An Assessment of the 1995 American Shad Spawning Run in the Annapolis River, Nova Scotia

1995 Final Report

to

Nova Scotia Power Inc.

prepared by

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EXECUTIVE SUMMARY

The causeway across the Annapolis Estuary and the Annapolis Tidal Generating Station present obstacles for migrating anadromous fish that spawn in the Annapolis River. These obstacles potentially affect both adults moving towards upriver spawning grounds, 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 150,000 individuals. Studies of the stock in 1989 and 1990, after the generating station came on-line, suggested that the population at that time was dominated by smaller, fast growing, virgin shad (Dadswell and Themelis 1990_b). This change was attributed to the virtual absence of larger, older shad once prevalent in the population.

The size of the 1995 spawning run was estimated at 57,839 (95 % confidence interval: 21,160 to 144,599). The large confidence interval is the results from there being only 2 recaptures out of 509 shad marked and 317 examined for marks. This estimate is not statistically significantly different from the 1981 and 1982 estimates at the 95 % confidence level.

The mean ages of the population recorded for the 1995 stock (5.94 years for males and 6.35 years for females) are intermediate between those recorded during the post-operational studies of 1989 and 1990, but are younger than those recorded during the pre-operational studies of 1981 and 1982 (means of 6.83 years and 8.31 years for males and females respectively). The mean sizes of shad captured in 1995 (fork lengths = 412 mm and 447 mm for males and females, respectively) were smaller than for those captured during the pre-operational studies (means of 462 mm and 516 mm for males and females). Maximum age observed decreased between these studies from 13 years of age in 1982, to 10 years of age in 1995, and similarly maximum length observed decreased from 605 mm to 525 mm. Shad captured during this study were smaller on average by about 30 mm than those captured during the 1989 and 1990 post-operational studies, although the maximum age observed was similar between these years.

It appears from the above that significant demographic changes may have occurred within this stock since the initial studies in 1981 and 1982. The decrease in size since the 1990 assessment suggests that these changes may still be ongoing. However, the use different sampling methodologies and equipment (trapnets versus various gillnets) without accounting for the selectivities of the sampling gear and methods, preclude any rigorous

comparisons at this time. Attempts to quantify the degrees of selectivity of the gillnets used in this study were not as successful as hoped. The influence of the sampling gear on the resulting stock descriptions needs to be factored out of the existing studies so that valid between year comparisons may be made.

When interpreting the changes occurring within this stock in terms of turbine-related mortality, the status of other shad stocks should be included as a gauge of the influence of other factors, either intrinsic or extrinsic, which may also be influencing demographic patterns within this stock. Given that this stock does not appear to be in a state of stasis, assessments should be continued so that current trends may be identified.

ACKNOWLEDGEMENTS

This project would not have been possible without the hard work of a number of people. The field crew consisted of one full time member, Mike Kellock, and part time assistance in the field was provided by Josée Parent, Donnie Burke, Sean Gillis and Ken Meade of Nova Scotia Power Inc., and Nicole Humble and Curtis Dolliver from the Acadia Centre for Estuarine Research. Mike Dadswell provided advice on experimental design, field methodology, data analysis and reading scales, and provided the supplementary gillnets when our smaller, panel nets were not catching many fish. Ms. Josée Parent also provided excellent logistic help and a wealth of ideas on behalf of Nova Scotia Power Inc..

TABLE OF CONTENTS

2.0 INTRODUCTION

The Annapolis River and Estuary in Nova Scotia support a large population of American shad which is one of the few that is not commercially fished by selective gear in its natal river (Melvin *et al* 1985). In 1960, a dam was built across the estuary near Annapolis Royal, limiting the tidal exchange upstream of the dam. The Annapolis Tidal Generating Station was constructed during 1980 - 84, which, together with the causeway, present obstacles for migrating anadromous fish that spawn 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: two fishways and the turbine tube.

A number of studies have attempted to assess the impact of the Annapolis Tidal Generating Station on migrating alosines by direct measurement of turbine mortality. Stokesbury and Dadswell (1991) reported that mortality of juvenile clupeids passing through the turbine was 46.3 %. This estimate is probably biased high (Andrews and McKee 1991) due to mortality problems associated with the fish collection techniques. During a fishway utilization study, Gibson and Daborn (1993) were unable to distinguish between mortality caused by the ichthyoplankton nets used to sample the fishways and turbine tailrace and mortality associated with passage through the turbine. Hogans (1987) reported that the results of a hydro-sonic telemetry study indicated that 21.3 % ± 15.2% (90 % C.I.) of adult, post-spawning American shad may not survive passage through the turbine. Andrews and McKee (1991) considered this to be a reliable estimate.

Turbine related mortality alone does not present a complete picture of the impacts of the Annapolis causeway and the Annapolis Tidal Generating Station upon migratory fish species, as two other routes of passage exist through the causeway. The results of studies of fishway utilization by migrating alosines are conflicting. Stokesbury and Dadswell (1991) reported less than 2 % of their juvenile alosine catch at the causeway came from the fishways, and concluded that the fishways do not play an important role in the passage of juvenile alosines to the sea. Gibson and Daborn (1993, 1995) used a modified net and found that 23.3 % and 19.4 % of the juvenile alosine catch came from the fishway located nearest the turbine, implying that this fishway may play a more important role in the passage of alosines than suggested by the earlier studies. Relative catch comparisons between the turbine tailrace and the fishways do not supply an adequate indication of the importance of each route as they do not take into consideration the relative cross-sectional areas of each route of passage (Gibson and Daborn 1995). The high degree of variability in the spatial and temporal flow regimes in the tailrace have so far precluded such a comparison.

Measurements of direct mortality do not provide information about the effects at the population level, because compensatory responses during other portions of the fishes' life cycle may offset the effects of turbine mortality. For this reason, a "top down" approach to the environmental effects of the Annapolis Tidal Generating Station has been recommended, in which characteristics of the shad population itself are used to determine whether the effects of the turbine are significant. The framework for such study was first laid out by Melvin *et al* (1985) and has been endorsed by Dadswell and Themelis (1990_a, 1990_b) and by Andrews and McKee (1991); both of the latter made minor changes to the framework. Parameters of interest within the framework are: population size (which could increase or decrease depending upon the level of turbine-induced mortality), mean length, mean age, maximum length, maximum age, percent repeat spawners, reproductive life span, and Von Bertalanffy's theoretical maximum length (all of which would be expected to decrease with increasing levels of mortality), and fecundity, the instantaneous mortality rate and the growth coefficient of the Von Bertalanffy growth equation (all of which would be expected to increase with increasing levels of mortality).

Melvin *et al* (1985) reported the results of pre-operational American shad population studies conducted in 1981 and 1982 which provide the basis for comparisons with post-operational studies to be conducted after the turbine came on-line in 1985. Such studies were conducted in 1989 and 1990 (Dadswell and Themelis 1990_a,1990_b), but, due to funding constraints, the population sizes were not estimated during those years. A number of potential trends were identified, including decreases in mean ages, maximum ages, and percent repeat spawners, and increases in instantaneous mortality rates, and growth coefficients. All these potential trends are consistent with significant adult turbine mortality. However, since 1989 was the first year that juveniles affected by the turbine would have returned to the river to spawn, it was probably too early to distinguish whether a real trend had developed, especially given that little is known about the year to year variability within the population.

Fluctuations in the year to year abundance of alosines have been documented. For example, O'Neill (1980), found what amounts to be a 4 to 5 year oscillation in the numbers of alewives and blueback herring in the Margaree River. It is not known whether a similar trend is inherent within Annapolis River American shad. It was therefore recommended that a series of similar studies be carried out over a number of years in order to distinguish between year to year variability within the stock and impacts the

Annapolis Tidal Generating Station may be having on the American shad utilizing the river (Andrews and McKee 1991, Dadswell and Themelis 1990_a, 1990_b).

Towards this end, the present project was undertaken with the following objectives.

1. To estimate the population size of adult American shad spawning in the Annapolis River during 1995.

2. To obtain information on 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 compare the stock characteristics with those determined by Melvin *et al* (1985) for the 1981 and 1982 stocks and those determined by Dadswell and Themelis (1990_a, 1990_b) for the 1989 and 1990 stocks to obtain information about the year to year variability inherent within this population and to assess whether an identifiable trend has developed since the Annapolis Tidal Generating Station came on-line.

The intention was to conduct the field portion of the study 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 chosen 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 in order that the ratio of unmarked to marked fish in the population could be determined, thus allowing the size of the population to be estimated using the Peterson's method (Ricker 1975).

3.0 METHODOLOGY

3.1 Field Work

The field portion of the study was partitioned into two phases, a marking phase and a recapture phase. During the marking phase, 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 monofilament gillnets that were continually monitored to minimize the length of time that a fish remained in the net. Panel nets were used during the initial fishing efforts. These nets were comprised of four 25 m long sections of differing mesh sizes (10.1, 14.0, 15.2, and 17.8 cm stretched mesh). Initial catches were low, so later efforts were supplemented by fishing 10.1 and 12.7 cm stretched mesh nets that were 100 m in length. Nets were generally fished from early evening until after midnight. Soak time, number of nets and water temperature were recorded for each sampling night. Fishing efforts were concentrated at two locations, one near Hebb's Landing and one 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' left eye, with a 3/8 inch, 26 gauge tuberculin needle. Length was recorded to the nearest 5 mm. A sample of shad was sacrificed so that otoliths could be removed for verification of the aging using scales. On each sampling trip, every i^{th} fish was retained for the sample. The value of i varied between nights depending upon fishing success. Sampling was kept to minimum in order to maximize the number of marked fish in the population.

The recapture phase consisted of surveying the river between Bridgetown and Aylesford with gillnets to determine the ratio of marked to unmarked fish in the population. Only the 10.1 cm mesh net was used during this phase and it was fished at a variety of more or less randomly chosen locations for about 0.5 hours each time. Captured fish were removed from the net, measured, examined for marks, and released back into the river.

3.2 Laboratory Analysis

American shad to be retained were measured and their sex determined prior to being sacrificed in the field. These fish were then processed in the laboratory either fresh (within 12 hours) or after freezing and thawing. Processing included weighing the fish to the nearest ten grams, and dissecting the fish to verify the sex determination from the field and to remove the otolith for verifying its age as determined by reading scales.

Age and age at first maturity 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 letting the otolith clear in 90% ethanol.

3.3 Statistical Analysis

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:

3.3.1 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 involve assuming the probability of encounter of fish of a single size class is equal with respect to the different meshes and that each mesh 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 a mathematical model over the different mesh sizes for fixed size classes. Data 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. Because of low catches in the larger mesh sizes data from this study were pooled with the data from the 1990 study (Dadswell and Themelis 1990) for the purpose of calculating selectivity.

3. 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.

4. 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 the two studies combined.

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

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

6. 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:

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

7. The relationships between m_0 and σ and size class *j* were estimated using linear regression. 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.

8. 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.

9. Weighting factors were calculated by adjusting each s_{ij} for the total soak time of the corresponding mesh size i during this study and for the area of the different nets. 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. The population estimate and stock characteristics are calculated both with and without weighting the data by this factor.

3.3.2 Population estimate

The population estimate is calculated using Chapman's adjusted Peterson's estimate (Ricker 1975):

$$N = \frac{(M+1)(C+1)}{(R+1)}$$

where:

N = population size estimate

M = the number of fish marked during the marking phase of the study

C = the number of fish examined for marks during the recapture phase of the study and

R = the number of recaptures.

Confidence intervals were obtained by treating R as a Poisson random variable, obtaining limits from a table of critical values (Appendix II, Ricker 1975), and substituting them in the above equation.

The population estimate was calculated two ways: using the unweighted data and after correcting for the probability of each fish being captured by the 10.1 cm stretched mesh used during the recapture phase of the study.

3.3.3 Stock characteristics

Mean length, maximum observed length, mean weight, mean age, maximum observed age, mean age at maturity, sex ratios, percent repeat spawners, length - weight relationships, 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 fishing efforts with the different 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.

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.

4.0 RESULTS

Field activities for this project commenced on May 5, 1995 and concluded on June 6, 1995. The time, location, nets used, number of American shad captured on each sampling day, and the fate of the captured fish are summarized in Appendix 1. During the marking portion of the study, 546 American shad were captured. Of these, 509 were marked and released back into the river, and 37 were retained for laboratory analysis. During the recapture portion of the study, 317 American shad were captured, examined for marks and then released.

4.1 Gillnet Selectivity

Mesh size and fork length information were recorded for 529 American shad for the purpose of developing gillnet selectivity curves. Of these, 45.1% were captured in the 10.1 cm mesh, 52.0% in the 12.7 cm mesh, 2.3% in the 14.0 cm mesh, and only 2 fish in the 15.2 cm mesh. No American shad were captured in the 17.8 cm mesh nets. The smaller mesh nets were fished more frequently than the larger sizes, as it was apparent in the field that the smaller nets were more efficient and one of the objectives was to maximize the number of marked fish in the river and estuary. Because the numbers of shad captured in the larger meshes was too small to be used for calculating selectivity, the data from this study were pooled with the data from the 1990 study (Dadswell and Themelis, 1990) in order to give enough points to fit the curves.

Normal probability density distributions were fitted to the proportion of shad captured by each mesh size (standardized by soak time) for each size class. Raw R^2 values for these distributions ranged from 0.973 to 0.432. The relationships between the means and variances, and the size classes were approximately linear, as shown in Figure 1. Lines fitted to these data were used to obtain final estimates of the means and variances describing the normal distribution for each size class. These distributions, overlaid against the proportion of fish captured by each mesh in each size class, are shown in Figure 2. The resulting probability distributions were standardized to a constant height and used to predict the probability of an American shad of a given size being captured by each of the meshes. These selectivity curves for each of the meshes are shown in Figure 3. Final weighting factors for each size class, which compensate for gillnet selectivity and soak time for each of the mesh sizes are shown in Figure 4.

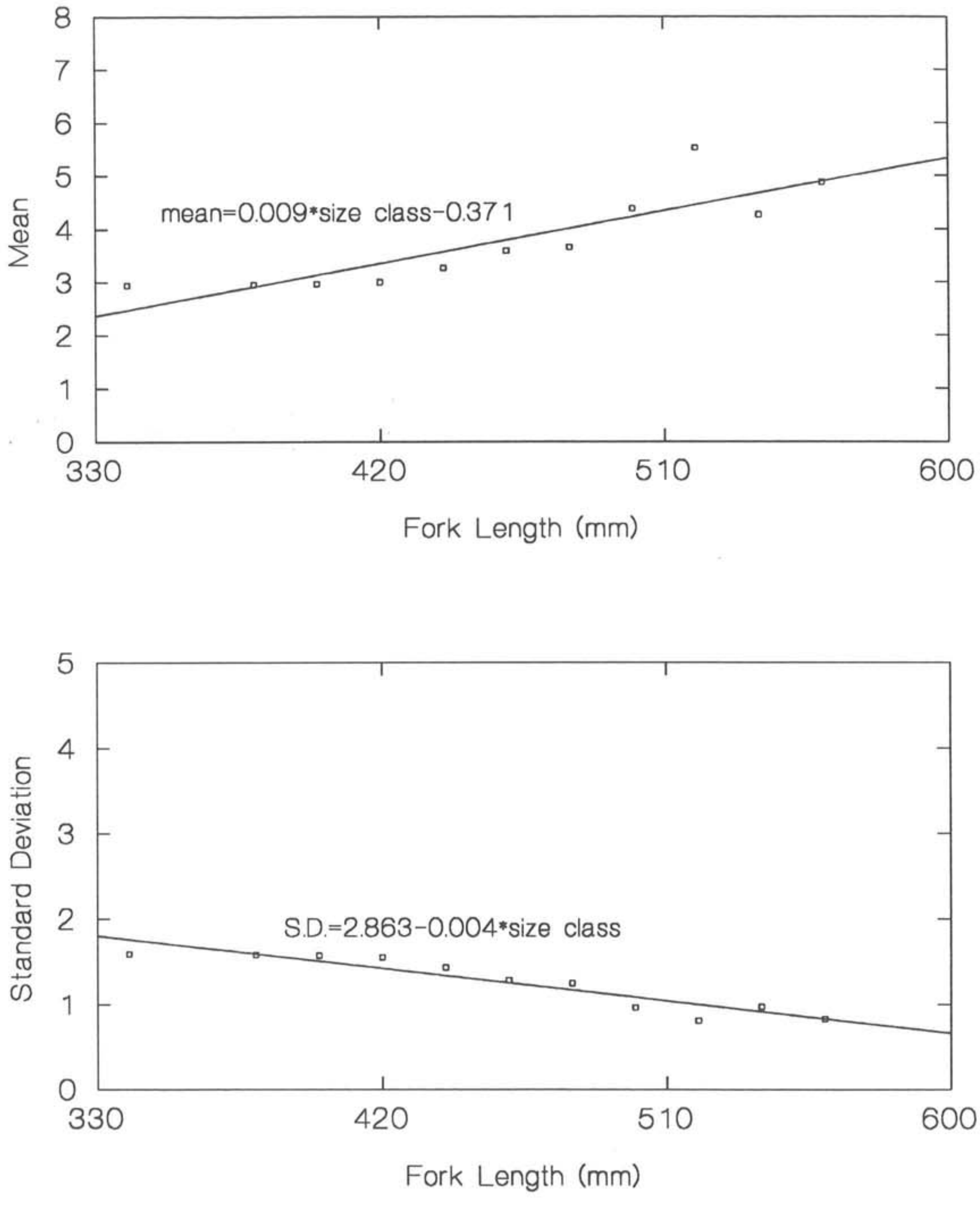

Figure 1. The relationships between the means and variances estimated from the normal distributions fitted to the proportion of shad in each size class captured by each mesh and the fork length of the fish.

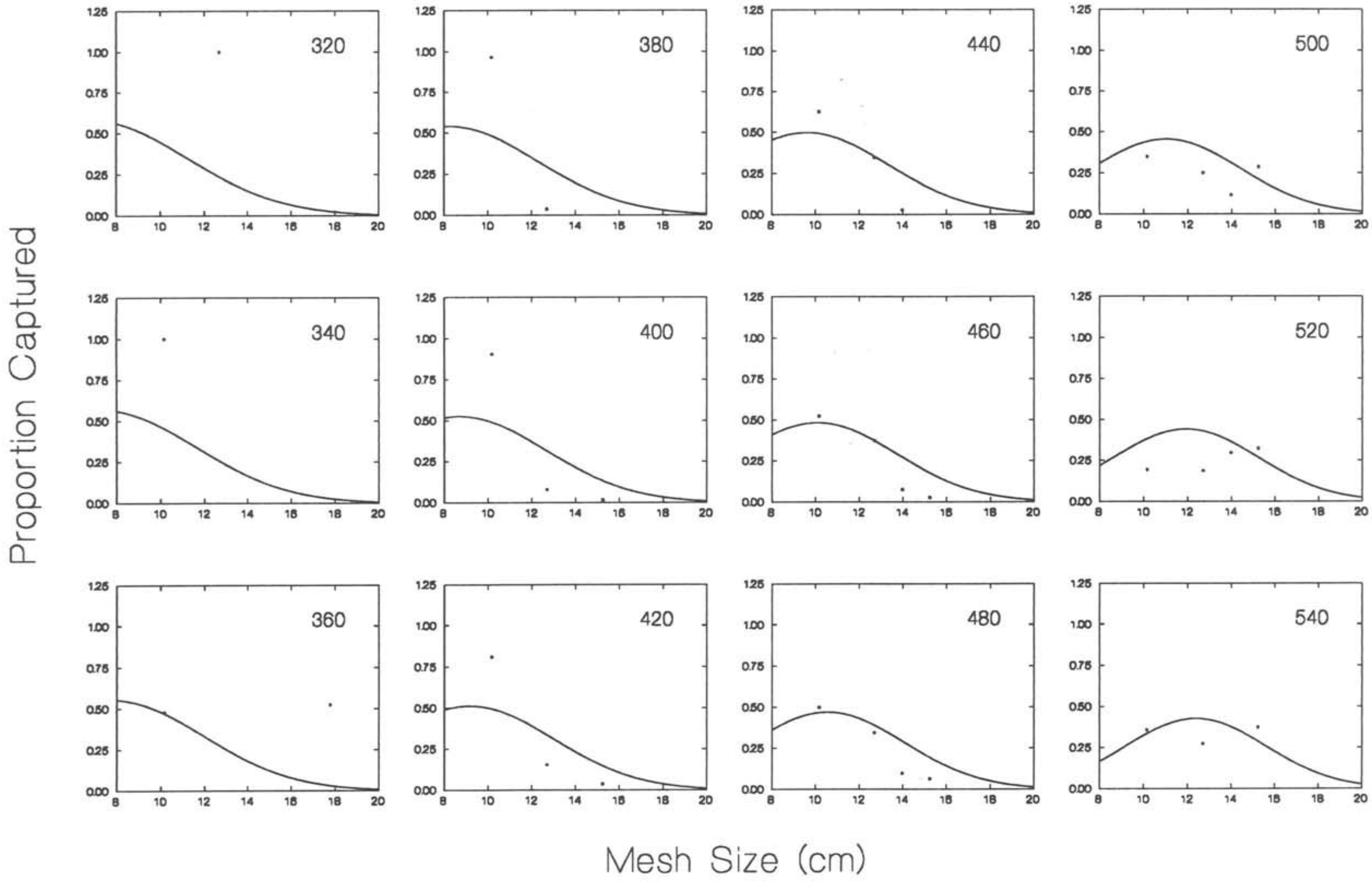

Figure 2. Normal probability density functions estimated to fit the proportion of shad captured by each mesh size for each size class. The numbers in the upper right corners refer to the size classes.

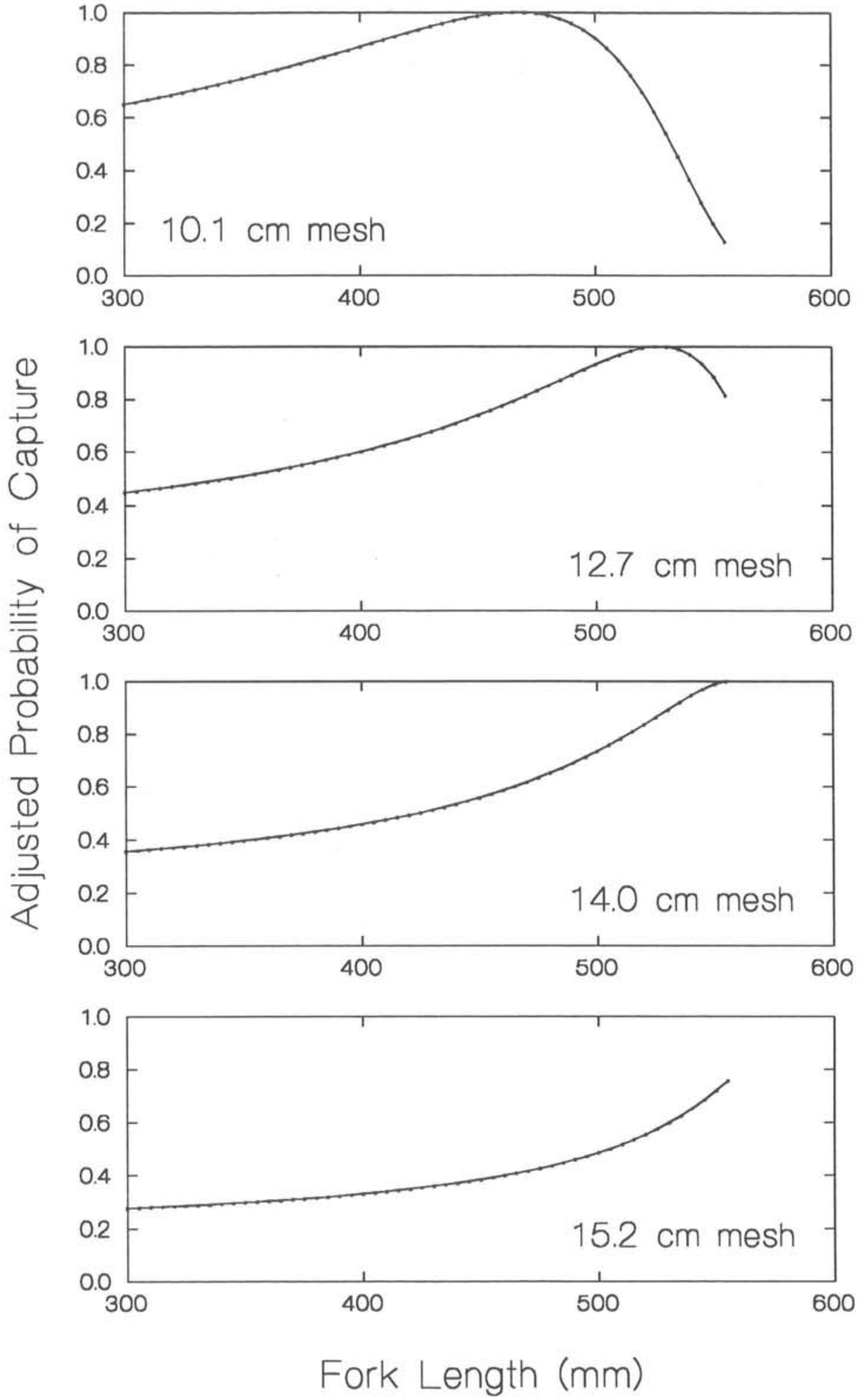

Figure 3. Selectivity curves as estimated for the gillnets used during this survey. The curves are adjusted so that the peak efficiency of each mesh equals 1.

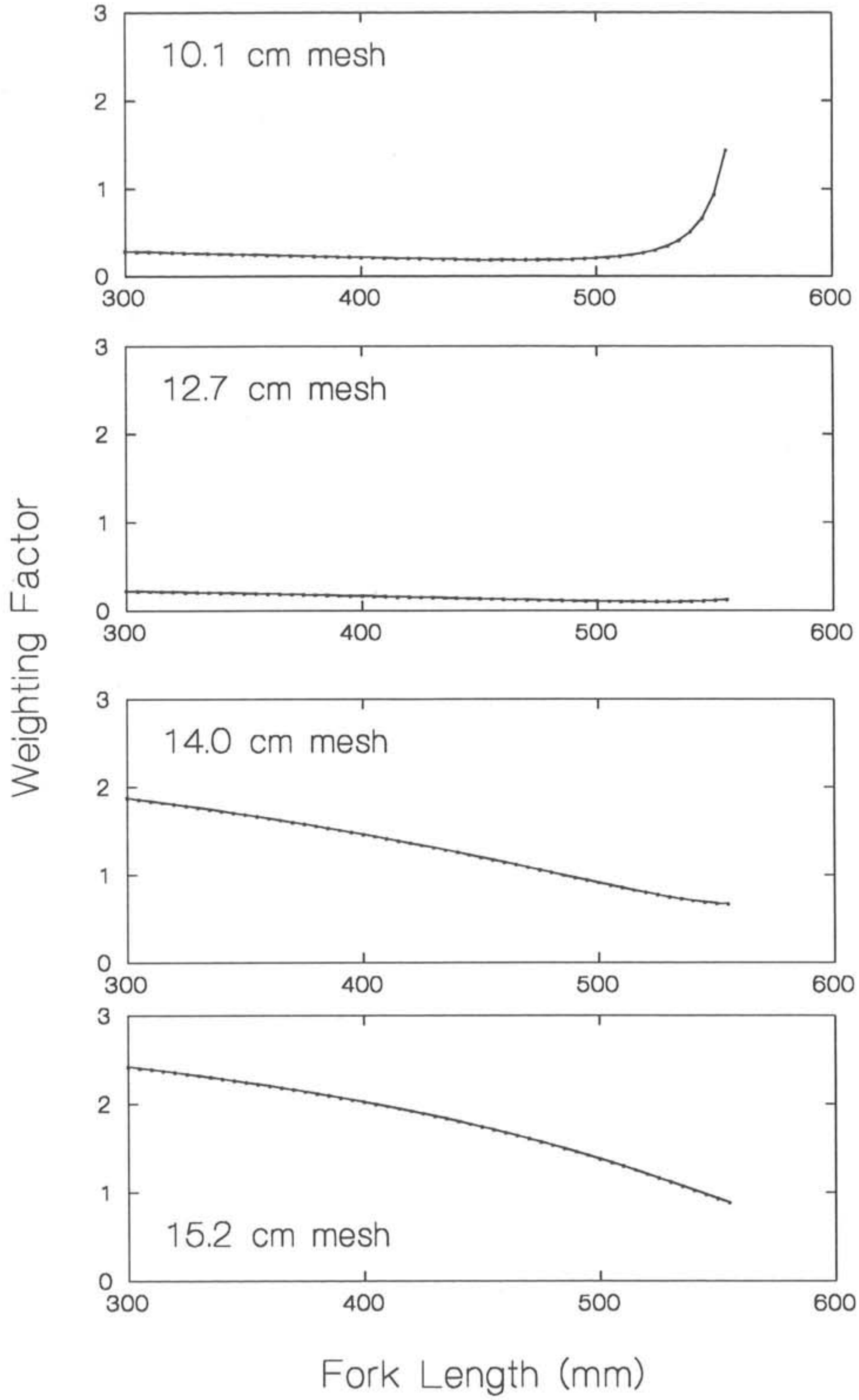

Figure 4. Weighting factors used to correct for the probability of capture for each fish based on its length, the mesh in which it was captured, and the soak time of that particular mesh.

4.2 Population Size Estimate

A total of 509 American shad were marked and released back into the estuary prior to their reaching the spawning areas. After allowing 6 days from the last marking trip for the shad to move upstream into the river, the spawning areas were surveyed, during which time 317 shad were examined for marks resulting in 2 recaptures. The population estimate was calculated two ways: directly from these uncorrected data, and after correcting for the probability of each marked fish being captured (based on its length) by the 10.1 cm stretched mesh net used in these surveys. The population size estimates and their corresponding 95% confidence limits are summarized in Table 1.

Table 1. Estimated size of the 1995 American shad spawning run in the Annapolis River calculated from the uncorrected data and from the data after correction for the probability of each fish being recaptured based on its length.

	Estimate of Stock Size		
estimate based on:	N	95% lower C.L.	95% upper C.L.
uncorrected data	54,060	19,778	135,150
corrected data	57,839	21,160	144,599

4.3 Stock Characteristics

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

4.3.1 Length and Weight

Length frequency distributions for males, females, and both sexes combined are shown in Figures 5, 6 and 7 respectively. The largest American shad captured during this study was a female with a fork length of 525 mm. The largest male captured was 490 mm in length. Means and standard deviations of the fork lengths of both sexes are presented in Table 2. These estimates are based on a sample of 400 females and 134 males.

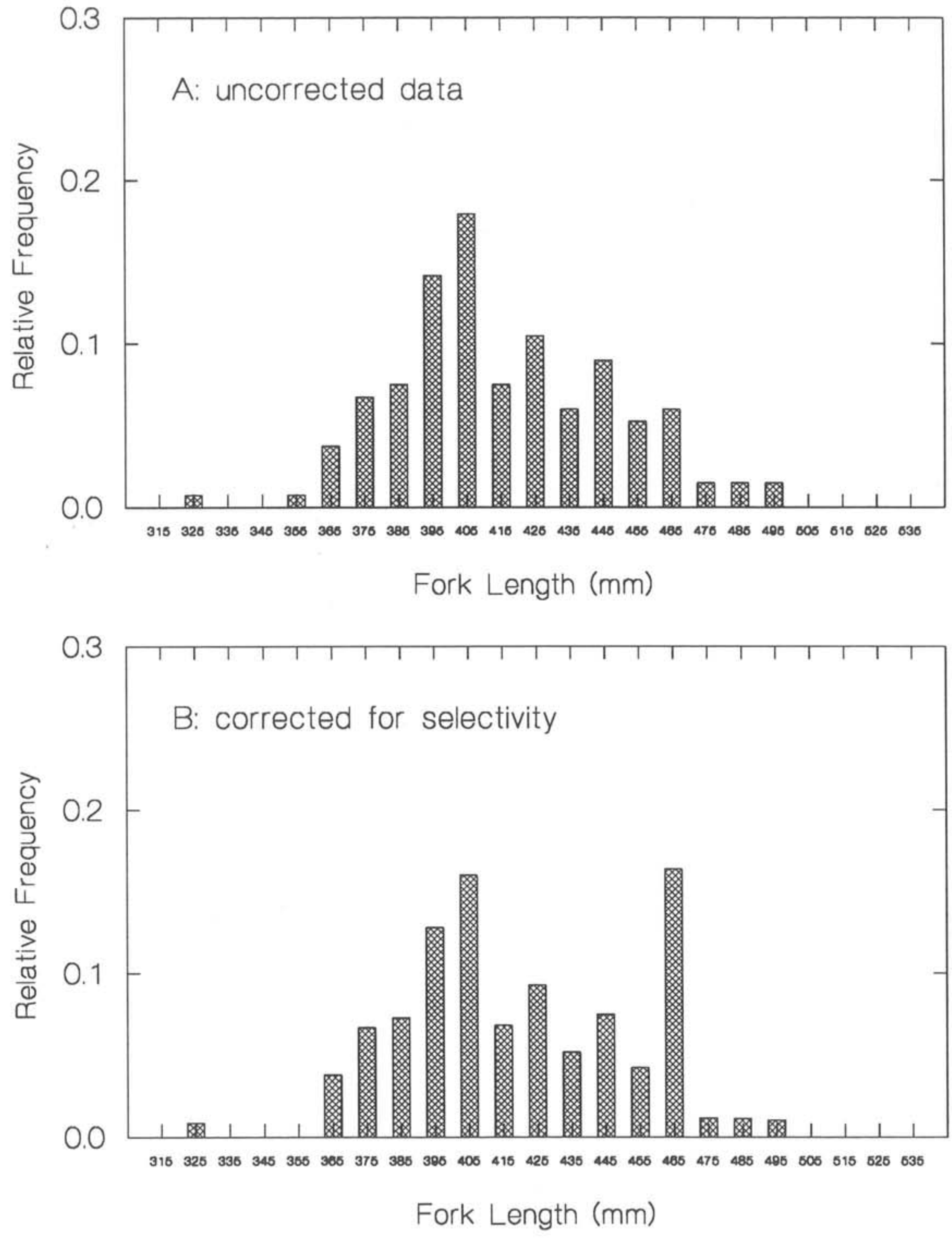

Figure 5. Fork length frequency distributions as estimated for male American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

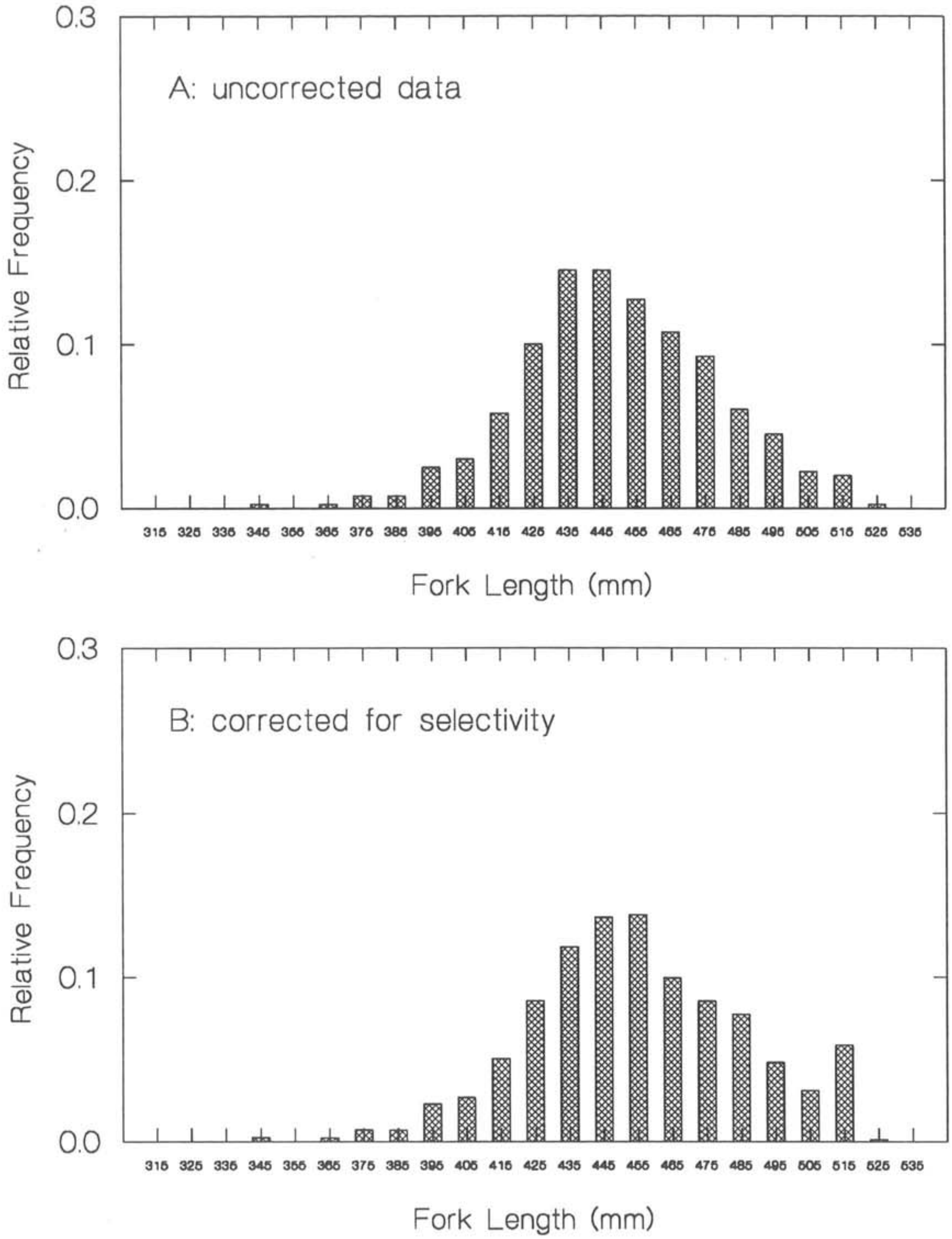

Figure 6. Fork length frequency distributions as estimated for female American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

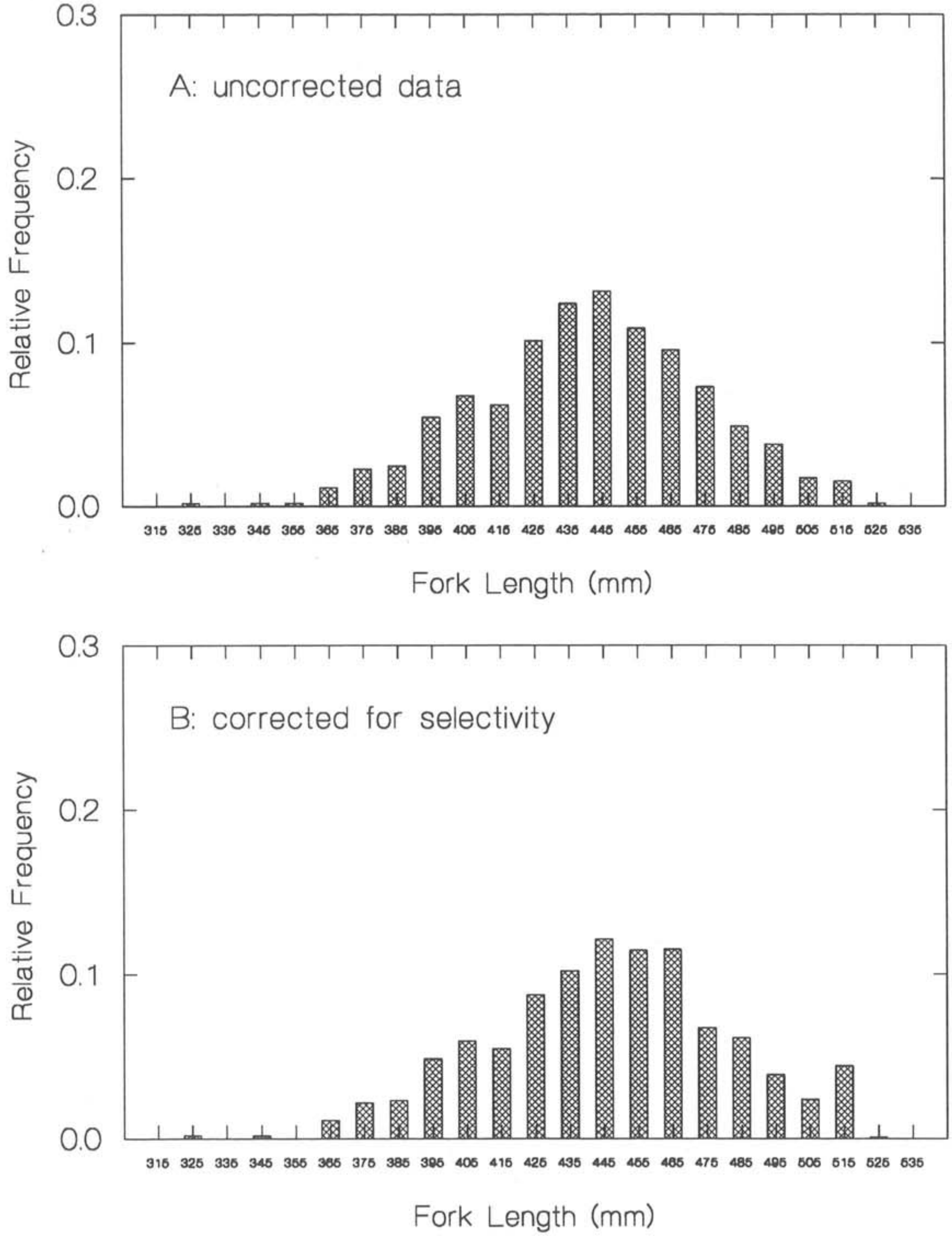

Figure 7. Fork length frequency distributions as estimated for both male and female American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

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	Female	both sexes
uncorrected data	412.7±31.7	447.2±28.8	438.5±33.1
corrected data	417.1±34.0	452.1±31.4	443.6±35.4

Mean weights of the American shad sampled from the 1995 spawning run are shown in Table 3. These estimates are based on samples of 50 females and 7 males. The mean weight of both sexes combined is standardized to reflect the population sex ratio (Table 4) rather than the male to female ratio of the sample.

Table 3. Mean weights and standard deviations for the 1995 Annapolis River American shad spawning run.

	Mean Weight (g) ± Standard Deviation		
estimate based on:	Males	Female	both sexes
uncorrected data	953 ± 264	1439 ± 387	1313 ± 355
corrected data	939 ± 257	1397 ± 381	1279 ± 349

The weight - length relationships for the 1995 spawning runs are:

males:

$\log(\text{weight}) = 4.29 \log(\text{length}) - 8.21;\ n = 7;\ r^2 = 0.91$

and females:

$\log(\text{weight}) = 3.26 \log(\text{length}) - 5.49;\ n = 50;\ r^2 = 0.85$

4.3.2 Sex Ratio

The sex ratio of the samples varied during the sampling period as shown in Table 4. Overall, during this portion of the study, females outnumbered males by a ratio of 2.87 : 1. The ratio of females to males during the recapture phase of the study was 1.16 : 1.

Table 4. Sex ratio of American shad captured during the marking portion of the study.

Date	Location	Total Catch	Sex Ratio Male:Female
May 5	Hebb's Landing	0	
May 9	Hebb's Landing	22	1 : 0.83
May 10	Hebb's Landing	89	1 : 1.67
May 11	Hebb's Landing	79	1 : 4.85
May 13	Hebb's Landing	6	1 : 1
May 17	Hebb's Landing	4	all female
May 19	Bridgetown	42	-
May 20	Bridgetown	106	1 : 3.24
May 22	Hebb's Landing	50	1 : 2.15
May 23	Bridgetown	32	1 : 2.2
May 25	Bridgetown	100	1 : 6.46
May 31	Bridgetown	35	1 : 2.18
	TOTAL		1 : 2.87

4.3.3 Age and Maturity

Otoliths were collected from 45 shad and were used for validating the ages derived from the reading of scales. The mean difference in age between the methods was 0.075 years and was not statistically significant (paired t-test: $p=0.412$). The data used for this comparison are depicted in Figure 8.

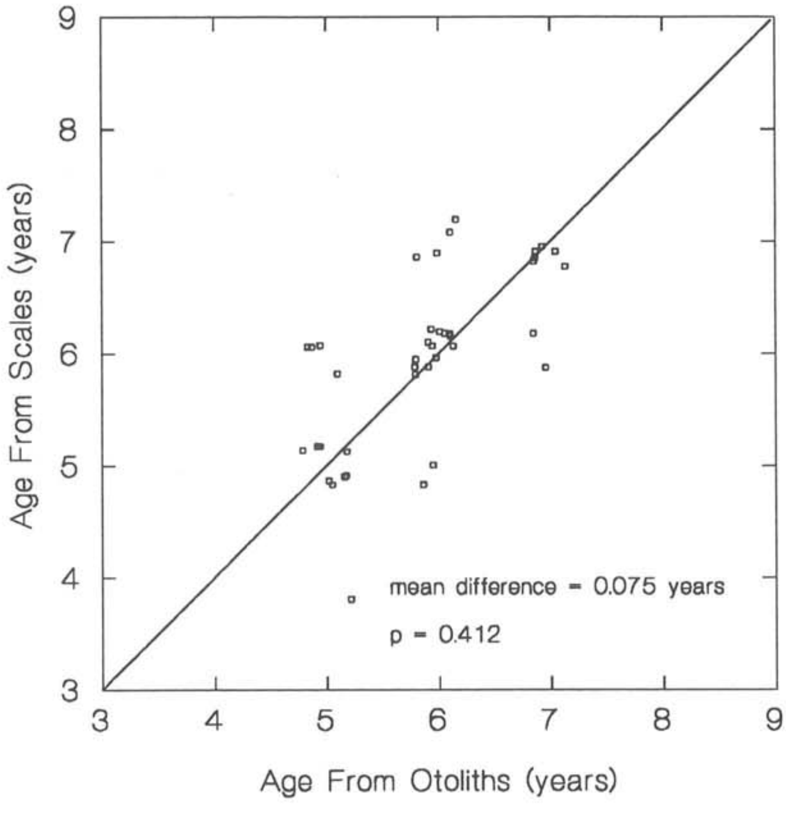

Figure 8. Comparison of ages determined by reading otoliths with the ages determined by reading scales from the same fish. Points are jittered so as not to overlap.

Scale samples from 389 females and 132 males were aged in order to determine the age structure of the population. Age frequency distributions for males, females, and both sexes combined are shown in Figures 9, 10 and 11 respectively. The oldest American shad captured during this study was a 10 year old female. The oldest male encountered was 9 years old. Means and standard deviations of the ages of both sexes may be found in Table 5. The distribution of age at first maturity for males and females is shown in Figure 12. Mean age at first maturity for males was 4.78 (s.d. = 0.75) and for females was 5.06 (s.d. = 0.84). 53.0 % of the males and 53.7 % of the females were repeat spawners.

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

	Mean Age (yr.) ± Standard Deviation		
estimate based on:	Males	Female	both sexes
uncorrected data	5.97 ± 1.11	6.24 ± 1.10	6.17 ± 1.11
corrected data	5.94 ± 1.04	6.35 ± 1.11	6.25 ± 1.10

4.3.4 Growth

The Von Bertalanffy growth equations for the male and female American shad captured in 1995 are shown in Figure 13. The theoretical maximum length for the males was estimated at 452.3 mm and for the females at 507.9 mm. Growth coefficients were estimated at 0.454 and 0.321 for the males and females respectively.

4.3.5 Mortality

Total instantaneous mortality rates were estimated as 0.52 (corrected for gillnet selectivity), and 0.47 (not corrected for gillnet selectivity) for males and similarly as 0.57 and 0.56 for females. These relationships, fitted to the adjusted size of each age class, are shown in Figure 14.

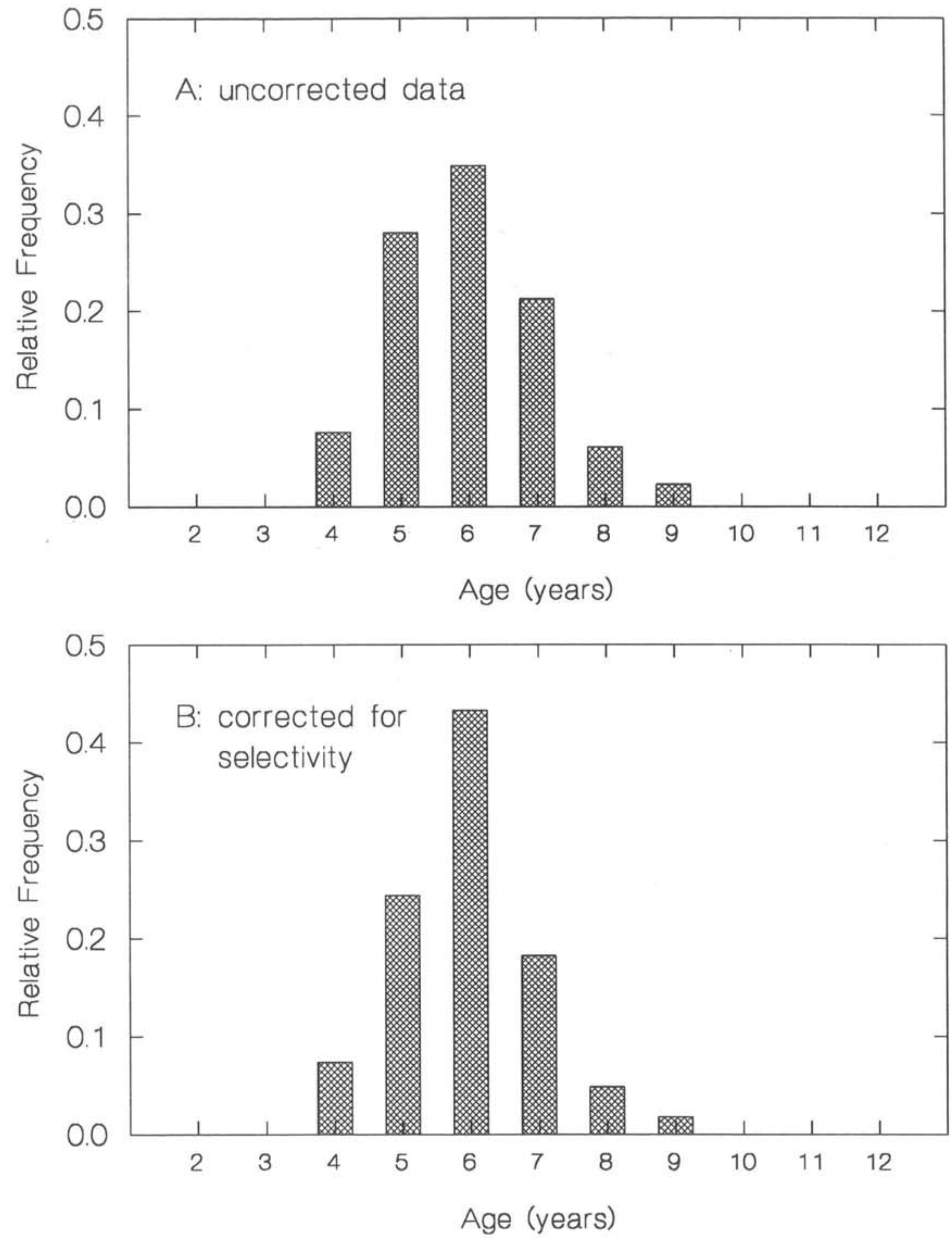

Figure 9. Age frequency distributions as estimated for male American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

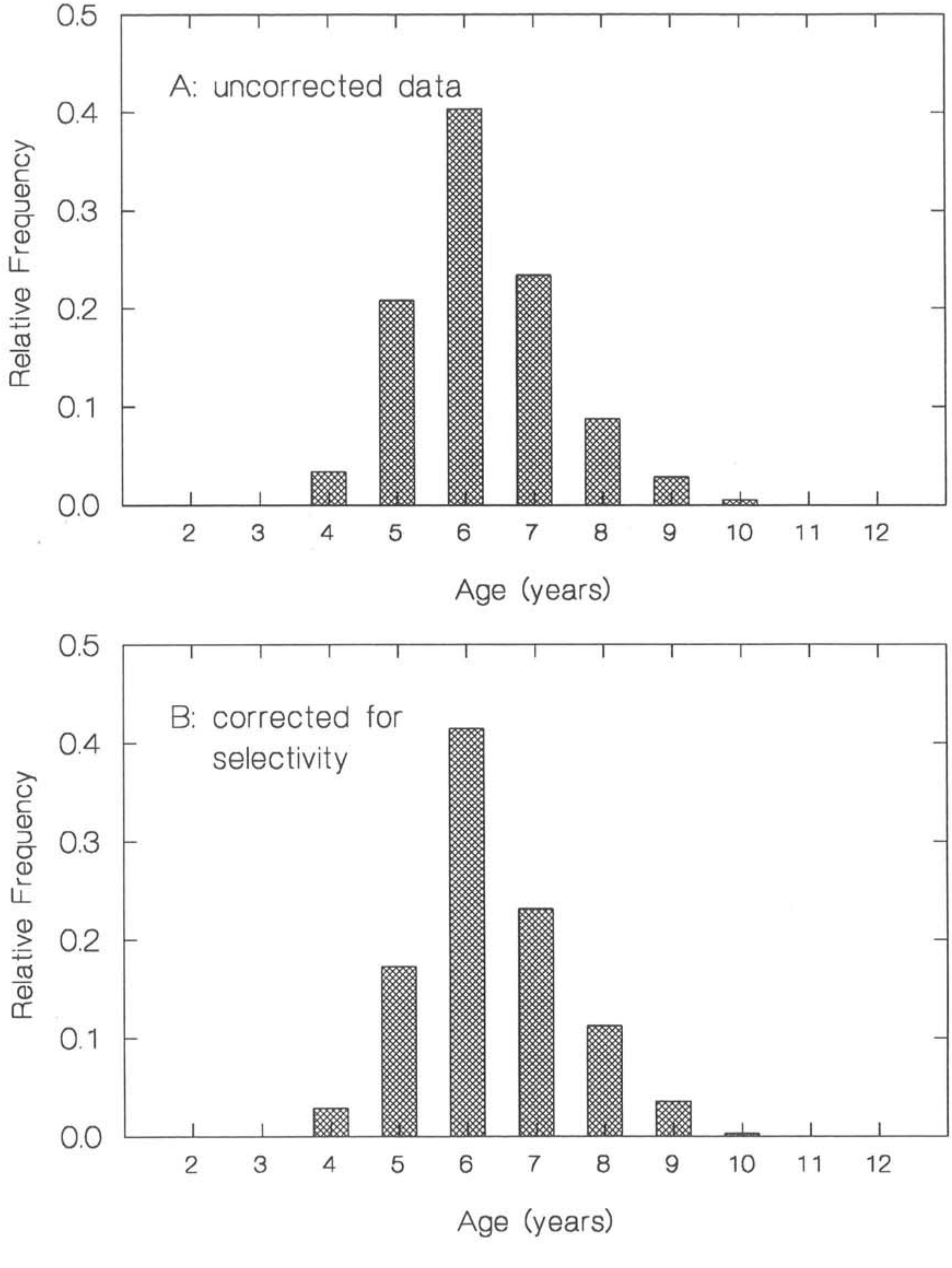

Figure 10. Age frequency distributions as estimated for female American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

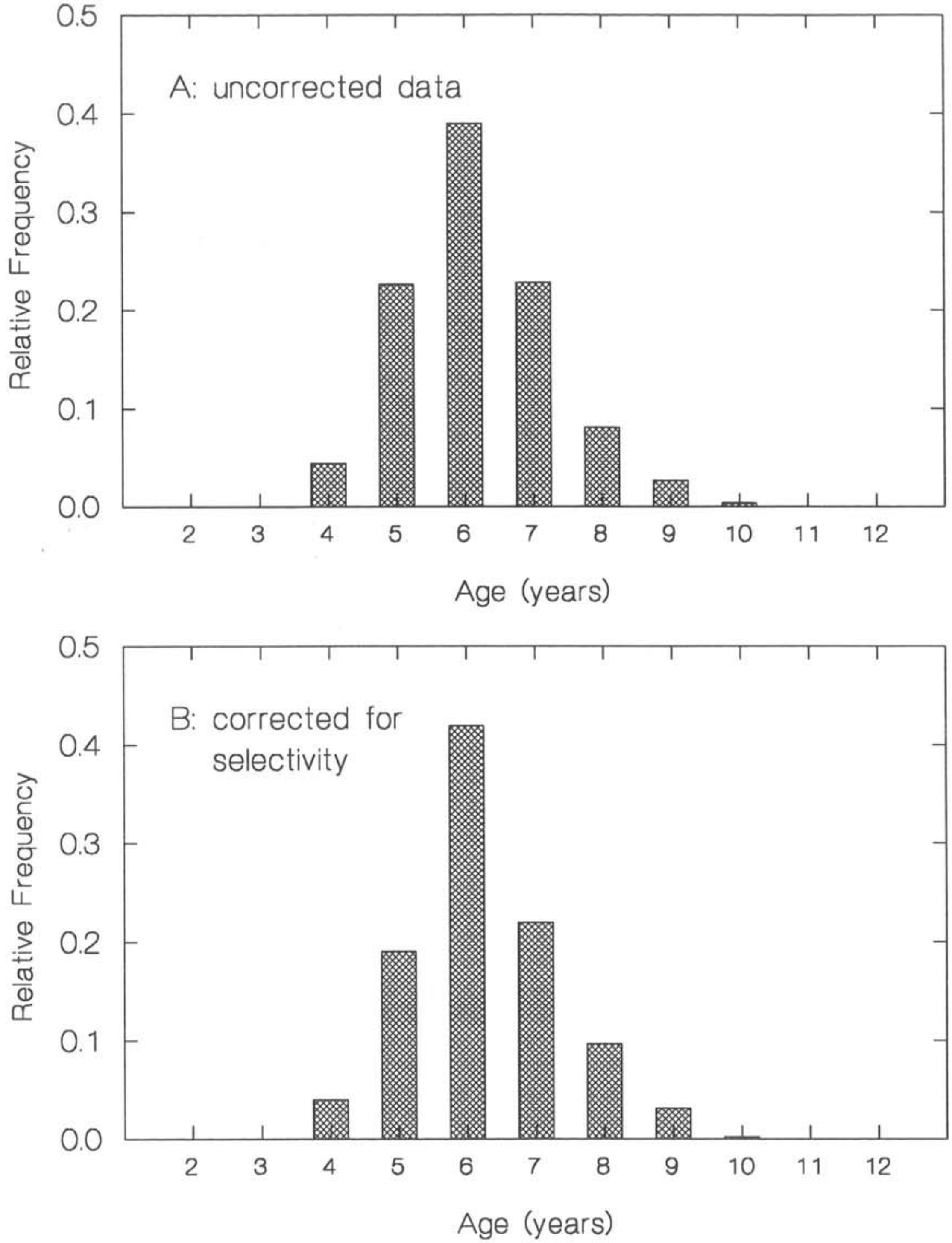

Figure 11. Age frequency distributions as estimated for both male and female American shad in the 1995 Annapolis River spawning run, both before and after correcting for gillnet and sampling selectivity.

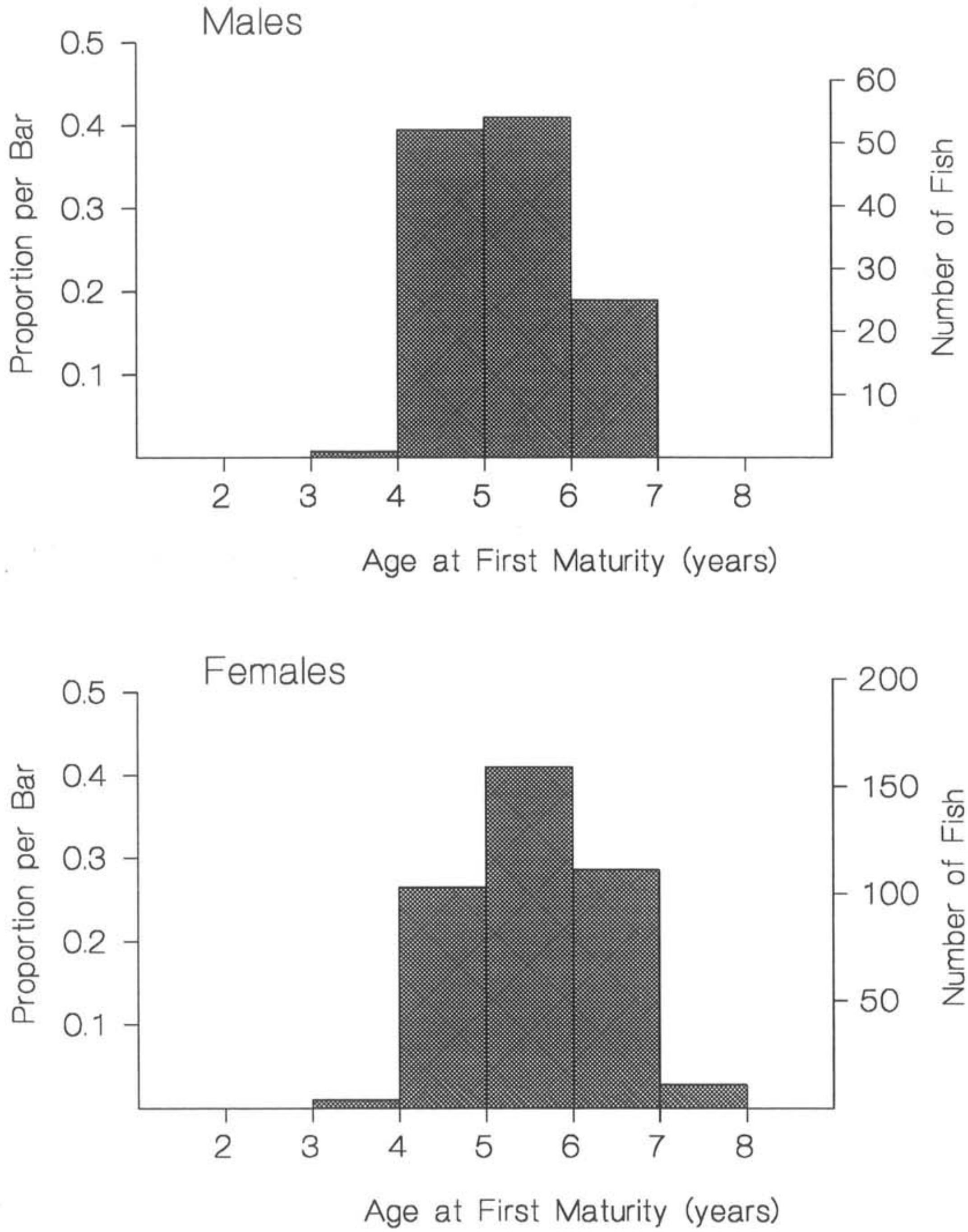

Figure 12. Frequency distibutions showing the age at first maturity for the male (top) and female (bottom) American shad captured during this assessment.

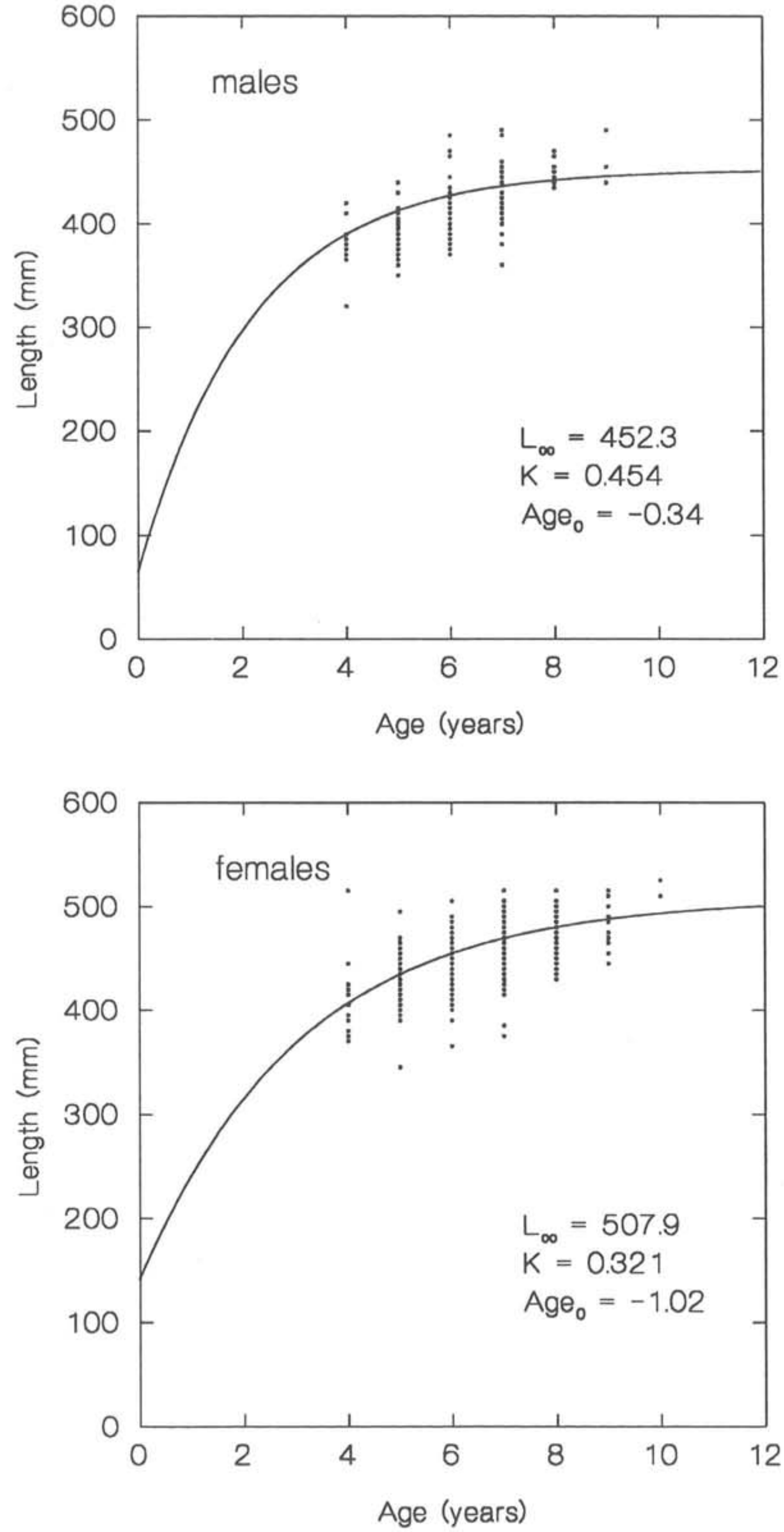

Figure 13. Von Bertalanffy fork length at age relationships for male and female American shad overlaid against the fork length at age data collected during the 1995 assessment.

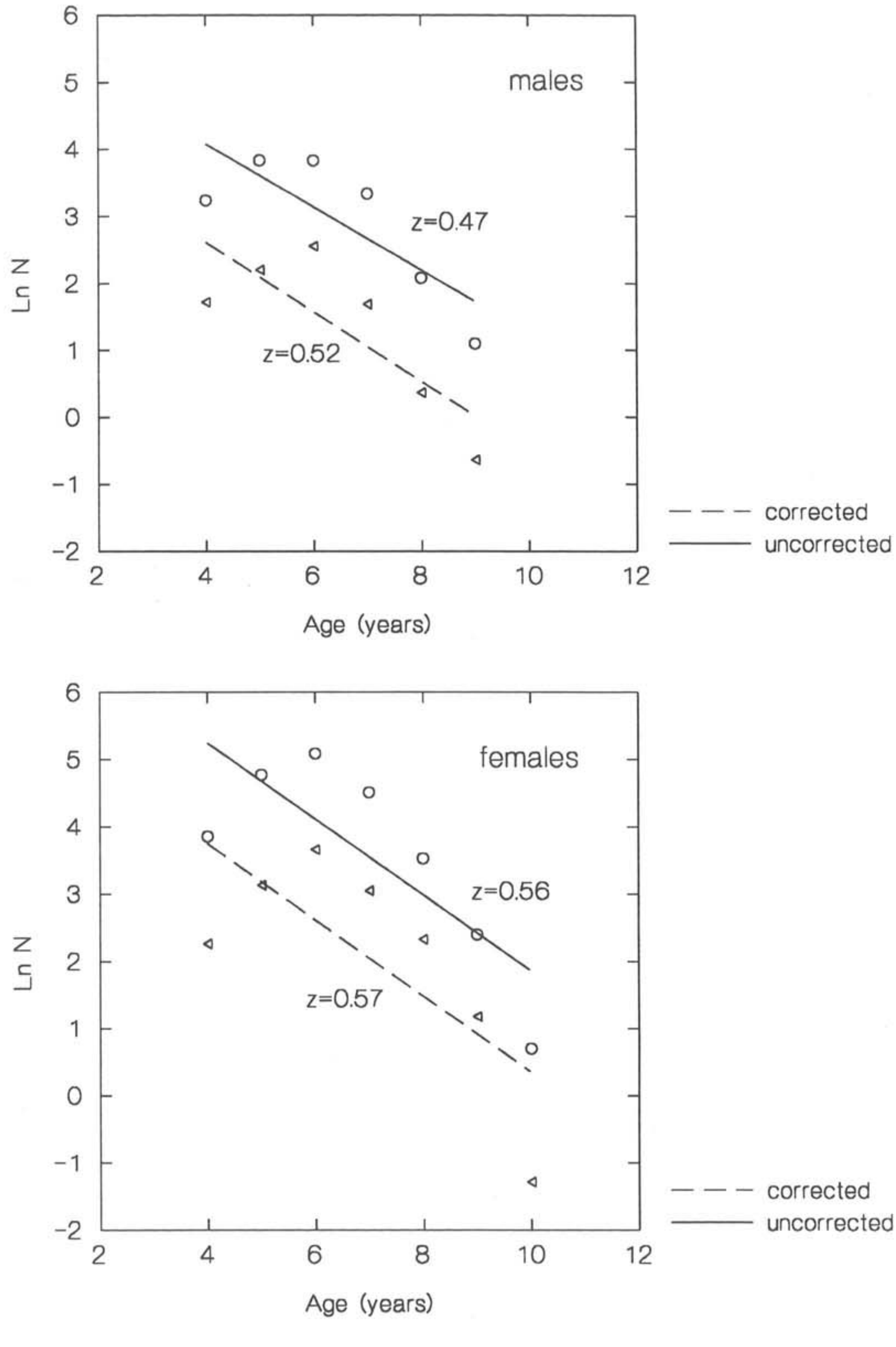

Figure 14. Total instantaneous mortality of male and female American shad from the 1995 Annapolis River spawning run.

5.0 DISCUSSION

5.1 Gillnet Selectivity

In hindsight, the range of mesh sizes initially selected for use during this project may not have been appropriate. Large mesh sizes were chosen in order to ensure that if larger, older shad were present in the population, they would not be missed due to the selectivity of the gear. Due to the small number of shad captured by these nets (15.2 cm and 17.8 cm stretched mesh) and the need to maximize the number of marked fish in the population, later fishing efforts were made with larger nets of a smaller mesh size (10.1 cm and 12.7 cm stretched mesh). The resulting data set was not appropriate for estimating selectivity, so the data were pooled with those of the 1990 survey in order to provide enough points for fitting the curves. Prior to fitting the curves, the data were standardized by soak time in order to meet the requirement of equal probability of encounter. However, because of the patchy distribution of the catches, this requirement was not really fulfilled. This, combined with only a few mesh sizes capturing shad, resulted in a rather poor fit of the selectivity curves shown in Figure 1. The result is that the selectivity curves shown in Figure 3 may greatly underestimate the selectivity of the gillnets. Gillnets are known to be highly selective for boney fish such as clupeids (Winters and Wheeler 1990).

5.2 Size of the 1995 American Shad Spawning Run (Objective 1)

The size of the 1995 American shad spawning run was estimated at 57,836 fish (95% C.I. = 21,160 to 144,599). This estimate is based on only 2 recaptures and, as shown by the wide confidence interval, may not be reliable. Recaptures totaling less than 4 can negatively bias a population estimate (Ricker 1975) resulting in an underestimation of the population size. Similarly, if any portion of the population was under-represented during the sampling, the estimate would also be low. For example, when applying the Peterson method for estimating population size, either the marking sample or the recapture sample must be random. Our intention was to fulfill this requirement during the recapture phase by fishing more or less at random throughout the spawning areas. The use of a gillnet during this phase violates this requirement, the extent of which depends on the selectivity of the net. While the estimate reported here is adjusted for this bias, the adjustment is only as valid as the selectivity curve upon which it is based. As discussed in Section 5.1, it is the opinion of the authors that the gillnets may be more selective than is shown in this report, and that this bias may have resulted in an underestimation of the population size. Inherent within this methodology is the assumption that handling and marking trauma do not effect the shad's behavior with respect to completing the spawning run. If any significant post-marking mortality or behavioral changes exist, the result would be an overestimation of population size. In summary, while the estimated stock size of the 1995 spawning run (app. 58,000) appears smaller than corresponding estimates for 1981 and 1982 of 155,000 and 132,800 individuals (Melvin *et al* 1985), it would not be appropriate to conclude that the population size has declined based on this estimate. Given that the lower limits of the 95% confidence interval for the 1981 and 1982 estimates (92,600 and 93,500, respectively) fall well within the 95% confidence interval for 1995 (upper limit = 144,900), the differences in the population estimates would not be statistically significant at the 95% confidence level.

5.2 Stock Characteristics (Objectives 2 and 3)

Table 6 contains a summary of some of the biological characteristics estimated during the pre-operational studies of the 1981 and 1982 spawning runs by Melvin *et al* (1985), for the 1989 and 1990 runs by Dadswell and Themelis (1990_a, 1990_b) and during this assessment of the 1995 spawning run. Both similarities and differences in the characteristics between 1995 and other years may be found in this table, however methodologies may account for some of these differences.

The sex ratio, reported at 2.87 females to each male in 1995, is higher than that reported in other years (mean = 1.38). This may be due in part to differential net usage in different years. For example, during the recapture phase of this assessment only 10.1 cm stretched mesh nets were used, yielding a sex ratio of 1.16 females to males. Timing of sampling may also have influenced this ratio. During both the 1989 and 1990 assessments, large catches of males occurred during the first night of sampling (not unreasonably, as males tend to move upstream first -Mike Dadswell, per. comm.). During this assessment no such large catch of males occurred (see Table 4). However, a night by night comparison of sex ratios reveals that on 8 out of 10 nights fished in 1995, the sex ratio was higher than 2 females per male. On 7 out of 8 nights fished in 1990, the ratio of females to males was 1.5 or lower. Finally, trimming out the two most extreme ratios during each of these years yields ratios of females to males of 2.2, 1.3 and 2.7 for 1989, 1990, and 1995 respectively, implying two things: that the year to year variability in sex

Table 6. Selected biological characteristics of the Annapolis River American shad spawning runs during 1981,1982, 1989, 1990, 1995.

Characteristic	Year	Males ± s.d.	Females ± s.d.
Sample Size	1981	166	143
	1982	68	127
	1989	165	251
	1990	241	379
	1995	134	400
Sex Ratio Females : Males	1981	1	0.8
	1982	1	1.6
	1989	1	1.5
	1990	1	1.6
	1995	1	2.87
Mean Length (mm)	1981	459 ± 38.0	506 ± 42.7
	1982	463 ± 40.5	527 ± 37.6
	1989	450 ± 25.8	484 ± 26.9
	1990	442 ± 24.9	479 ± 25.1
	1995	412.7±31.7	447.2±28.8
Max. Length Observed	1981	577	602
	1982	530	605
	1989	544	587
	1990	544	554
	1995	490	525
Mean Weight (g)	1981	1158 ± 400.6	2232 ± 529.7
	1982	1473 ± 382.2	2252 ± 499.5
	1989	1376 ± 206.3	1711 ± 288.8
	1990	1272 ± 270.3	1734 ± 341.2
	1995	939 ± 257	1397 ± 381

Table 6 (con't). Selected biological characteristics of the Annapolis River American shad spawning runs during 1981,1982, 1989, 1990, 1995.

Characteristic	Year	Males ± s.d.	Females ± s.d.
Mean Age (yr)	1981	6.68	7.34
	1982	6.98	8.28
	1989	6.61 ± 1.06	6.87 ± 1.02
	1990	5.76 ± 1.14	6.03 ± 1.03
	1995	5.94 ± 1.04	6.35 ± 1.11
Max. Age Observed	1981	12	12
	1982	12	13
	1989	10	11
	1990	9	9
	1995	9	10
Repeat Spawners (%)	1981	76.5	72.2
	1982	80.0	93.6
	1989	87.9	87.4
	1990	82.5	59.8
	1995	53.0	53.7
Mean Age at Maturity (yr.)	1981	4.4	4.7
	1982	4.5	4.8
	1989	4.5 ± 0.63	5.0 ± 0.58
	1990	4.1 ± 0.39	4.9 ± 0.41
	1995	4.78 ± 0.75	5.06 ± 0.84
Growth Coefficient (k)	1981	0.22	0.16
	1982	0.20	0.16
	1989	0.19	0.17
	1990	0.38	0.30
	1995	0.45	0.32

Table 6 (con't). Selected biological characteristics of the Annapolis River American shad spawning runs during 1981,1982, 1989, 1990, 1995.

Characteristic	Year	Males ± s.d.	Females ± s.d.
Theoretical Max. Length (L_{∞}) (mm)	1981	570	645
	1982	565	640
	1989	560	640
	1990	494	552
	1995	452	508
Mortality (Z)	1981	0.36	0.25
	1982	0.36	0.22
	1989	0.81	0.85
	1990	0.89	0.93
	1995	0.52	0.57

ratio may be higher than implied by the earlier studies, and that the differences seen in 1995 may be at least to some extent real.

The mean ages of the stock (males = 5.94 years, females = 6.35 years) fall between the values reported for the 1989 and 1990 spawning runs (means of 6.18 years and 6.45 years for males and females respectively), but are lower than those reported for the 1981 and 1982 runs (means of 6.83 years and 8.31 years for males and females). Trends in maximum age observed are similar, showing little or no decrease relative to the 1989 and 1990 assessments, but having decreased on average 2.7 years from 1981 and 1982. The mean length of the stock appears to have decreased by about 30 mm relative to 1990 and by about 60 mm relative to 1981 and 1982. This decrease is supported by the decrease in observed maximum length (about 30 mm from 1990 and 80 mm from 1981 and 1982). It is not known whether the discrepancy that mean age appears to have remained constant relative to 1989 and 1990 while the mean length of the population has decreased relative to those years is due to turbine-related, size selective mortality within an age class, differences in sampling methods, or between year variability inherent within the stock.

The mean age at maturity recorded during this assessment was slightly higher than reported in other years (see Table 6). Andrews and McKee (their Table 7.2) state that a decrease in age at maturation would be consistent with post-spawning adult mortality associated with the Annapolis Tidal Generating Station. While fish may mature at the same age under different levels of turbine mortality, fish which mature later should become more prevalent in the population, as younger maturing fish would pass by the turbine a greater number of times than older maturing fish of the same age.

Theoretical maximum lengths (L_{∞}).have decreased by about 120 mm from 1981 and 1982 and by about 45 mm from 1990, which mainly may be a function of the lack of older, larger fish in the 1995 sample. The increased growth rates (see Table 6) may be a function of the fish reaching their theoretical maximum size more quickly than if they were living longer, rather than a statement about how quickly fish are growing in their early years. For example, Dadswell and Themelis (1990_b) claim appreciable differences in size at age did not exist (other than for age class 4) between the 1990 spawning run and those of the 1981 run, but report a growth coefficient in 1990 (0.38 for males and 0.30 for females) that is nearly 2 times that of the 1981 run (0.22 and 0.16 for males and females respectively). The data therefore do not support the claim that "the population is now dominated by smaller, faster growing shad", although based on the samples collected in 1990 and 1995 it does appear that the shad are smaller.

The total instantaneous mortalities for males and females in the 1995 run are intermediate between those reported in the pre-operational studies and those reported for 1989 and 1990. It is difficult, however, to determine whether this is a manifestation of the data. The age 4 and age 5 year classes appear under-represented in the sample (see Figure 13), even after correcting for gillnet selectivity and immature fish not returning to spawn, and an increase in the size of these age classes would significantly increase the mortality estimate. The 1989 and 1990 estimates of mortality are significantly higher than those of other years. Dadswell and Themelis (1990_a,1990_b), reported that the data were corrected for immature fish not returning to spawn and "for gillnet selectivity using the indirect method (Hamley 1975)". They did not specify which indirect method (Hamley lists 4 indirect methods) or the shape of the probability distribution fitted. This correction was apparently not deemed necessary for estimating any of the other characteristics. Without more information about how this estimate was calculated, it is difficult to comment upon the validity of comparisons between these years and any other. However, it appears that total instantaneous mortalities have increased since the pre-operational studies and, given that the 1995 estimate appears conservative, the increase may be substantial.

Differences in methodologies may invalidate comparisons between the spawning runs of the five years for which these data exist. Not the least of these is the question of how the fish were collected. Gillnet selectivity was not adequately addressed during this study and that in itself is enough to call into question any between year comparisons. For example, a general rule of thumb is that "few fish are caught [by a gillnet] whose lengths differ from the optimum by more than 20%" (Hamley 1975). For this reason, the size frequency distribution of a gillnet sample may bear little resemblance to that of the sampled population. Hessier *et al* (1990), Regier and Robson (1965), Winters and Wheeler (1989), Borgstrom and Plahte (1992) and McCombie and Fry (1960) are just a few of the authors who have worked on this problem. Statements like "The length frequency of our sample exhibited a normal distribution about this mean and probably represents the true distribution of the population since it is the composite of the selectivities of the three gillnets used." (Dadswell and Themelis 1990_b) are simply not in agreement with the literature on gillnet selectivity.

The problems of sampling selectivity are not limited only to the post-operational studies (this study included). Dadswell and Themelis (1990_b) state "Sampling during 1981 and 1982 was thorough and used small-mesh, non-selective trapnets." This is inconsistent with statements by Melvin *et al* (1985) that "Shad were captured with a 10 cm stretched mesh spearhead trapnet, and 100 m , 12.4 and 13.5 cm stretched mesh multifilament and monofilament gillnets placed on the seaward face of the causeway." and that "upriver sampling was with gillnets of 8-15 cm stretched mesh". It appears therefore that before any comparisons may be made with the 1981 and 1982 spawning runs, the effects of sampling selectivity must be factored out of the data. The influence of this bias is reported by Melvin *et al* (1985) in the statements that the "mean fork length of the 1981 and 1982 samples, sexes combined, was 481 ± 46.4 mm and 504 ± 52.4 mm respectively." and "Mean fork length of these [implying those captured in the trapnets] shad was 501 mm in 1981 and 517 mm in 1982.". The effects of this bias would be reflected in all subsequent calculations and comparisons.

Other sampling biases also exist. For example, if gillnets are used for the sampling, and a composite size-frequency distribution is to be presented, then fishing efforts with the different meshes should be equal or the data should be standardized by the soak time of each mesh. Dadswell and Themelis (1990_b) did not report using this correction when the smallest mesh (10 cm stretched mesh) was fished on 6 nights, the middle-sized mesh (12.7 cm stretched mesh) was fished on five nights and the largest mesh (15.2 cm stretched mesh) was only fished 4 times. Similar biases exist in the 1989 sample.

Different aging methods and differences between scale and otolith readers may make between year age comparisons difficult. For example, as shown in Table 6, the mean length of the shad captured in this study was substantially lower than in other years, while the mean age remained more or less the same as that of the 1990 sample. This potential trend could be real (i.e., the effect of size selective mortality acting within year classes or some other factor influencing mean size-at-age) or it could be a manifestation of the aging technique. Other discrepancies exist within the reported ages. For example, Dadswell and Themelis (1990_a) report that in 1989, 52.4% of the males sampled had matured by their fourth year, however, they failed to capture any 4 year old males. Similarly, in 1990 (Dadswell and Themelis 1990_b), when 84.5% of the males captured had matured by their fourth year, less than 10% of the sampled males were 4 years old.

While the biases that exist within these data preclude any rigorous comparisons, it appears intuitively from the data that significant changes in the nature of this stock may have occurred since the pre-operational studies during 1981 and 1982. While the declines in mean age and length may be difficult to interpret for the reasons given above, the older, larger shad of the pre-turbine years were not encountered during this study, implying that they may now be absent from the population, and this in itself implies a significant change.

While interpreting these results as they relate to turbine mortality, it is important to keep in mind that other factors may cause similar changes within the population. One indicator may be changes that are occurring within populations utilizing other rivers. For example, it appears that in that both males and females in the Susquehanna River displayed 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).

6.0 CONCLUSIONS

While biases in the data limit the conclusions that may be drawn by pre- and post-operational comparisons, it does appear that substantial changes in the composition have occurred or are occurring within Annapolis River American shad stock, most notably, the absence of the larger, older fish once prevalent in the population. It is unknown whether these changes are due to turbine mortality or factors intrinsic to some other part of their life cycle.

While the current database of stock assessments contains some biases, it is still a large and potentially useful database. In order to apply this database towards understanding these changes, factors such as sampling selectivity and differential gear usage need to be factored out of the database. The current database should be adequate to accomplish this. For example, selectivity curves could be developed with or validated by comparisons of the trapnet and gillnet catches at the causeway during 1981 and 1982. Even if some bias still exists in the sampling methods, bringing all the studies to a common base would greatly enhance their interpretability. Variations in aging methods may also introduce inconsistencies into the database. If samples still exist, a random sample from each study could be read by a single individual or group to ensure that aging is consistent between these studies.

Any trends identified by pre- and post-operational comparisons should be interpreted within a framework that includes changes occurring in other stocks, which could serve as an indicator of wider scale change. For this reason, a review of the current status of other American shad stocks and of changes that may have occurred within these stocks during the late 1980's and early 1990's, would greatly enhance the interpretability of the Annapolis River stock database.

The framework for interpreting changes in stock characteristics in terms of turbine mortality was initially laid out by Melvin *et al* (1985) and has been endorsed by Dadswell and Themelis (1989, 1990) and by Andrews and McKee (1991), both of whom made minor changes to the framework. However, the possible scenarios were developed intuitively and contain some inconsistencies such as that discussed above under age at maturity. Testing the framework with a model could help identify other such problems. For example, one could incorporate the existing data into a matrix model (Usher 1972), and manipulate survivorship within the age/size classes to mimic turbine mortality.

Removing the sampling biases from the existing database and refining the framework for interpreting these data should be carried out prior to further stock assessments and also should result recommendations of methodologies for future assessments in order to ensure their compatibility with the existing database. However, future assessments, including population estimates, are crucial to understanding the nature and the extent of the changes that appear to be ongoing. Sampling should be conducted using non-selective methods if possible, and should be "environmentally friendly", i.e., large collections and hence large mortalities of American shad are not a necessary part of the assessment, if properly designed. Even when continually monitored, 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. When possible, some other method 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.

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Date	Location	Hours Fished	No. and Type of Gillnets Fished	Total Catch	Fate of Captured Fish
May 5	Hebb's Landing	5	1, panel	0	
May 9	Hebb's Landing	4.5	2, panel	22	all marked and released
May 10	Hebb's Landing	8	1, panel 1, 12.7 cm mesh	89	all marked and released
May 11	Hebb's Landing	5	1, 12.7 cm mesh	79	3 were previously marked; 76 were marked and released
May 13	Hebb's Landing	4	1, panel 1, 12.7 cm mesh	6	all marked and released
May 17	Hebb's Landing	7	1, panel 1, 12.7 cm mesh	4	all marked and released
May 19	Middleton Bridgetown	3 4	1, panel 1, 12.7 cm mesh	0 42	 all marked and released
May 20	Bridgetown	6	1, 10.1 cm mesh 1, 12.7 cm mesh	106	74 marked and released; 32 were retained for lab. analysis
May 22	Hebb's Landing	5	1, 10.1 cm mesh 1, 12.7 cm mesh	50	4 were previously marked; 41 were marked and released; 5 were retained for lab. analysis

Appendix 1 (con't.)

Date	Location	Hours Fished	No. and Type of Gillnets Fished	Total Catch	Fate of Captured Fish
May 23	Bridgetown	5	2, panel	32	
May 25	Bridgetown	7	1, 10.1 cm mesh 1, 12.7 cm mesh	100	2 were previously marked; 98 were marked and released
May 31	Bridgetown	5	1, 10.1 cm mesh 1, 12.7 cm mesh	35	35 were marked and released
June 6	Middleton	8 sets: app 0.5 hr. each	1, 10.1 cm mesh	77 inc 1 recap	all examined for marks and released
June 7	between Kingston and Middleton	10 sets: app 0.5 hr. each	1, 10.1 cm mesh	120 inc 1 recap	all examined for marks and released
June 8	between Middleton and Larwencetown	7 sets: app. 0.5 hr. each	1, 10.1 cm mesh	117	all examined for marks and released
June 9	Between Larwencetown and Bridgetown	6 sets: app. 0.5 hr. each	1, 10.1 cm mesh	3	all examined for marks and released