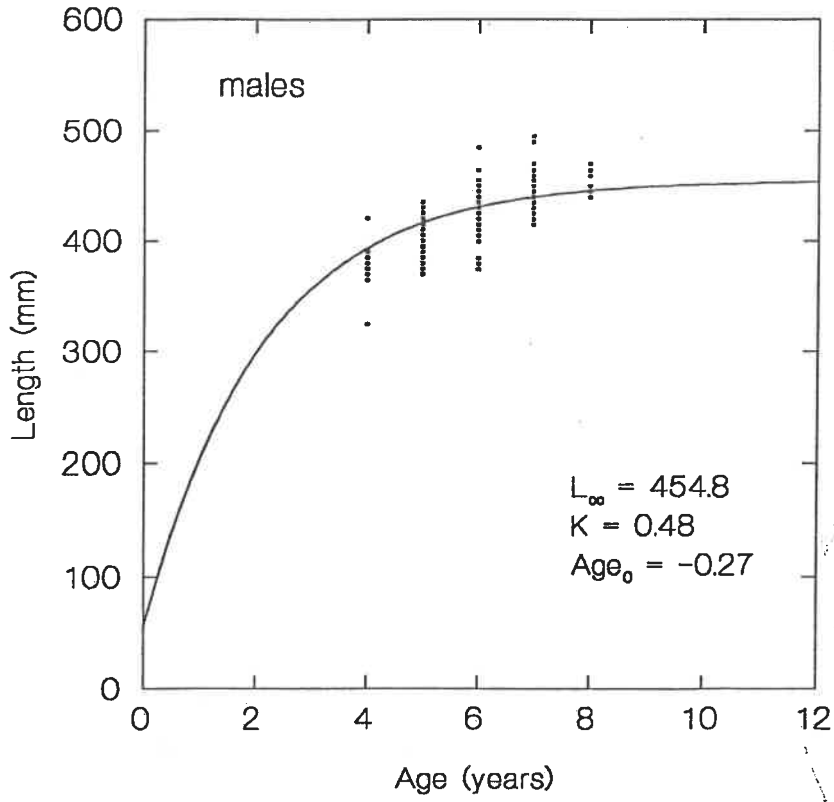


Figure 9. Frequency distributions showing the age at first spwning for male (top) and female (bottom) American shad captured during this assessment.



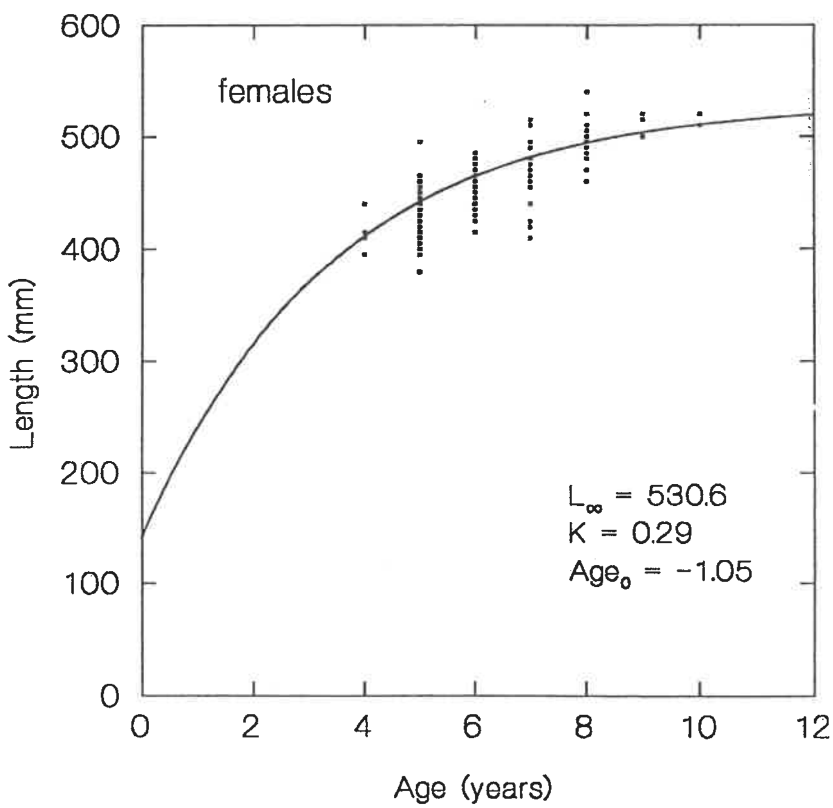


Figure 10. Von Bertalanffy growth curves overlaid against the fork length at age data collected during this assessment for males (top) and females (bottom).

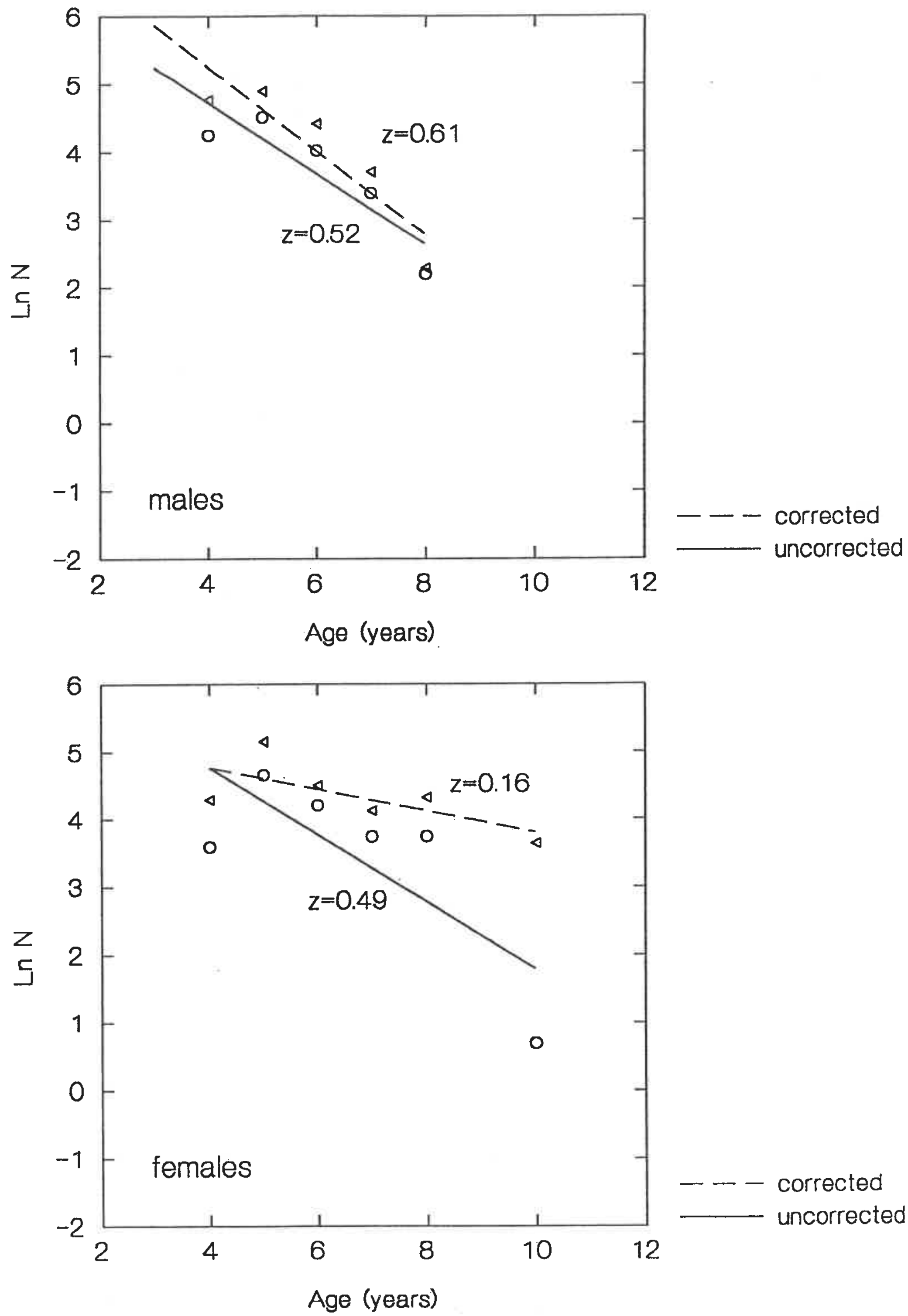


Figure 11. Total instantaneous mortality of male (top) and female (bottom) American shad from the 1996 Annapolis River spwning run.

3.4 Comparisons With Previous Assessments

A number of trends appear evident when comparing the results of this assessment with those of previous years. The mean fork lengths of both males (414 mm) and females (460 mm) were slightly higher than those determined in the 1995 assessments (413 mm and 447 mm for males and females respectively), but lower than those of either the 1981 and 1982 pre-operational assessments (means of 461 mm and 516 mm for males and females) and the 1989 and 1990 post-operational assessments (males = 446 mm, females = 482 mm F.L.), as shown in Figure 12.

A similar pattern exists for maximum observed fork length (Figure 13). While higher than the maximums observed in 1995 (males = 490 mm, females = 525 mm F.L.), the 1996 maximum lengths (males = 510 mm, females = 540 mm F.L.), are substantially lower than those encountered in either the pre-operational assessments (means of 553 mm and 603 mm F.L. for males and females respectively), or the 1989 and 1990 assessments (males = 544 mm, females = 570 mm F.L.).

The mean age of male American shad (5.56 yr.) was lower than that determined in any of the previous assessments (Figure 14a), while the mean age of females (6.32 yr.) was lower than that determined for all years except 1990 (Figure 14b). The maximum observed age of a male was 8 years, which is the lowest observed in any of the assessments (Figure 15a). The oldest female encountered in this assessment was 10 years old. This age is consistent with other post-operational assessments, but represents a decrease from pre-operational years (Figure 15b).

The mean age at first spawning (determined from the location of the first spawning mark on all scales aged) may be increasing in the population (Figure 16). The mean age at first spawning for females (5.27 years) was higher than in any of the previous assessments, while this statistic for males (4.66 years) was higher than in all previous assessments except 1995. Corresponding with this pattern, we captured relatively fewer repeat spawning females than in previous assessments (Figure 17b), while repeat spawning males appeared less abundant during 1996 than in any of the previous assessments except 1995 (Figure 17a).

As determined in these assessments, Von Bertalanffy's theoretical maximum length has apparently decreased from about 567 mm for males and 642 mm for females in pre-operational assessments (the means of the 1981 and 1982 assessments), to 455 mm and 530 mm for males and females respectively in 1996 (Figure 18). Consistent with this decrease is a corresponding increase in Von Bertalanffy's growth coefficient from about

0.22 for males and 0.16 for females in 1981 to 0.48 and 0.29 for males and females respectively in 1996.

Various transformations have been applied to the data prior to calculating total instantaneous mortality in different assessments, and therefore mortality is not really comparable between years (see Gibson and Daborn 1995). However, mortality was estimated as about 0.36 (males) and 0.23 (females) in the pre-operational assessments (Figure 20). Without correcting for sampling selectivity, mortality was estimated as 0.52 and 0.49 for males and females respectively during this assessment.

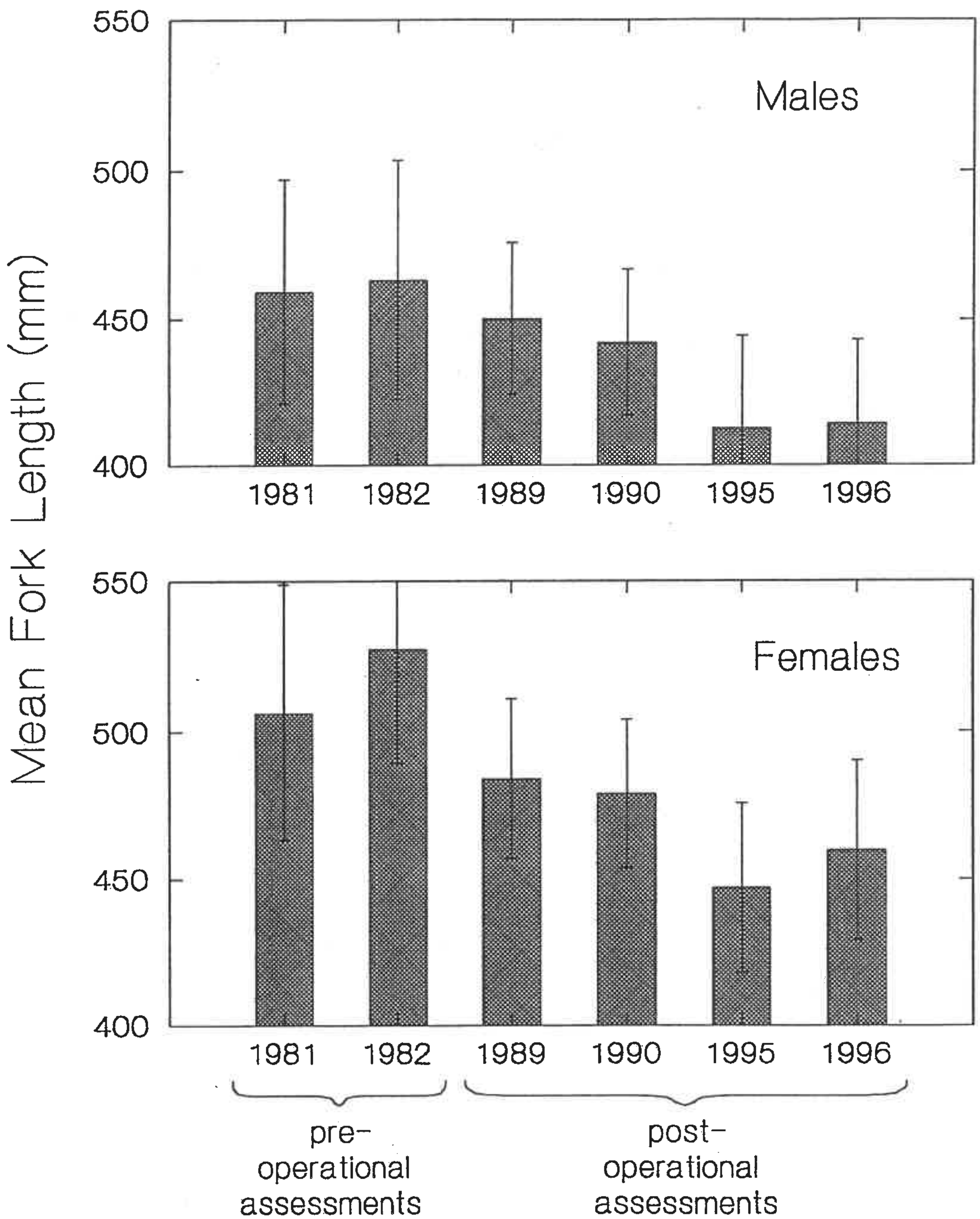


Figure 12. Mean fork lengths of male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River (error bars are standard deviation).

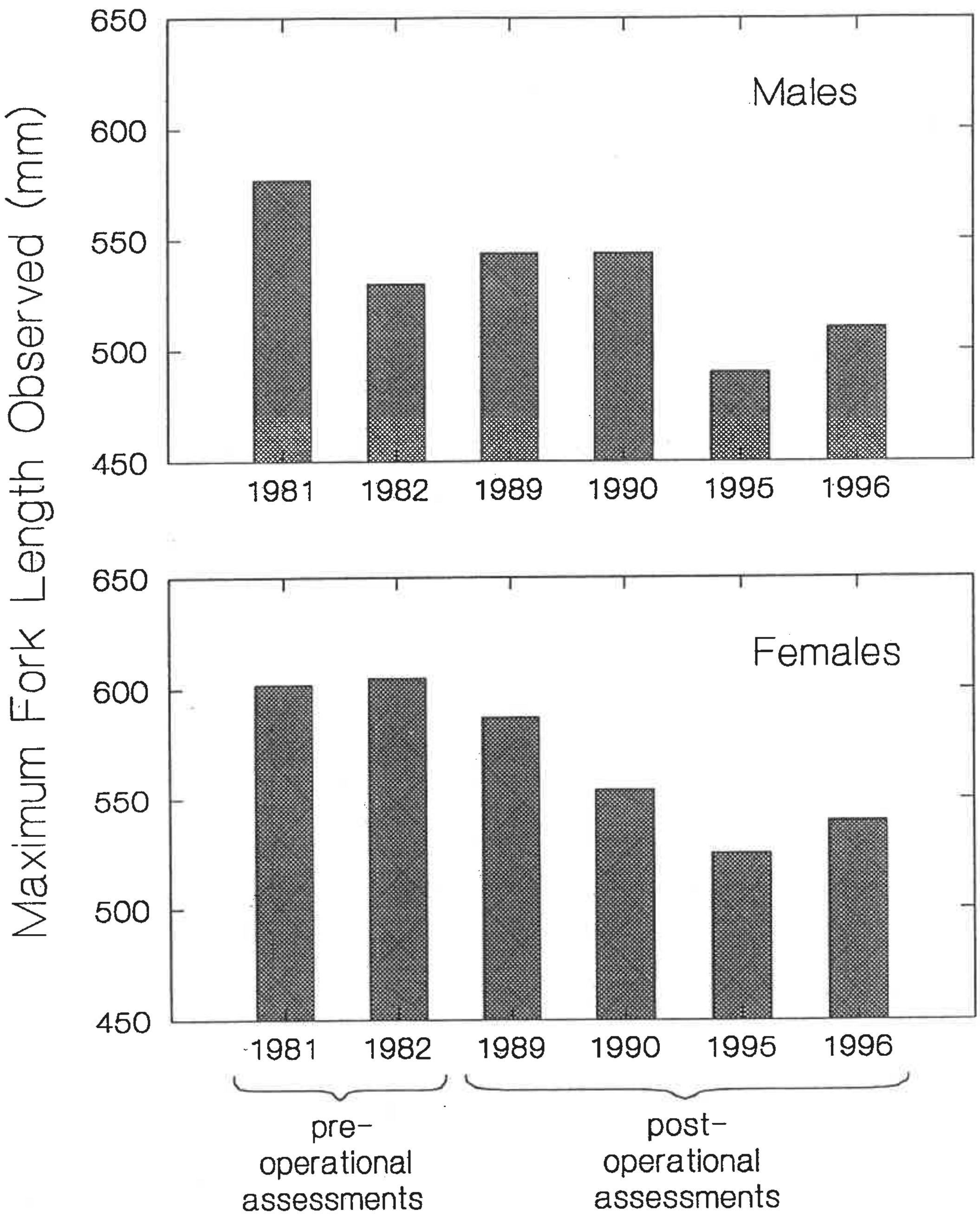


Figure 13. Maximum fork lengths of male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River.

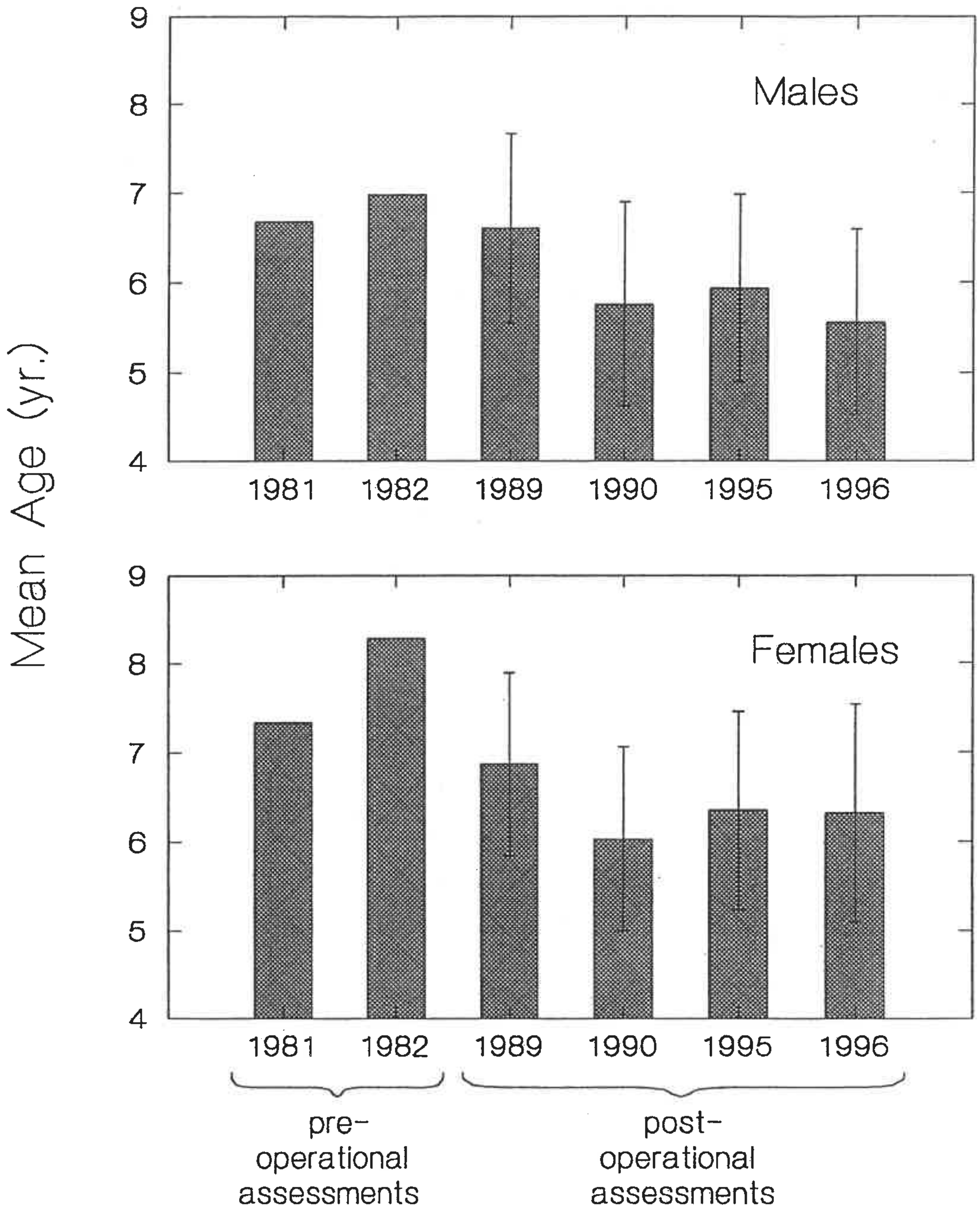


Figure 14. Mean ages of male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River (error bars are standard deviation).

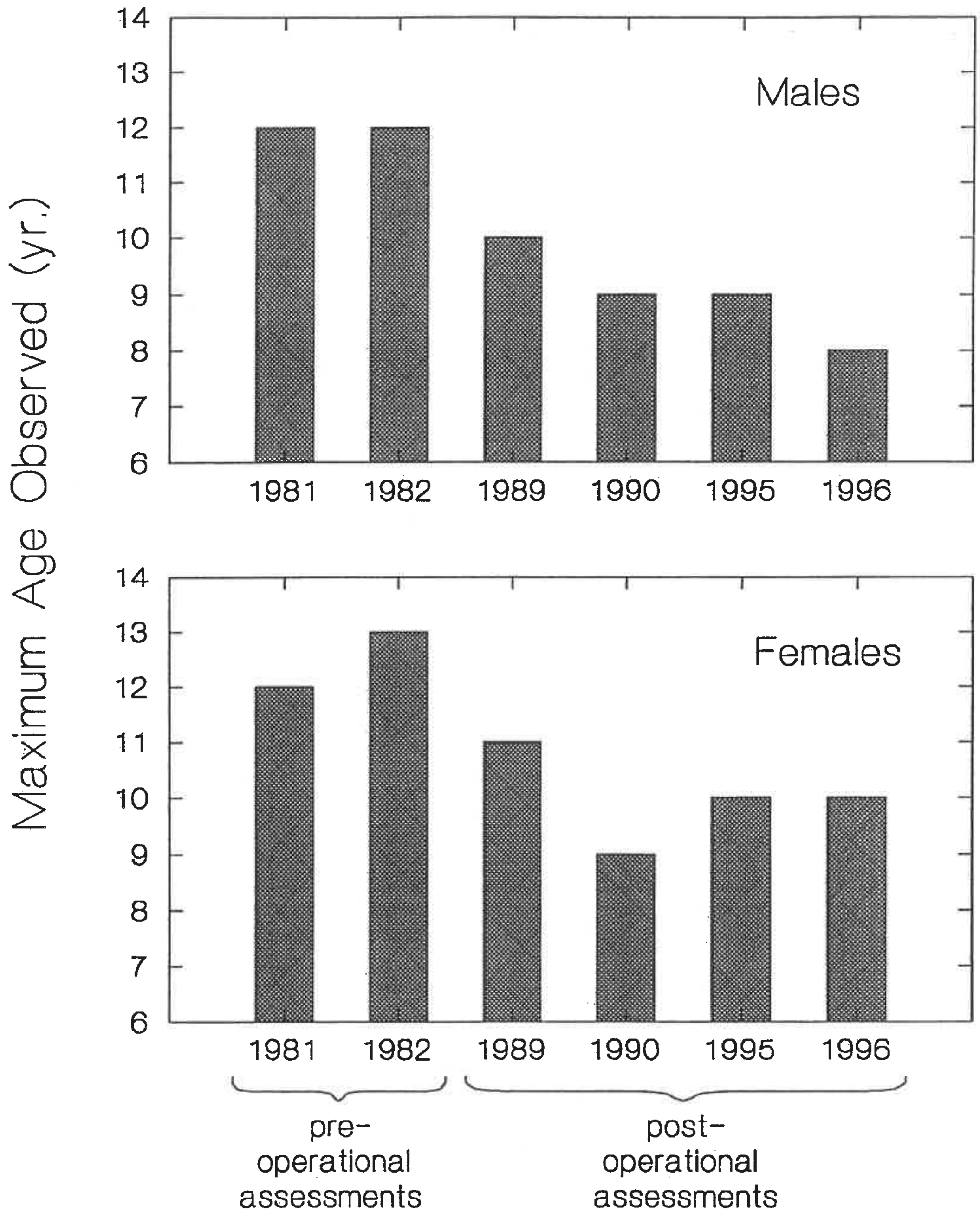


Figure 15. Maximum ages of male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River.

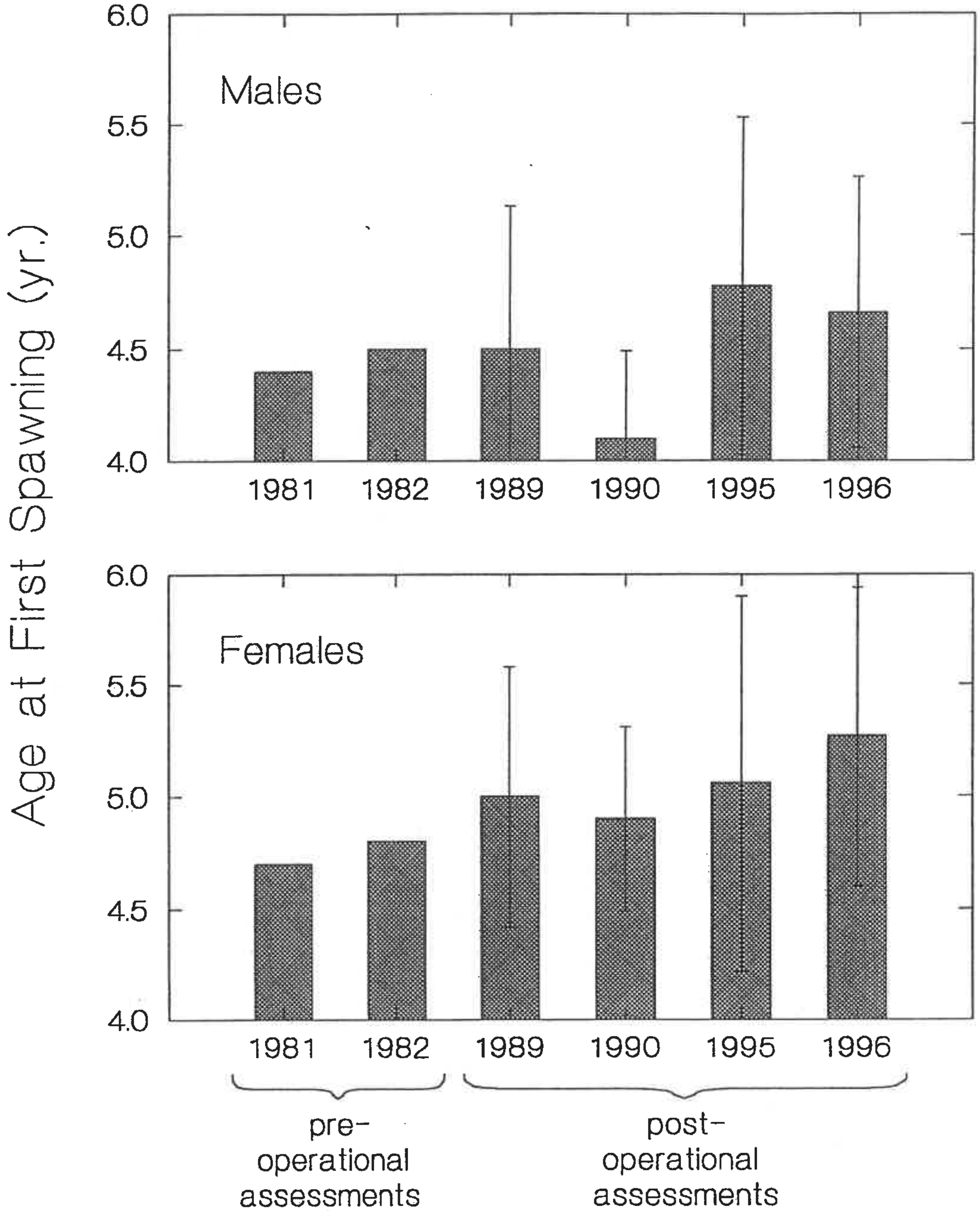


Figure 16. Mean age at first spawning of male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River (error bars are standard deviation).

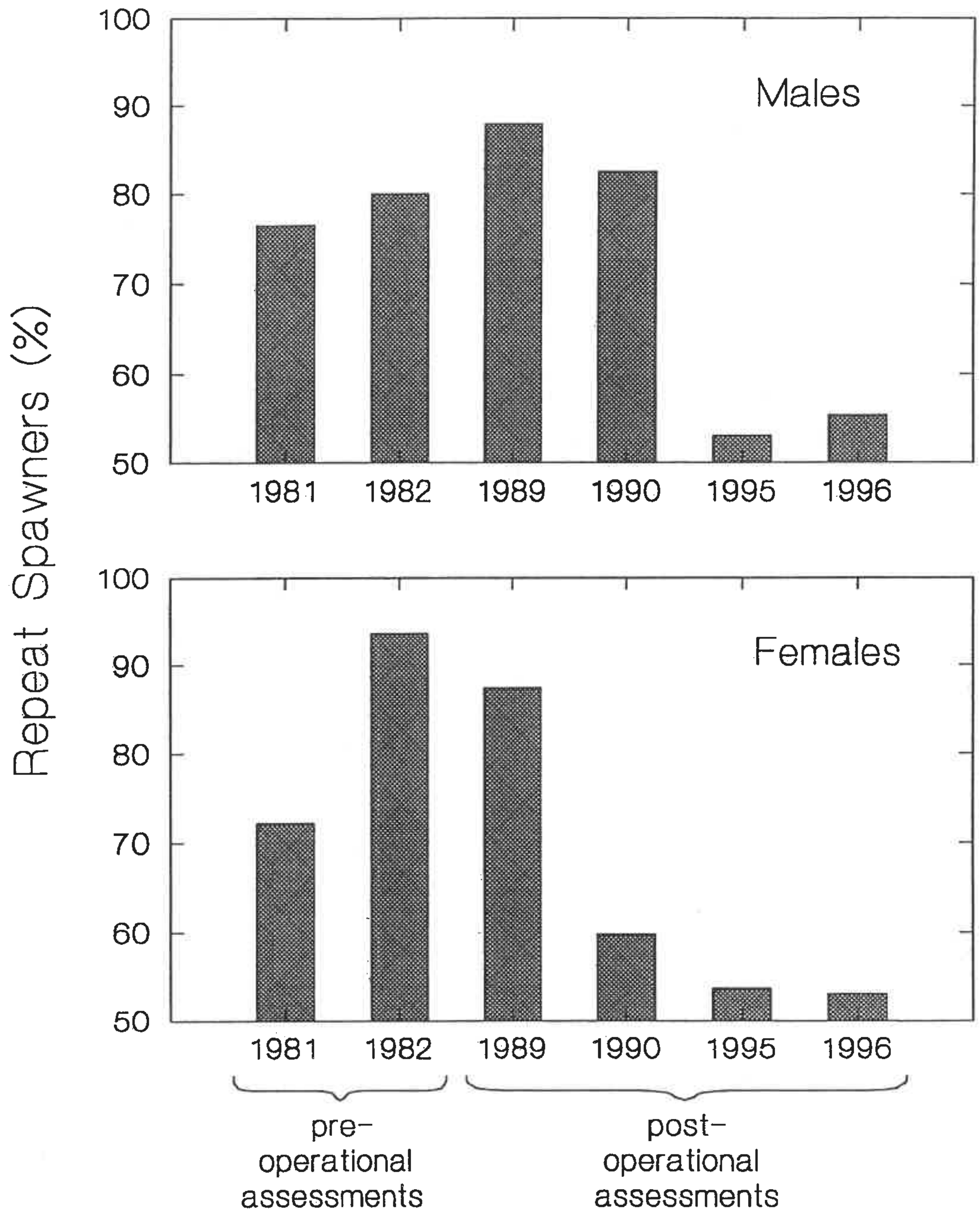


Figure 17. Percentage of male (top) and female (bottom) American shad which had previously spawned as estimated during each of the 6 assessments conducted on the Annapolis River.

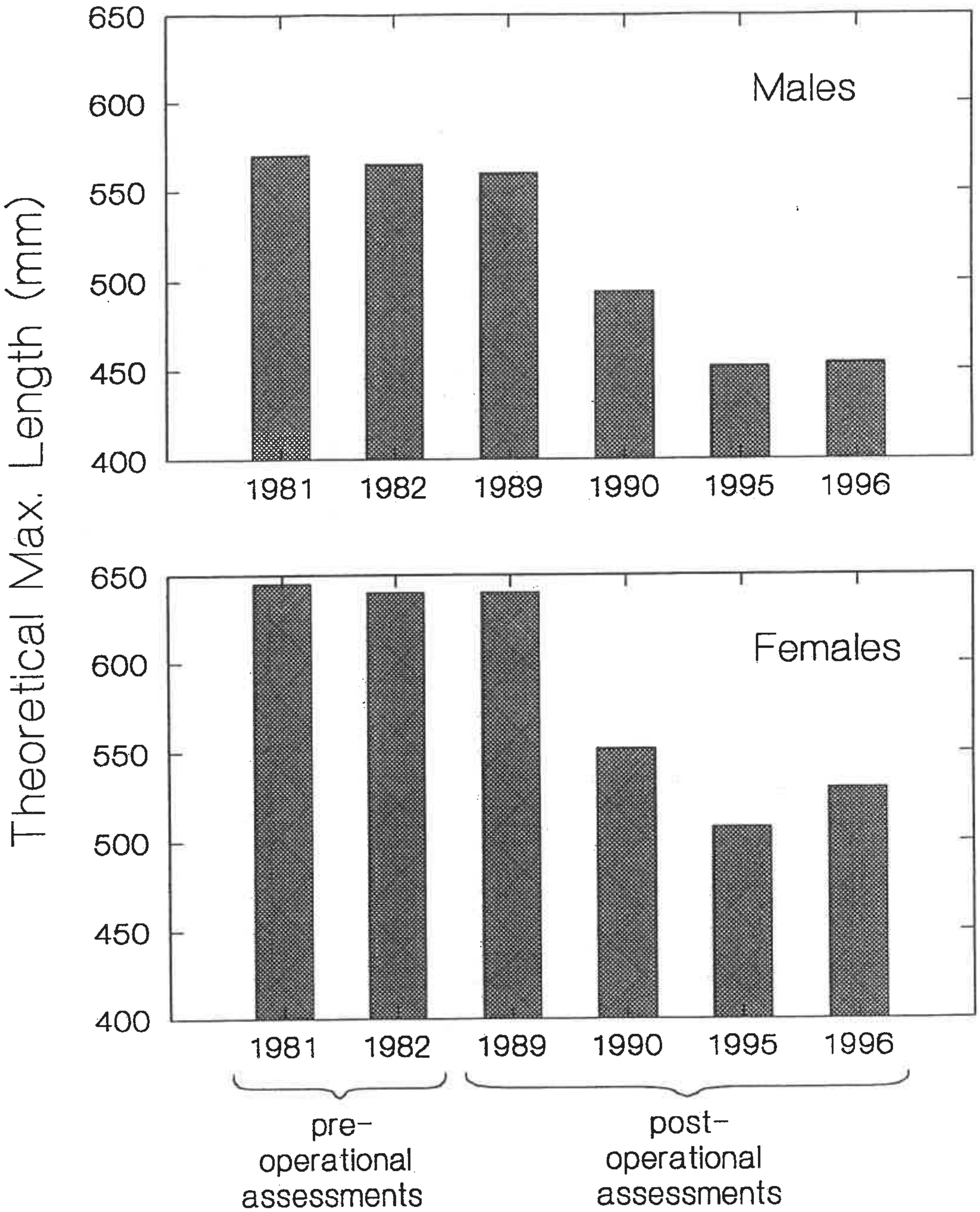


Figure 18. Von Bertalanffy's theoretical maximum lengths estimated for male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River.

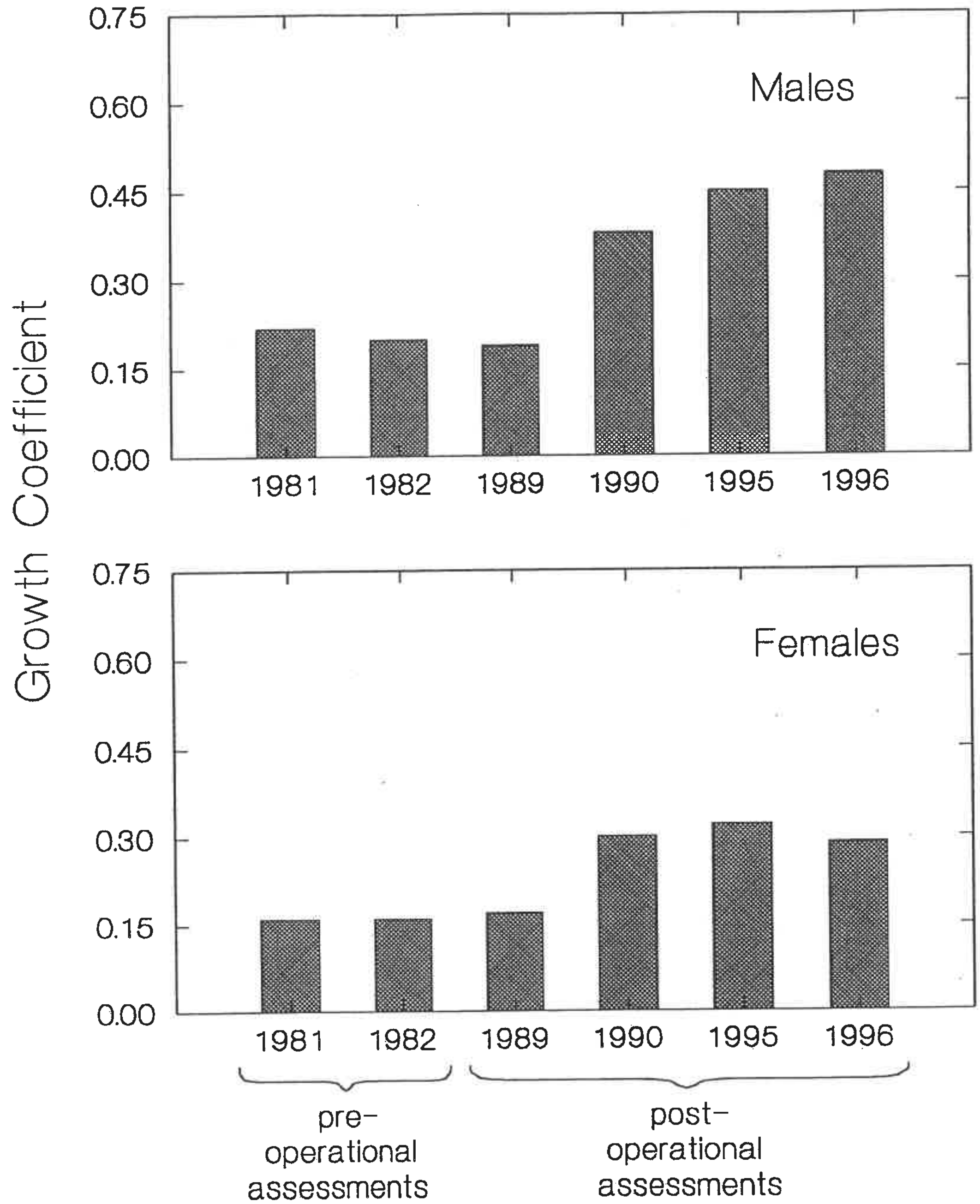


Figure 19. Von Bertalanffy's growth coefficients estimated for male (top) and female (bottom) American shad captured in each of the 6 assessments conducted on the Annapolis River.

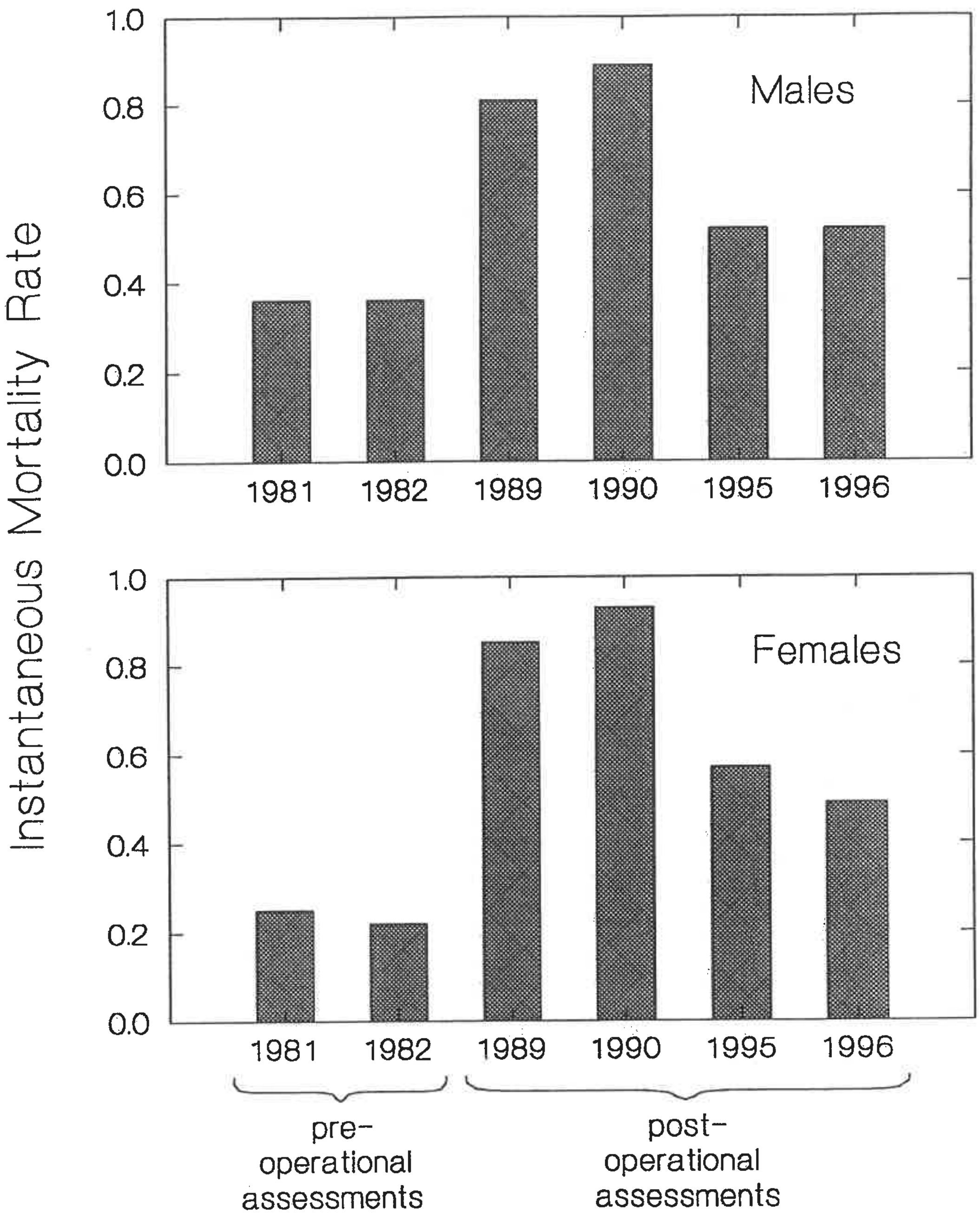


Figure 20. Total instantaneous mortality of male (top) and female (bottom) American shad estimated each of the 6 assessments conducted on the Annapolis River.

4.0 DISCUSSION

4.1 Population Estimate

We began this assessment with the understanding that a certain element of luck would be required if we were to obtain a precise population estimate. We hoped to be able to mark about 1500 to 2000 shad during the upstream migration, but only succeeded in marking 774. The number of fish examined for marks upriver (484) was also considerably lower than hoped for, due at least in part to higher water levels encountered this year in comparison with 1995. In 1995, American shad could be found holding in pools rendering them more accessible for capture, a phenomenon only encountered on a few occasions during this assessment.

Obtaining only one valid recapture given the number of shad marked and the number examined for marks is not an unlikely scenario if the size of the 1996 American shad spawning run was about the same size as during the pre-operational assessments. As shown in Table 1, if the population were about the same size, the number of valid recaptures during the first part of recapture phase given the number of shad marked and examined for marks would be expected to be one or less about 20 % of the time, while during the second part of the recapture phase the number of valid recaptures should be one or less about 34 % of the trials (although the probability of both events occurring simultaneously is 0.07). If the population were larger, the above scenario becomes more likely.

Besides the relationship between population size, number of fish marked and the number of fish examined for marks, other factors could also help to account for the low number of recaptures. Efforts are made to randomize the distribution of marks throughout the population. However, because shad upriver travel in schools, the probability of fish in the same school being marked or unmarked is not independent of other fish in the school (the "patchiness" of the catches during the marking phase is shown in part in Appendix 1). If fish in the same school traveling upriver tend to spawn in the same section of the river, then marked fish are not distributed randomly throughout the population. While we attempted to alleviate this problem by randomizing the recapture sampling as much as possible, there are areas which were missed due either to poor accessibility by boat (upriver of Kingston and tributaries were not sampled)) or because they are unsuitable for sampling with gillnets (too shallow, water velocity too high, deadfalls, etc.). It is possible, therefore, that marked fish were missed due to non random assignment of marks and non random recapture effort. However, it is equally as possible that marked fish were more vulnerable to recapture due to their destination in the river, which would lead to an underestimation of the population size. Also possible is the scenario that the school structure breaks down as shad move upriver and that marked fish are move or less randomly distributed throughout the population resulting in no bias at all. We therefore do not know whether marked fish were randomly or non randomly distributed relative to unmarked fish, or whether that bias is positive or negative if a bias actually exists. Additional factors, such as post-handling mortality or abandonment of the spawning run after handling may also in part contribute to the low number of recaptures. Melvin et al (1985) corrected the 1981 and 1982 stock estimates for a 10 % delayed gillnet mortality.

Reducing the role of chance in estimating the size of subsequent spawning runs would require the assessments be conducted at higher levels of intensity than this assessment and preferably using gear other than gillnets. The use of gillnets for capturing fish to be marked and released requires finding a balance in fishing intensity (the number of nets fished at the same time) between maximizing the catch so as to maximize the number of marked fish while at the same time attempting to minimize the length of time fish remain in the net so as to ensure that marked fish are released in good condition (the length of time a fish remains in the net is more or less proportional to the number of fish in the net at a given time). The use of a trapnet to capture fish to be marked would resolve this dilemma as the trap could be closed when it becomes full. Additionally, handling of the fish would be significantly less as the fish would not have to be disentangled from the net, resulting in the release of healthier specimens. For these reasons a second trapnet located further upriver but below the lower limit of the spawning range should be used for recapture and both traps should be monitored for the full duration of the spawning run (traps should be in place mid-April and monitored into June). This proposed methodology is similar to that used in part by Melvin et al. (1985) for the pre-operational assessments. Placing the traps further upriver than the locations used in the 1981 and 1982 assessments should significantly improve fishing success over these studies. We tentatively suggest the lower trap should be located near Bridgetown and the upriver trap near Paradise. By monitoring the traps throughout the entire spawning run, biases associated with non random mark distributions and non random fishing effort would also be alleviated.

In summary, the biases discussed above may or may not have been responsible in part for the low number of recaptures this year. Regardless, given the number of fish marked and examined for marks, the low number of recaptures is evidence that American shad were abundant in the Annapolis River this year.

4.2 Gillnet Selectivity

The gillnet selectivity curves developed from and applied to this assessment's data are a marked improvement over those developed in for the 1995 assessment. Retention in a gillnet is really a function of girth rather than length, although length data is frequently used as it is easily collected in the field. Because female pre-spawning American shad have quite a different profile than pre-spawning males, developing separate curves for the two sexes seems appropriate. As shown in Figure 2, a single gillnet is highly selective for shad of a particular size class. A visual comparison of the corrected and uncorrected data for gillnet selectivity curves (Figures 4 and 5) show that our overall sampling protocol was slightly selective for smaller fish (particularly females), but the degree of this bias was not overly large (about 2 mm average fork length). This was more the result of chance than design, and changing the soak times of different mesh sizes or the sizes of the meshes used in the assessment would influence the degree of this bias.

The selectivity curves developed during this assessment have not been applied to the results of previous assessments. During the pre-operational studies, shad were captured using both trapnets and gillnets, and the data were pooled when reporting the results of the assessment. As discussed by Gibson and Daborn (1995), these results are not comparable with the post-operational assessments without adjusting for the selectivity of the two types of sampling gear. The 1989, 1990, 1995 and 1996 post-operational assessments were conducted with gillnets only, and to some extent, the results of these assessments are a function of the sizes of the mesh in the gillnets used during these assessments. Without correcting for gillnet selectivity, the direction of the bias can be determined by comparing the mean mesh size (weighted by soak time) used each year. The weighted mean mesh size of gillnets deployed in this assessment was 12.96 cm, larger than that of the other three post-operational assessments (Table 6), implying that the overall selectivity of the sampling protocol used in this assessment should tend to catch larger fish relative to the other post-operational assessments.

Indirect methods of estimating gillnet selectivity may not be the optimal method of adjusting data from all assessments for sampling selectivity. They require the assumptions that the probability of encounter of fish of a single size class is equal with respect to the different meshes, and that each mesh size captures the same proportion of fish in the size-class for which that mesh is most efficient (assumption of equal catchability). The first of these may be valid if net selection on a trip to the field is random and sampling intensity is relatively high. However, one objective of the field work was to mark as many fish as possible, which requires using the most efficient net sizes. Nets were therefore chosen

Table 6. Mean mesh size, weighted by soak time, of gillnets used in each of the post-operational assessments and the direction of the resulting bias relative to the 1996 assessment.

Year	Weighted Mean Mesh Size (cm)	Mean Fork Length (mm)		Direction of sampling bias
		males	females	
1996	12.96	414	460	-
1989	12.68	450	484	underestimation
1990	12.29	442	479	underestimation
1995	12.53	412	447	underestimation

haphazardly while trying to meet both these objectives. The second assumption is required if the size distribution in the population is not known, but is not valid and tends to lead to an overestimation of selectivity on the left side of the curve and an underestimation of selectivity on the right (Hamley 1975). Additionally, based on these assumptions, the selectivity of a particular mesh for a particular size class can be estimated by fitting any one of several mathematical models over the different mesh sizes for fixed size classes. The choice of a model is somewhat arbitrary and not based on a biological concept, and influences the shape of the transformed size frequency distribution. If the purpose of correcting for gillnet selectivity is to compare the resulting distributions with data collected with a trap net (such as the ones used during the pre-operational assessments), then the selectivity of the trapnet becomes a confounding factor. These problems could be circumvented by fishing gillnets beside a trapnet. In this manner the selectivity of the gillnets relative to the trapnet would be measured directly, resulting in a much more precise method of bringing all the data to a common base.

4.3 Stock Characteristics and Comparisons with Previous Years

While biases associated with the sampling methods utilized in the various assessments preclude rigorous comparisons, it appears evident that some significant changes either are occurring or have occurred in the Annapolis River American shad stock.

Mean fork lengths for both males and females (as determined by the assessments) have decreased from 461 mm for males and 517 mm F.L. for females (means of the 1981 and 1982 pre-operational assessments) to 414 mm and 460 mm F.L. for males and females in 1996 (Figure 12). This comparison is invalidated by gear selectivity and, as pointed out by Gibson and Daborn (1995), the influence of the biases comparing trapnet catches to gillnet catches is reported by Melvin et al. (1985) in the statements that the "mean fork length of the 1981 and 1982 samples [implying all shad captured using both gillnets and trapnets], sexes combined, was 481 ± 46.4 mm and 504 ± 52.4 mm respectively." and "Mean fork length of these [implying only those captured in the trapnets] shad was 501 mm in 1981 and 517 mm in 1982.".

Comparisons between 1996 and the other post-operational assessments may be more valid. Shad captured in 1996 were slightly larger on average than those captured in 1995 (414 mm vs. 413 mm FL. for males and 460 mm vs. 447 mm F.L. for females, respectively). However, given the mean size of the nets used in the assessments (Table 6), mean fork lengths would have been underestimated in 1995 relative to 1996, so it would be inappropriate to conclude that the shad were actually slightly larger this year. In 1989 and 1990, male shad captured during the assessment averaged 446 mm F.L., while females averaged 482 mm, about 28 mm larger than in 1996. Again, from Table 6 it appears that mean fork lengths in 1989 and 1990 are underestimates relative to 1996, implying that the difference in size may be even greater than shown in this comparison.

The apparent decline in maximum fork lengths (Figure 13) could also be in part due to the differences in sampling gear. As shown in Figure 2, the probability of catching large shad appears quite low relative to smaller fish given the range of mesh sizes used, and sampling selectivity again invalidates pre- and post-operational comparisons. But, as mentioned above, the mean mesh size used in this assessment was larger than that of the 1989 and 1990 assessments, implying that the probability of catching larger shad was higher in 1996. Sample size may also influence maximum lengths observed, but is probably not adequate to explain the decline since 1989 and 1990. In 1996, 827 shad were examined during the assessment, in comparison with 416 in 1989 and 620 in 1990. Given that sampling was more intensive during this assessment and that gear selectivity this year may have favoured larger fish, it appears that the decline of 34 mm for males and 30 mm for females in maximum fork length size 1989 and 1990 may be a real indication that larger fish once present in the population at that time may now be absent.

Mean and maximum ages are subject to the same sampling biases as mean and maximum fork lengths, invalidateing rigorous pre- and post-operational comparisons.

Therefore, while the mean age of both male (5.56 yr.) and female (6.32 yr.) American shad reported in this assessment are substantially lower than the mean ages in the pre-operational assessments (means of 6.83 yr. for males and 7.81 yr. for females, 1981 and 1982 combined), the extent of the decline in mean age cannot accurately be quantified without removing sampling bias from the data. This decline however, appears real, as shown by the trends in maximum ages. During this assessment, the oldest male American shad encountered was 8 years old. Eight fish of the 208 males that were aged, implying 4% of the male population were this old. In 1982, the oldest male American shad encountered was 12 years of age and about 35 % of the males aged were 8 years old or older. Similarly, the oldest female American shad encountered in 1996 was 10 years old (2 shad were this age representing <1 % of the females aged). In 1982, the oldest female American shad encountered was 13 years of age and about 20 % of the females aged were 10 years old or older. While sampling selectivity may account for part of the difference between 1982 and 1996, it is seems unlikely that 35 % of the male and 20 % of the female American shad would be under-represented in 1996 to this degree for this reason. Sampling biases would have to be factored out of both the pre-operational and post-operational data in order to determine more accurately the degree of this change.

Mean ages have not decreased between the 1989 (males = 6.61 yrs., females = 6.87 yrs.) and 1990 assessments (males = 5.76 yrs., females = 6.03 yrs.) and 1996 (males = 5.56 yrs., females = 6.32 yrs.) to the same extent as the decrease in mean length, possibly indicating a decrease in size at age. The validity of this trend is dependent in part on the representiveness of the samples collected each year (differences in timing and net choice could influence representiveness) and on the consistency of aging methods between assessments. Assuming the trend is valid, it could be consistent with size-selective turbine mortality acting within age classes, but given that the between age size differences are small relative to the size of the fish, it seems more likely some other factor influencing mean size at age. This trend also seems to be to be occurring in other populations. For example, it appears that in that both males and females in the Susquehanna River display a reduction in mean size (FL) at ages 4 through 7 between the mid-1980's and mid-1990's. The amount of this reduction is about 5 - 10% (Richard St. Pierre, unpublished data). A more thorough review of trends occurring in other American shad stocks would help interpret these statistics, and between year size at age (corrected of gear selectivity) comparisons should be made for each age class to determine whether the trend is real.

Age at first spawning, as determined by the location of the first spawning mark on scales, may be increasing in the population (Figure 16). This increase would be consistent with a decrease in survivorship associated with the spawning run relative to the pre-operational years. Even if the proportion of shad in each year class spawning for the first time remained the same, this statistic would tend to increase with increasing turbine mortality or some other factor acting during the spawning run, since fish spawning at earlier ages would be selected against in the population. So even if no behavioral changes have occurred, because the statistic is estimated from the position of the first spawning mark on all scales aged, shad which spawned at younger ages would have a lower probability of surviving to be captured in other years, causing an apparent increase in this statistic. The increase observed between pre- and post operational years is interesting because it is consistent with increased mortality associated with the spawning run during this time period. Again, sampling selectivity would need to be factored out of all assessments to determine the degree of this increase. The argument however, is that sampling with gillnets selects for smaller, younger fish, which would tend to increase the percentage of young, virgin fish, negatively biasing the age at first spawning. For this reason, the increase in age at first spawning may actually be greater between the pre- and post-operational assessments than reported here. Consistent with this pattern is the decrease in percent repeat spawners from about 78 % for males and 83 % for females as determined in the pre-operational assessments to about 55 % for both sexes in 1995 and 1996.

The increase in Von Bertalanffy's growth coefficient from about 0.22 for males and 0.16 for females in 1981 to 0.48 and 0.29 for males and females respectively in 1996. This increase should not be interpreted as an increase in growth rate, but as an increase in the rate of change of growth. Because, older, larger shad are missing from the population, theoretical maximum lengths are apparently decreasing, so that shad are reaching the maximum lengths encountered at a younger age, hence the increase in the growth coefficients.

Andrews and McKee (1991) suggest that post-spawning adult turbine mortality should reduce adult abundance which should increase the growth rates of survivors due to decreased competition for food (this hypothesis assumes that growth of shad while at sea is actually limited by food availability). This hypothesis could better be tested using size at age comparisons rather than Von Bertalanffy's growth equation.

We suggest here that size at age is a function of both growth and age at maturity (a shad which matured at an earlier age should be smaller than a shad of the same age which matured later, other factors being equal). Shad which mature earlier have a greater probability of not surviving turbine passage and therefore are selected against in the population. This should lead to a increase in size at age if other factors influencing the population have not changed. A decrease in size at age therefore, which is implied by the overall decrease in mean length without a corresponding decrease in mean age, is not consistent with the hypothesis that turbine mortality is the only factor responsible for the changes being observed in the population. This data requires further analysis to determine if this is indeed the case.

Instantaneous mortality rates are reported for the population as a whole in each assessment after adjusting for immature fish not present in the spawning run and in 1995 and 1996, for sampling selectivity. Because these transformations have a marked influence in the rates reported (see Figure 11, for example) and this influence may mask the actual between year trends, a better comparison might be to compare mortality rates in each age class rather than a single statistic summarizing the population as a whole. While it is difficult to interpret mortality rates in this assessment for the above reasons, it appears accurate to say that mortality rates have increased substantially since the pre-operational assessments simply because the larger, older fish once prevalent in the population are now absent.

If year class size is mediated in a manner similar to the Connecticut River stock, that is not by the size of the spawning run, but by hydrographic, meteorological conditions and and their effects on larval feeding (Crecco and Savoy 1984), juvenile turbine mortality may actually be a more serious problem than that of adult turbine mortality. Juvenile mortality would directly reduce year-class recruitment after the effects of compensatory processes that normally stabilize population size. This could lead to a reduction in the size of the population in direct proportion to the rate of mortality. Adult turbine mortality, on the other hand, would tend to remove post-spawning adults (except when sluicing through the turbine during upstream migration) thus decreasing only the size of older year classes. In other words, juvenile mortality would directly reduce recruitment into the spawning population, whereas post-spawning adult mortality acts only after the fish have had a chance to spawn once. While juvenile mortality caused by passage through the turbine has been estimated (Stokesbury 1987, Stokesbury and Dadswell 1991), the lack of an adequate control calls to question the validity of these estimates (Gibson 1996). Further work is needed in this area to resolve this issue.

The Annapolis River American shad population appears now to be comprised of younger, smaller fish than was the case about 15 years ago. If year class strength is determined by hydrographic and meteorological conditions shortly after the time of hatching, then a population comprised of fewer year classes may leave the population susceptible to recruitment failure if unfavorable environmental conditions occur in sequential years.

5.0 CONCLUSIONS

Assessments of the American shad spawning run have been conducted for 6 years to date. Two of these assessments (1981 and 1982) should be indicative of population demographics prior to the Annapolis Tidal Generating Station coming on-line. The 1989 and 1990 assessments represent its status at about the time that the first juveniles passing through the turbine would be returning to spawn (first generation adults), and the 1995 and 1996 assessments were conducted after sufficient time has passed that second generation adults are returning to spawn. While the resulting database contains numerous biases due to factors such sampling methodologies, timing of sampling and data transformations, there is still considerable evidence that major changes have occurred in the population. While the biases may preclude rigorous statistic comparisons determining the degree to which parameters have changed, it appears these changes are real and not a manifestation of methodological changes. In some instances, for example mean length comparisons between 1990 and 1996, sampling biases would be expected to under estimate the degree of the change.

Many of these changes, such as decreases in mean and maximum lengths, mean and maximum ages, percent repeat spawners and theoretical maximum lengths, and increases in age at first spawning, growth coefficients and instantaneous mortality rates are consistent with significant post-spawning adult turbine mortality. Others, such as a decrease in size-at-age, may be consistent with turbine mortality but are more likely indicative that other factors are also causing changes within this stock.

As previously discussed, a primary function of future assessments should be to collect data that could be used to adjust existing data for sampling bias, specifically by fishing primarily with trapnets, and by sampling with gillnets in the vicinity of the trap. The resulting selectivity curves could then be applied to data from the existing assessments.

The data from these assessments are not currently stored in one location in a single format, meaning that comparisons must be drawn based on statistics in the resulting reports. These statistics are not always calculated in the same manner (for example, population growth rates vs. individual growth rates based on back-calculated size at age data) rendering comparisons difficult. Calculation of other statistics is not always possible in the absence of raw data. Efforts should be made to compile this information in a single location.

It should be apparent to a reader reviewing these assessments sequentially (including the review of the first four assessments by Andrews and McKee 1991), that the framework for interpreting comparisons relative to the effects of the Annapolis Tidal

Generating Station has changed over time, as have opinions as to what constitutes a valid comparison. No doubt, the framework and opinions will continue to change, as more information is gathered about both the Annapolis stock and American shad stocks in general. However, a cost effective way of gaining further insight into the potential impacts of the generating station on American shad demographic patterns would be to test the existing framework with a model. Besides testing the validity of the framework, the model could be used to explore the intercompatability of changes in various stock characteristics under different turbine mortality regimes, thus determining whether turbine effects alone are adequate to explain the changes which are occurring. The model should also be able to give an indication of where the population parameters may stabilize if only the turbine is responsible for these changes.

Many population characteristics estimated in this assessment were similar to 1995, but it unknown whether trends are ongoing or if the stock has stabilized. This question can only be answered through future assessments (although a model would predict when the population should stabilize) thus expanding our knowledge of the nature and the extent of the changes. Sampling in future assessments should incorporate non-selective methods and should be "environmentally friendly", i.e. large collections, and hence large mortalities, of American shad are not a necessary part of a properly designed assessment. Gillnets are not an optimal method of capturing fish to be released, as they result in a high degree of fish handling, scale loss and stress. They are also highly selective and are difficult to manage when trying to maximize catches while ensuring that fish being released are in good condition. When possible other methods of capture should be used.

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APPENDIX 1. SUMMARY OF FIELD SAMPLING AND THE FATE OF CAPTURED AMERICAN SHAD DURING THIS STUDY.

Appendix 1. Summary of field sampling and the fate of captured American shad during this study.

Date	Location	Time	Gillnets Fished	Total Catch	Fate of Captured Fish
May 2	Bridgetown	1720 - 2300	10.1, 11.4, 12.7, 14.0, 15.2	8	all fish released unmarked
May 4 - 5	Bridgetown	2000 - 0330	11.4, 12.7, 15.2	117	112 shad marked and released, 5 sacrificed for lab. analysis
May 6 - 7	Bridgetown	2200 - 0200	10.1, 11.4, 12.7, 14.0, 15.2	91	87 shad marked and released, 4 sacrificed for lab. analysis
May 7 - 8	Bridgetown	2100 - 0200	10.1, 11.4, 14.0	38	36 shad marked and released, 2 sacrificed for lab. analysis
May 9	Bridgetown	1100 - 1330	10.1, 11.4, 14.0	84	82 shad marked and released, 2 shad sacrificed for lab. analysis
		1330 - 1700	10.1, 11.4		
May 12	Bridgetown	1530 - 2230	10.1, 12.7, 14.0, 15.2	152	137 shad marked and released, 15 sacrificed for lab. analysis
May 14	Bridgetown	0930 - 1230	10.1, 12.7, 14.0, 15.2	111	101 shad marked and released, 10 sacrificed for lab. analysis
		1500 - 1800	12.7, 15.2		
May 16	Bridgetown	0900 - 1330	11.4, 12.7	104	94 shad marked and released, 10 sacrificed for lab. analysis
		1400 - 1700	10.1, 14.0		
May 17	Bridgetown	0950 - 1430	10.1, 12.7	26	24 shad marked and released, 2 sacrificed for lab. analysis

Appendix 1 (con't). Summary of field sampling and the fate of captured American shad during this study.

Date	Location	Time	Gillnets Fished	Total Catch	Fate of Captured Fish
May 18	Bridgetown	1545 - 2030	11.4, 12.7	20	all marked and released
May 20	Bridgetown	0835 - 1700	11.4, 12.7	36	33 shad marked and released, 3 sacrificed for lab. analysis
May 23	Bridgetown	1945 - 2400	10.1, 14.0, 15.2	51	48 shad marked and released, 3 sacrificed for lab. analysis
May 29	between Middleton and Lawrencetown	0830 - 1530	11.4	28	all examined for marks, marked and released
May 31	between Middleton and Lawrencetown	0900 - 1700	11.4	49	all examined for marks, marked and released
June 3	between Kingston and Middleton	0910 - 2115	10.1, 12.7	41	all examined for marks, marked and released
June 6	Middleton	1500 - 2130	10.1, 12.7	68	all examined for marks, 67 marked and released, 1 sacrificed for lab. analysis
June 7	between Kingston and Middleton	0900 - 1645	10.1, 12.7	23	all examined for marks, 21 marked and released, 2 sacrificed for lab. analysis

Appendix 1 (con't). Summary of field sampling and the fate of captured American shad during this study.

Date	Location	Time	Gillnets Fished	Total Catch	Fate of Captured Fish
June 11	Middleton	1500 - 2110	10.1, 12.7	164	all examined for marks, 159 marked and released, 5 sacrificed for lab. analysis
June 12	between Kingston and Middleton	0930 - 1830	10.1, 12.7	106	all examined for marks, 102 marked and released, 4 sacrificed for lab. analysis
June 14	between Middleton and Lawrencetown	0855 - 1545	10.1, 12.7	5	all examined for marks, marked and released
June 17	Bridgetown	1520 - 1715 1715 - 2100	10.1, 12.7, 14.0 10.1	73	65 examined for marks and released, 8 sacrificed for lab. analysis
June 18	Bridgetown	1400 - 1935	10.1	64	62 examined for marks and released, 2 sacrificed for lab. analysis
June 20	Bridgetown	0830 - 1630	10.1	67	60 examined for marks and released, 7 sacrificed for lab. analysis
June 22	Bridgetown	0830 - 1600	10.1	24	23 examined for marks and released, 1 sacrificed for lab. analysis