Impact of Lowhead Hydroelectric Tidal Power Development on Fisheries

I. A Pre-operation Study of the Spawning Population of American Shad, *Alosa sapidissima* (Pisces:Clupeidae), in the Annapolis River, Nova Scotia, Canada

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IMPACT OF LOWHEAD HYDROELECTRIC TIDAL POWER DEVELOPMENT ON FISHERIES. I. A PRE-OPERATION STUDY OF THE SPAWNING POPULATION OF AMERICAN SHAD, *ALOSA SAPIDISSIMA* (PISCES:CLUPEIDAE), IN THE ANNAPOLIS RIVER, NOVA SCOTIA, CANADA

by

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ABSTRACT

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The first hydroelectric tidal power generating station in Canada has been constructed on the estuary of the Annapolis River, Nova Scotia. To assess the future impact of turbine passage on anadromous fish populations, baseline biological data were obtained from the adult spawning population of American shad during 1981 and 1982. A total of 8371 shad were captured and 7894 marked and released. Estimated adult population ranged from 100 500-155 000 in 1981 and 78 200-132 800 in 1982. Mean age of spawning shad was 6.8 yr in 1981, and 7.8 yr in 1982. The number of repeat spawners was 75% of adults in 1981 and increased to 89% in 1982. Fecundity of females ranged from 70 000-290 000 ova. Mean virgin fecundity was 1.76×10^5 in 1981 and 1.21×10^5 eggs in 1982. Mean lifetime fecundity of each female was estimated as 2.2×10^5 eggs. Sex ratio of adults was 2:1 in favor of females.

Growth of individual shad was slow but the fish were long-lived and reached a large size. The von Bertalanffy growth parameters L_∞ and K were 570 mm and 0.21 for males and 645 mm and 0.16 for females. The oldest male observed was 12 yr, the oldest female 13. Instantaneous total mortality was 0.30 for males and 0.23 for females. Combined sports and commercial fishing exploitation was estimated to be less than 5%.

RÉSUMÉ

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La première centrale électrique marémotrice au Canada a été construite dans l'estuaire de la rivière Annapolis, en Nouvelle-Ecosse. Afin d'évaluer les répercussions futures du passage dans les turbines des populations de poissons anadromes, des données biologiques de référence ont été recueillies sur la population d'aloses savoureuses reproductrices en 1981 et 1982. Un total de 8 371 aloses ont été capturées, dont 7 894 marquées et relâchées. La population adulte a été estimée à 100 500 -- 155 000 en 1981 et 78 200 -- 132 800 en 1982. L'âge moyen des aloses reproductrices était 6,8 en 1981 et 7,8 en 1982. La proportion de reproducteurs récidivistes a été de 75 % des adultes en 1981 et avait augmenté à 89 % en 1982. La fécondité des femelles variait entre 70 000 et 290 000 oeufs. La fécondité moyenne des aloses vierges était de $1,76 \times 10^5$ en 1981 et $1,21 \times 10^5$ oeufs en 1982. La fécondité moyenne durant toute la vie d'une femelle a été estimée à $2,2 \times 10^5$. La proportion des sexes des adultes était de 2:1 en faveur des femelles.

La croissance d'aloses individuelles était lente, mais les poissons ont une longue durée de vie et atteignent une grande taille. Les paramètres de croissance de von Bertalanffy L_∞ et K sont de 570 mm et 0,21 pour les mâles et 645 mm et 0,16 pour les femelles. Le mâle le plus âgé observé avait 12 ans, alors que la plus vieille femelle avait 13 ans. La mortalité totale instantanée était de 0,30 pour les mâles et 0,23 pour les femelles. On a estimé â moins de 5 % l'exploitation sportive et commerciale combinée.

INTRODUCTION

The construction of the Annapolis Tidal Barrage between Granville Ferry and Annapolis Royal in 1960 created a large reservoir known as French Basin. Today this basin is the headpond for Canada's first tidal powered hydroelectric station which officially opened in August of 1984.

Physical changes in the course and flow of the river channel resulting from the original tidal dam construction appear to have no major effect upon the migration of anadromous fish species (Smith 1960; Jessop and Doubleday 1976; Anon. 1980). The Annapolis River supports large runs of American shad (*Alosa sapidissima*) and gaspereau (*Alosa pseudoharengus*, *A. aestivalis*) and smaller runs of striped bass (*Morone saxatilis*) and Atlantic salmon (*Salmo salar*). Declines in the abundance of the latter two species in recent years have been related to upriver obstruction and degradation of juvenile nursery grounds (Wildsmith 1980), pollution (Parker and Doe 1981; Ray et al. 1984), and the natural fluctuation of year-class success of striped bass (Jessop and Vithayasai 1979). The ability of fish to negotiate the original fish passage system (pre hydroelectric station development) has not been implicated as a reason for these declines.

The installation of an hydraulic turbine and its additional flow channels has created the potential for mortality of fish during turbine passage (Cramer and Oligher 1964) and for alteration of migration routes and timing (Ruggles 1980). The extent of these effects will be related to the characteristics of the turbine and the way fish will migrate past the tidal dam under the new set of conditions. The lowhead STRAFLO turbine at this site is the first of its kind in marine conditions (Douma and Stewart 1981). There has been no previous analysis on fisheries impacts of the STRAFLO turbine.

The Annapolis River supports perhaps the only large American shad population in eastern North America not commercially fished in the river by selective gear and is unique in this respect. Commercial and sport fisheries are confined to relatively inefficient and non-selective methods (scoop nets, hook and line). As such, this shad run should prove a sensitive, natural monitor for the impact of STRAFLO-type, lowhead turbines on fishes because it is unnecessary to account for changing population parameters of a commercially fished population caused by effort and/or gear use. Furthermore, since shad are large and adults have a probability of only one or two passages through the turbine a year (depending on the mode of reservoir filling), change or similarity of population structure between pre-operation spawning runs and future runs should elucidate some of the near-field effects of hydroelectric development in the ocean.

The purpose of this report is to document a 2-yr pre-operational study on the Annapolis River American shad spawning run. The study was designed to:

1. determine biological characteristics of the pre-operational adult shad spawning run;

2. estimate size of the annual spawning run;

3. determine shad migration patterns and rates of movement around the tidal dam, within the river, and at sea;

4. document injuries to shad associated with present tidal dam and fishway conditions.

DESCRIPTION OF STUDY AREA

The Annapolis River is a second order, warmwater stream, flowing southwesterly through Nova Scotia's fertile Annapolis Valley (Trescott 1968). The river has a meander length of approximately 97 km and drains an area of 1603 km^2 comprised of mixed farm lands, fruit orchards, and upland forests (Fig. 1). Valley soil was derived from nearby shale and sandstone, as well as from easily eroded glacial-outwash deposits. Most soil is clay or silt with local deposits of sand (Trescott 1968). Upland drainage is on granitic outcrop with extensive lakes and bogs (Smithingale 1973). The river has an average drop by meander of 8.0 m/km from its headwaters near Berwick to Wilmot, 44.8 km downstream. From Wilmot, the river gradient declines with a mean drop by meander of 0.64 m/km to its mouth on Annapolis Basin. There are three principal tributaries, the Nictaux, the Paradise, and the Round Hill Rivers. The Nictaux and the Paradise Rivers both have power dams, three on the former and two on the latter. Mean annual flow at Annapolis Royal is 38.2 m^3/s (Anon. 1969). Annual summer temperature of the river often exceeds 26°C (Jessop 1976).

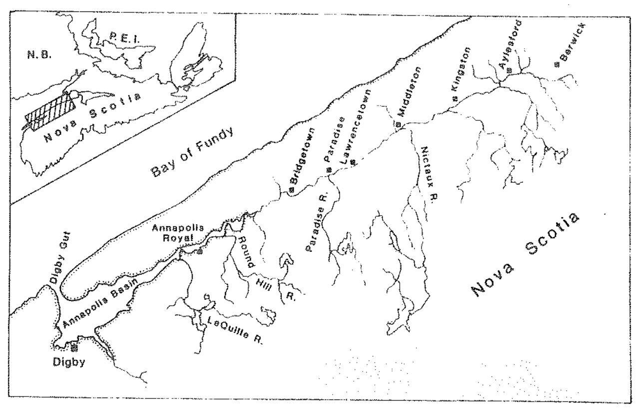

Fig. 1. The Annapolis River drainage system.

The tidal dam at Annapolis Royal created a reservoir area of 10.8 x 10^6 m^2 at geodetic datum. The structure consists of three units: a rock-fill causeway between Granville Ferry and Hog's Island, a central island, and an open concrete structure containing sluice gates and a permanently open fishway between Hog's Island and Annapolis Royal (Fig. 2). The sluiceway has two gates with a 7.3 x 9.1 m opening; the fishway is 3.0 m wide by 7.3 m deep (Fig. 3; Anon. 1980). Hog's Island is the site of the hydroelectric tidal plant (Fig. 4). Installation of the plant has resulted in two additional channels for migratory fish passage, a 15 x 15 m turbine intake and draft tube and an additional 3 x 3 m box culvert fishway (Fig. 5).

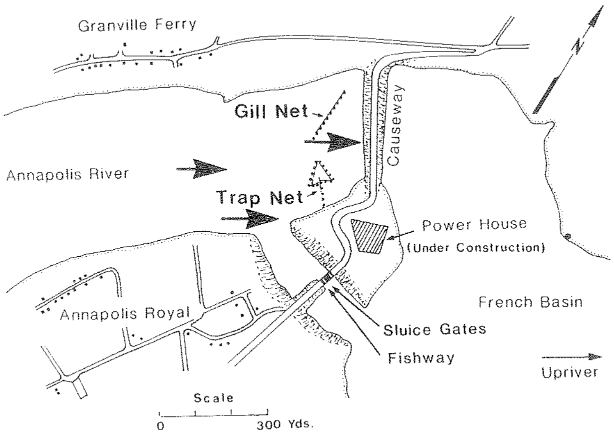

Fig. 2. Tidal dam structure at Annapolis Royal, May 1981, and placement of fish sampling gear. Shad schools were present during low tide at sites indicated by thick arrows.

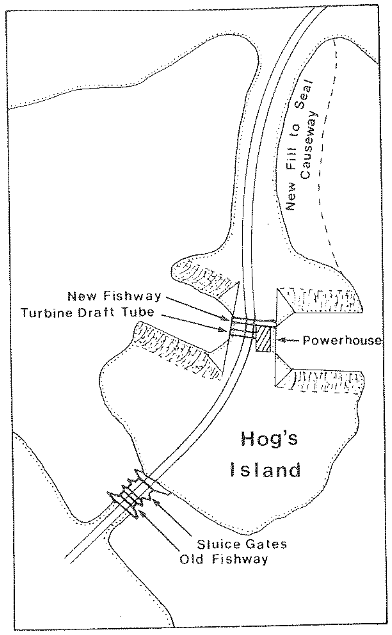

Fig. 4. Tidal dam structure at Annapolis Royal, May 1983.

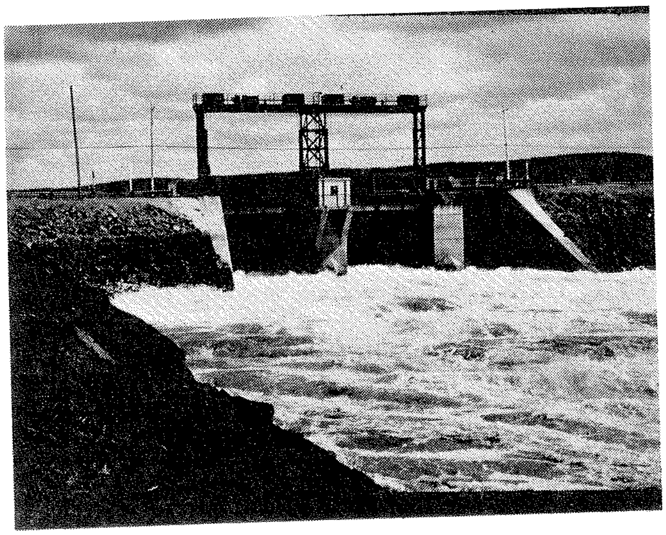

Fig. 3. Sluice gate and fishway structure of the tidal dam at Annapolis Royal. At the time of this photograph, the tide is low and water is being sluiced. The fishway is the oblong opening on the right-hand side of the structure.

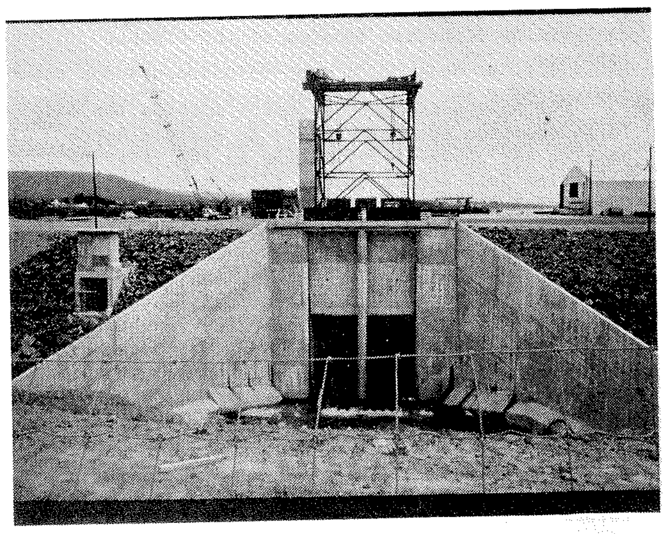

Fig. 5. Downstream view of turbine draft tube outlet opening and the box culvert fishway (far left) on Sept. 15, 1982.

FIELD METHODS

Field studies were conducted between April and June in 1981 and 1982. Shad were captured with a 10 cm stretched mesh spearhead trap net and 100 m, 12.4 and 13.5 cm stretched mesh multifilament and monofilament gillnets placed on the seaward face of the causeway (Fig. 2). The trapnet consisted of two chambers 4 m deep with a distance of 10 m between the posterior tips of the spear and measured 7 m from head to leader. Entrances to the outer and inner chambers were 3 m and 15 cm wide, respectively. A 50-m leader of 10-cm, stretched mesh extended from shore to the head. The trapnet was opened to fish each morning and closed when sufficient shad for analysis were in the head. During 1981, gillnet sampling was used for the period April 22-28 only (Table 1). In 1982, gillnet sampling supplemented trapnet sampling whenever shad abundance declined to a level at which the trapnet became inefficient (Table 2). During 1982, an additional trapnet was set in the headpond 6 km above the causeway to monitor rate of movement of shad through the causeway (Table 3).

Upriver sampling stations for recapturing marked shad were established after May 20, 1981, and June 1, 1982, at Upper Granville, Bridgetown, Lawrencetown and Middleton (Fig. 1). A period of approximately 1 wk separated tagging and recapture phases to permit mixing of marked shad into the population. Upriver sampling was with gillnets of 8-15 cm stretched mesh. Nets were extended bank to bank and sampled each night from dusk to 3.00 a.m. During 1981, upriver sampling continued until June 4 and in 1982, until June 21 for a total of 10 and 21 net nights, respectively (Table 4). During the period June 8-14, 1982, gillnets were fished simultaneously at two localities to provide further estimates of river migration rate.

Each shad captured at the causeway was measured for fork length, total length, and body depth and a scale sample removed for examination of spawning history and age. Shad were then visually examined for wounds, marked with an individually numbered dart tag (Floy FTI) inserted just below the dorsal fin, and released at the site of capture. Since the trapnet entrance was closed, tagged shad could not re-enter the trapnet until the following morning, if they remained seaward of the causeway.

During 1981, all shad captured upriver were measured as at the causeway and scale samples taken. They were then examined for wounds, marked and released. Due to tag shortages, most of the upriver captures were marked by clipping a pectoral fin. In 1982, only the first 50 shad captured upriver each night were measured and scale samples taken. The remainder of the night's catch was examined for damage, tagged, and released.

Shad captured at the causeway and in the headpond trapnet were sacrificed at selective intervals, labeled, and frozen for laboratory analysis. Netting mortalities were utilized, whenever possible, at the causeway and upriver. Weights and lengths of all sacrificed shad were recorded prior to freezing, except when large numbers of fish were present.

Daily number of sports fishermen along the seaward face of the causeway was recorded during the trapnet fishing period.

LABORATORY ANALYSIS

Shad were removed from the freezer and thawed before analysis. Each shad was remeasured for total length, fork length, body depth, and weighed to determine the effects of freezing. Otoliths were excised by a transverse cut through the head, removed with forceps, cleaned, and mounted in a black, plastic tray with 1,2-diethyl chloride. Gonads were excised for determination of sex and maturity stage, then weighed. Female gonads were preserved in Gilson's solution until egg counts were made.

Ages from scales and otoliths and spawning history from scales were enumerated by using a dissection microscope equipped with an ocular micrometer. Measurements of otoliths for growth computations followed standard methods outlined by Ricker (1975). Fecundity was determined by counting all ova in three 0.1-g subsamples of gonad and extrapolated to overall gonad weight.

All data were transcribed to standard 80-column computer sheets for key punching. Statistical analysis was conducted on an HP 3000 computer, using SPSS and author-compiled Fortran programs.

Three capture-recapture models were employed to estimate the adult spawning run population size: Peterson, Schumacher, and Chapman (Ricker 1975).

RESULTS AND DISCUSSION

FIELD SAMPLING

Nets were fished at the causeway between April 22 and May 12, 1981. A total of 2356 shad were tagged (Table 1). In 1982, 2718 shad were tagged at the causeway between April 27 and May 28 (Table 2). The spawning run began later in 1982 (May 4) than in 1981 (April 23). During 1982, shad disappeared from the seaward face of the causeway between May 9-18 when there was a prolonged period of northeast wind and cold temperatures, which coincided with a marked decline in water temperature (Fig. 6).

The headpond trapnet at Center Granville, operated between May 10-28, 1982 (Table 3), captured 241 shad; 8 were recaptures from the causeway, and 59 were tagged and released. The remainder (182 fish) were retained for laboratory analysis.

During 1981, a total of 1389 shad were captured in the upriver gillnets; 18 of the 32 recaptures were tagged at the causeway (Table 4). In 1982, 1517 shad (total recaptures 56) were captured by gillnet at upriver locations, and 29 of 56 tagged shad had been marked at the causeway (Table 4).

A total of 309 shad in 1981 and 196 in 1982 were sacrificed for complete laboratory analysis.

LENGTH AND WEIGHT

Values used to determine weight-length relationships of the 1981 and 1982 Annapolis shad runs were mostly obtained from dead fish before freezing. A significant difference ($P < 0.01$) between lengths of laboratory samples and live shad was found. It may be accounted for by the difficulty of measuring an active fish and shrinkage

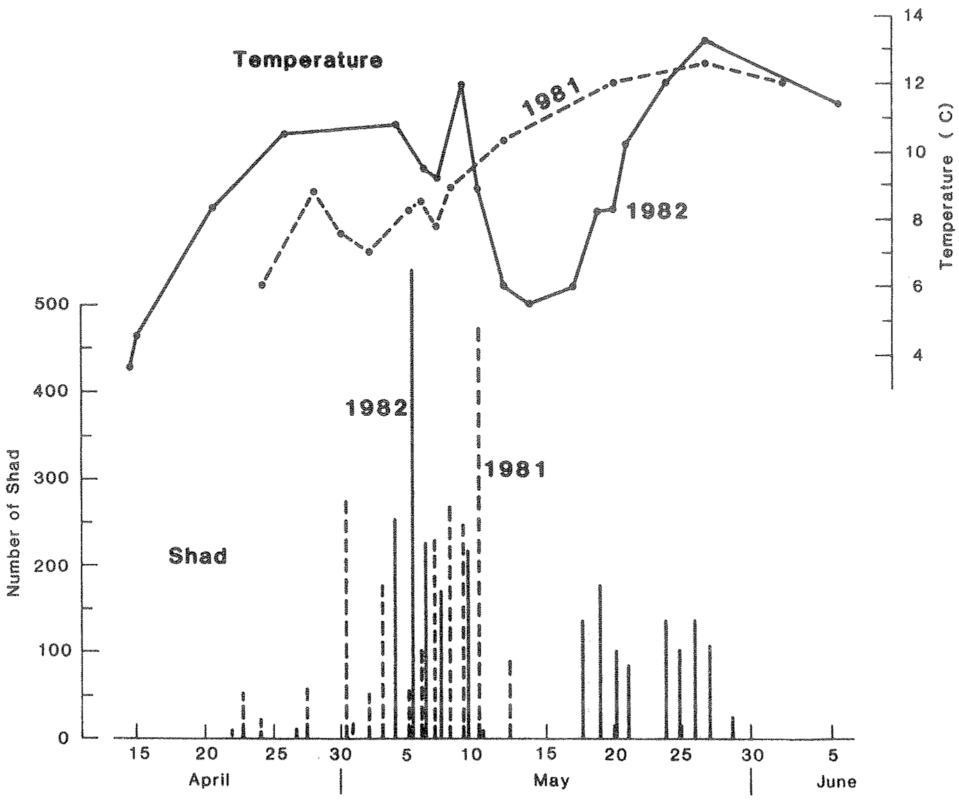

Fig. 6. Surface water temperature and daily abundance of American shad at the seaward face of the Annapolis causeway during the spring of 1981 and 1982.

after death. For shad frozen before measurement, the laboratory length was adjusted to fresh length by the factor 1.021 (Melvin, unpubl. data).

Mean fork length of the 1981 and 1982 samples, sexes combined, was 481 ± 46.4 mm and 504 ± 52.4 mm, respectively (Table 5). The increase in mean length of spawning shad in 1982 over 1981 was similarly reflected in the over 1000 measured and released shad captured each year in the nonselective trapnets. Mean fork length of these shad was 501 mm in 1981 and 517 mm in 1982.

Mean fork length of males in both years was less than females (Table 5), a characteristic common to shad populations (Walburg and Nichols 1967). The mean length of males sampled in 1982 was slightly but not significantly greater than in 1981 ($P < 0.01$). Mean length of sampled females in 1982 was significantly greater than in 1981 ($P < 0.01$). In 1981, the largest shad captured were a 617-mm FL female and a 552-mm FL male compared to a 596-mm FL female and a 530-mm male in 1982.

Mean weight of shad sampled from the spawning run increased from 1870 ± 573.3 g in 1981 to 1918 ± 563.1 g in 1982 (Table 5). Increase in average weight of fish sampled in 1982 can be accounted for by the increase in the number of older females.

The weight-length relationships for males and females in 1981 and 1982 were:

1981 males	$\text{LogW} = 2.95\,(\text{Log FL}) - 4.69$ $r^2 = 0.87$
1982 males	$\text{LogW} = 2.88\,(\text{Log FL}) - 4.52$ $r^2 = 0.93$
1981 females	$\text{LogW} = 2.54\,(\text{Log FL}) - 3.52$ $r^2 = 0.80$
1982 females	$\text{LogW} = 2.48\,(\text{Log FL}) - 3.43$ $r^2 = 0.78$

where W = weight (g) and L = fork length (mm) (Fig. 7).

AGE

Each shad from the laboratory sample was aged by using both scales (Cating 1953; Judy 1961) and otoliths (Barney 1924). Final assigned age for individual shad was a reconciliation of independent otolith and scale readings by two experienced readers (GDM and JDM), but they were weighted for the otolith readings because this method resulted in the highest percent agreement between readers.

Males from both 1981 and 1982 spawning runs ranged from 4-12 yr old; females in 1981 were 4-12 yr old, and in 1982, 5-13 yr old (Table 6). Mean age of the 1981 spawning run (sexes combined) was 6.87 yr (scales) and 6.83 yr (otoliths) compared to 7.76 yr and 7.82 yr, respectively for 1982 (Fig. 8). No significant difference ($P < 0.01$) was found between ageing methods; however, the difference in mean age between the 1981 and 1982 spawning runs was

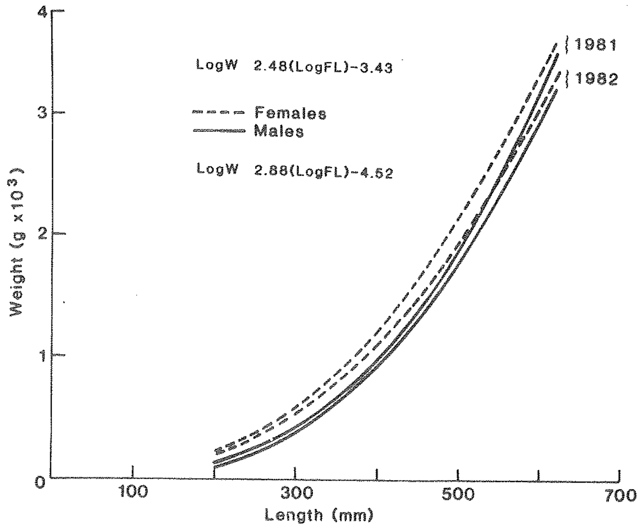

Fig. 7. Weight-length relationships for male and female American shad from the 1981 and 1982 Annapolis River spawning runs.

significant ($P < 0.01$). Since mean fork length at age did not differ significantly between 1981 and 1982 for either sex (Table 6), a difference in the age structure of the run or some bias in sampling caused the change. The proportion of virgin shad in the 1982 run was 11%, down from 25% in 1981 (Table 7). Poor recruitment of virgin adults in 1982, combined with the previous year's run returning 1 yr older, would create the observed shift in the mean age of the 1982 run.

Previous spawning history determined from scales indicated 75% of the 1981 sample and 89% of the 1982 sample were repeat spawners (Table 7). A greater proportion of females lived longer and spawned more often than males. Males, on the other hand, matured at a younger age than females (4.4-4.5 yr vs 4.7-4.8 yr; Fig. 9). In the samples from both years, all shad were mature at age six (Fig. 10). Mean age at maturity of Annapolis River males for both years was greater than all other shad populations investigated to date, but mean age at maturity of females was similar to other northern rivers (Table 8; Shoubridge and Leggett 1978). Combined mean age at maturity (both sexes) was greater than other studied populations (Leggett and Carscadden 1978). The increase in age at maturity of the 1982 run over the 1981 run was significant ($P < 0.01$).

GROWTH

Growth computations were based on measurements from otoliths. The reabsorption or erosion of the outer edge of scales while shad are in fresh water creates marks identified as spawning checks (Cating 1953) but prevents any growth calculations beyond the year of first spawning. For back calculation of growth, a relationship between body length and scale or otolith length is developed. This relationship is then used to estimate body length at each successive annulus, and the difference of natural logarithms of the length intervals multiplied by the slope of the weight-length relationship gives the instantaneous rate of growth for fish between those years (Ricker 1975). Separate calculations can be made for males and females if different growth rates are suspected. The reliability of these estimates are dependent upon the "goodness of fit" between body length and the morphological character which demonstrates the yearly growth pattern (e.g. scales, otoliths, fin rays).

Since bivariant analysis of fork length with total otolith length resulted in a very poor correlation coefficient ($r^2 = 0.57$ for males, 0.51 for females), a stepwise multiple regression approach was used. Fork length was regressed against otolith length and distance to the first, second, third, and fourth year annuli. The addition of these variables, particularly length to 1st and 4th year, resulted in much improved correlation ($r^2 = 0.76$ males, 0.70 females). No significant ($P < 0.01$) information was gained by incorporating the other two measurements. The following equations were used to calculate fork length at each age (Tables 9, 10):

Males:

$$FL = 4.976\ (OL) - 4.31\ (A4) + 1.49\ (A1) + 285.06$$

Females:

$$FL = 4.758\ (OL) - 5.45\ (A4) + 1.62\ (A1) + 4.12.72$$

where FL = fork length, OL = otolith length, A4 = length to end of 4th annulus, A1 = length to end of 1st annulus. The importance of these annule in estimating FL can be explained from the life history of this species. In their first year of life shad spend 3-4 mo in fresh water and are subject to its variable environment, migrating to sea after adjusting growth to tolerate physiological stress (Walburg and Nichols 1967). Age 4 corresponds to the period when most shad first mature (Fig. 9) and allocate energy to gonad rather than somatic growth.

Calculated lengths of females were always greater than similar aged males, which agreed with observed data (Table 6). Both sexes exhibited decreasing growth rates (G) with increasing age (Tables 11, 12). Individual growth rate of males exceeded females for ages beyond 4 yr. Observed differences in G_x (mean population growth rates) between 1981 and 1982 were possibly the result of more repeat spawners and increased mean age of the population in 1982.

The von Bertalanffy growth equation

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

where: L_t = length at age t,
L_∞ = asymptotic length,
K = growth coefficient,
t_o = theoretical age at start of growth

were calculated for both sexes for 1981 and 1982 (Fig. 11). The parameters L_∞, t_o, and K were estimated by using a Walford plot (Ricker 1975;

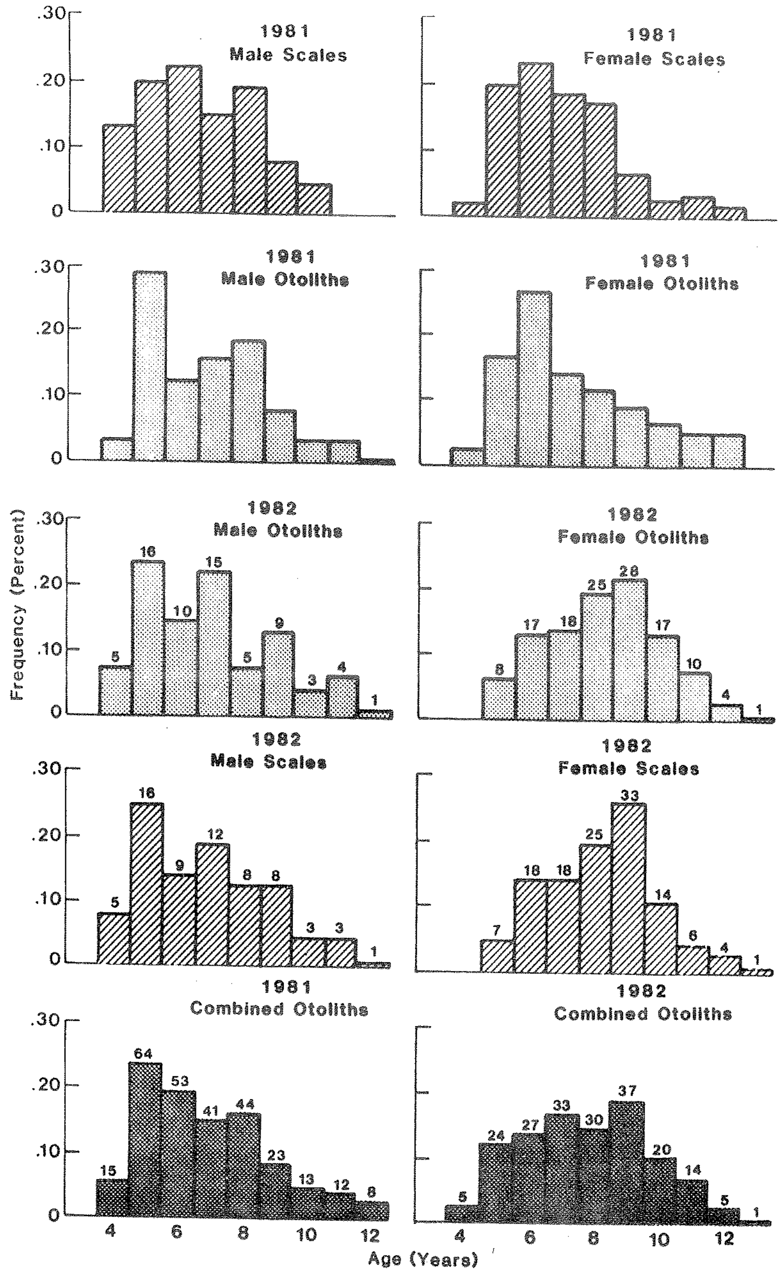

Fig. 8. Age frequency distribution of male and female American shad from scales and otoliths for the 1981 and 1982 spawning runs.

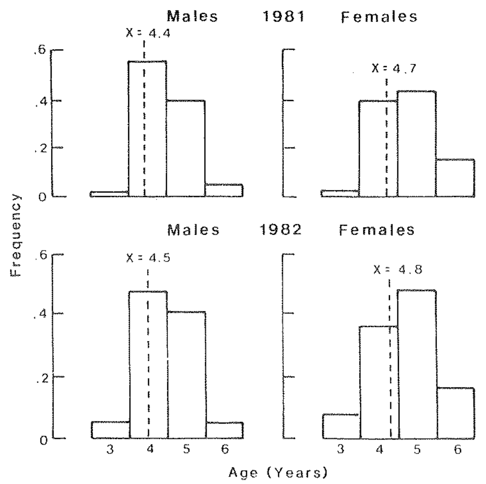

Fig. 9. Age at first spawning of male and female Annapolis River American shad for the 1981 and 1982 spawning runs.

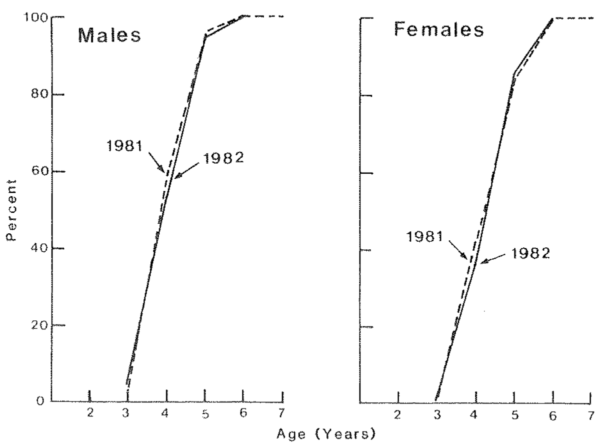

Fig. 10. Maturity ogives of male and female Annapolis River American shad.

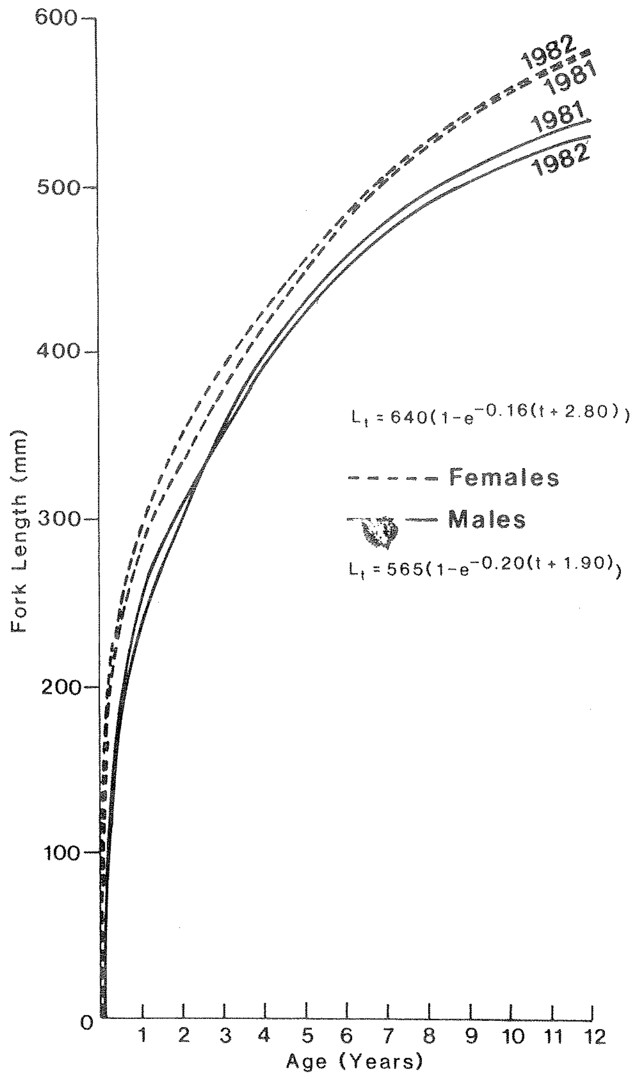

Fig. 11. von Bertalanffy fork length at age relationships for male and female American shad from the 1981 and 1982 Annapolis River spawning runs.

Table 13). The growth equations are:

Males:

$$1981 \quad L_t = 570\ (1-e^{-0.22(t+1.32)})$$
$$1982 \quad L_t = 565\ (1-e^{-0.20(t+1.90)})$$

Females:

$$1981 \quad L_t = 645\ (1-e^{-0.16(t+2.44)})$$
$$1982 \quad L_t = 640\ (1-e^{-0.16(t+2.80)})$$

where L_t = fork length (mm) and t = age (yr). Differences in growth parameters for the same sex between years are not significant ($P < 0.01$). Males exhibited slower growth and reached a smaller maximum size than females, possibly because they matured at a younger age.

MORTALITY

Total instantaneous mortality rates (Z) for males and females in both 1981 and 1982 were calculated from otolith-determined ages and age-class sizes from the trapnet samples (Fig. 8). The size of age 4 and 5 male year-classes were adjusted to account for immature male shad unrepresented in the spawning run using determined percentage at maturity from scale spawning histories (Fig. 9). Total size of year-class is sample size/proportion mature. Because of the marked decline of age 5 females in the 1982 sample the 4 and 5 yr age-classes were not used to determine total female instantaneous mortality.

Total instantaneous mortality determined for males was 0.36 in 1981 and 0.26 in 1982 and for females, 0.22 in 1981 and 0.25 in 1982 (Fig. 12). Differences in mortality rates between years may be attributable to sampling bias (small sample of males in 1982) and/or year-class dominance. Dominance of 8-yr-old males in 1981 and 9-yr-old females in 1982 suggests the 1973 year-class recruitment was above normal in size.

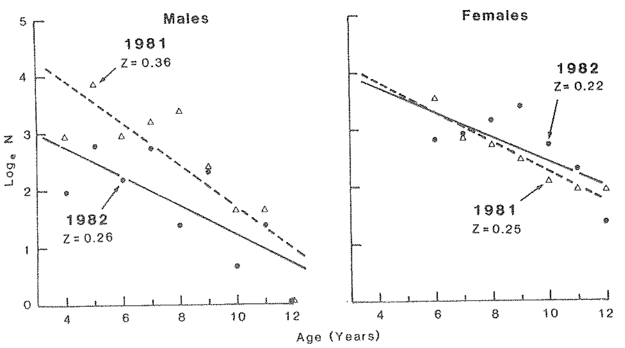

Fig. 12. Mortality [$\log_e$ of age-class size from trapnet catch sample] of male and female American shad from the 1981 and 1982 Annapolis River spawning runs.

SEX RATIOS, GONAD WEIGHTS AND FECUNDITY

Sex ratio determined from laboratory samples collected by trapnet were 0.8:1.0 female to male in 1981 and 1.6:1.0 in 1982. Sex ratios determined for shad sampled upriver (fish running ripe) indicated female to male proportion varied, depending on when the run was sampled (Table 14). In 1981, sampling at Bridgetown and further upriver at Lawrencetown indicated the sex ratio of the run was close to 2:1 dominated by females. The overall sex ratio of the 1981 Annapolis spawning run for shad captured upriver and for the total shad sample was 2.5:1 and 2.0:1, respectively, in favor of females (Table 14).

Leggett (1976) and Miller et al. (1982) found that males were numerically most abundant during the first half and females the last half of both the Connecticut and Delaware River shad runs but overall sex ratio was close to 1:1. Our data suggest the Annapolis River shad run is predominantly females (approximately 2:1). This could be the result of a commercial fishery unselective for larger females.

Mean gonad weight of Annapolis River shad did not differ significantly between 1981 and 1982 ($P < 0.01$; Table 15). Gonad weight averaged 10% of female total weight and 6% of male total weight. The relationship between fork length (FL) and gonad weight (GW) by sex for each year was:

Males:

$$1981 \quad GW = 0.77(FL) - 225.88 \quad (r^2 = 0.79)$$
$$1982 \quad GW = 0.75(FL) - 246.08 \quad (r^2 = 0.86)$$

Females:

$$1981 \quad GW = 1.20\ (FL) - 375.01\ (r^2 = 0.71)$$
$$1982 \quad GW = 1.37\ (FL) - 424.44\ (r^2 = 0.74)$$

No difference was observed between males in the 2nd yr; female gonad weight increased slightly in 1982 over 1981 (Fig. 13).

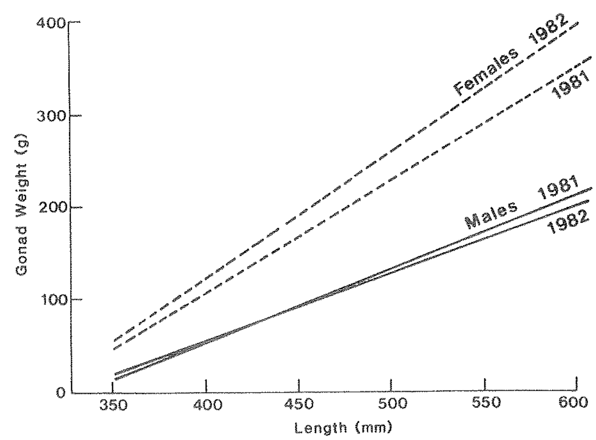

Fig. 13. Regression of gonad weight against fork length for Annapolis River male and female American shad.

Twenty-five ovary counts were made in 1981 and 90 in 1982. Mean ova/g was 847.1 in 1981 and 978.2 in 1982. The relationship between fecundity and female fork length was:

$$1981 \quad F = 1.01 \times 10^3\ (FL) - 3.18 \times 10^5$$
$$1982 \quad F = 0.65 \times 10^3\ (FL) - 1.14 \times 10^5$$

where F is fecundity in eggs x 10^3 and FL is fork length in mm. Comparison of the fecundity relationship with other Atlantic coast populations indicates the Annapolis lies in the expected region of the graph for its geographical location (Fig. 14). Mean lifetime fecundity of Annapolis River females was 2.1 x 10^5 eggs in 1981 and 2.3 x 10^5 in 1982. Mean virgin fecundity was calculated as 1.76 x 10^5 eggs (Table 16). Although mean virgin fecundity of the Annapolis River population was within the expected range for the river's geographic location, mean lifetime fecundity was lower than that of any population previously studied (Leggett and Carscadden 1978).

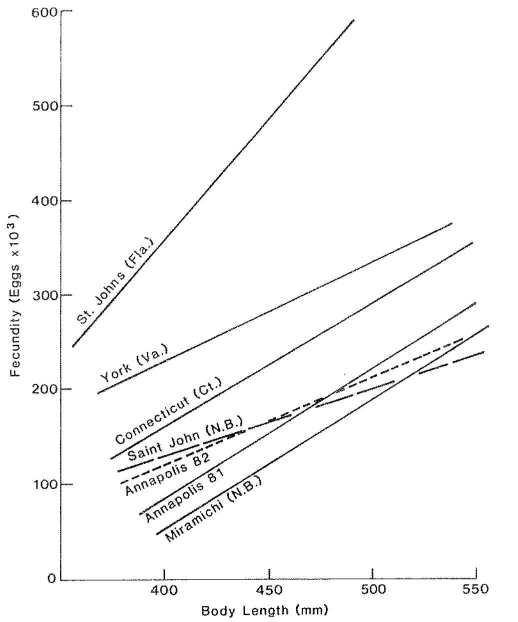

Fig. 14. Relative fecundity of five Atlantic coast populations of American shad compared to fecundity of Annapolis River female shad from the 1981 and 1982 spawning runs. Fecundity relationship of rivers other than the Annapolis is after Shoubridge and Leggett (1978).

MIGRATION

The best way to characterize the spawning run of American shad ascending the Annapolis River is to begin as the fish approach the tidal dam. Much of the description which follows is based on direct observation and interviews with local fishermen. However, tagging results are incorporated, where possible, to further establish the validity of observations. Movement at sea will be summarized later.

Schools of shad are first observed moving upriver at the site of the old ferry crossing between Granville Ferry and Annapolis Royal just before or after high tide. Their presence and movement were marked by a bow wave generated as the schools swam up the tidal basin (Fig. 15). This behavior could only be seen on calm days but it is assumed a similar pattern was followed with each tidal cycle since shad were not abundant at the causeway except early on the rising tide or an hour or two after high tide. Dodson and Leggett (1973), using sonic-tagged shad, found shad moved upstream with flood tides in the Connecticut River estuary.

Approaching the tidal dam at high tide slack, the shad continued straight up the basin past the sluiceway channel, apparently following the old river channel. The flow through the fishway by the sluice gates appeared too little to attract them during or near high tide. Upon reaching the causeway, the shad began a systematic back and forth movement across its seaward face (Fig. 15). Attraction to the face of the causeway during the falling tide and the early part of the rising tide appeared to be influenced by the pre-1984 flow from seepage through the causeway, which could amount to 10.0 m^3/s (G. Baker, pers. comm.). It was at this time the sport fishery operated. Anglers along the seaward face of the causeway jigged shad each time the school passed.

Fig. 15. School of shad moving along the seaward face of the causeway.

During the same period, a second group of shad was normally present in the back eddy at the edge of the spillway/fishway outflow (Fig. 2). The drifting of gill nets across the sluiceway flow-eddy interface consistently caught the majority of shad in the eddy portion. The shad were obviously attracted by the spillway flow and were holding in the eddy until rising tide allowed movement through the fishway.

When the rising tide reached a height where downstream seepage through the barrage ceased, the shad school began to make a wider search pattern along the face of the tidal dam. They moved rapidly along its seaward face until they encountered the sluiceway/fishway flow and would then remain there until able to move through the fishway. During this period, large numbers of shad were captured in the trapnet. When the flood tide level equalized with basin level, shad moved rapidly upstream through the fishway.

Low recapture rates for shad at the causeway during 1981 (0.2%) indicate most leave the area soon after tagging and probably after one tide cycle. However, not all shad present below the tidal dam migrated through the fishway during their first rising tide period on its seaward side. Recapture data suggest some shad spent two or three tide cycles here (Table 17). Delayed movement upriver, however, may have been caused by tagging trauma and/or retention in the trapnet during the time of possible fishway passage. In 1982, shad movement into the river ceased during the period of adverse weather (May 9-18) and some tagged shad remained seaward of the causeway for 15 d (Table 18). Shad tagged after this period were found to move past the tidal dam after the normal delay (i.e. 2-3 tidal cycles).

During 1981, mean upriver migration rate of tagged shad was 3.1 km/d (Table 17, ripe shad). During 1982 upriver migration rates were determined from two sources, shad tagged at the causeway in 1982 and recaptured upriver, and shad tagged in 1981 which were recaptured with the 1982 spawning run. They ranged from 1.27 to 3.33 km/d (Table 19). Rate of upstream movement was slowest in the tidal basin. Mean migration rate from Annapolis Royal to upper Granville in 1981 was 1.70 km/d. Migration rates in the estuary for 1982 were 1.27 km/d from Annapolis Royal to Center Granville and 1.68 km/d from Annapolis Royal to Bridgetown (Table 19). Osmotic adaption to fresh water apparently occurs in this region of the estuary and such physiological change is known to slow migrations (Dodson and Leggett 1974; Dodson et al. 1972). The observed average rate of upstream migration in the Annapolis River was similar to but slightly faster than reported for the Connecticut River shad run (Leggett 1976). The Greater upstream migration rate may be attributed to a lack of dams or rapids on the Annapolis, obstructions the Connecticut shad must overcome during their spawning migration.

The return of tags from the length of the river (Table 17) and observed distributon of running ripe shad encountered during the study suggest spawning on the Annapolis occurs from Lawrencetown to Aylesford. Peak spawning period, estimated from numbers of downrunning spent shad, occurs about June 10 (Table 17), when water temperatures in the river average 17.5°C (Daborn et al. 1982). Mean time at large for recovery of spent shad, originally tagged at the causeway, during downstream migration was 27.3 d in 1981 compared to 34.3 d in 1982.

After spawning, most shad rapidly descend to the sea. Mean rate of fourteen downrunning shad tagged at Middleton and recaptured at Bridgetown was 10.4 km/d. Seven shad tagged at Lawrencetown descended to Bridgetown at a rate of 13.6 km/d. Some shad, however, remain in the river for an indefinite period of time. Local anglers report their presence as late as August and two shad were caught by anglers in mid-July, 69 and 71 d after tagging.

On two occasions in 1982, observations were made on shad moving back to sea through the fishway. Drift gillnetting in the sluiceway channel during late June failed to capture shad except for a short period around slack tide. Apparently shad preferred to negotiate the fishway when currents were at a minimum in either direction.

OCEAN MIGRATION

After leaving the river, Annapolis shad migrate around the Bay of Fundy in a counter-clockwise pattern during the summer (Fig. 16; Dadswell et al. 1983). Tag returns indicate that shad migrate to the inner Bay of Fundy (Cobequid Bay, Cumberland Basin) during June to August and then move along the New Brunswick shore out of the Bay of Fundy past Grand Manan in September (Table 20). Mean migration rate in the Bay of Fundy was 3.7 km/d.

Tag returns from the United States indicate at least part of this population migrates as far south as Pamlico Sound, North Carolina (Fig. 17). To some extent, they follow the seasonal migratory pattern for this species described by Talbot 1954, Leggett and Whitney (1972) and Neves and Depres (1979). To date, no shad tagged in the study have been captured in river systems other than the Annapolis, which agrees with the generally accepted hypothesis that shad home to their natal rivers (Table 20) (Hollis 1948; Dodson and Leggett 1974).

POPULATION ESTIMATES

During both 1981 and 1982, mark-recapture experiments were conducted to obtain population estimates. Single-census (Peterson) and multiple-census models (Schumacher and Chapman) were used. Robson and Regier (1964) provide charts for determining combinations of numbers of marked fish (M) and the number subsequently examined for marks (C) over a series of populations sizes (N) when using Peterson's population models - the assumption being a reasonable estimate can be made of the true population size. Using a best approximation of the possible population size, one inspects the appropriate chart, depending on the degree of confidence desired, to obtain the number of marked fish required and the subsequent number of fish to be examined. The data are then applied to the modified Peterson formula (Ricker 1974):

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

where: $\tilde{N}$ = estimated population size at marking,
M = number marked,
C = number subsequently examined for marks,
R = numbers of marked fish in C.

Multiple census models were utilized by partitioning the mark-recapture data into weekly sampling periods. This permitted analysis of data with an increased proportion of marked fish and improved the confidence limits of the estimates. Allowance was made in all models for possible delayed netting mortality (10% gillnet, 5% trapnet) and for downstream movement because of tagging trauma (5% trapnet). Research on the Delaware River has shown that 5% of tagged shad fall back to the sea without continuing the spawning run (Miller et al. 1982).

For 1981, a spawning population of 50 000 shad was anticipated in the Annapolis River (5x the mean annual commercial catch), which meant, if 95% of trials were not to deviate more than 25% from true population size, it was necessary to mark at least 2000 shad and later examine a minimum of 1300. A total of 2200 shad were successfully marked and 1389 later captured which complied with model requirements, but the subsequent population estimate was 155 000 and the 95% confidence interval was greater than 25% of the estimate (Table 21). Accordingly, in 1982, initial marks were increased to approximately 2700 and subsequent captures to 1800, resulting in a population estimate of 132 000 shad

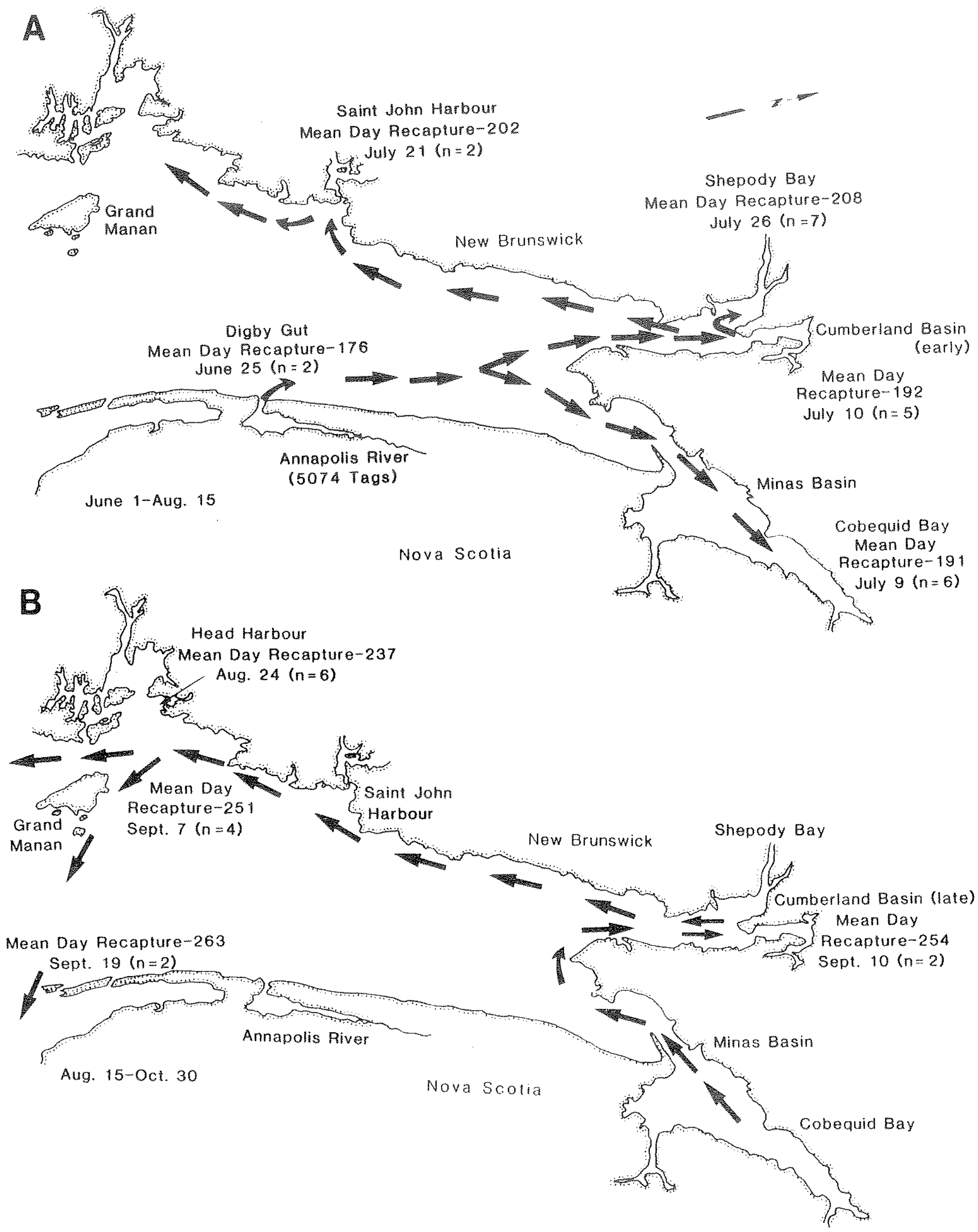

Fig. 16. Migration of the Annapolis River American shad population in the Bay of Fundy after its spring spawning run. A) June 1-Aug. 15. Annapolis population migrates inward in the Bay of Fundy, divides into two possibly equal groups, and moves to the head of the inner embayments. Cumberland contingent migrates out of inner end and down western shore first. B) Aug. 15-Oct. 30. Minas Basin contingent moves to Cumberland Basin, then follows Cumberland contingent down west side of Bay and out of Bay past Grand Manan and Brier Island.

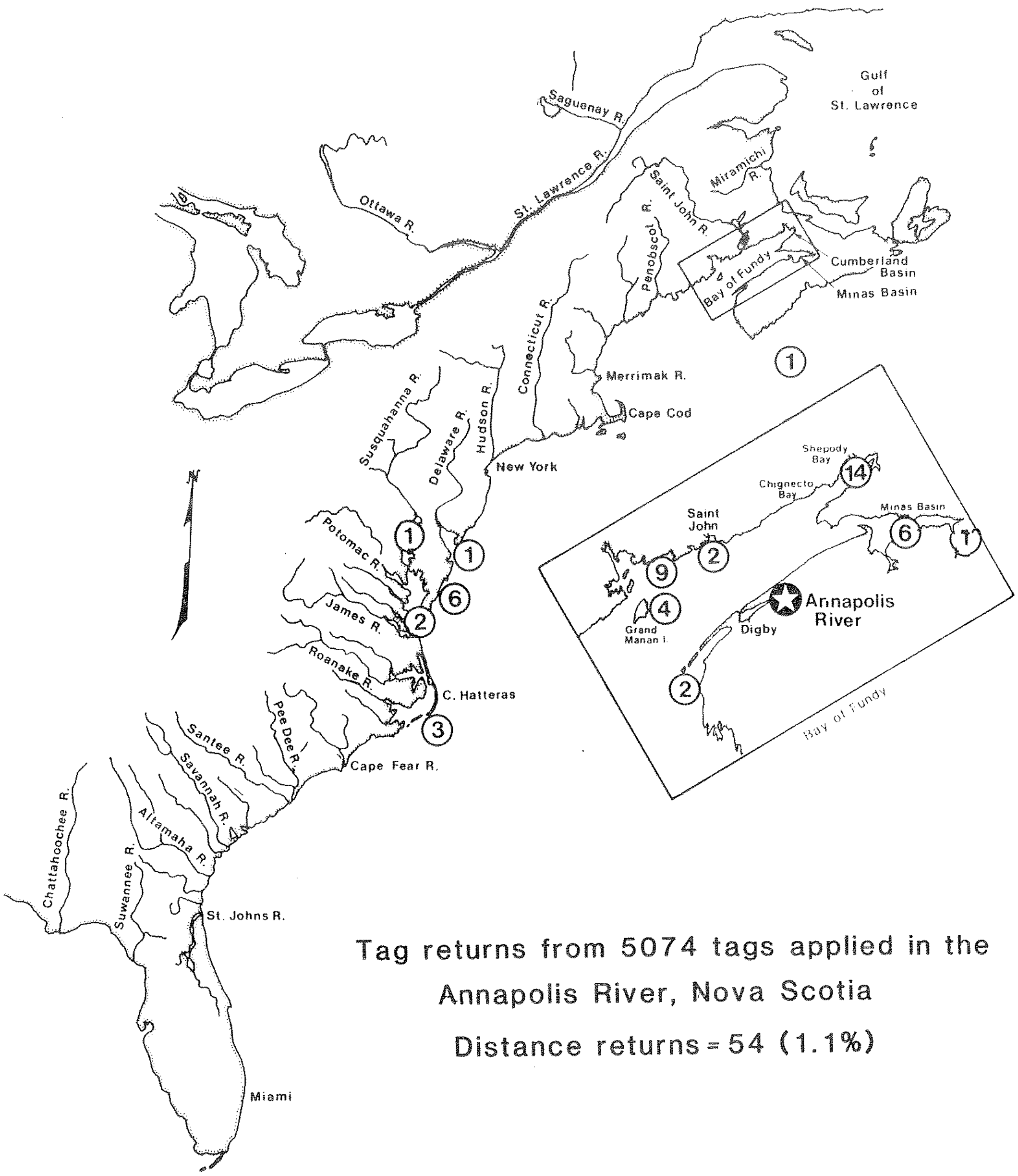

Fig. 17. Tag returns from the east coast of North America for American shad tagged in the Annapolis River.

and a 95% confidence interval within 25% of the true population size.

In both 1981 and 1982, the multiple census models estimated the population consistently lower than did the Peterson model (Table 22). The multiple census models may have been more accurate since the proportion of marked shad was substantially increased (Table 22) and the 95% confidence intervals improved. All models estimated the 1982 spawning population at 20 000-30 000 less shad than in 1981, tending to support the observed increase in mean age of the 1982 run, the decline in virgin fish, and the decreased number of 5-yr-old females. The mean annual spawning run of American shad to the Annapolis River was concluded to be about 100 000.

FISHERIES

COMMERCIAL DIPNET FISHERY

During both years, the Middleton dipnet fishery stand was visited on several occasions. The dipnet fishery legally operates on Mondays and Tuesdays from May 1-31, and the catch is limited by dipnet gear regulations. High-water levels in 1981 prevented the normal concentrated movement of shad through narrows in the river and observed catches were small. During one evening of observation, 15 fishermen captured only four shad. On other nights, the weather was poor and no fishermen were present. However, reported catch from this fishery for 1981 was 3650 kg (Table 23).

In 1982, water levels were lower and on one night 17 fishermen were observed catching 2 to 3 shad/h. An estimate for total 1982 catch was 2295 shad or 4200 kg based on 17 fishermen catching 2.5 shad/hour, 6 h/night for nine nights (Mondays and Tuesday in May 1982). Reported landings for the district (Statistical District 35) were 8200 kg in 1982 but part of this was made by anglers selling their catch (Mr. Watson, Fisheries Officer, pers. comm.). The summary of reported landings from 1895-1912 and 1947-1982 indicates mean annual landings are about 6200 kg/yr (Table 23). Reported 1982 landings for this fishery may were above average.

Two tags were received from fishermen involved in the dipnet fishery in 1982, providing an estimate of minimum exploitation rate by this fishery of 0.1%, far below the expected and probably unreliable.

SPORTS FISHERY

A shad sports fishery operates, with the exception of federally closed waters, along the entire length of the river from Annapolis Royal to Aylesford. Two forms of angling are used: jig or snag fishing along the seaward face of the causeway, using large treble hooks which impale shad from the large, visible schools, and upriver angling, using shad darts for lures. The Annapolis River is one of the few rivers in eastern Canada with a dedicated sports angling fishery for shad similar to the large sports fisheries on many United States rivers.

The major angling effort occurs at the Annapolis Royal tidal dam. Anglers line the seaward face of the causeway, snagging shad with each pass of the large schools. No records are kept of shad angling catches, except the estimated catch sold to commercial fishermen at Middleton, yet data suggest sports landings are equal to or greater than the commercial dipnet fishery. From April 22 until May 22, 1981, the number of anglers along the causeway was recorded as well as their catch/hour. During the 31-d period, an average of 21 anglers was observed catching shad at a rate of 4/h. If a conservative estimate of 4 h/d was spent for each angler for 21 anglers (on weekends up to 40 anglers were present all day), about 10 500 shad (18 000 kg) were landed by the causeway snag fishery. However, the calculated exploitation rate from tag returns for the 1981 snag fishery was only 0.2% compared to 9% estimated. We think the apparent low exploitation rate was really an expression of how rapidly the shad left the causeway fishing area and moved upstream.

Similar observations were made from May 4-28, 1982. Shad disappeared during the May 9-18 cold snap; consequently, effort during these days was not included in the catch estimates. In 1982, the observed mean number of anglers/day was 18 and their catch was 3 shad/h over an average angling time of 4 h. The resulting catch estimate for 1982 was 3240 shad (5900 kg) or about 4% of the estimated 1982 population. Daily estimated catch in 1982 was 216 shad, down from 336 shad/d in 1981. Exploitation rate by the causeway snag fishery in 1982 estimated from tag returns increased to 0.8%. In fact, more shad tagged during 1981 were jigged at the causeway during 1982 than 1981 (7 vs 3). The increase in exploitation during 1982 may have had two causes: longer residency of shad at the causeway face because of the cold spell (Table 18) (i.e. shad at the causeway in early May moved seaward for a period, then returned a second time, subjecting them to twice the effort), and selective fishing for tagged shad by the anglers who knew there was a reward for tags and could see the tagged fish to catch them.

Observations on number of anglers or their catch were not made for the upriver sports fishery. Exploitation rates by this fishery, computed from tag returns, were 0.5% in 1981 and 0.7% in 1982 for estimated catches of approximately 500 shad in 1981 and 600 in 1982. Because exploitation rates calculated from tag returns significantly underestimated shad catches by the other fisheries, the upriver sports catch was probably also underestimated. Although total estimated sports landings of approximately 20 400 kg in 1981 and 7 300 kg in 1982 were conservative, they are equal to or larger than the reported commercial landings.

INJURIES TO SHAD

The extent and frequency of injuries to shad were assessed visually at the causeway and at upriver stations. Injuries were classified as abrasive (Fig. 18), jig or snag wound (Fig. 19), seal bites and lamprey wounds (Table 24). Abrasive injuries were absent among shad captured on the seaward face of the causeway but occurred in about 1% of shad examined upriver (Table 24). Because of the difference of incidence in relation to capture site, abrasive injuries were thought to be caused by shad striking the walls of the fishway during upstream passage. Large sections of the sides of the fish were abraided and hemorraging was often extensive. The shad, however, were otherwise active and healthy and did not seem to suffer lasting or mortal damage.

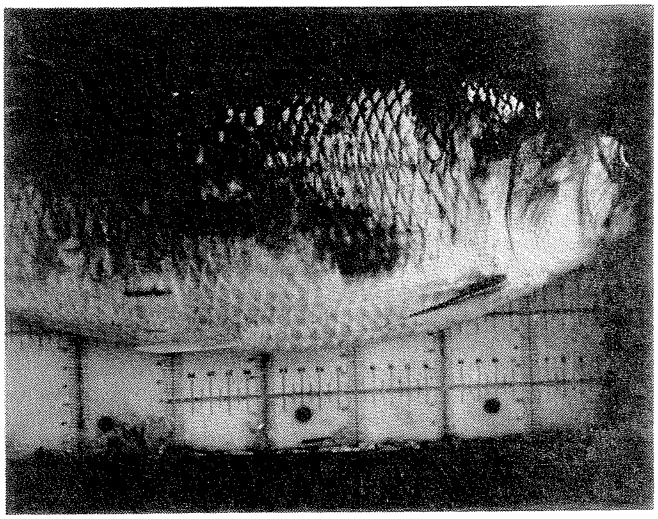

Fig. 18. Abrasion wound on side of American shad captured upriver on the Annapolis.

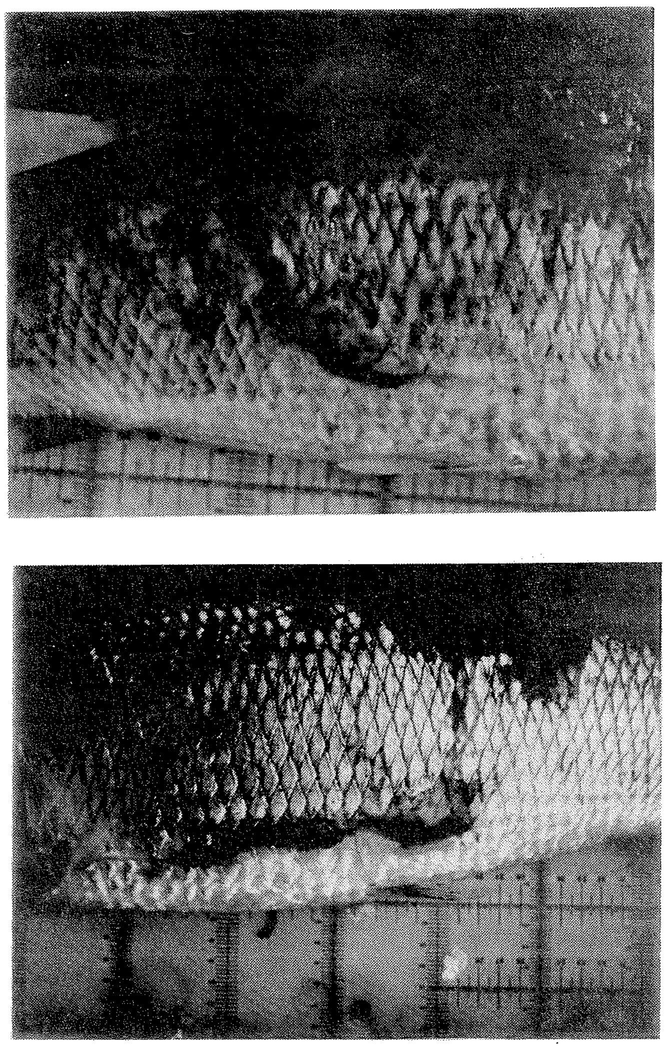

Fig. 19. Snag or jig wounds on the side (upper) and abdomen (lower) of American shad captured in the Annapolis River.

Jig or snag wounds comprised the greatest number of injuries observed, 4.7% of all shad examined. Large, three-prong hooks are used in the causeway sports fishery to snag the shad and those fish which escaped or were released were severely gashed or torn and often the treble hook was still imbedded in their body. Of 1524 shad caught in the trap net seaward of the causeway during 1981, 3.8% had snag wounds. In 1982, 4.4% of 915 shad examined at this site had jig wounds. The number of wounded shad varied with time of week. On Mondays, following heavy weekend angling pressure at the causeway, up to 40% of shad examined were wounded. By Fridays, the proportion wounded often declined to less than 1%. Snag-wounded shad were often lethargic and weak. Mortality of shad with this type of injury may be high.

Seal bites were distinctive and consisted of three or four parallel tears on both sides of the shad's venter around the anus region. Seal wounds were most common during the early part of the shad spawning run when as many as a dozen harbour seals were observed at one time in the sluiceway channel. An average of 0.2% of the shad examined in 1981 and 1982 had seal wounds. Lamprey wounds were observed on about 1% of shad examined in 1981 (Table 24).

Operation of the turbine at Annapolis Royal, especially if it is used for sluicing, may increase the seal predation rate. Most predators target prey displaying unusual movement and only slight turbine blade damage may increase the susceptibility of predation. Predation has often been cited as a major problem around turbines at other hydroelectric developments (Ruggles 1980).

SUMMARY DISCUSSION

The results of this 2-yr study provide a description of the unique Annapolis River shad population and the necessary baseline data for future assessment of tidal power impacts. Important population characteristics for the 1981 and 1982 spawning runs are summarized in Table 25. The mean estimates of the 1981 and 1982 runs were 130 000 and 100 000 shad, respectively. The adult shad population of this river is composed largely of older shad (mean age 6-9 yr). Mean age of males at maturity was greater than in any other river studied to date but mean age of mature females was similar to that of most northern populations (Leggett and Carscadden 1978). Mean percent repeat spawners in the run was 75.0 in 1981 and 89.0 in 1982 (sexes combined) and were greater than any other river previously investigated (Leggett and Carscadden 1978). Both growth rate (K) and the total instantaneous mortality rate (Z) were lower than for shad populations previously examined (Leggett 1976). Fecundity, however, was similar to that in other northern rivers and was in the expected range for the geographical location (Leggett and Carscadden 1978). Many of the characteristics of the Annapolis River shad population, describing it as an old, slow-growing population, are directly attributable to the lack of an appreciable commercial fishery on this river. Most shad runs fished commercially with selective gillnets, sustain annual exploitation rates in excess of 20% (Leggett 1976). Gillnet selectivity removes the older, large shad, decreasing observed mean age, mean size, and the number of repeat spawners. The Annapolis River seldom sustains more than 5% fishing mortality a year. The level of mortality is negligible in comparison to annual natural mortality (approx. 25%), resulting in the old age-structure of the population.

Year-to-year comparisons of most biological parameters did not differ significantly ($P < 0.01$) except those most affected by year-class success or failure (mean age, percent virgins). A dominant year-class appears to have recruited in 1973, leading to greater representation of age 8 shad in 1981 and age 9 shad in 1982. Similarly, a poor year-class in 1977 may have decreased numbers of virgin spawners in 1982. These two events were the major contributors to the increased mean age, and mean length, lower mortality rate, and increased mean fecundity of the population in 1982. However, because of the large number of older shad in this population, environmental perturbations or other factors causing year-class fluctuations have little effect on the total population size.

Knowing the present structure of the Annapolis River shad spawning population and assuming that the turbine could selectively damage larger fish, it is possible to develop a scenario of possible future changes in the adult population based on hypothetical turbine mortalities (Table 26). If turbine mortality is low (1-10%), the shad population parameters should remain as they are (subject to year-class variations). If mortality is moderate (annual rate 10-50%), some changes will occur. Because mortality of this level is comparable with that experienced by populations with relatively heavy commercial exploitation, the effect could be similar to classical "fishing up" (Ricker 1975). The mean age of the population should decline and number of repeat spawners decrease appreciably. The population size may increase because of increased growth rates and associated better condition factors of the adults. Mean population fecundity should also increase. If turbine mortalities are high (50-90%), the effects would represent classical "overfishing" (Ricker 1975). The population will decline, there will be few repeat spawners and mean age will decrease to levels near some of the heavily fished southern shad populations (Leggett and Carscadden 1978). Unacceptably high turbine mortality (90-100%) may not occur but, if it did, the population would become unstable and strongly dependent on single year-class strength, resulting in sharp swings in the annual population size and the possibility for a population collapse.

Using the turbine mutilation relationship developed by von Raben (1957), the calculated mutilation rate for a 50-cm shad is 9.5%. Since mortality rate usually is approximately 50% of the expected mutilation rate (Ruggles 1980), mortality is expected to range from 5-10% of each spawning run. It must be noted, however, that the von Raben relationship was developed for Kaplan and Francis turbines and may not apply to the STRAFLO. If this estimate is valid and other turbine mortality effects are not manifested, (cavitation, gas bubble disease), the demography of shad population in the Annapolis River should change little from its present form as a result of tidal power generation at Annapolis Royal. This study has documented that shad move through the present tidal dam region after a delay of one or two tide cycles. Using the basin for tidal generation, which means opening the sluice gates until high water, may further decrease delay time at Annapolis Royal and thereby decrease the jig fishing mortality along the causeway. This decrease in fishing mortality may offset some or all of the anticipated turbine mortality.

Once the hydroelectric plant begins operation, some additional questions will arise and investigation should be initiated to resolve the answers. These include:

1) What is the real mutilation/mortality rate associated with fish passage through the STRAFLO lowhead turbine? Is it related to fish size, species and/or mode of turbine operation?

2) How will fish species respond to the various flow patterns established upstream and downstream of the turbine, and the new fishway? How will the fish select which passageway to take or will selection be random? What will the timing of fish passage be through the various structures?

3) If mortality is detectable and appreciable, can operational strategems (efficiency, wicket gate placement, sluicing methods) be developed to decrease it.

Operation of the Annapolis River pilot project will provide an excellent opportunity to examine possible fish passage problems related to lowhead hydroelectric development of all kinds. It will also be a cost-effective way to evaluate anadromous fish passage and turbine mortality problems related to future, large-scale Fundy tidal power development.

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Frank Cunningham prepared the figures. Jeanine Hurley typed the manuscript.

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Table 1. Daily record of American shad tagged at the Annapolis River causeway during 1981.

Date	Number tagged	Method of capture
April 22	2	Gillnet
April 23	49	Gillnet
April 24	8	Gillnet
April 28	63	Gillnet
April 30	260	Trapnet
May 1	1	Trapnet
May 2	46	Trapnet
May 3	180	Trapnet
May 4	31	Trapnet
May 5	51	Trapnet
May 6	103	Trapnet
May 7	231	Trapnet
May 8	286	Trapnet
May 9	266	Trapnet
May 10	473	Trapnet
May 11	223	Trapnet
May 12	83	Trapnet
	Total 2356	

Table 2. Daily record of American shad tagged at the Annapolis River causeway during 1982.

Date	Number tagged	Method of capture
April 27	5	Gillnet
May 4	287	Trapnet
May 5	532	Trapnet
May 6	236	Trapnet
May 7	168	Trapnet
May 8	174	Trapnet
May 9	227	Trapnet
May 10	1	Trapnet and gillnet
May 12	2	Trapnet and gillnet
May 18	159	Trapnet and gillnet
May 19	192	Trapnet and gillnet
May 20	104	Trapnet and gillnet
May 21	90	Trapnet and gillnet
May 24	147	Trapnet and gillnet
May 25	108	Trapnet and gillnet
May 26	146	Trapnet and gillnet
May 27	109	Trapnet and gillnet
May 28	31	
	Total 2718	

Table 3. Summary of daily American shad catch in trapnet at Center Granville during 1982.

Date	Total catch	Number of recaptures	Number tagged and released
May 10	59	–	29
May 11	6	–	–
May 12	7	1	5
May 13	2	–	1
May 17	7	1	4
May 18	23	–	6
May 19	23	1	1
May 20	17	2	5
May 21	23	1	1
May 26	69	1	1
May 28	6	1	6
Totals	242	8	59

Table 4. Summary of upriver gillnet catches during 1981 and 1982.

Date	Location	No. tagged or clipped	No. recaptures	Total catch
May 20/81	Upper Granville	103	4	110
May 21/81	Bridgetown	153	6	153
May 24/81	Bridgetown	2	–	2
May 25/81	Middleton	9	–	9
May 26/81	Bridgetown	58	3	61
May 27/81	Lawrencetown	240	8	245
May 28/81	Lawrencetwon	175	1	175
June 2/81	Bridgetown	261	4	161
June 3/81	Bridgetown	267	5	267
June 4/81	Bridgetown	106	1	106
	Total	1374	32	1389
May 17	Upper Granville	20	–	22
May 18/82	Upper Granville	9	–	17
May 26/82	Upper Granville	28	2	30
May 27/82	Upper Granville	35	3	39
June 1/82	Middleton	52	1	54
June 2/82	Paradise	11	–	11
June 3/82	Middleton	127	1	128
June 8/82	Middleton	50	1	51
June 8/82	Lawrencetown	158	19	223
June 9/82	Middleton	122	5	128
June 9/82	Bridgetown	150	0	150
June 10/82	Middleton	50	2	52
June 10/82	Lawrencetown	39	1	40
June 11/82	Paradise	3	0	3
June 14/82	Lawrencetown	162	14	179
June 14/82	Bridgetown	50	–	52
June 15/82	Bridgetown	93	–	94
June 16/82	Bridgetown	163	5	172
June 19/82	Bridgetown	24	2	26
June 20/82	Bridgetown	30	–	30
June 21/82	Bridgetown	16	–	16
	Total	1392	56	1517

Table 5. Mean for length (mm) and weight (g) of the 1981 and 1982 Annapolis River American shad spawning runs.

	N	Sex	Mean	Standard deviation	Minimum	Maximum
Length (mm)						
1981	309	Both	481	46.4	370	602
1982	196	Both	504	52.4	250	605
1981	166	Male	459	38.0	370	577
1982	68	Male	463	40.5	373	530
1981	143	Female	506	42.8	411	602
1982	118	Female	527	37.6	429	605
Weight (gm)						
1981	309	Both	1870	573.3	760	3750
1982	196	Both	1918	563.1	720	3370
1981	166	Male	1558	400.6	760	3000
1982	68	Male	1473	382.2	720	2260
1981	143	Female	2232	529.7	1200	3750
1982	127	Female	2252	499.5	1270	3370

Table 6. Mean for length at age by sex and year for American shad samples from the 1981 and 1982 Annapolis River spawning runs.

Age (yr)	Year	N	% total	Sex	Mean length (mm)	Standard deviation (mm)	Minimum (mm)	Maximum (mm)
4	1981	13	8.6	Male	397	13.6	370	417
	1982	5	8.3	Male	396	16.0	373	417
	1981	2	1.6	Female	420	12.7	411	429
	1982	-	-	Female	-	-	-	-
5	1981	44	29.1	Male	431	11.3	411	463
	1982	13	21.6	Male	430	19.4	392	450
	1981	20	16.4	Female	456	16.1	425	479
	1982	7	5.9	Female	464	19.2	429	490
6	1981	19	12.6	Male	456	11.3	428	476
	1982	9	15.0	Male	439	27.8	392	492
	1981	34	27.8	Female	472	14.3	440	508
	1982	16	13.5	Female	489	31.8	449	564
7	1981	24	15.9	Male	472	12.8	443	491
	1982	13	21.6	Male	478	17.8	450	515
	1981	17	14.0	Female	499	15.9	462	521
	1982	16	13.5	Female	504	16.6	483	536
8	1981	29	19.2	Male	495	13.3	473	532
	1982	5	8.3	Male	494	14.5	473	510
	1981	15	12.3	Female	530	18.9	490	559
	1982	24	20.3	Female	526	30.6	449	605
9	1981	11	7.3	Male	503	11.4	488	521
	1982	7	11.7	Male	501	16.8	476	530
	1981	12	9.8	Female	539	13.9	514	565
	1982	26	22.0	Female	542	22.4	489	578
10	1981	5	3.3	Male	525	12.8	510	539
	1982	3	5.0	Male	507	12.3	498	521
	1981	8	6.6	Female	550	9.3	540	565
	1982	16	13.5	Female	564	15.8	541	596
11	1981	5	3.3	Male	534	10.0	525	551
	1982	4	6.7	Male	508	9.9	500	522
	1981	7	5.7	Female	569	13.9	553	586
	1982	9	7.6	Female	558	16.0	530	571
12	1981	1	0.6	Male	552	-	-	-
	1982	1	1.7	Male	526	-	-	-
	1981	7	5.7	Female	587	17.4	565	617
	1982	3	2.5	Female	579	2.3	577	581
13	1981	-	-	Male	-	-	-	-
	1982	-	-	Male	-	-	-	-
	1981	-	-	Female	-	-	-	-
	1982	1	0.9	Female	548	-	-	-

Table 7. Spawning history of Annapolis River American shad by sex from the 1981 and 1982 spawning runs. Spawning history is determined from spawning marks on each shad's scales.

No. of spawnings	1981 Males No.	1981 Males %	1981 Females No.	1981 Females %	1981 Combined No.	1981 Combined %	1982 Males No.	1982 Males %	1982 Females No.	1982 Females %	1982 Combined No.	1982 Combined %
0	35	23.5	31	27.8	66	25.0	13	20.0	8	6.4	21	11.0
1	35	23.5	18	15.7	53	20.1	14	21.0	14	11.2	28	14.7
2	23	15.4	11	9.6	34	12.9	10	15.4	15	12.0	25	13.1
3	21	14.1	19	16.4	40	15.2	8	12.3	28	22.4	36	18.8
4	25	16.8	20	17.5	45	17.0	9	13.8	26	20.8	36	18.8
5	8	5.4	7	6.1	15	5.8	4	6.2	18	14.4	22	11.5
6	2	1.3	6	5.2	8	3.0	5	7.7	13	10.4	18	9.2
7	-		2	1.7	2	1.0	2	7.1	2	1.6	4	2.0
8	-	-	-	-			-		1	0.8	1	0.5
Total	149	100	115	100	264	100	68	100	115	100	196	100
% repeat spawners	76.5		72.2		75.0		80.0		93.6		89.0	
Sex ratio	1	:	0.8				1	:	1.6			

Table 8. Mean age at maturity for males and females of Atlantic coast American shad populations. Data for rivers other than the Annapolis are from Shoubridge and Leggett (1978).

River	Males Sample size	Males Mean age (yr)	Females Sample size	Females Mean age (yr)	Combined mean age
St. John's (Fla.)	1360	3.9	2218	4.3	4.14
York (Va.)	654	3.8	1232	4.5	4.23
Hudson (N.Y.)	1259	4.2	1165	4.6	4.39
Connecticut (Ct.)	2036	4.0	2909	4.8	4.47
Saint John (N.B.)	553	4.1	418	4.5	4.27
Annapolis 81	149	4.4	115	4.7	4.53
Annapolis 82	68	4.5	127	4.8	4.69
Miramichi (N.B.)	151	4.3	87	4.5	4.37

Table 9. Calculated fork lengths of Annapolis River male American shad from the 1981 (upper) and 1982 (lower) spawning runs.

Age	No. of fish	Length at capture	Calculated length at successive annuli											
			1	2	3	4	5	6	7	8	9	10	11	12
1981														
12	1	552	213	318	357	392	417	437	452	467	477	487	497	507
11	5	533	193	295	349	388	415	435	453	468	481	491	502	
10	5	525	203	296	344	385	419	444	461	476	485	496		
9	11	503	211	299	347	387	416	438	457	472	489			
8	29	495	208	299	346	387	421	442	461	476				
7	24	472	203	297	343	387	423	442	459					
6	19	456	186	288	342	385	419	442						
5	44	430	187	288	341	385	419							
4	13	397	169	282	340	385								
		Mean	197	296	345	387	419	440	457	472	483	491	500	507
1982														
12	1	526	214	310	358	413	454	468	488	502	516	529	543	557
11	4	526	202	315	368	411	439	458	477	496	510	520	529	
10	2	500	220	313	371	412	453	477	491	504	518	532		
9	10	502	217	310	372	414	443	463	482	496	510			
8	4	504	217	311	359	415	449	473	482	506				
7	15	475	206	315	367	411	442	462	479					
6	9	442	208	306	366	412	442	463						
5	15	436	199	314	373	412	439							
4	5	395	216	308	371	418								
		Mean	211	311	367	413	445	466	484	501	514	527	536	557

Table 10. Calculated fork lengths of Annapolis River female American shad from the 1981 (upper) and 1982 (lower) spawning runs.

Age	No. of fish	Length at capture	Calculated length at successive annuli											
			1	2	3	4	5	6	7	8	9	10	11	12
1981														
12	7	587	240	333	384	421	454	479	496	512	526	541	555	567
11	7	569	241	329	379	420	451	478	493	510	524	537	549	
10	8	550	248	334	382	421	451	476	491	503	516	528		
9	12	539	239	332	379	419	449	478	497	512	527			
8	15	530	241	326	376	419	456	479	494	505				
7	17	499	236	324	376	418	452	476	493					
6	34	471	228	324	375	416	450	471						
5	20	455	238	328	374	419	455							
4	2	420	187	296	360	410								
		Mean	233	325	376	418	452	476	494	508	523	535	552	567
1982														
12	4	578	225	318	366	409	451	477	496	509	523	534	544	552
11	10	555	215	318	370	413	449	469	487	503	515	528	539	
10	15	561	216	310	366	412	446	467	482	497	509	519		
9	30	545	220	311	362	412	452	475	493	508	521			
8	24	528	207	306	363	412	450	471	489	505				
7	19	510	210	309	368	410	449	475	493					
6	17	480	204	311	365	412	449	474						
5	7	476	175	303	367	417	443							
		Mean	209	311	366	412	449	473	490	504	517	527	542	552

Table 11. Mean population and individual growth rates of male American shad for each age interval from the 1981 (upper) and 1982 (lower) Annapolis River spawning runs.

Age interval	Mean population growth: Length interval (mm)	Mean population growth: Difference of natural logarithms	Mean population growth: Instantaneous growth rate G_X	Mean individual growth: Length interval	Mean individual growth: Difference of natural logarithms	Mean individual growth: Instantaneous growth rate G_X
1981						
4-5	385-419	0.0831	0.2458	385-419	0.0831	0.2458
5-6	419-442	0.0534	0.1581	419-442	0.0534	0.1581
6-7	442-459	0.0386	0.1143	442-459	0.0386	0.1143
7-8	459-476	0.0363	0.1074	461-476	0.0331	0.0980
8-9	476-489	0.0269	0.0796	472-489	0.0341	0.1009
9-10	489-496	0.0142	0.0420	485-496	0.0225	0.0665
10-11	496-502	0.0120	0.0355	491-502	0.0221	0.0654
11-12	502-507	0.0099	0.0293	497-507	0.0199	0.0590
1982						
4-5	412-439	0.0633	0.1822	413-445	0.0746	0.2149
5-6	442-463	0.0471	0.1355	445-466	0.0461	0.1328
6-7	462-479	0.0363	0.1047	466-484	0.0379	0.1091
7-8	489-506	0.0347	0.0999	484-501	0.0345	0.0994
8-9	496-510	0.0281	0.0808	501-514	0.0256	0.0738
9-10	518-532	0.0267	0.0768	514-527	0.0250	0.0719
10-11	520-529	0.0167	0.0481	527-536	0.0169	0.0488
11-12	543-557	0.0255	0.0733	536-557	0.0384	0.1107

Table 12. Mean population and individual growth rates of female American shad for each age interval from the 1981 (upper) and 1982 (lower) Annapolis River spawning runs.

Age interval	Mean population growth: Length interval (mm)	Mean population growth: Difference of natural logarithms	Mean population growth: Instantaneous growth rate G_X	Mean individual growth: Length interval	Mean individual growth: Difference of natural logarithms	Mean individual growth: Instantaneous growth rate G_X
1981						
4-5	410-455	0.1041	0.2641	419-455	0.0830	0.2107
5-6	455-471	0.0346	0.0876	450-471	0.0449	0.1141
6-7	471-493	0.0457	0.1158	476-493	0.0352	0.0894
7-8	493-505	0.0240	0.0610	494-505	0.0213	0.0542
8-9	505-527	0.0426	0.1081	512-527	0.0283	0.0720
9-10	527-528	0.0018	0.0048	516-528	0.0214	0.0541
10-11	528-549	0.0390	0.0990	537-549	0.0213	0.0541
11-12	549-567	0.0323	0.0818	555-567	0.0221	0.0561
1982						
4-5	417-443	0.0605	0.1500	412-449	0.0860	0.2133
5-6	449-474	0.0542	0.1344	449-473	0.0521	0.1291
6-7	475-493	0.0372	0.0922	473-490	0.0353	0.0876
7-8	489-505	0.0322	0.0798	490-504	0.0282	0.0699
8-9	508-521	0.0253	0.0627	504-517	0.0255	0.0632
9-10	509-519	0.0195	0.0483	517-527	0.0192	0.0475
10-11	528-539	0.0206	0.0511	527-542	0.0281	0.0696
11-12	544-552	0.0146	0.0362	542-552	0.0183	0.0453

Table 13. Summary of von Bertalanffy growth coefficients calculated for male and female American shad from the 1981 and 1982 Annapolis River spawning runs.

Sex	Year	L_∞	K	t_o
Male	1981	570	0.22	-1.32
	1982	565	0.20	-1.90
Female	1981	645	0.16	-2.44
	1982	640	0.16	-2.80

Table 14. Sex ratio of American shad at different sampling locations and times for the 1981 Annapolis River spawning run.

Location	Date	Females captured	Males captured	Sex ratio F:M
Upper Granville	May 20	71	32	2.2:1
Bridgetown	May 21	96	62	1.6:1
Bridgetown	May 24	14	11	1.2:1
Bridgetown	May 26	48	10	4.8:1
Lawrencetown	May 27	105	128	0.8:1
Lawrencetown	May 28	131	34	3.9:1
Bridgetown	June 1	234	44	5.3:1
Bridgetown	June 3	195	48	4.1:1
Bridgetown	June 4	89	22	4.0:1
Total upriver		983	391	2.5:1
Trapnet sample		115	149	0.8:1
Overall total		1098	540	2.0:1

Table 15. Mean gonad weight of male and female Annapolis River American shad from the 1981 and 1982 spawning runs.

Year	Sample size	Sex	Mean (g)	Standard deviation	Minimum (g)	Maximum (g)
1981	309	Both	162.2	87.8	43.0	447.4
1982	196	Both	180.9	121.8	29.4	542.4
1981	167	Male	100.9	37.3	43.0	299.6
1982	68	Male	92.9	30.0	39.7	164.7
1981	144	Female	234.2	73.3	95.0	447.4
1982	127	Female	225.9	125.4	29.4	542.4

Table 16. Mean fecundity at age, mean lifetime fecundity, and mean virgin fecundity of female American shad from the 1981 and 1982 Annapolis River spawning run.

Age (yr)	Mean fecundity		Proportion females		Relative contribution		% first maturity	Average fecundity	Relative contribution
	1981	1982	1981	1982	1981	1982			
4	157660	-	0.016	-	2522	-	37	157660	59122
5	180916	186084	0.164	0.059	29670	11024	49	183500	89915
6	191252	202234	0.278	0.135	53168	27301	14	196743	27544
								Mean virgin fecundity	176581
7	208694	211924	0.140	0.135	29217	28609			
8	228720	225490	0.123	0.203	28132	45774			
9	234534	236472	0.098	0.220	22984	52023			
10	241640	250684	0.066	0.135	15948	33842			
11	253914	246808	0.057	0.076	14473	18757			
12	265542	260374	0.057	0.025	15135	6509			
13	-	240348	-	0.009	-	2163			
			Mean lifetime fecundity		211249	226002			

Table 17. Recaptures of American shad captured and tagged seaward of the Annapolis Royal tidal dam during April-May 1981 and 1982.

Tagging date	Recapture site	Recapture date	Time at large (d)	Minimum travel distance (km)	Migration rate (km/d)
1981					
Causeway recaptures					
May 6	Causeway	May 7	1	0	0
May 6	Causeway	May 7	1	0	0
May 8	Causeway	May 9	1	0	0
May 9	Causeway	May 10	1	0	0
Ascending migrants in estuary					
May 8	Upper Granville	May 20	12	20	1.66
May 10	Upper Granville	May 20	10	20	2.00
May 10	Upper Granville	May 20	10	20	2.00
May 3	Upper Granville	May 20	17	20	1.17
					$\bar{X}$ = 1.70 km/d
Ascending migrants (ripe shad) in river					
April 28	Middleton	May 12	14	60	4.30
April 30	Middleton	May 19	19	60	3.15
May 7	Middleton	May 22	15	60	4.00
May 8	Bridgetown	May 21	13	30	2.30
May 8	Bridgetown	May 21	13	30	2.30
May 7	Bridgetown	May 21	14	30	2.14
May 7	Bridgetown	May 21	14	30	2.14
May 8	Middleton	May 30	22	60	2.72
May 8	Middleton	May 29	21	60	2.86
May 8	Wilmot	May 29	21	75	3.57
May 10	Middleton	June 1	22	60	2.72
May 12	Waterville	May 28	16	80	5.00
May 8	Bridgetown	May 21	13	30	2.30
					$\bar{X}$ = 3.10 km/d
Descending migrants (spent)					
April 28	Lawrencetown	May 27	29	78	2.68
May 5	Middleton	May 27	22	60	2.72
May 6	Middleton	June 7	32	60	1.87
May 7	Middleton	June 6	30	60	2.00
May 10	Middleton	June 11	32	60	1.87
May 10	Middleton	June 6	27	60	2.22
April 30	Bridgetown	May 21	21	9028	4.28
May 10	Bridgetown	May 26	16	90	5.62
May 10	Bridgetown	May 26	16	90	5.62
May 7	Bridgetown	May 26	19	90	4.73
April 28	Lawrencetown	May 27	29	75	2.58
May 10	Bridgetown	June 2	23	90	3.91
May 11	Bridgetown	June 3	23	90	3.91
May 9	Bridgetown	June 3	25	90	3.60
May 10	Bridgetown	June 3	24	90	3.75
May 10	Bridgetown	July 3	69	90	1.30
					$\bar{X}$ = 2.73 km/d

Table 17. (cont'd.)

Tagging date	Recapture site	Recapture date	Time at large (d)	Minimum travel distance (km)	Migration rate (km/d)
1982					
Ascending migrants in estuary					
May 5	Center Granville	May 17	12	7	0.58
May 9	Center Granville	May 12	3	7	2.33
May 18	Center Granville	May 19	1	7	7.00
May 18	Center Granville	May 21	3	7	2.33
May 19	Center Granville	May 20	1	7	7.00
May 19	Center Granville	May 20	1	7	7.00
May 24	Center Granville	May 26	2	7	3.50
May 8	Upper Granville	May 26	18	20	1.11
May 24	Upper Granville	May 27	3	20	6.66
May 24	Upper Granville	May 27	3	20	6.66
					$\bar{X}$ = 4.40 km/d
Ascending migrants in river					
May 5	Bridgetown	May 17	12	30	2.50
May 18	Bridgetown	June 9	22	30	1.36
May 19	Bridgetown	June 9	21	30	1.43
May 21	Bridgetown	June 9	19	30	1.59
June 24	Bridgetown	June 9	16	30	1.87
June 24	Bridgetown	June 9	16	30	1.87
May 5	Bridgetown	May 17	12	30	2.50
May 21	Brickton	June 11	21	45	2.14
May 5	Brickton	June 11	21	45	2.14
May 18	Millville	May 31	13	40	3.07
May 19	Springfield	May 31	12	35	2.92
May 5	Middleton	May 31	26	60	2.31
May 5	Middleton	May 31	26	60	2.31
May 5	Middleton	May 29	24	60	2.50
May 18	Middleton	June 8	21	60	2.85
May 24	Middleton	June 18	25	60	2.40
May 24	Middleton	June 12	19	60	3.16
May 24	Middleton	June 8	15	60	4.00
May 5	Wilmot	May 8	3	75	25.00
May 5	Wilmot	May 15	10	75	7.50
May 9	Wilmot	May 31	22	75	3.40
May 24	Wilmot	June 18	25	75	3.00
May 5	Auburn	June 2	28	80	2.85
May 4	Kingston	May 31	27	85	3.15
					$\bar{X}$ = 3.81 km/d
Descending migrants in River					
May 5	Bridgetown	June 9	35	120	3.42
May 5	Bridgetown	June 9	35	120	3.42
May 5	Bridgetown	June 17	43	120	2.79
May 5	Bridgetown	June 10	36	120	3.33
May 5	Bridgetown	June 9	35	120	3.42
May 9	Bridgetown	June 9	31	120	3.87
May 9	Bridgetown	June 17	39	120	3.07
May 9	Bridgetown	June 10	32	120	3.75
May 5	Lawrencetown	June 19	36	105	2.91
May 5	Lawrencetown	July 20	76	105	1.38
May 18	Lawrencetown	June 23	36	105	2.91
May 4	Middleton	June 12	39	90	3.30
					$\bar{X}$ = 3.13 km/d

Table 18. Period at large of American shad tagged at the causeway and recaptured seaward of the tidal dam during the 1982 Annapolis River spawning run.

Tagging period	Recapture period	Number tagged	Number recaptured	Mean days at large
May 4-9	May 4-9	1624	9	0.78
May 4-9	May 10-17	1624	0	-
May 4-9	May 18-31	1624	6	14.67
May 10-17	May 10-17	3	-	-
May 10-17	May 18-31	3	-	-
May 18-28	May 18-31	1086	16	1.88

Table 19. Upstream migration rates of American shad in the Annapolis River during the 1982 spawning run.

Capture site	River km	Recaptures		Mean time at large (d)		Migration rate (km/d)	
		1981	1982	1981	1982	1981	1982
Annapolis Royal	0	19	-	373 (0)[a]	-	-	-
Center Granville	6	-	7	-	4.7	-	1.27
Bridgetown	20	9	12	382 (9)	11.9	2.20	1.68
Paradise - Lawrencetown	40	9	7	388(15)	17.7	3.33	2.26
Middleton and upriver	60	3	5	394(21)	22.0	2.86	2.73

[a]Number in brackets is mean time to recapture at site minus mean time to recapture at Annapolis Royal.

Table 20. Summary of American shad tagged in the Annapolis River during 1981 and 1982 and recaptured at sea. UK = unknown; NA = not applicable.

Tag no. MD series	Date tagged	Date recaptured	Location	Depth (m)	Days at large	Minimum distance travelled (km)	Migration rate (km/d)
1981							
			Bay of Fundy				
04600	May 11	July 15/81	Cobequid Bay	<6	65	200	3.1
04292	May 10	June 15/82	Minas Basin	<6	400	U.K.	NA
03718	May 9	July 11/82	Minas Basin	<6	428	U.K.	NA
00772	Apr. 30	July 15/83	Cumberland Basin	<6	441	U.K.	NA
00889	May 3	June 29/81	Cumberland Basin	<6	57	170	3.0
03783	May 09	July 6/81	Cumberland Basin	<6	58	170	2.9
04522	May 11	July 25/81	Cumberland Basin	<6	75	170	2.3
04081	May 10	Sept. 8/81	Cumberland Basin	<6	121	170	1.4
00859	May 3	June 25/81	Shepody Bay	<6	54	200	3.7
03430	May 8	June 25/81	Shepody Bay	<6	48	200	4.2
03470	May 8	Aug. 3/81	Shepody Bay	<6	87	200	2.3
00572	Apri130	Aug. 6/81	Shepody Bay	<6	98	200	2.0
04235	May 10	July 13/81	Shepody Bay	<6	64	200	3.1
00647	April 30	July 10/81	Saint John Harbour	<10	71	380	5.3
00216	April 28	Sept. 15/81	Yankee Bank	40	140	400	2.8
00574	April 30	Sept. 14/81	Grand Manan	60	136	500	3.7
03417	May 8	Sept. 17/81	Grand Manan	60	127	500	3.9
04420	May 11	Sept. 16/81	Briar Island	100	128	550	4.4
1982							
08462	May 5	June 15/82	Annapolis Basin		41		
12277	June 21	July 5/82	10 km off Digby Gut		18		
08268	May 5	July 7/82	Cobequid Bay	<6	63	200	3.2
10034	May 9	July 7/82	Cobequid Bay	<6	59	200	3.4
10520	May 21	Aug 3/83	Minas Basin	<6	59	200	3.4
11545	June 14	Aug. 1/82	Minas Basin	<6	439	U.K.	NA
10182	May 9	June 29/82	Cumberland Basin	<6	51	170	3.3
08542	May 5	July 23/82	Cumberland Basin	<6	79	170	2.2
08233	May 5	Sept. 13/82	Cumberland Basin	<6	131	170+	1.3
10410	May 19	July 19/82	Shepody Bay	<6	61	200	3.3
11242	June 17	Aug. 2/82	Shepody Bay	<6	46	200	4.3
10148	May 9	July 31/84	Deadman's Harbour	100	813	U.K.	NA
08628	May 5	Aug. 30/82	Head Harbour	100	117	400	3.4
10210	May 18	Aug. 18/82	Head Harbour	100	92	400	4.3
10444	May 19	Aug. 15/82	Grand Manan	80	88	500	5.7
10210	May 18	Aug. 18/82	Grand Manan	100	92	450	4.9
10245	May 18	Aug. 18/82	Grand Manan	100	92	450	4.9
10026	May 9	Aug. 29/82	Grand Manan	100	112	450	4.0
10286	May 18	Aug. 24/82	Grand Manan	100	98	450	4.6
08628	May 5	Aug. 30/82	Grand Manan	100	117	450	3.8
10346	May 18	Aug. 30/82	Grand Manan	100	104	450	4.3
08497	May 5	Sept. 22/82	St Mary's Bay, N.S.		140	550	3.9

Mean Bay of Fundy migration rate $\bar{X}$ = 3.7 km/d

Table 20. (cont'd.)

Tag no. MD series	Date tagged	Date recaptured	Location	Depth (m)	Days at large	Minimum distance travelled (km)	Migration rate (km/d)
			Atlantic Coast				
1981							
03138	May 6	April/82	Delaware Bay		U.K.	U.K.	NA
00433	April 28	June 16/82	Chesapeake Bay		414	U.K.	NA
04415	May 11	April 12/82	Virginia		336	U.K.	NA
04118	May 10	May 1/82	N. Carolina		356	U.K.	NA
04440	May 11	June 10/82	Roseway Bank	100	395	U.K.	NA
04415	May 11	Apr. 4/82	Chincoteaque, VA		326	U.K.	NA
1982							
10955	May 18	Mar. 31/83	Chesapeake Bay		317	U.K.	NA
08701	May 5	Mar. 9/83	Cable Island, VA		308	U.K.	NA
10494	May 21	Mar. 22/83	Mochipongo Inlet, VA		305	U.K.	NA
10829	May 12	Apr. 7/83	Rudee Inlet, VA		330	U.K.	NA
08437	May 5	Apr. 11/83	Exmore, VA		331	U.K.	NA
09021	May 8	Apr. 19/83	Assateaque Inlet, VA		346	U.K.	NA
10593	May 24	Mar. 22/83	Croaton Sount, NC		302	U.K.	NA
10101	May 9	Apr. 20/83	Pamlico Sound, NC.		346	U.K.	NA

Table 21. Summary of single- and multiple-census population estimates for the 1981 and 1982 Annapolis River spawning runs.

Population model	Year	M	C	R	Estimated population	95% confidence interval
Modified Peterson	1981	2234	1378	21	155000	92600-223100
	1982	2718	1758	35	132800	93500-195300
Schumacher	1981	3159	3745	32	114500	82500-168000
	1982	3851	4476	64	80300	54300-103900
Chapman	1981	3159	3745	32	100500	73600-152000
	1982	3851	4476	64	78200	52000-101400

Table 22. Summary of mark-recapture data for 1981 and 1982 multiple-census population estimates.

Period	Catch C	Recaptures R	Marked less removals	Tagged at large M	Cm x 10^3	MR	Cm^2 x 10^6
1981							
1	2356	0	2121	0	0	0	0
2	755	22	587	2121	1601	46662	3397
3	634	10	451	2708	1717	27080	4649
Total	3745	32	3159	3159	3318	73742	8446
1982							
1	2718	0	2446[a]	0	0	0	0
2	349	13	146[b]	2446	854	31798	2088
3	193	1	174[b]	2592	500	2592	1297
4	647	29	572[b]	2766	1796	80214	4950
5	497	19	448[b]	3338	1659	63422	5538
6	72	2	65[b]	3786	273	7672	1032
Total	4476	64	3851	3851	5082	185598	14905

[a]Number includes 5% mortality and 5% fall back.
[b]Number includes 10% delayed gillnet mortality.

Table 23. Selected yearly commercial landings of the Annapolis dipnet American shad fishery.

Year	Kg x 10^2	Year	Kg x 10^2	Year	Kg x 10^2
1895	145.1	1947	90.7	1965	49.9
1896	172.0	1948	81.6	1966	54.4
1897	190.0	1949	72.6	1967	2.9
1898	1.4	1950	77.1	1968	14.5
1899	0.5	1951	72.6	1969	2.5
1900	45.4	1952	54.4	1970	211.1
1901	0	1953	63.5	1971	97.5
1902	22.7	1954	49.9	1972	36.3
1903	36.3	1955	49.9	1973	79.4
1904	54.4	1956	36.3	1974	72.6
1905	0.5	1957	0	1975	81.6
1906	0	1958	63.5	1976	81.6
1907	99.8	1959	59.0	1977	108.9
1908	104.3	1960	81.6	1978	0
1909	122.5	1961	27.2	1979	59.0
1910	145.1	1962	0	1980	70.3
1911	36.3	1963	127.0	1981	36.5
1912	18.1	1964	86.2	1982	82.0

$\bar{X}$ 1895 -1912 = 6100 kg/yr $\quad$ $\bar{X}$ 1947 -1982 = 6200 kg/yr

Table 24. Injuries observed on Annapolis River American shad at the Annapolis Royal causeway and at upriver sites during the 1981 and 1982 spawning runs. (NR = not recorded).

Site	Year	Fish examined	Abrasive injuries %	Snag wounds %	Seal bites %	Lamprey wounds %
Causeway (seaward)	1981	1524	0	3.8	0.3	1.5
	1982	915	0	4.4	0.2	NR
Upriver	1981	997	0.4	5.7	0.2	0.3
	1982	565	1.8	6.4	NR	NR

Table 25. Demography of the Annapolis River American shad spawning runs of 1981 and 1982.

Characteristic	Year	Males	Females
Mean age	1981	6.68	7.34
	1982	6.98	8.28
Mean age at maturity	1981	4.4	4.7
	1982	4.5	4.8
Repeat spawners (%)	1981	76.5	72.0
	1982	80.0	93.6
Weight-length relationship	1981	Log W = 2.95(Log FL)-4.69	Log W = 2.54(Log FL)-3.52
	1982	Log W = 2.88(Log FL)-4.52	Log W = 2.48(Log FL)-3.43
Growth coefficient (K)	1981	0.22	0.16
	1982	0.20	0.16
Instantaneous total	1981	0.362	0.218
mortality (Z)	1982	0.258	0.255
Condition factor	1981	1.5	1.6
	1982	1.4	1.5
Mean length (mm)	1981	459	506
	1982	463	527
Mean weight (gm)	1981	1558	2232
	1982	1473	2252
Mean lifetime fecundity	1981		211249
	1982		226002

Table 26. Possible scenarios for the effects of different levels of turbine mortality on the Annapolis River American shad spawning population as a consequence of tidal power development.

Turbine mortality	Population size	Growth rate	% repeat spawners	Mean age	Mean lifetime fecundity
Low (1-10%)	Stable	No change	Slightly lower	6-8 yr	No increase
Moderate (10-50%)	May increase (fishing up)	Slight	Less than 50%	4.5-5.5	Slight increase
High (50-90%)	Decline (overfishing)	Increase	Few or none	4.0-4.5	Increase
Unacceptable (90-100%)	Variable (possible collapse)	Increase	None	4.0-4.2	Decline