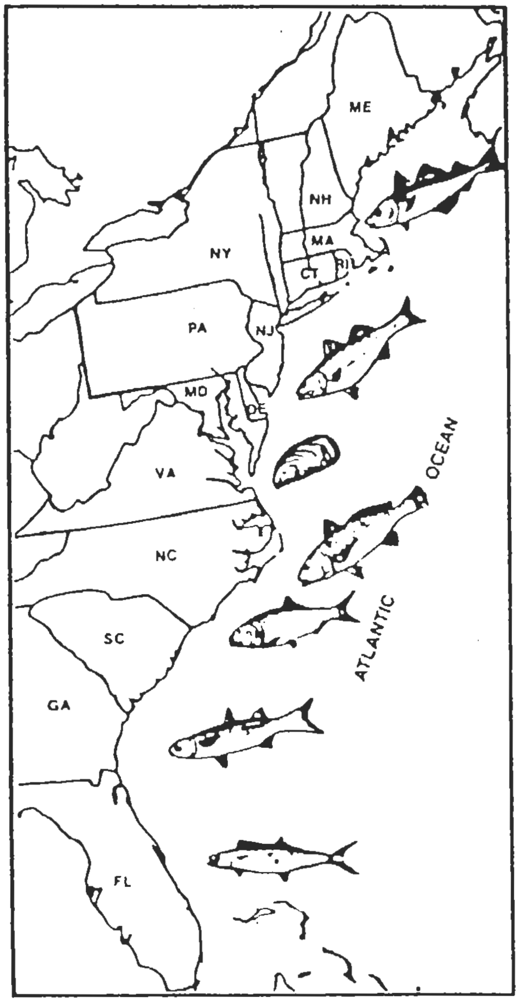
Special Report No. 19
of the
ATLANTIC STATES MARINE FISHERIES COMMISSION



STOCK ASSESSMENT OF RIVER HERRING FROM SELECTED ATLANTIC COAST RIVERS

November 1990

Stock Assessment of River Herring from Selected Atlantic Coast Rivers

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PREFACE

This report was developed under the Atlantic States Marine Fisheries Commission's (ASMFC) Interstate Fisheries Management Program (ISFMP). The project was carried out with the cooperation of the ISFMP Shad and River Herring Scientific and Statistical (S&S) Committee. Funding for development of the report was provided by the U.S. Department of Commerce, NOAA/National Marine Fisheries Service, Interjurisdictional Fisheries Act of 1986, State of Pennsylvania allocation, ASMFC Project #3-IJ-28. ASMFC is especially grateful for the considerable contributions of time and expertise provided by the report authors from the States of Connecticut and Rhode Island.

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Executive Summary

In this report, the current status of 15 river herring stocks located between New Brunswick Canada and North Carolina was assessed with long-term commercial catch-effort, age composition, fishing mortality and relative population abundance data. The primary objectives were: 1) estimate maximum sustainable yield (MSY), the annual fishing rate at MSY (u_{msy}) and the annual fishing rate at stock collapse (u_{coll}) based on the stock-recruitment (S-R) properties and intrinsic rate of population increase (r_m) of each stock; 2) determine whether current and historical fishing rates exceed the estimated u_{msy} and u_{coll} levels and whether recent trends in stock abundance are consistent with overfishing; and 3) examine how coastal fishing mortality affects u_{msy} and u_{coll} for two (Connecticut and Chowan Rivers) river herring populations.

The degree of fit (r^2) of the Shepherd S-R model to observed S-R data was highly variable among the seven river herring stocks. The Shepherd S-R model best described the observed stock-recruitment data for Lamprey River alewife (r^2=0.75), the blueback herring in the St. John (r^2=0.56) and Connecticut (r^2=0.59) Rivers and for alewife (r^2=0.56) in the Damariscotta River. The poorest fit occurred for the blueback herring stock in the Chowan (r^2=0.15) River and alewife in the Annaquatucket River (r^2=0.32).

The overall mean u_{msy} for all 15 stocks was 0.66 (95% CI:

0.64 - 0.67), but the mean u_{msy} across all river systems was significantly ($t=3.0, P<0.01$) higher for the six blueback herring stocks ($\bar{u}_{msy}=0.68$, SE=0.010) than for the nine alewife stocks ($\bar{u}_{msy}= 0.64$, SE=0.016). This indicated that blueback herring can generally tolerate higher fishing rates than alewife. The maximum harvest rates, 0.64 for alewife and 0.68 for bluebacks, apply only to river herring stocks that are fully restored. Severely depleted stocks should be harvested at much lower fishing rates.

The fishing rate at stock collapse (u_{coll}) was also significantly higher ($t=3.2$, $P<0.01$) for bluebacks ($\bar{u}_{coll}=0.83$, SE=0.015) than for alewife ($\bar{u}_{coll}=0.78$, SE=0.016). The overall mean fishing rate at stock collapse ($\bar{u}_{coll}=0.80$; 95% CI: 0.77 to 0.83) for the 15 stocks was only 20% higher than the average u_{msy} level ($\bar{u}_{msy}=0.66$). As a result, there is a relatively narrow margin of safety between safe harvest rates ($<u=0.66$) and those ($u > 0.75$) that could eventually cause a stock collapse.

Based on these analyses, five of the 15 river herring stocks (St. John blueback and alewife, Damariscotta, Potomac and Chowan River alewife) are or have been overfished ($u > u_{msy}$ or u_{coll}) to the extent that recruitment failure was apparent in recent years. Four other stocks (Potomac and Chowan river blueback herring and Nanticoke and Rappahannock river alewife), were not overfished ($u < u_{msy}$) but have experienced a stock decline in recent years. There were significant weir or pound net fisheries within all nine stocks considered to be depleted or overfished. To rebuild the spawning population and stabilize recruitment in these river herring stocks, additional conservation measures should be imposed to reduce the current fishing mortality rates.

The model results showed that a rise in coastal fishing mortality would greatly reduce the MSY, F_{msy} and F_{coll} levels for river herring fisheries in the Chowan and Connecticut Rivers. For each 10% rise in coastal fishing mortality on blueback herring, the MSY level for directed riverine fisheries would drop by about 20%, whereas the F_{msy} and F_{coll} levels would decline by about 10%. These findings suggest that riverine fishing mortality rates would have to be kept below F_{msy} in direct proportion to the coastal fishing rates.

Introduction

The alewife, Alosa pseudoharengus, and the blueback herring, Alosa aestivalis, are anadromous and are commonly referred to as river herring. Both species are found in rivers, estuaries and coastal waters along the Atlantic coast of the United States and Canada (Hildebrand 1963), and have been subject to coastal and riverine commercial fisheries that differ considerably in magnitude in both a temporal and spatial scale (ASMFC 1985). Total USA landings of river herring varied without trend (40-65 million pounds) from 1950 through 1970 (Figure 1), but declined steadily thereafter to less than 12 million pounds by 1980 following a dramatic rise in the foreign fleet landings (14 to 80 million pounds) from offshore waters during the late 1960's. Due to intensive quota management in the mid-1970's, the magnitude of foreign fleet landings of river herring was reduced to less than four thousand pounds annually by 1980 (Boreman 1982). Despite these conservation measures, total river herring landings from USA fishermen during the mid-1980's remained well below the pre-1970s levels. Although overfishing from distant water fleets has been implicated as a major cause for the dramatic decline in river herring landings at least from the Mid-Atlantic region (Street and Davis 1976; Loesch and Kriete 1984), no study has ever attempted to estimate historical and current annual fishing mortality rates (u) on specific river herring stocks, and compare them to specific biological reference points (i.e. u_{msy},u_{coll}).

In this report we assessed the current status of 15 river herring stocks located between New Brunswick, Canada and North Carolina (Appendix 1) with long-term commercial catch-effort, age composition, fishing mortality and relative population abundance data. A coast-wide stock assessment is needed for river herring to compare current fishing rates from different regions to specific biological reference points. This comparison can then serve as a basis for determining the occurrences of overfishing and for developing river-specific and regional regulations for USA commercial fisheries. After considering these problems, the objectives of this study were to assess the status of each river herring population by: 1) estimating maximum sustainable yield (MSY), the annual fishing rate at MSY (u_{msy}) and the annual fishing rate at stock collapse (u_{coll}) based on the stock-recruitment (S-R) properties and intrinsic rate of population increase (r_m) of each stock; 2) determining whether current and historical fishing rates exceed the estimated u_{msy} and u_{coll} levels for each river and whether trends in stock abundance are consistent with overfishing; and 3) examining the combined effects of riverine and ocean fishing mortality on the F_{msy} and F_{coll} values from two typical (Connecticut and Chowan Rivers) river herring populations.

Methods

Data Source

We used a combination of commercial landings, fishway and weir abundance estimates, juvenile abundance indices, age structure and fishing mortality (F) data to assess the current status of 15 river herring stocks distributed from New Brunswick, Canada to North Carolina (Appendix 1). The quality and quantity of the fisheries data differed greatly among the 15 river herring stocks. A sufficiently long (>15 years) time series of stock-recruitment (S-R) data was either available directly, or was reconstructed for seven river herring stocks: the alewife and blueback herring populations in the St. John River, New Brunswick (Jessop 1986); the alewife population in the Damariscotta River, Maine (Walton and Smith 1976; Walton 1987); the alewife population in the Lamprey River, New Hampshire (Robert Fawcett pers. comm.); the alewife population in the Annaquatucket River, Rhode Island (Richkus 1974; Gibson 1987); the blueback herring population in the Connecticut River, Connecticut (Scherer 1974; Moffitt et al. 1982; O'Leary and Booke 1987); and the blueback herring population in the Chowan River, North Carolina (Winslow 1987, 1989; Winslow et. al. 1985; Paul Fallon pers. comm NCDMF). Stock-recruitment analyses were originally planned for several other river herring stocks (Hudson, Delaware, Potomac, Rappahannock Rivers), but the river herring S-R data from these rivers were considered to be unreliable because recruitment estimates were either missing for certain years, were of unacceptably short duration (<15 years), or yielded imprecise and implausible S-R parameters. The S-R modeling approach was used here only for those river herring stocks where all parameter estimates for the Shepherd S-R model were statistically significant ($P<0.05$).

Parent stock estimates (P_t) in weight (lbs) in the St. John, Damariscotta, Lamprey, Annaquatucket and Connecticut Rivers were based on annual weir or fishway counts which represent total escapement in numbers to the spawning grounds. To obtain an estimate of P_t, the annual escapement estimates were multiplied by the average weight of an adult blueback herring (0.35 lbs) and alewife (0.45 lbs) (Blumberg et al. 1990; Gibson 1987). Since there are no weirs or fishways on the Chowan River, NC with which to estimate blueback herring escapement, we estimate P_t in the Chowan indirectly. A time series of adult blueback population estimates (N_t) in weight (lbs) in the Chowan was estimated from 1972-1988 with commercial landings (C_t) by the Leggett (1976) equation:

$$N_t = C_t/(1 - \exp(-F_t)) \qquad (1)$$

where: F_t is the instantaneous fishing mortality rate during each year. A relative index of fishing mortality (F_{in}) was derived between 1972 and 1988 as the ratio of landings (C_t) to the composite average juvenile index (Juv) based on the juvenile production in years t-4 to t-6:

$$F_{in} = C_t/Juv. \qquad (2)$$

The 4-6 year time lag used to represent the composite juvenile index was justified, given that river herring stocks are usually dominated by age 4-6 year old spawners (ASMFC 1985). The relative fishing rates (F_{in}) were then scaled to the magnitude of the average fishing mortality rate (F) derived directly from catch curve analyses (Appendix 2). Since commercial fishing on river herring usually occurs downriver of the spawning grounds, the parent stock size (P_t) for blueback herring in the Chowan River was estimated by subtraction:

$$P_t = N_t - C_t. \tag{3}$$

Annual recruitment (R_t) of alewife and blueback herring from the 1968-1983 year-classes in the St. John River, New Brunswick (Appendix 1) was based on the sum of virgin 3-6 year old fish from the 1967-1988 spawning runs based on stock abundance and age structure data (Jessop 1986). Annual alewife recruitment for the 1948-1981 year-classes in the Damariscotta River, ME, for the 1972-1985 year-classes in the Lamprey River, NH, and for the 1944-1975 year-classes for the Annaquatucket River, RI was estimated in the same manner as in the St. John River. Recruitment estimates (R_t) for blueback herring from the Connecticut and Chowan rivers were represented by the annual juvenile indices that were scaled in magnitude to the adult stock size in numbers (Appendix 1).

Extensive restoration programs for river herring have occurred in numerous New England and New Brunswick rivers in recent decades (ASMFC 1985). These restoration efforts involve the construction of fish passage facilities at numerous mill dams. These restoration programs provide an excellent opportunity to study the population growth rate of river herring stocks in the process of colonization. In lieu of stock-recruitment models, we estimated u_{msy} and u_{coll} values based on the intrinsic rate of population increase (r_m) for 11 river herring stocks located from New Brunswick to Connecticut (Appendix 1, Figures A1-A11). The estimates of r_m were derived from a long time series (>15 years) of annual fishway or weir counts of adult and juvenile river herring during the period of initial restoration to a time of full colonization. The full colonization period occurs in later years when the total annual abundance no longer grows exponentially with time (years) because of density-dependent processes. Since stock-recruitment data and fish passage data are both available for the St. John, Lamprey, Annaquatucket and Connecticut Rivers (Appendix 1), we were given the unique opportunity to corroborate the alpha (a) parameter from the S-R models in these four river herring stocks based on the derived interrelationship (Eberhardt 1977) between the intrinsic rate (r_m) and alpha (a):

$$a = \exp(r_m * t_m)/w, \qquad (4)$$

where: t_m is the average generation time (4 years) for river herring (Hildebrand 1963), and w is the average weight of an adult blueback herring (0.35 lbs) and alewife (0.45 lbs).

Fishing Mortality Rates

Historical (>10 years old) and current fishing mortality rates (F) on river herring were estimated for 15 stocks distributed from New Brunswick, Canada to North Carolina (Appendix

1). Catch curve analysis (Crecco and Gibson 1987) was used to estimate total mortality (Z) based on the age and spawning frequencies of 5 river systems (Appendix 2). Since total mortality (Z) is the sum of fishing (F) and natural (M) mortality, an estimate of M was needed so that fishing mortality (F) rates could be derived indirectly by subtraction (F=Z-M). We estimated the mean instantaneous natural mortality (M) of adult river herring to be about 1.0 (range: 0.8 to 1.2) based on the average of two life history models (Pauly 1980; Hoenig 1983). The input parameters (longevity and von Bertalanffy growth parameters) in these models were modified to reflect high post-spawning mortality that is typical of anadromous alosids (Crecco and Gibson 1987). Since adult river herring from lightly or unexploited stocks (i.e. Lamprey and Connecticut Rivers) seldom survive past age eight, we estimated M using a maximum longevity of nine years for blueback herring and alewives. The von Bertalanffy growth parameters (K, L_{∞}, t_0) were estimated for alewife and blueback herring based on the age-length data from the Connecticut (Marcy 1969), Annaquatucket (Gibson 1987), Chowan (Winslow 1988; Winslow et. al. 1985) and Rappahannock Rivers (Loesch and Kriete 1984). Since there are no apparent differences in survival rates of adult river herring among Atlantic coast stocks (ASMFC 1985), we assumed that the natural mortality rate (M) of 1.0 was constant among all adult age groups (ages 3-8) and for all river herring stocks.

The historical and current rates of exploitation (u) on river herring were estimated with the expression (Ricker 1975) for a type 1 (seasonal) fishery:

$$u = 1\text{-}\exp(-F). \qquad (5)$$

The exploitation rate (u) is the fraction of the available stock that is harvested each year. A time series of exploitation rates (u) was also derived for blueback herring and alewife in the St. John, Damariscotta and Herring Rivers (Appendix 2) by dividing the natal river commercial landings (C_t) each year by the corresponding spawning escapement estimate (P_t) plus the catch:

$$u = C_t/(P_t + C_t), \qquad (6)$$

from which the instantaneous fishing rate (F) was determined by:

$$F = -\log(1-u). \qquad (7)$$

Stock-Recruitment Modeling

A knowledge of the stock-recruitment (S-R) characteristics of exploited fish stocks is becoming increasingly important in defining safe levels of fishing and for determining how excessive fishing mortality rates (F) can adversely affect future stock persistence (Hankin and Healey 1986; Winter and Wheeler 1987; Gibson et al. 1988). The problem of evaluating the long-term effects of F on seven river herring stocks was addressed here with a steady-state model developed by Shepherd (1982). This model predicts average changes in spawning stock biomass (P_t), recruitment (R_t) and commercial yield (Y_t) under various levels of F by combining the biomass-per-recruit (B/R), yield-per-recruit (Y/R) and S-R properties of each river herring stock. This approach is very similar to the one used in a previous

American shad stock assessment (Gibson et al. 1988).

The Thompson-Bell yield-per-recruit model (Thompson and Bell 1934) was used to generate B/R and Y/R values for alewife and blueback herring (sexes combined) at various fishing rates ($F=0.1$ to 2.1 by 0.1 increments) (Table 1). The model runs were generated at constant natural mortality ($M=1.0$), assuming that all age groups (ages 3-8) in the spawning population were equally susceptible to commercial exploitation. The Y/R and B/R were generated (Table 1) under the following composite maturity schedule for each year-class (both sexes combined): 10% age three, 50% age four, 30% age five, 10% age six based on average age-at-maturity data reported in several studies (ASMFC 1985; Gibson 1987). Only one maturity schedule was used here for both species since there is no apparent difference in the age-specific maturity rate of alewife and blueback herring (PSEGC 1982). Weight-at-age estimates (Table 1) for alewife and blueback herring were derived from average von Bertalanffy growth parameters (ASMFC 1985).

River herring recruitment (R_t) in numbers and spawning stock biomass (P_t) from the seven stocks (Appendix 1) were fitted to the Shepherd S-R model:

$$R_t = a*P_t/(1 + (P_t/K)**B), \qquad (8)$$

where: a = the alpha parameter and the slope of the S-R curve at the origin. Alpha is sometimes referred to as the compensatory reserve parameter (Savidge et al. 1988), and the magnitude of alpha (a) is directly proportional to the intrinsic rate of population increase (r_m). The B parameter defines the slope of the S-R curve, and is a relative measure of compensatory density-dependent mortality. The K parameter defines the spawning stock biomass at which density-dependent effects begin to dominate. The K parameter is used basically to scale the spawning stock, recruitment and yield to observed levels. The estimates of the parameters (a) and K and their standard errors (SE) were determined by nonlinear least squares regression (SAS 1985). During the fitting procedure, the shape parameter (B) was held constant between 0.7 and 2.0 depending on the slope of the descending limb. These values of B are typical for American shad, a closely related species (Gibson et. al. 1988; Lorda and Crecco 1987), as well as for alewife populations in the Great Lakes (O'Gorman et al. 1987; Hanson 1987). Because of the versatility and extreme non-linear properties of the Shepherd S-R model, we found through experience (Gibson et al. 1988) that the model is very difficult to fit precisely to noisy S-R data, typical of most fisheries, unless the shape parameter (B) is held constant during the fitting procedure.

Once Y/R and B/R values were generated at each fishing mortality rate (F) in the Thompson-Bell model (Table 1), the equilibrium spawning stock (P) at each F was predicted by substituting the corresponding B/R value into the rearranged Shepherd model:

$$P = K(a*(B/R)-1)**1/B. \qquad (9)$$

In this context, the term "equilibrium" refers to the long-term average and does not consider annual fluctuations in recruitment that inevitably occur from abiotic factors. The corresponding equilibrium recruitment (R) of river herring at each F was expressed by:

$$R = P/(B/R), \tag{10}$$

and the predicted equilibrium commercial yield (Y) was expressed as the product of recruitment (R) and yield-per-recruit (Y/R):

$$Y = R*(Y/R). \tag{11}$$

The maximum sustainable yield (MSY) was represented by the peak of the equilibrium yield (Y) and F curve, and F_{msy} was the fishing mortality rate at which MSY takes place. The fishing mortality rate (F_{coll}) at stock collapse corresponded to the F when the equilibrium yield drops to zero on the descending limb, The annual fishing rate at MSY (u_{msy}) and at stock collapse (u_{coll}) were derived by substituting F_{msy} and F_{coll} into equation 5.

To determine the current status of each river herring stock, we compared the observed annual fishing rate (u) for the 15 river herring stocks to the stock-specific u_{msy} and u_{coll} levels. A stock was considered <u>overfished</u>, if the u value exceeded u_{msy}, whereas <u>severe overfishing</u> occurred if u exceeded u_{coll}. A stock was regarded as <u>fully exploited</u> if u was within 75% of u_{msy}, and a stock was considered <u>partially exploited</u> if u was less than 75% of u_{msy}.

To determine whether there is a relationship between observed exploitation rates (u) and trends in stock abundance, we examined the time series trend in relative or absolute abundance of adult and juvenile river herring from each of the 15 stocks. A stock was considered <u>severely depleted</u> if there was at least a 50% decline in average abundance in the last five years relative to the average stock abundance in the first five years. Otherwise, the river herring stock abundance was considered to exhibit no trend over time.

Alternative Estimates of Alpha

Because of the high degree of scatter typical of most stock-recruitment plots, the major limitation of the Shepherd S-R model, as with all S-R models, is substantiating the precision and accuracy of the alpha parameter (a). The alpha (a) parameter is known to directly determine the annual fishing rate at stock-collapse (u_{coll}) (Ricker 1975), and indirectly governs the annual fishing rate (u_{msy}) at maximum sustainable yield (Shepherd 1982). Clearly, therefore, the alpha (a) parameter should be estimated with a high degree of accuracy and precision. In an effort to corroborate the magnitude of alpha from the S-R analysis, we compared the alpha (a) parameters from the S-R models to the alpha values from two independent methods. In the first approach, we estimated alpha (a) for alewife and blueback herring based on four life history models (Cushing 1971, 1973; Boudreau and Dickie 1989; Hoenig et al. 1987; Longhurst 1983) that require estimates of average body weight (kcal), average generation time (years), average fecundity per female fish and von Bertalanffy growth parameters (L_∞, K) for river herring (Tables 2 and 3). Three of the four life history models actually estimate the intrinsic rate of population increase (r_m) rather than alpha (a). However, r_m values can be readily transformed into alpha (a) in weight as in the Shepherd S-R model by equation 4. Direct estimates of alpha (a) from the Cushing equation (Tables 2 and 3) require an estimate of average lifetime fecundity per female river herring. Although fecundity estimates of female alewife and blueback herring appear to vary between 100,000 to 350,000 eggs (Loesch 1969; Scherer 1972; Mayo 1974), we used an average estimate of 300,000 eggs per female for both river herring species in the Cushing equation. This relatively high average lifetime fecundity (300,000 eggs) considers an average repeat spawning rate of 30-40% for blueback herring (Loesch and Lund 1977) and alewife (Kissil 1974).

In the second method, we estimated the intrinsic rate of population increase (r_m) directly for 11 river herring stocks from New England and New Brunswick based on weir and fishway counts (Appendix 1, Figures A1-A11). Since these river herring stocks were colonizing previously unspawned habitat, there is a clearly defined ascending limb of exponential growth between annual fishway counts and time (Appendix 1) for all 11 stocks. Therefore, the intrinsic rate of population increase (r_m) was expressed as the slope of the exponential regression:

$$N_t = C*\exp(r_m*t), \tag{12}$$

of annual abundance (N_t) against years (t). The regression was confined to the first 8-10 years of colonization which corresponded to the exponential limb of the abundance curve when density-dependent processes are at their lowest (Ricker 1975). The parameters (C, r_m) and their standard errors (SE) were estimated by nonlinear least squares regression. We then transformed the r_m values into alpha (a) by substituting r_m into equation 4.

Effects of Coastal Fishing Mortality

To determine how changes in coastal fishing mortality might alter the biological reference points (MSY, F_{msy}, F_{coll}) for river herring, the Shepherd S-R and Thompson-Bell models (Table 1) for Chowan and Connecticut River bluebacks were modified to include both a seasonal riverine fishery (F_s) and an annual coastal fishery (F_c). Total mortality (Z) for fully recruited age groups was then expressed as:

$$Z = F_c + F_s + M. \tag{13}$$

The analysis was confined to only two stocks because they adequately represent the extreme geographical range of river herring stocks along the Atlantic coast. For each stock, the biological reference points (MSY, F_{msy}, F_{coll}) were derived at various combinations of coastal (F_c=0.0 to 0.5 by 0.1) and riverine (F_s=0 to 2.1 by 0.1) fishing mortalities at a constant natural mortality for adult (M=1.0) and pre-adult (M=0.3) age groups. The higher natural mortality for adults (ages 4-8) reflect high postspawning mortality. The harvest rate for the riverine fishery (u_s) was expressed as a seasonal fishery:

$$u_s = 1-\exp(-F_s), \tag{14}$$

whereas the coastal harvest rate (u_c) was represented as an annual fishery:

$$u_c = F_c*(1-\exp(-F_c + M))/(F_c + M). \qquad (15)$$

Blueback herring were assumed to be fully recruited to the coastal gill net fishery at nine inches (ASMFC 1985).

Results

Stock-Recruitment Properties

The degree of fit of the Shepherd S-R model to observed data was highly variable among the seven river herring stocks (Table 4, Figure 2-7). There was, however, no apparent latitudinal trend ($r = -0.43$, $P<0.2$) in the degree of fit (r^2) of the Shepherd S-R model to the observed river herring data from New Brunswick, Canada to North Carolina. The Shepherd S-R model best described the observed stock-recruitment data for alewife in the Lamprey River ($r^2=0.75$), the blueback herring in the St. John ($r^2 = 0.56$) and Connecticut ($r^2 = 0.59$) rivers and for alewife ($r^2=0.56$) in the Damariscotta River. The poorest fit occurred for the blueback herring stock in the Chowan ($r^2 = 0.15$) river and for the alewife in the Annaquatucket ($r^2=0.30$) River. The fact that stock-dependent effects usually explain less than 55% of the river herring recruitment variability is not surprising, given the potential measurement errors in the data, and the acknowledged significance of density-independent factors (abiotic variables) in causing erratic fluctuations in year-class strength.

The shape of the predicted S-R curves among the seven river herring stocks was highly variable, ranging from power ($B<1.0$), asymptotic ($B=1.0$) to dome-shaped ($B>1.0$) (Figures 2-7). The S-R curves for alewife stocks from the St. John (Figure 2) and Annaquatucket (Figure 5) rivers were clearly a power function over the observed range of spawners (P), where recruitment levels were linearly related to low levels of spawning stock, then recruitment rates (R/P) rose more slowly at high spawning stock levels. The shape of the S-R curve for Damariscotta alewife was asymptotic (Figure 4); that is, recruitment levels were linearly related to spawning stock up to about 100 X 10^3 lbs, then recruitment levels approached a constant level (2000 x 10^3 fish) when spawning stock biomass exceeded 300 x 10^3 lbs. The S-R curves for St. John blueback herring (Figure 3), Lamprey alewife (Figure 3b), Connecticut blueback herring (Figure 6) and Chowan bluebacks (Figure 7) were parabola shaped, in which recruitment levels rose to a maximum at low to intermediate spawning stock sizes then declined slightly thereafter at higher spawning stock levels.

The relative precision of the S-R parameters (a, K) for the seven river herring stocks (Table 4) was expressed by the coefficient of variation (CV=SE/mean), where low CV values indicate high precision. Although the relative precision of the alpha parameter estimate (a) varied greatly (CV range: 0.06 to 0.33) among the seven stocks, the alpha estimate (a) differed significantly ($P<0.05$) from zero in all seven stocks. Neither the alpha ($r=0.30$, $P<0.35$) nor the K parameters ($r=-0.55$, $P<0.15$) exibited significant latitudinal trends among the seven river herring stocks, although the K parameter estimate, a rough index of carrying capacity, was positively and significantly correlated to total river area ($r=0.86$, $P<0.02$). This positive relationship between K and river size is reasonable, since relatively large river systems (St. John, Connecticut, Chowan rivers) are known to contain more spawning and nursery habitat, and therefore support more abundant populations of river herring than smaller rivers (Lamprey and Annaquatucket rivers).

Biological Reference Points

Sustainable annual fishing rates (u_{msy}) generated from the Shepherd S-R model ranged from a low of 0.59 for the St. John and Annaquatucket River alewife to a high of 0.75 for St. John River blueback herring (Table 5). The annual fishing rate at stock collapse (u_{coll}) followed a similar trend among the seven river systems as u_{msy}, being lowest for Annaquatucket River alewife ($u_{coll} = 0.67$) and highest for Connecticut River bluebacks ($u_{coll} = 0.89$). The average $\bar{u}_{msy}$ and $\bar{u}_{coll}$ values for the three blueback herring stocks ($\bar{u}_{msy}$=0.73, $\bar{u}_{coll}$=0.86) were about 12% higher than the average $\bar{u}_{msy}$ and $\bar{u}_{coll}$ for the four alewife stocks ($\bar{u}_{msy}$=0.65, $\bar{u}_{coll}$=0.79), but these differences between species were not statistically significant based on only seven river systems. There was, however, a very significant positive correlation between alpha (a) from the S-R models and F_{msy} ($r=0.91$, $P<0.01$):

$$F_{msy} = 0.676 + 0.027*a, \qquad (16)$$

and between alpha (a) and F_{coll} ($r=0.95$, $P<0.005$):

$$F_{coll} = 0.732 + 0.059*a \qquad (17)$$

among the seven river herring stocks (Figures 8 and 9); The instantaneous rates (F_{msy}, F_{coll}) can be transformed into annual rates (u_{msy}, u_{coll}) by equation 5. Therefore, it is clear that biological reference points (u_{msy}, u_{coll}) can be estimated from equations 16 and 17 for other river herring stocks with only an estimate of alpha.

The estimates of maximum sustainable yield (MSY) among the seven river herring stocks varied between a low of 13 x 10^3 lbs for Lamprey River alewife to a high of 707 x 10^4 lbs for Chowan River blueback herring (Table 5). The very high MSY estimate for the Chowan is overestimated by about 15% (Winslow 1989) since it includes landings for other river herring tributaries of Albemarle Sound. As with the K parameter of the S-R models, the magnitude of the MSY estimates among the seven river herring stocks was positively correlated ($r=0.87$, $P<0.01$) to river area, indicating that potential river herring yield is highest from the larger river systems.

Alternative Estimates of Alpha (a)

The estimates of alpha (a) for 11 river herring stocks (Appendix 1, Figures A1-A11) based on the estimation of intrinsic rates of population increase (r_m) varied from a low of 7.47 for St. John river alewife to a high of 20.10 for Connecticut river blueback herring (Table 6). Based on this analysis, the average (a) estimate for blueback herring along the Atlantic coast ($\bar{a}=18.25$, SE=1.85) was significantly ($t=3.8$, $P<0.01$) greater than the average (a) for alewife ($\bar{a}=12.85$, SE=1.17). Since alpha is positively correlated to F_{msy} and F_{coll} (Figures 8 and 9), the higher alpha for blueback herring, indicates that this species may tolerate higher fishing mortality rates than the alewife.

The overall average and range of alpha for river herring based on the r_m analysis ($\bar{a}$=13.83, range: 7.47 to 20.10) were very similar to the mean and range of alpha from both the S-R models ($\bar{a}$=16.99, range: 8.21 to 28.18) (Table 4) and the four life history models ($\bar{a}$=13.59, range: 8.76 to 20.78) (Tables 2 and 3). The relative precision (CV=SE/a) about alpha, however, was generally higher for alpha estimates based on r_m (CV=0.15) and the life history models (CV=0.11) than for alpha values derived from the S-R models (CV=0.21). That the average alpha estimates for river herring were similar among the three methods lends support to our contention that the seven alpha estimates from S-R models (Table 4) provide relatively accurate and precise biological reference points (MSY, u_{msy} and u_{coll}).

Biological reference values for 15 stocks

Given the significant positive relationships between alpha and F_{msy} (Figure 8) and between alpha and F_{coll} (Figure 9) for the seven stocks in the S-R model, we estimated u_{msy} and u_{coll} for other river herring stocks by substituting their respective alpha (a) value from the r_m analysis (Table 6) or the life history models (Tables 2 and 3) into equation 16 and 17. Since we were interested in assessing stock status by comparing current or historical annual fishing rates (u) to the river-specific u_{msy} and u_{coll} levels, our analysis was confined to 15 river herring stocks where current or historical u estimates were available (Table 7, Appendix 2). Two independent estimates of alpha (a) were available from both the S-R (Table 4) and r_m (Table 6) analyses for St. John alewife and blueback herring, Lamprey alewife, Annaquatucket alewife and Connecticut river blueback herring with which to estimate u_{msy} and u_{coll}. However, for these stocks we elected to estimate u_{msy} and u_{coll} based only the alpha values derived from the r_m analysis since these alpha estimates were generally more precise than those from the S-R models. In the case of the Damariscotta alewife and Chowan river bluebacks, only one estimate of alpha was available from the S-R model (Table 4), so u_{msy} and u_{coll} estimates for these stocks were determined directly from the S-R model (Table 5). There were eight additional river herring stocks (Herring River alewife/blueback, Potomac River blueback and alewife, Nanticoke blueback and alewife, Rappahannock River blueback herring and alewife and Chowan River alewife) with current or historical fishing rates (u), but with no S-R or r_m estimates of alpha (a). We estimated u_{msy} and u_{coll} indirectly for these herring stocks by substituting the average alpha for blueback herring and alewife based on the life history models (Tables 2 and 3) into equations 16 and 17.

The overall mean u_{msy} for all 15 stocks was 0.66 (95% CI: 0.64 - 0.67) which corresponds to an instantaneous fishing mortality (F_{msy}) rate of 1.07 (Table 7). The mean u_{msy} across all river systems was significantly (t=3.0, P<0.01) higher for blueback herring ($\bar{u}_{msy}$=0.68, SE=0.010) than for alewife

($\bar{u}_{msy}$=0.64, SE=0.016), indicating that blueback herring can generally accomodate higher fishing rates than alewife. These results strongly suggest that maximum annual harvest rates (u) should not exceed 0.64 for alewife and 0.68 for bluebacks for a long period (>5 years) of time. It should be noted that these u_{msy} levels apply to the combined harvest rates for both the riverine and coastal fisheries. The maximum harvest rates, 0.64 for alewife and 0.68 for bluebacks, apply only to river herring stocks that are fully restored. Severely depleted stocks should be harvested at much lower fishing rates.

The annual fishing rate at stock collapse (u_{coll}) was also significantly higher (t=3.2, P<0.01) for bluebacks ($\bar{u}_{coll}$=0.83, SE=0.015) than for alewife ($\bar{u}_{coll}$=0.78, SE=0.016) (Table 7). The overall mean fishing rate at stock collapse ($\bar{u}_{coll}$=0.80, 95% CI: 0.77 to 0.83) for the 15 stocks was only about 20% higher than the average u_{msy} level ($\bar{u}_{msy}$=0.66). As a result, there is a relatively narrow margin of safety between safe harvest rates (< u_{msy}) and those (u>0.75) that could cause a stock collapse. Therefore, every effort should be made to restrain annual fishing rates (u) below the u_{msy} levels given in Table 7.

Stock Status

Current and historical fishing mortality rates (u) varied greatly across the 15 river herring stocks (Table 7). The highest fishing mortality rates (u>0.60) on river herring occurred mainly near the northern (St. John and Damariscotta

Rivers) and southern (Potomac, Rappahannock, Chowan Rivers) end of the distribution, where there are directed riverine fisheries. Very low fishing rates ($u<0.3$) were noted for Annaquatucket River alewife and Connecticut River blueback herring where there are no directed riverine fisheries.

Our results indicated that current or historical fishing rates (u) for St. John, Damariscotta and Potomac River alewife exceeded the respective u_{coll} level (Table 7), indicating that these stocks are or have been severely overfished (Table 8). The time series of alewife abundance from these three rivers all exhibited a pronounced downward trend in recent years which is consistent with excessive fishing mortality (Figures 10-12). In the case of the Chowan River alewife and St. John River blueback herring, the current u values exceeded the river-specific u_{msy} level (Table 7), and these stocks were therefore considered to be overfished (Table 8) . Alewife abundance in the Chowan has shown a recent decline (Figure 13) that is consistent with overfishing, but no such decline was evident for blueback herring in the St. John River (Figure 14). The current or historical u values for Chowan and Potomac River blueback herring and Nanticoke alewife were within 75% of the u_{msy} levels, and therefore were considered by our criteria to be fully exploited. Abundance from these river herring stocks has exhibited a significant decline in recent years (Figures 15, 16 and 23). The remaining seven stocks (Lamprey River alewife, Herring River alewife, Annaquatucket River alewife, Connecticut River blueback, Rappahannock River alewife and blueback, and Nanticoke River blueback) were considered to be partially exploited, since the current and historical fishing rates (u) for these stocks were less than 75% of the river-specific u_{msy} levels. Trends in stock abundance for six of seven stocks in the partially exploited category showed no apparent decline over time (Figures 17-21 and 24), but the alewife stock abundance in the Rappahannock River did exhibit a pronounced decline (Figure 22) despite relatively low levels of exploitation. Based on these analyses, we conclude that five river herring stocks (St. John alewife and blueback, and Damariscotta, Potomac and Chowan River alewife) are or have been overfished ($u>u_{msy}$ or u_{coll}) to the extent that recruitment failure is apparent in recent years. In order to rebuild the spawning population and stabilize recruitment in these river herring stocks, additional conservation measures should be imposed to reduce the fishing mortality rates below the u_{msy} levels.

Effects of Coastal Fishing Mortality

The results of the Shepherd model showed that a rise in coastal fishing mortality (F_c) would greatly reduce the MSY, F_{msy} and F_{coll} levels for riverine fisheries in the Chowan and Connecticut Rivers (Tables 9 and 10). For each 10% rise in coastal fishing mortality, the MSY level for the riverine fisheries would drop by about 20%, whereas the F_{msy} and F_{coll} levels would decline by about 10%. Since coastal fishing mortality appears to proportionally errode the F_{msy} and F_{coll}

levels for riverine fisheries, these findings suggest that riverine fishing mortality rates should be restrained well below the total F_{msy} level if the coastal fishing mortality rates exceed 0.1. These results have important management implications since river herring stocks could be subject to recruitment overfishing by a combination of moderately high riverine fishing mortality rates (F_s=1.0) and relatively low (F_c=0.3) but unknown coastal fishing rates. Since there are no directed riverine fisheries on Annaquatucket and Connecticut river herring, the observed fishing rates in these systems (F_c=0.19 to 0.30) (Table 7) may reflect the current coastal fishing mortality rates. If so, then we strongly recommend that riverine harvest rates (u_s) on all river herring stocks be kept about 20 to 30% below the estimated u_{msy} levels (Table 7).

Discussion

Our analysis clearly showed that a rapid rise in directed or bycatch ocean fisheries could cause a dramatic reduction in sustainable yields (MSY) and fishing rates (F_{msy}) for directed riverine fisheries in the Connecticut and Chowan Rivers (Tables 9 and 10). Ocean fisheries on river herring usually operate as bycatch fisheries in offshore waters of the Federal Conservation Zone (FCZ), or as directed fisheries along known nearshore migration routes (ASMFC 1985). Since these ocean fisheries can occur throughout the year and exploit both mature and immature fish, a rapid rise in ocean fishing mortality (F_c>0.4) would cause a steady reduction in adult and subadult survival, leading eventually to an erosion of spawning stock biomass and recruitment. The problem of excessive ocean exploitation would be particularly troubling for those river herring stocks (Maine, Virginia, North Carolina) already exposed to heavy riverine fisheries. Given the potential adverse effects of excessive ocean fishing, it is likely that the dramatic upsurge in river herring landings (60-80 million lbs.) from distant water fleets in the late 1960's (Figure 1) was at least partially responsible for the steady decline in river herring stock abundance and in the total USA landings in the 1970's. However, since foreign fleet landings of river herring have been reduced to less than 300,000 lbs by 1980 (ASMFC 1985), it is difficult to use excessive ocean landings as a determining factor to explain the persistant decline in USA river herring landings between 1980 and 1987 (Figure 1).

The current ocean fishing mortality rate (F_c) on river herring stocks is difficult to estimate, particularly in the presence of high riverine fishing (F_s) and adult natural mortality (M). Since there are little if any directed fisheries on river herring in the Lamprey, Annaquatucket and Connecticut Rivers, it might be assumed that the average fishing mortality rate (F=0.32, u=0.27) from these three rivers (Table 7) approximates the current ocean fishing rate on Atlantic coast river herring. Because the average total fishing mortality rate ($F_c + F_s$) on heavily exploited stocks from Maine, Virginia and North Carolina rivers was 1.18 (SE=0.23) (Table 7), we might also assume that current ocean fishing mortality rates account for about 27% of the total F on river herring (i.e. (0.32/1.18)*100). If long-term changes in ocean river herring landings are directly proportional to changes in F, then ocean landings should also comprise about 20-30% of the total river herring landings. However, Harris and Rulifson (1989) reported that ocean landings of river herring by all Atlantic coast states were relatively small (56-688 thousand lbs), accounting for only about 3% of the total river herring landings between 1978 and 1987. Even when recent foreign and joint venture landings of river herring (100-300 thousand lbs) are considered (ASMFC 1988), the total ocean landings would still constitute only about 5-6% of the recent total landings (5-13 million lbs).

This discrepancy between F_c and ocean landings could be caused by several factors acting alone or in combination. Firstly, there could be substantial amounts of discard mortality (up to 80%) occurring in the coastal and nondirected ocean fisheries. This would cause the ocean fishing mortality rate (F_c) to rise without causing a proportional increase in the ocean landings. Secondly, it is possible that the total ocean landings of river herring are underreported, or that the total riverine landings are overestimated. Either or both sources of bias would cause the ratio of ocean landings to total landings to be underestimated. Thirdly, since ocean fisheries harvest both mature and immature river herring, the average weight of a river herring in the ocean fishery could be as much as 25% lower than the average (mean weight = 0.4 lbs) of an adult fish from the riverine fisheries. As a result, when the ocean landings are expressed in weight, their contribution to the total landings would be underestimated by about 25%. However, this bias alone would not account for the observed disparity (i.e. 0.06 versus 0.32) between the fraction of observed ocean landings and average F_c. Finally, since we had to estimate fishing mortality rates (F) indirectly as the difference between total mortality (Z) and an estimated M of 1.0, it is possible that our estimate of natural mortality (M=1.0) is too low. This would result in an overestimate of our average F_c of 0.32 based on the collective fishing rates from the Lamprey, Annaquatucket and Connecticut Rivers. It is not possible at this time to determine which, if any, of these factors could inflate F_c or underestimate the ocean landings. Therefore, our best estimate of ocean fishing mortality is somewhere between 0.06 and 0.32.

The magnitude and latitudinal patterns in the biological reference points (u_{msy}, u_{coll}) for the 15 river herring stocks differed considerably from the u_{msy} and u_{coll} levels for American shad, Alosa sapidissima, a closely related species. The estimates of alpha (a) for river herring from the S-R and r_m analyses (Tables 4 and 6) and their corresponding biological reference points (u_{msy}, u_{coll}) showed no latitudinal trends from New Brunswick, Canada to North Carolina. This is in sharp contrast to the relatively clear parabolic relationship reported for American shad between u_{msy} and latitude for shad stocks distributed between Rhode Island and Florida (Gibson et. al. 1988). American shad from northern rivers are known to exhibit lower lifetime fecundity, greater longevity and delayed maturity when compared to the same suite of life history characteristics for shad from southern rivers (Leggett 1976). Therefore, the observed parabolic relationship between u_{msy} and latitude for American shad probably reflects their ability to alter their life history patterns in order to adapt to markedly changing river flow and temperature gradients that exist between northern and southern rivers. Unlike American shad, blueback herring and alewife do not exhibit noticeable latitudinal shifts in lifetime fecundity, longevity and age at maturity (ASMFC 1985). This stability in life history characteristics for river herring over vast areas would help explain the consistency in the estimates of u_{msy} and u_{coll} across the 13 river systems (Table 7).

There are other clear differences in the S-R properties between river herring and American shad. The overall mean alpha for the 15 river herring stocks ($\bar{a}$=13.83, SE=1.18) was an order of magnitude greater than the mean alpha ($\bar{a}$=0.91, SE=0.11) for American shad (Gibson et. al. 1988). Since alpha is linearly related to F_{msy} and F_{coll} (Figures 8 and 9), it follows that the overall mean u_{msy} (0.66) and u_{coll} (0.80) for river herring would be considerably higher than those (u_{msy}=0.51; u_{coll}=0.66) reported for American shad. This indicated that river herring can sustain proportionally higher exploitation rates than American shad and require lower escapement levels (33%) to perpetuate the stock. We believe that river herring are less susceptible to fishing than American shad because of the ecological scaling relationship of body weight to fecundity and its effect on alpha as reported recently by Boudreau and Dickie (1989). Although the lifetime fecundity of river herring and American shad is roughly comparable (ASMFC 1985), adult American shad (mean weight = 4 lbs) outweigh adult river herring (mean weight = 0.4 lbs) by an order of magnitude. Therefore, river herring produce about ten times as many eggs per unit of body weight than American shad. Since alpha (a) represents the maximum recruitment rate (R/P) per unit spawner in the absence of density-dependent effects, the magnitude of alpha is directly proportional to fecundity per unit weight. It is likely, therefore, that the evolution of relatively high fecundity (100-300 thousand eggs) coupled with relatively small body size is the primary reason for the relatively high tolerance of river herring to heavy fishing pressure (u>0.50).

Of the 15 river herring stocks examined in this study, nine stocks were judged by our criteria to be either overfished ($u>u_{msy}$) or severely depleted (Table 8). These overfished stocks were confined to the northern (St. John blueback and alewife, Damariscotta alewife) and mid-southern end (Nanticoke alewife, Potomac alewife and blueback, Rappahannock alewife, Chowan alewife and blueback) of the geographic range for river herring. There are substantial weir fisheries on the river herring stocks within the St. John (Jessop 1986) and Damariscotta Rivers (ASMFC 1985), whereas river herring from mid-southern rivers (Nanticoke, Potomac, Rappahannock and Chowan Rivers) are harvested primarily by pound nets that are set in or just outside these river systems (ASMFC 1985). In fact, over 90% of the total coastwide landings of river herring between 1978 and 1987 were taken from rivers in Maine, Virginia and North Carolina (Harris and Rulifson 1989), with 54% of the total being taken primarily by the North Carolina pound net fishery. The North Carolina landings alone between 1978 and 1987 (3.6 to 12.4 million lbs) were about 10 times greater than the total ocean harvest of river herring (Harris and Rulifson 1989). These results strongly suggest that heavy fishing pressure by the states of Maine, Virginia and North Carolina is primarily responsible for the continued decline of river herring stocks in the Damariscotta, Potomac, Rappahannock and Chowan Rivers.

Acknowledgements

The authors wish to especially thank all the members of the ASMFC scientific and statistical committee for their contribution of essential data to the river herring assessment. We are also very grateful to Tammy Dethlefsen for her editorial comments and helpful advice in preparing the graphs and typing the manuscript.

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Table 1. Thompson-Bell Yield per Recruit for Blueback and Alewife Populations

Input Parameters

	Bluebacks	Alewife
L_∞=	12.4 in. TL	13.0 in. TL
W_∞=	0.60 lbs	0.65 lbs
Age at first spawning=	3 years	3 years
M=	1.0	1.0
K=	0.52	0.42
	Ages 3 to 8	Ages 3 to 8

	Blueback		Alewife	
F	Y/R	B/R	Y/R	B/R
0.1	0.050	0.479	0.057	0.542
0.2	0.091	0.412	0.103	0.466
0.3	0.125	0.356	0.141	0.404
0.4	0.152	0.310	0.173	0.351
0.5	0.175	0.270	0.199	0.307
0.6	0.195	0.237	0.220	0.268
0.7	0.211	0.208	0.238	0.235
0.8	0.225	0.184	0.254	0.208
0.9	0.237	0.163	0.268	0.184
1.0	0.248	0.144	0.280	0.163
1.1	0.257	0.128	0.290	0.145
1.2	0.265	0.114	0.299	0.129
1.3	0.272	0.102	0.307	0.115
1.4	0.278	0.091	0.314	0.103
1.5	0.283	0.081	0.320	0.092
1.6	0.288	0.073	0.325	0.082
1.7	0.292	0.065	0.330	0.073
1.8	0.295	0.059	0.333	0.067
1.9	0.299	0.053	0.340	0.060
2.0	0.302	0.047	0.343	0.054
2.1	0.304	0.043	0.346	0.048

Table 2. Indirect methods of estimating the average compensatory reserve parameter (a) for blueback herring based on the intrinsic rate of population increase (r_m).

Reference	Equation	Input	(a)[5/] estimate
Boudreau and Dickie(1989)[1/]	$r_m=2.88*w^{-0.33}$	w=207 kcal (0.35 lbs)	20.78
Hoenig et al(1987)[2/]	$r_m=425.2*t_m^{-0.949}$	t_m=1460 4 years	15.45
Longhurst(1983)[3/]	$r_m=3K[L_\infty/\bar{L})-1]$	L_∞=12.0 in K=0.52 $\bar{L}$=9.5 in	14.73
Cushing(1971,1973)[4/]	$a=1.98+0.0306*Fec^{0.33}$	Fec=300x10^3eggs	11.27
		Mean A	15.56
		SE A	1.97

1/ Can. J. Fish. Aquat. Sci. 46:614-623

2/ Can. J. Fish. Aquat. Sci. 44:324-338

3/ Estu. Coast Shelf Sci. 17(3)261-285

4/ Rapp. R-V Reun. Cons. Explor. Perm Int. Mer. 164:142-155

5/ $a=\exp(r_m*t_m)/\bar{w}$,

where: $\bar{w}$=average weight (0.35 lbs) of a spawner in the absence of fishing.

Table 3. Indirect methods of estimating the average compensatory reserve parameter (a) for the alewife based on the intrinsic rate of population increase (r_m).

Reference	Equation	Input	(a)[5] estimate
Boudreau and Dickie(1989)[1]	$r_m=2.88*w^{-0.33}$	w=266 kcal (0.45 lbs)	13.77
Hoenig et al(1987)[2]	$r_m=425.2*t_m^{-0.949}$	t_m=1460 4 years	12.02
Longhurst(1983)[3]	$r_m=3K[L_\infty/\bar{L})-1]$	L_∞=14.0 in K=0.42 $\bar{L}$=10.5 in	11.92
Cushing(1971,1973)[4]	$a=1.98+0.0306*Fec^{0.33}$	Fec=300x10^3eggs	8.76
		Mean A	11.62
		SE A	1.04

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[1] Can. J. Fish. Aquat. Sci. 46:614-623

[2] Can. J. Fish. Aquat. Sci. 44:324-338

[3] Estu. Coast Shelf Sci. 17(3)261-285

[4] Rapp. R-V Reun. Cons. Explor. Perm Int. Mer. 164:142-155

[5] $a=\exp(r_m*t_m)/\bar{w}$,

where: $\bar{w}$=average weight (0.45 lbs) of a spawner in the absence of fishing.

Table 4. Estimates of the parameters (a, K) and standard errors (SE) of the Shepherd stock-recruitment model for alewife and blueback herring from selected Atlantic coast rivers based on nonlinear regression analyses. During the fitting procedure the shape parameter (B) of the Shepherd model was fixed at a value between 0.7 and 2.0. The r^2 refers to coefficient of determination.

Stock	Years	a	SE_a	K (lbs)	SE_k	r^2
St. John NB						
Alewife	1968-87	8.21	2.72	726,600	458,400	0.341
Blueback	1968-87	20.28	5.62	103,000	28,804	0.562
Damariscotta ME						
Alewife	1948-87	19.73	1.22	165,700	20,801	0.555
Lamprey NH						
Alewife	1972-90	19.72	4.27	4,600	552	0.751
Annaquatucket RI						
Alewife	1944-83	8.85	1.56	162,800	60,811	0.302
Connecticut CT						
Blueback	1971-89	28.18	8.48	647,000	129,000	0.587
Chowan NC						
Blueback	1972-88	16.67	4.15	3,436,000[1/]	819,600	0.152

1/ Includes stock abundance from other tributaries of Albemarle Sound.

Table 5. Estimates of the instantaneous fishing mortality rate at MSY (F_{msy}), fishing mortality rate at stock collapse (F_{coll}) and maximum sustainable yield (MSY) for seven river herring stocks based on their stock-recruitment properties (Table 4). The numbers in parenthesis refer to the annual rate of fishing at MSY (u_{msy}) and stock collapse (u_{coll}).

Stock	F_{msy}	F_{coll}	MSY (lbs x 10^3)
St. John NB			
Alewife	0.90 (0.59)	1.20 (0.70)	756
Blueback	1.40 (0.75)	2.00 (0.86)	288
Damariscotta ME			
Alewife	1.20 (0.70)	2.00 (0.86)	542
Lamprey NH			
Alewife	1.20 (0.70)	1.90 (0.85)	213
Annaquatucket RI			
Alewife	0.90 (0.59)	1.10 (0.67)	95
Connecticut CT			
Blueback	1.40 (0.75)	2.20 (0.89)	1652
Chowan NC			
Blueback	1.10 (0.67)	1.80 (0.83)	7072 1/

1/ Chowan River MSY may include landings from other tributaries of Ablemarle Sound.

Table 6 Estimates of the intrinsic rate of population increase (r_m), the compensatory reserve parameter (a) and their standard errors (SE) for 11 blueback and alewife populations from New England and New Brunswick, Canada. Data are plotted in Appendix 1 (Figures A1-A11).

River	Species	r_m estimate	SE(r_m)	a[1/] estimate	SE_a
St. John New Brunswick	Alewife Blueback	0.303 0.437	0.031 0.080	7.47 16.40	0.76 3.00
Androscoggin R. ME	Alewife	0.380	0.058	10.16	1.55
St. Croix ME	Alewife	0.382	0.110	10.24	2.95
Royal, ME	Alewife	0.407	0.107	11.32	2.98
Union River ME	Alewife	0.472	0.053	14.28	1.65
Long Pond,ME	Alewife	0.441	0.059	12.97	1.74
Lamprey NH	Alewife	0.480	0.081	15.21	2.57
Oyster NH	Alewife	0.540	0.048	19.30	1.72
Annaquatucket RI	Alewife	0.472	0.076	14.70	2.37
Connecticut CT	Blueback	0.550	0.061	20.10	2.23

[1/] Compensatory reserve (a)=exp(r x 4.0)/w
where: w is the average weight of adult blueback(0.35 lbs) and alewife(0.45 lbs) in each stock.
The value of 4.0 years represents the average generation time for river herring.

Table 7. Estimates of the annual fishing rate at MSY (u_{msy}), the annual fishing rate at stock collapse (u_{coll}) and current and historical average rates of exploitation (u) on 13 river herring stocks.

River	Species	u_{msy}	u_{coll}	u	Years when u was est.
St. John, NB	Alewife	0.58[1/]	0.69	0.76	1975-82
	Blueback	0.67[1/]	0.82	0.72	1975-82
Damariscotta, ME	Alewife	0.70[2/]	0.86	0.89	1971-87
Lamprey, NH	Alewife	0.66[1/]	0.80	0.38	1983-86
Herring, MA	Alewife/Blueback	0.66[3/]	0.80	0.44	1980-87
Annaquatucket, RI	Alewife	0.66[1/]	0.80	0.17	1980-87
Connecticut, CT	Blueback	0.70[1/]	0.85	0.26	1968
Nanticoke, MD	Alewife	0.62[3/]	0.75	0.49	1989-90
	Blueback	0.67[3/]	0.81	0.24	1989-90
Potomac, VA	Alewife	0.62[3/]	0.75	0.80	1975-80
	Blueback	0.67[3/]	0.81	0.67	1975-80
Rappahannock, VA	Alewife	0.62[3/]	0.75	0.37	1980-85
	Blueback	0.67[3/]	0.81	0.42	1980-85
Chowan, NC	Alewife	0.62[3/]	0.75	0.69	1983-87
	Blueback	0.68[2/]	0.83	0.68	1983-87

Table 7. continued

1/ u_{msy} and u_{coll} values were derived from the linear relationship between alpha (a) and F_{msy} and between (a) and F_{coll} for the six herring stocks with S-R data (Table 4, Figures 8 and 9):

$$F_{msy} = 0.676 + 0.027*a, \ r = 0.91$$

$$F_{coll} = 0.732 + 0.059*a, \ r = 0.95$$

where: $u_{msy}=1-\exp(-F_{msy})$ and $u_{coll}=1-\exp(-F_{coll})$.

2/ u_{msy} and u_{coll} were taken directly from the Shepherd S-R model (Table 5).

3/ Alpha (a) value based on the average indirect estimates of alpha (a) for blueback herring and alewife based on the four life history models (Tables 2 and 3). u_{msy} and u_{coll} were then derived as in 1/.

Table 8. Current status of several blueback and alewife runs along the Atlantic coast based on data from Table 7. Severely overfished indicates that u exceeds u_{coll}, overfished indicates that (u) exceeds u_{msy}, fully exploited indicates that u is within 75% of u_{msy}, and partially exploited means that u is less than 75% of u_{msy}.

River	Species	Status	Stock Condition[1/]
St. John, NB	Alewife	severely overfished	severely depleted
	Blueback	overfished	no trend
Damariscotta, ME	Alewife	severely overfished	severely depleted
Lamprey, NH	Alewife	partially exploited	no trend
Herring, MA	Alewife/ Blueback	partially exploited	no trend
Annaquatucket RI	Alewife	partially exploited	no trend
Connecticut, CT	Blueback	partially exploited	no trend
Nanticoke, MD	Alewife	fully exploited	severely depleted
	Blueback	partially exploited	no trend
Potomac, VA	Alewife	severely overfished[2/]	severely depleted
	Blueback	fully exploited	severely depleted
Rappahannock VA	Alewife	partially exploited	severely depleted
	Blueback	partially exploited	no trend
Chowan, NC	Alewife	overfished	severely depleted
	Blueback	fully exploited	severely depleted

1/ See Figures 10-22 for graphical trends: "severely depleted" was defined as at least a 50% decline in recent landing or juvenile indices relative to the landings and juvenile indices from the first five years.

2/ Overfished during the 1960's and 1970's, see Appendix 3.

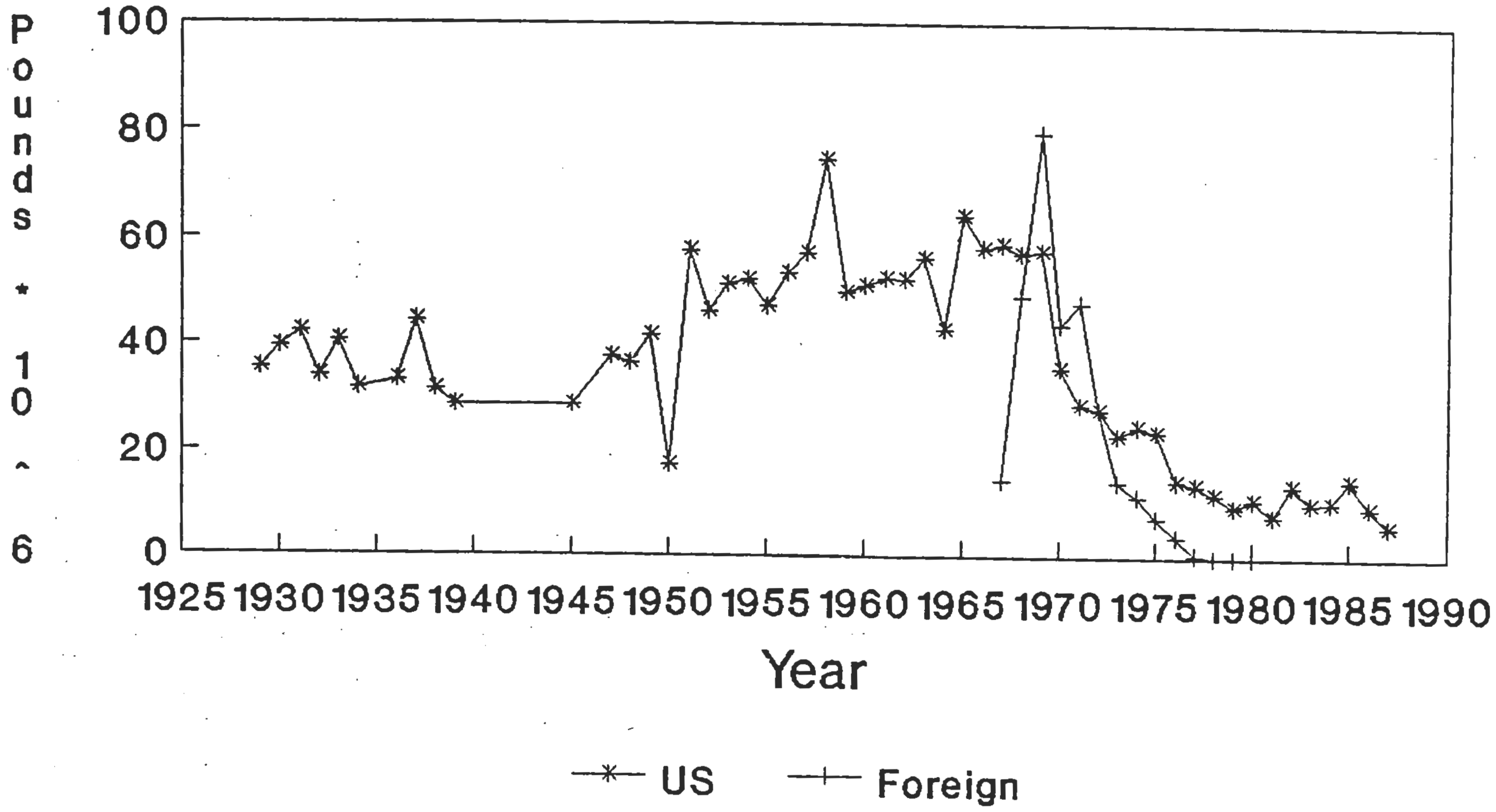
Table 9. Changes in MSY, F_{msy} and F_{coll} for blueback herring in the Chowan River, N.C. with changes in fishing mortality rates in the river and along the Atlantic coast. Total MSY and total F_{msy} refer to the combined maximum sustainable yield and the corresponding fishing rate, respectively.

Coast F	River MSY (lbs*10^3)	F_{msy} River	F_{coll} in River	Total MSY (lbs*10^3)	F_{msy} Total
0.0	7072	1.3	1.8	7072	1.3
0.1	5708	1.1	1.6	7491	1.2
0.2	4605	1.0	1.5	7790	1.1
0.3	3693	0.9	1.3	8059	1.1
0.4	2941	0.8	1.2	8236	1.1
0.5	2391	0.7	1.1	8375	1.0

Table 10. Changes in MSY, F_{msy} and F_{coll} for Connecticut River blueback herring with changes in fishing mortality rates in the river and along the Atlantic coast. Total MSY and total F_{msy} refer to the combined maximum sustainable yield and the corresponding fishing rate, respectively.

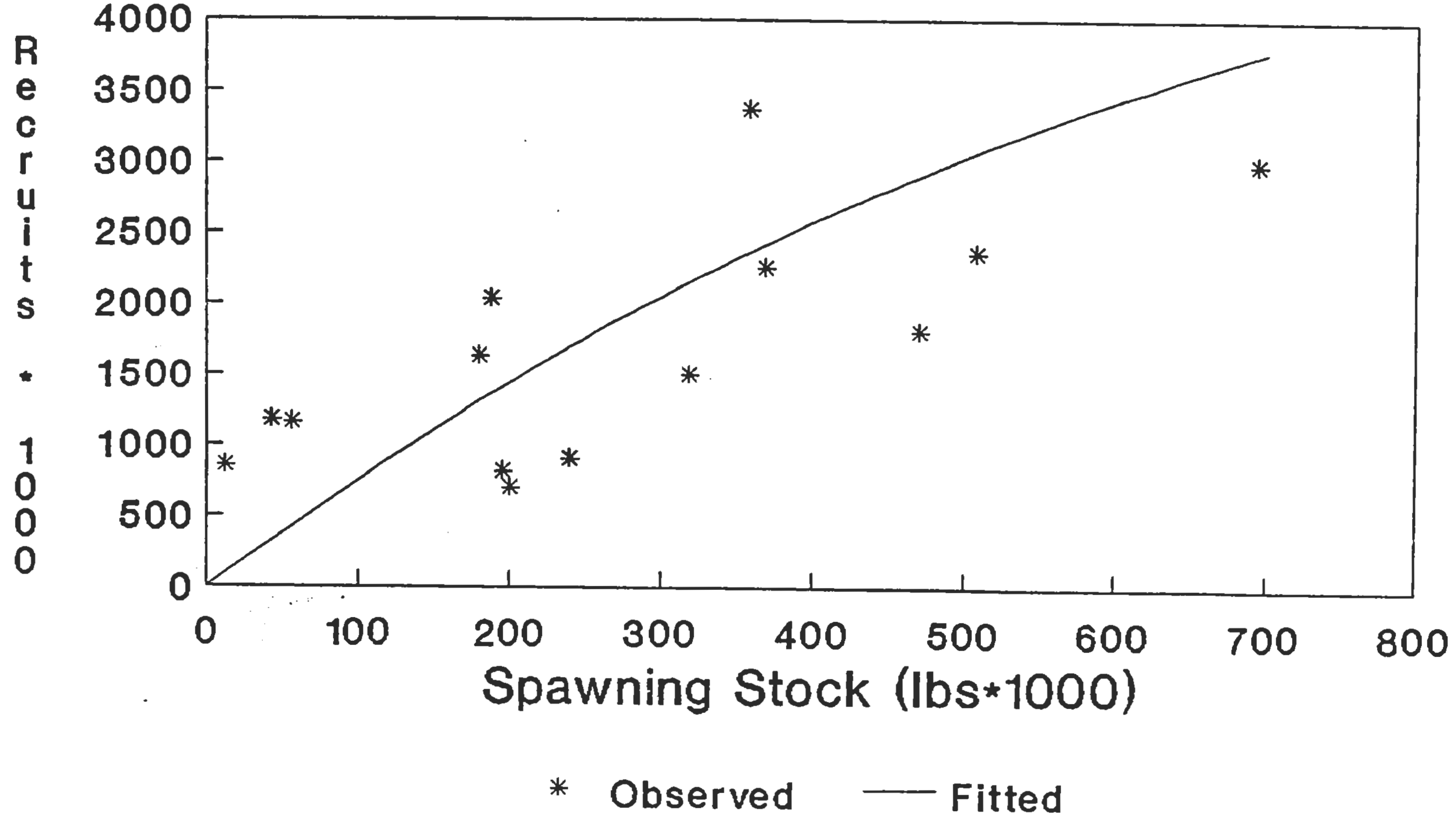
Coast F	River MSY (lbs*10^3)	F_{msy} River	F_{coll} in River	Total MSY (lbs*10^3)	F_{msy} Total
0.0	1652	1.2	2.0	1652	1.2
0.1	1333	1.1	1.8	1750	1.2
0.2	1057	1.0	1.7	1831	1.1
0.3	844	0.9	1.5	1887	1.0
0.4	632	0.8	1.4	1939	1.0
0.5	484	0.7	1.3	1974	1.0

Fig.1-River Herring Landings
Along the Atlantic Coast 1929-1987



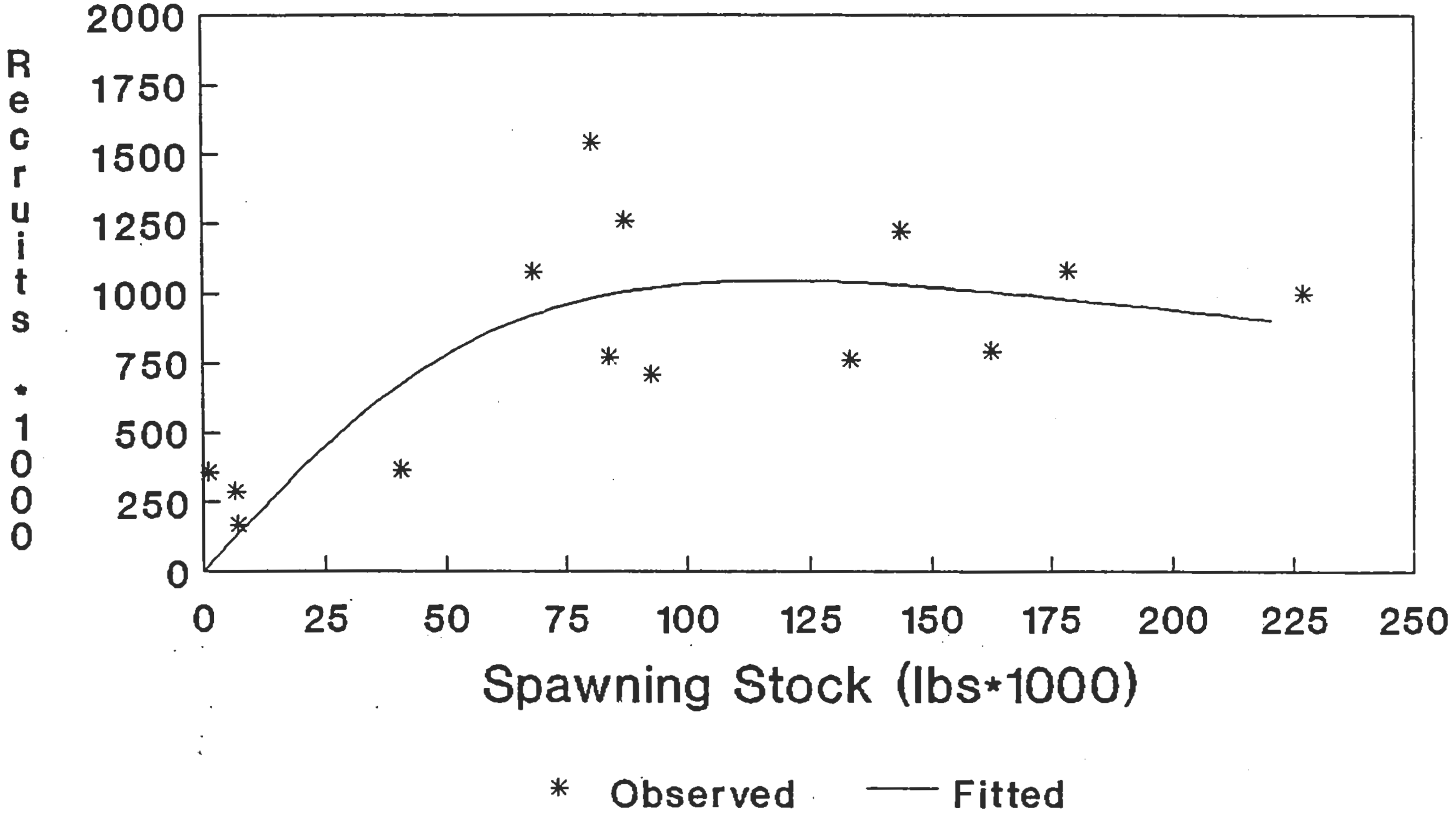
Data from ASMFC (1985), Harris
and Rulifson (1989)

Fig.2-Alewife Stock and
Recruitment St. John R., 1968-1981



Data from Jessop (1986)

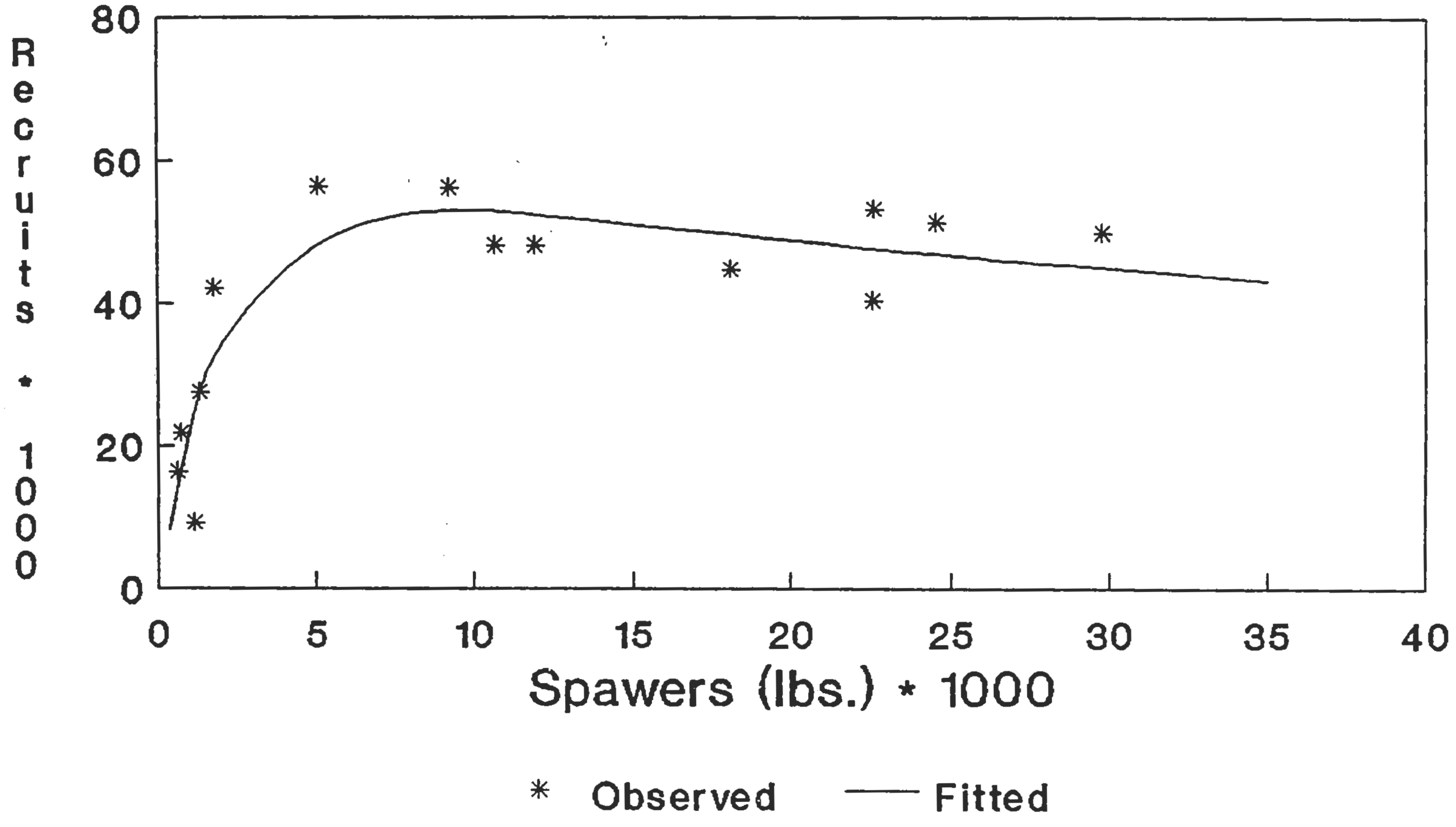
Fig.3-Blueback Herring Stock
Recruitment, St. John River 1968-1981



Data from Jessop (1986)

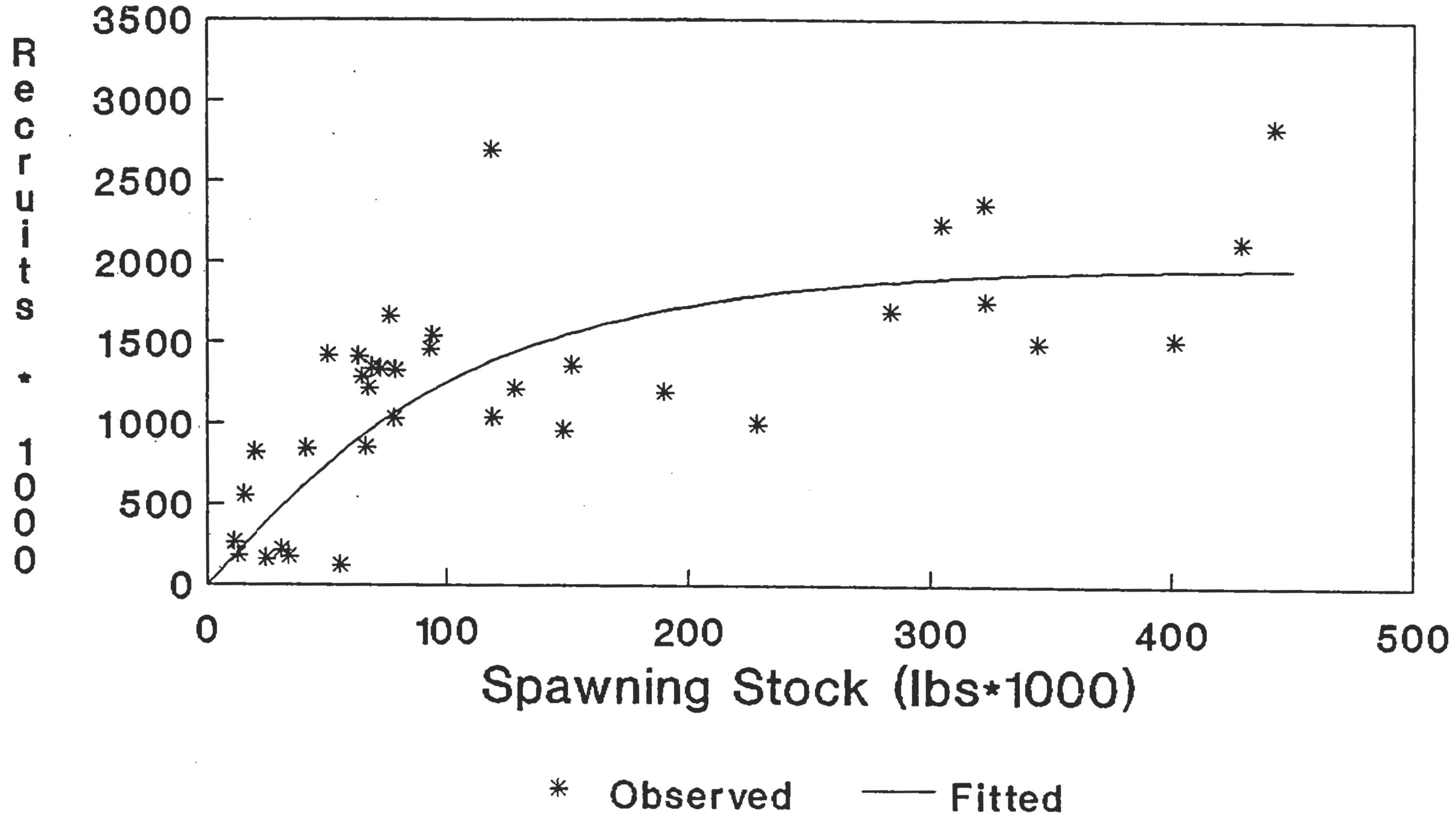
Fig.3b- Lamprey River Alewife

Stock and Recruitment, 1972-1985



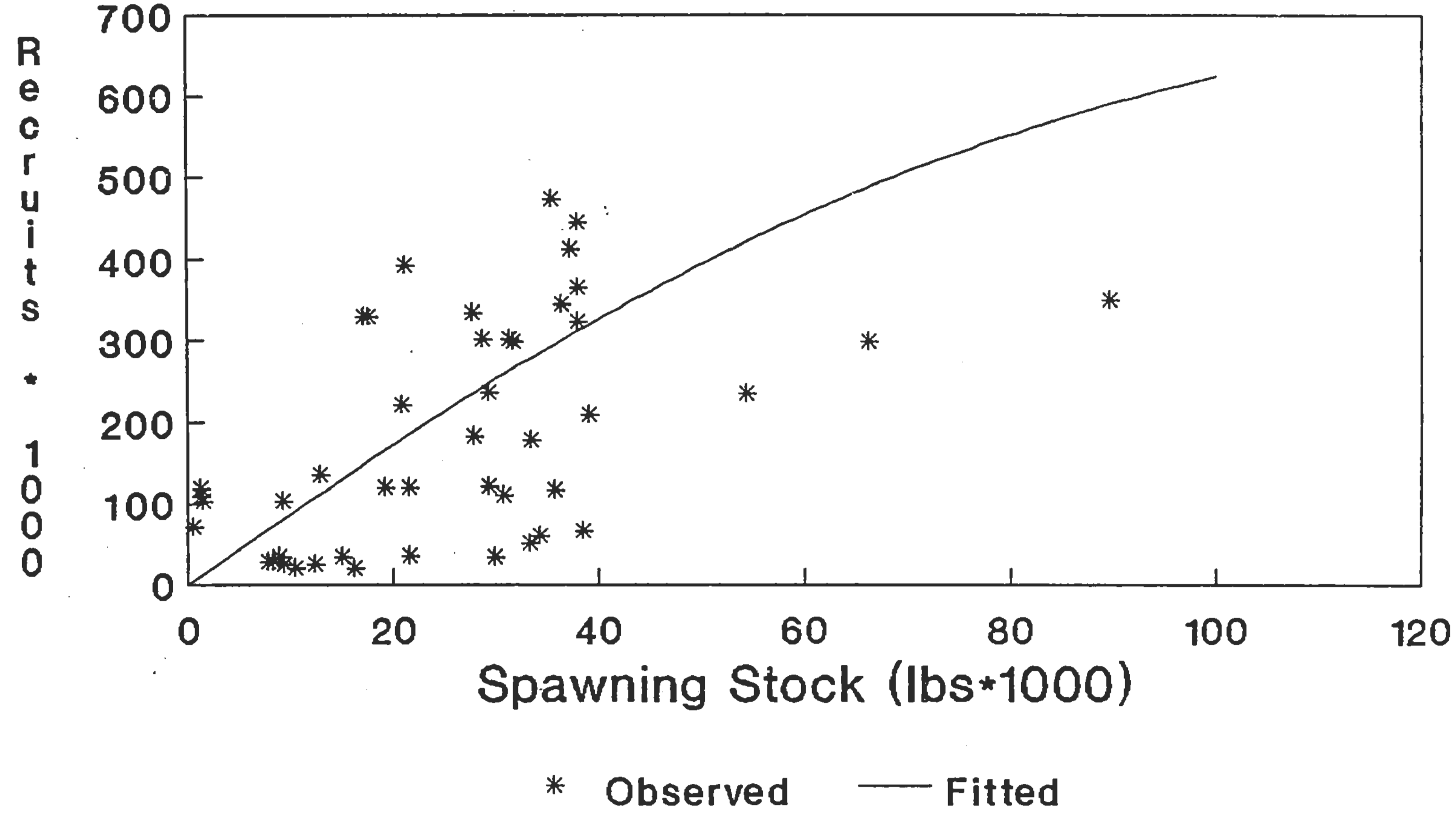
Data from NH Fish and Game

Fig.4-Alewife Stock and Recruitment Damariscotta R., 1948-81



Data from ME Dept. Mar. Res.

Fig.5-Alewife Stock and
Recruitment Annaquatucket R.1944-83



Data from RI Div. Fish And Wild.

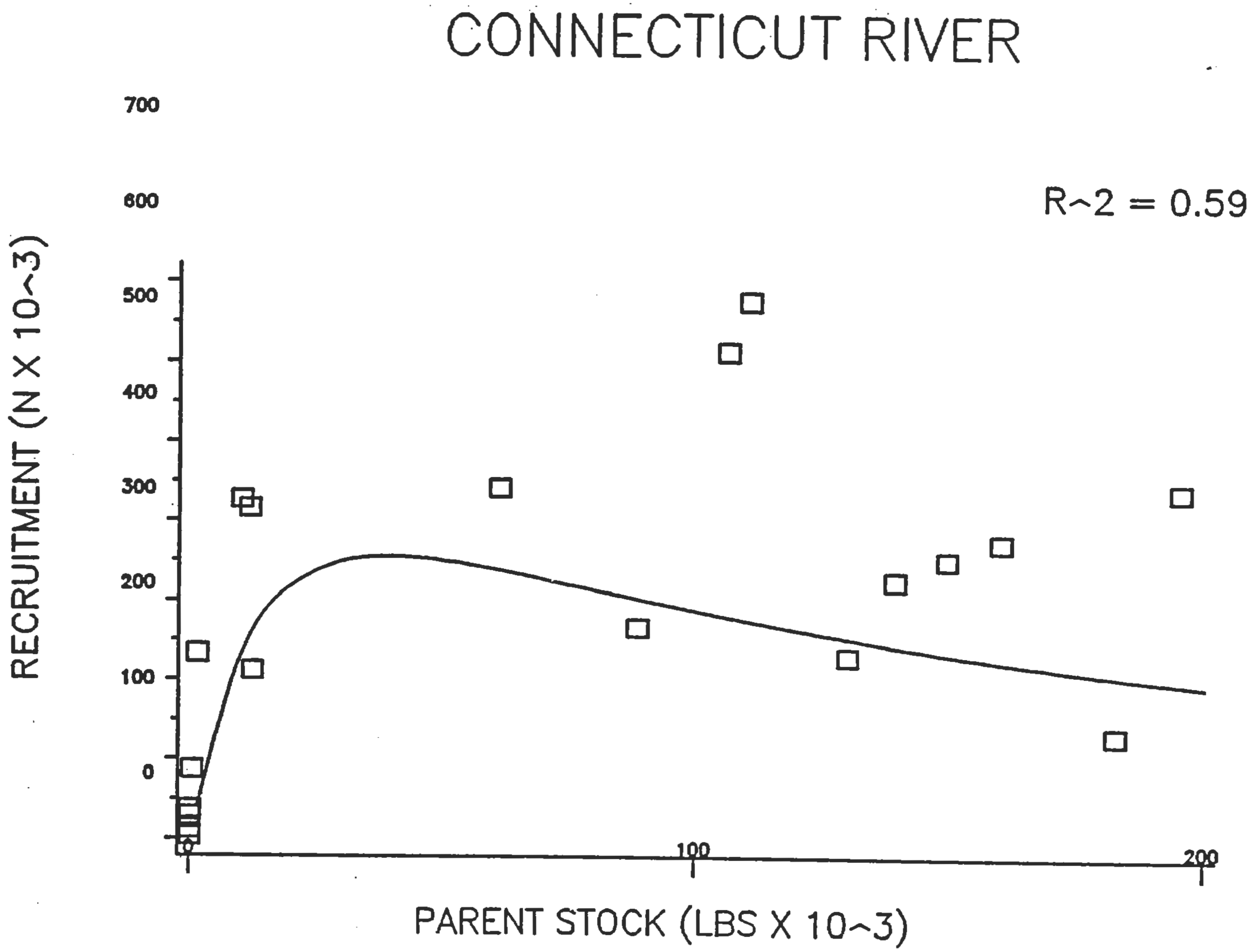


FIGURE 6 STOCK–RECRUITMENT RELATIONSHIP FOR BLUEBACK HERRING IN THE CONNECTICUT RIVER, CT BASED ON THE 1971–1989 DATA.

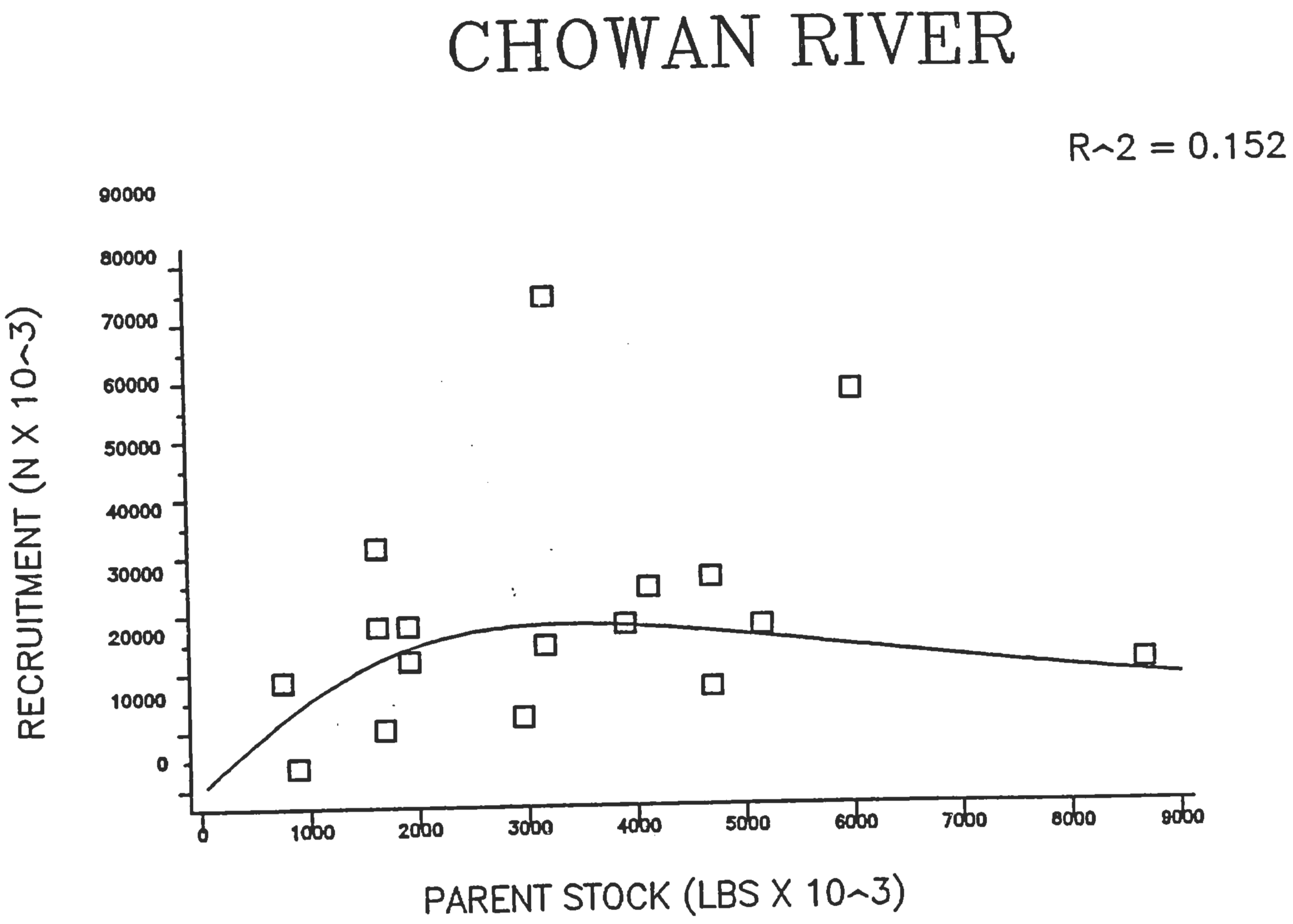


FIGURE 7 STOCK–RECRUITMENT RELATIONSHIP FOR BLUEBACK HERRING IN THE CHOWAN RIVER, NC BASED ON THE 1972–88 DATA. RECRUITMENT IS ADJUSTED FOR APRIL, MAY, JUNE FLOW EFFECTS.

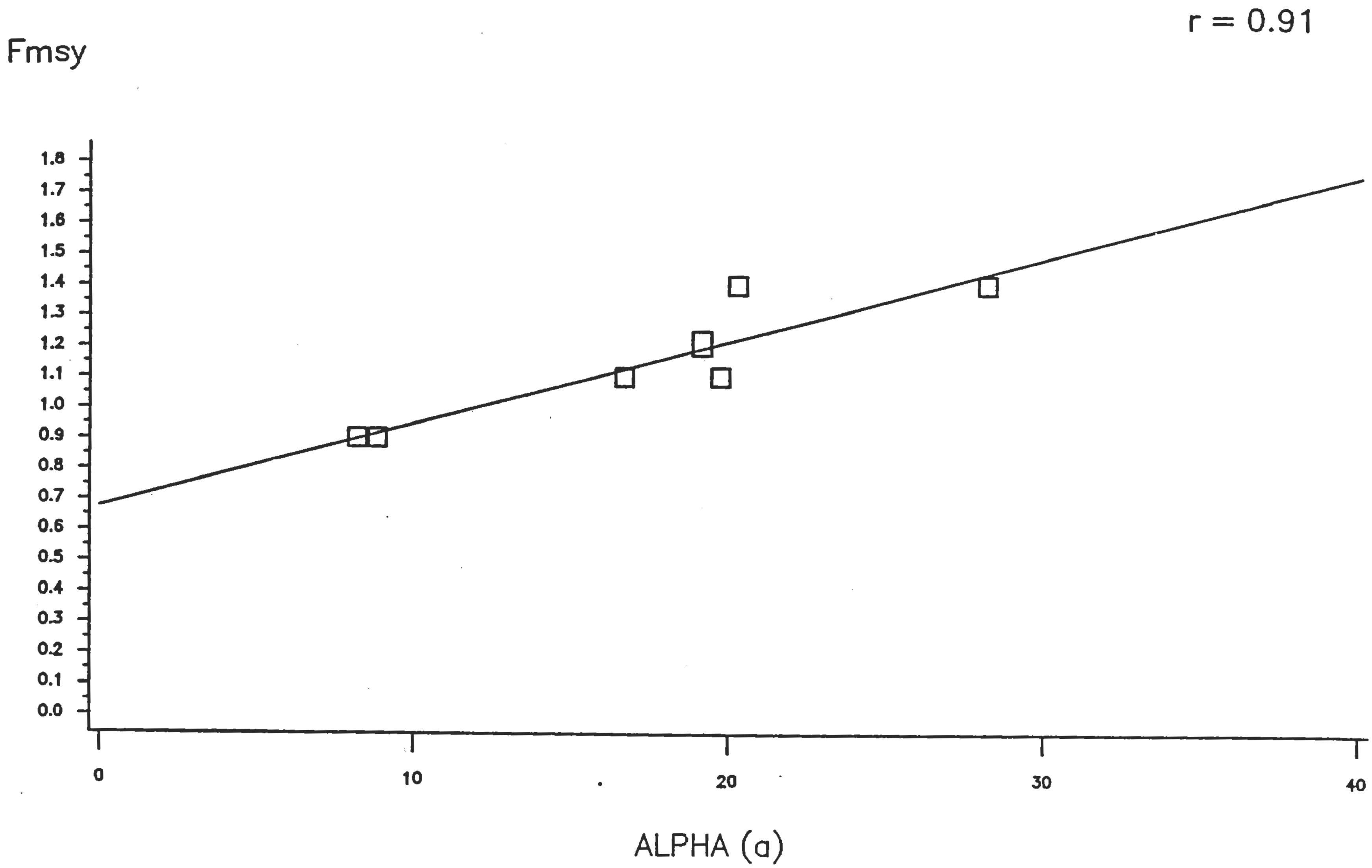


FIGURE 8 RELATIONSHIP BETWEEN Fmsy AND ALPHA FROM THE S–R MODELS FOR SEVEN RIVER HERRING STOCKS.

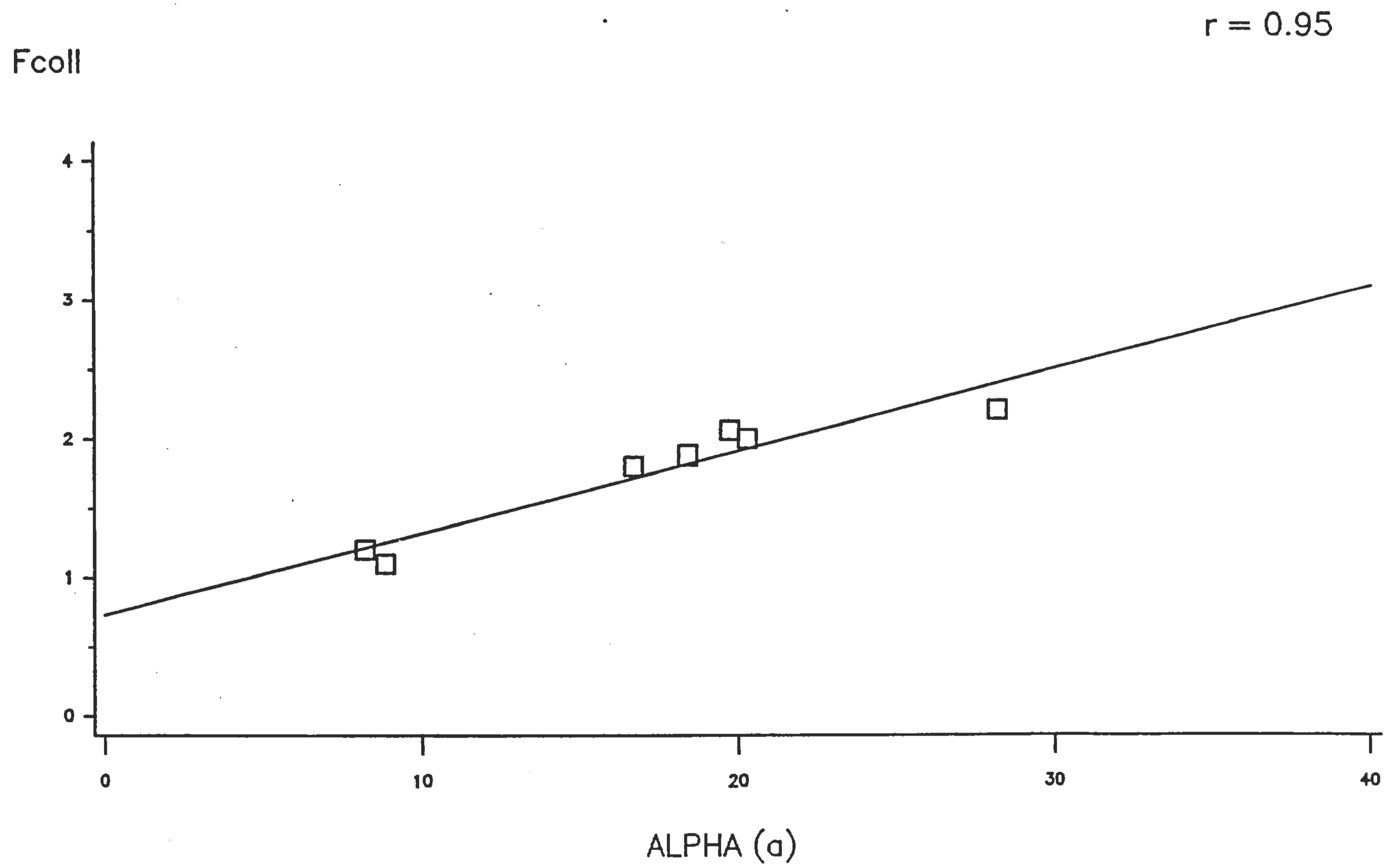
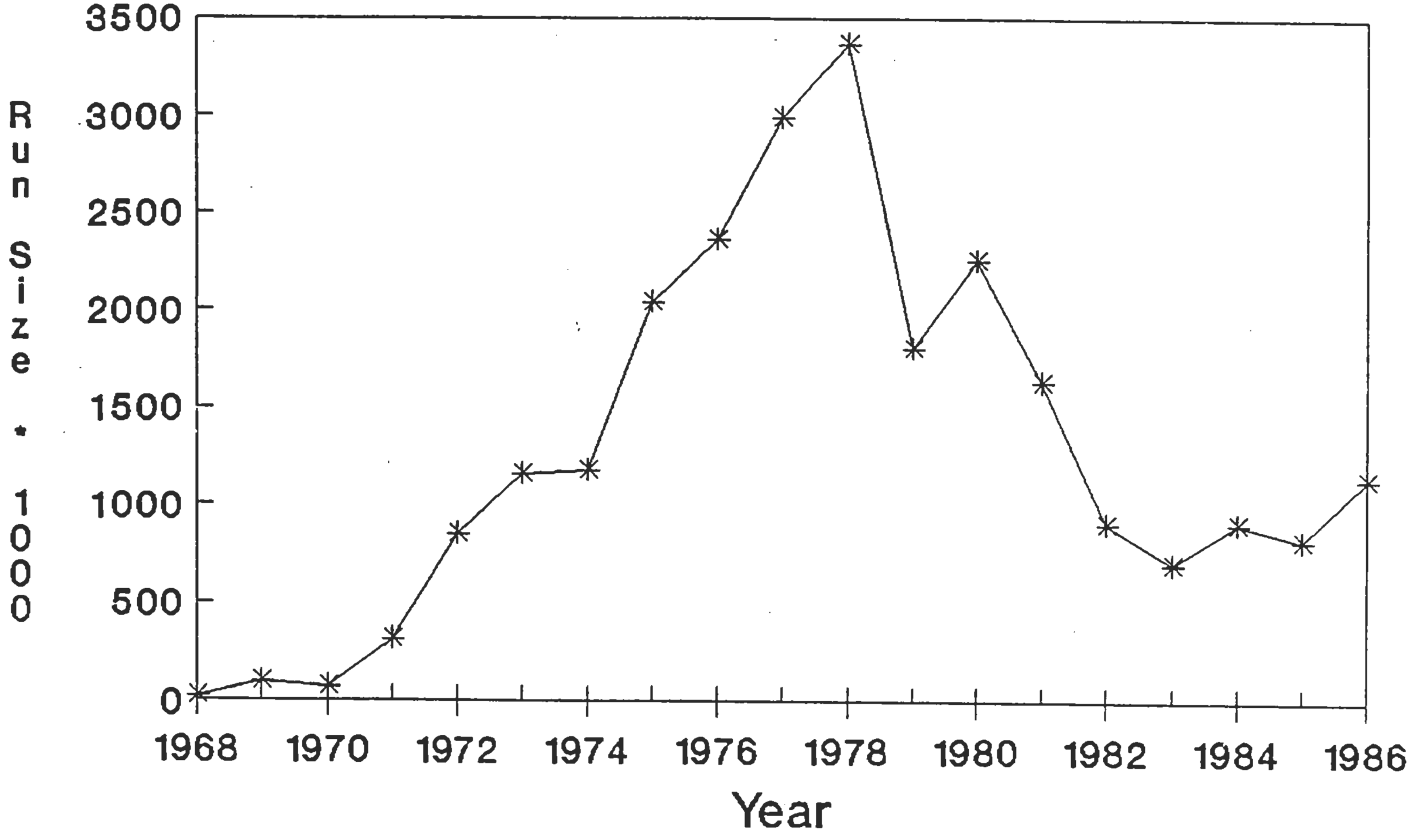


FIGURE 9 RELATIONSHIP BETWEEN Fcoll AND ALPHA FROM THE S–R MODELS FOR SEVEN RIVER HERRING STOCKS.

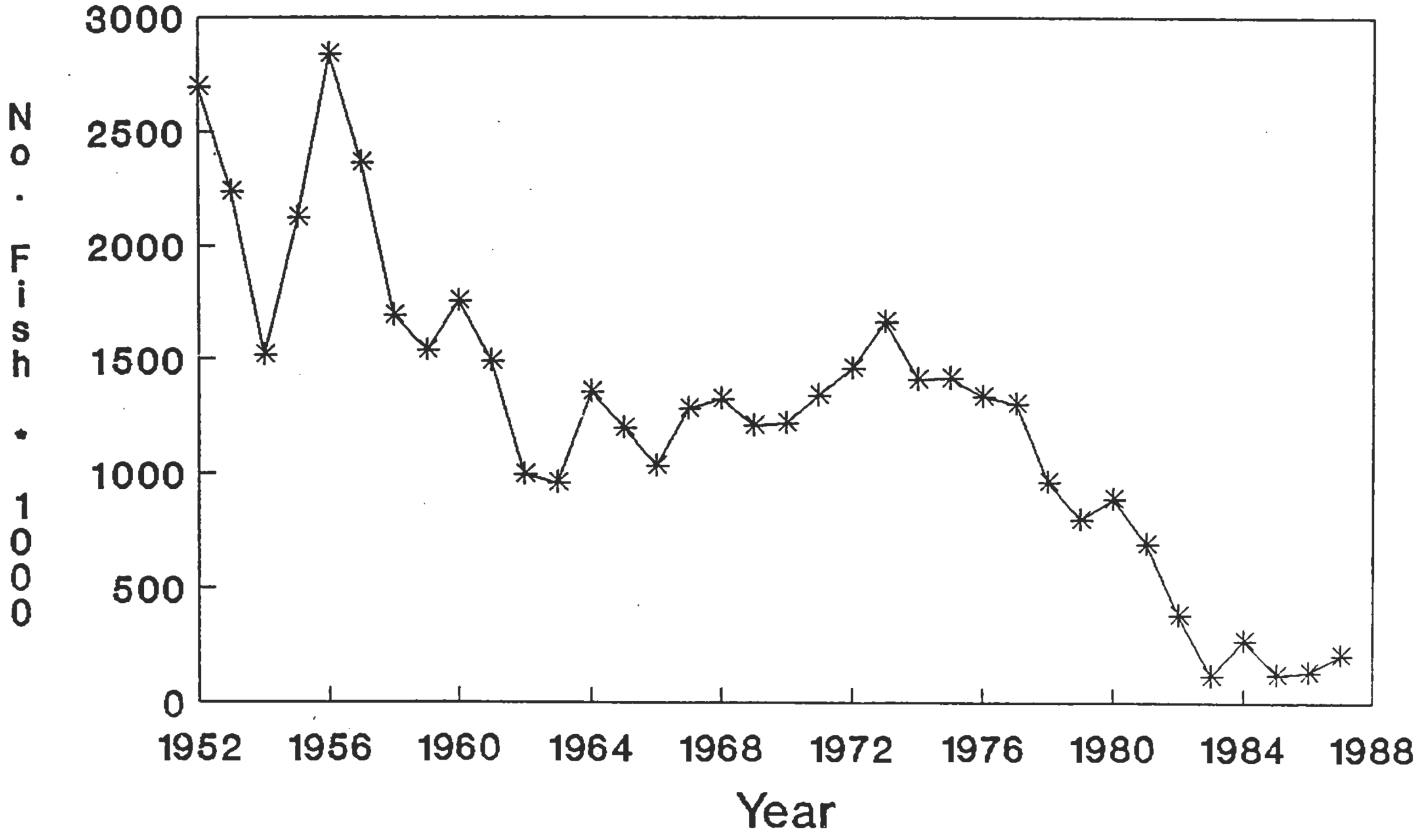
Fig.10-St. John River Alewife
Population Trends, 1968-1986



Data from Jessop (1985)

Fig.11-Damariscotta R. Alewife

Population Trend, 1952-1987



Data from ME Dept. Mar. Res.

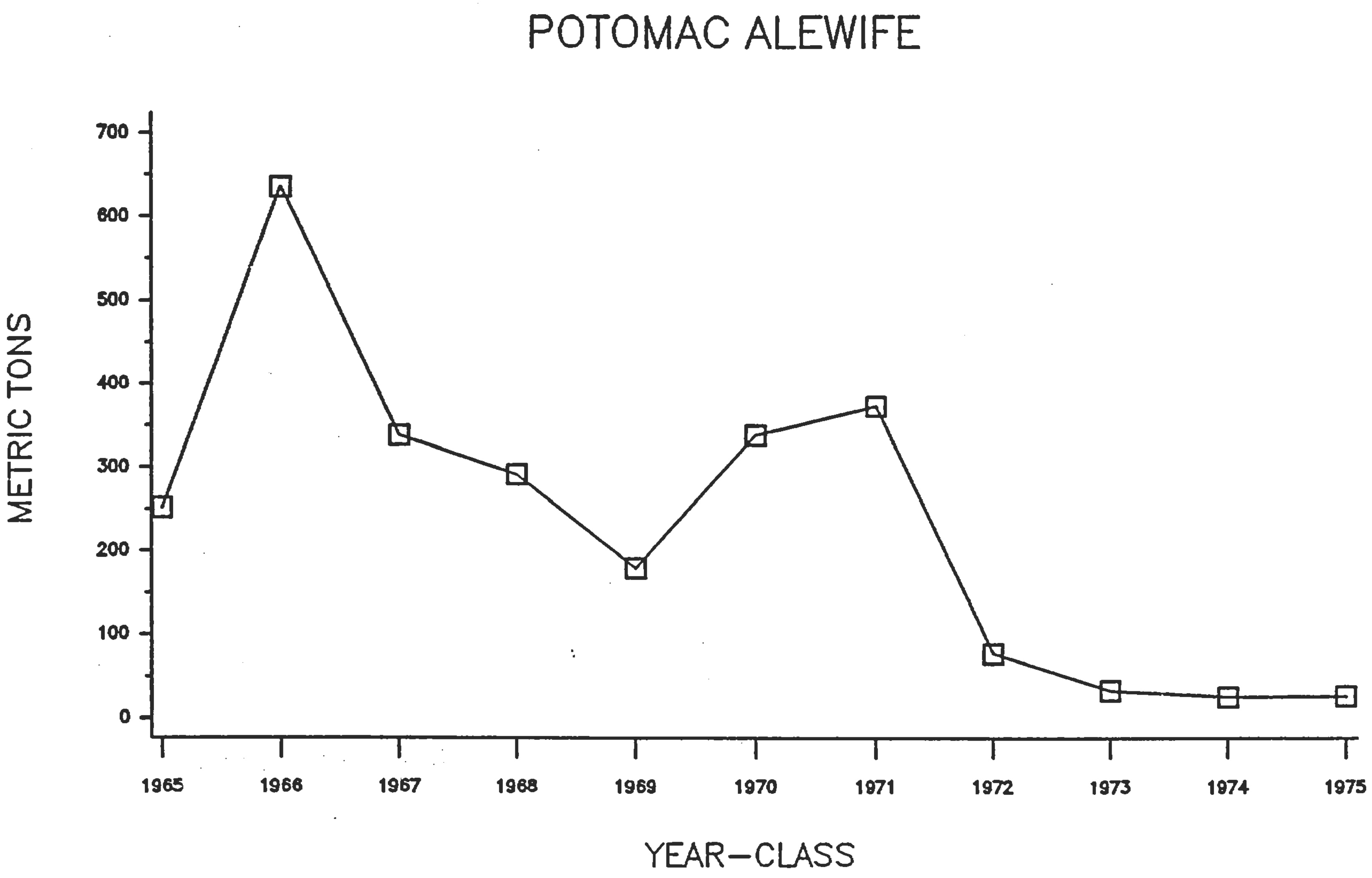


FIGURE 12 ABUNDANCE OF THE 1965—1975 YEAR—CLASSES IN THE 1969—1981 ALEWIFE POPULATION IN THE POTOMAC RIVER (ASMFC 1985)

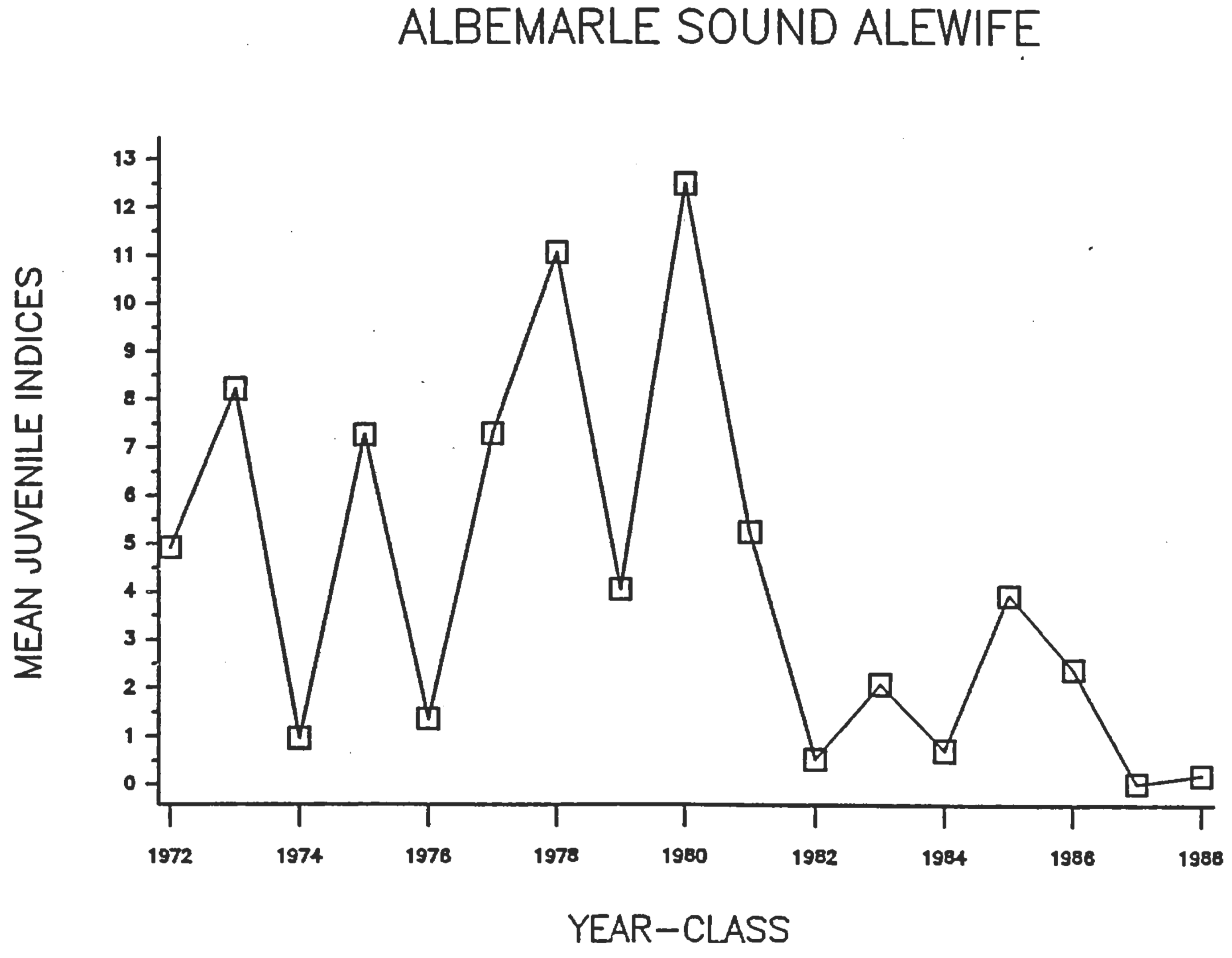
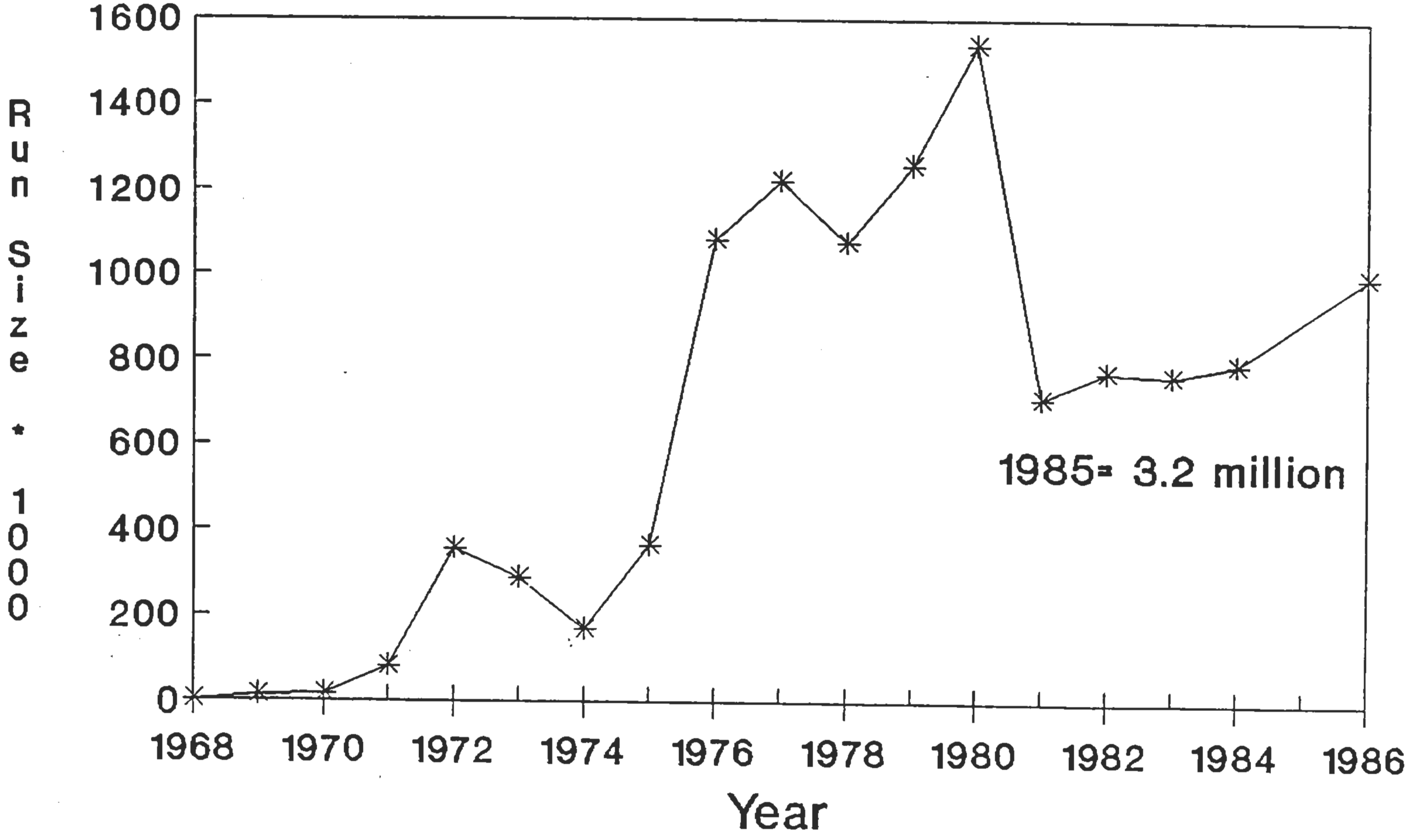


FIGURE 13 TREND IN MEAN JUVENILE INDEX FOR ALEWIFE IN ALBEMARLE SOUND FOR THE 1972–88 YEAR–CLASSES (NCDMR 1988)

Fig.14-St. John R. Blueback

Population Trends, 1968-1986



Data from Jessop (1985)

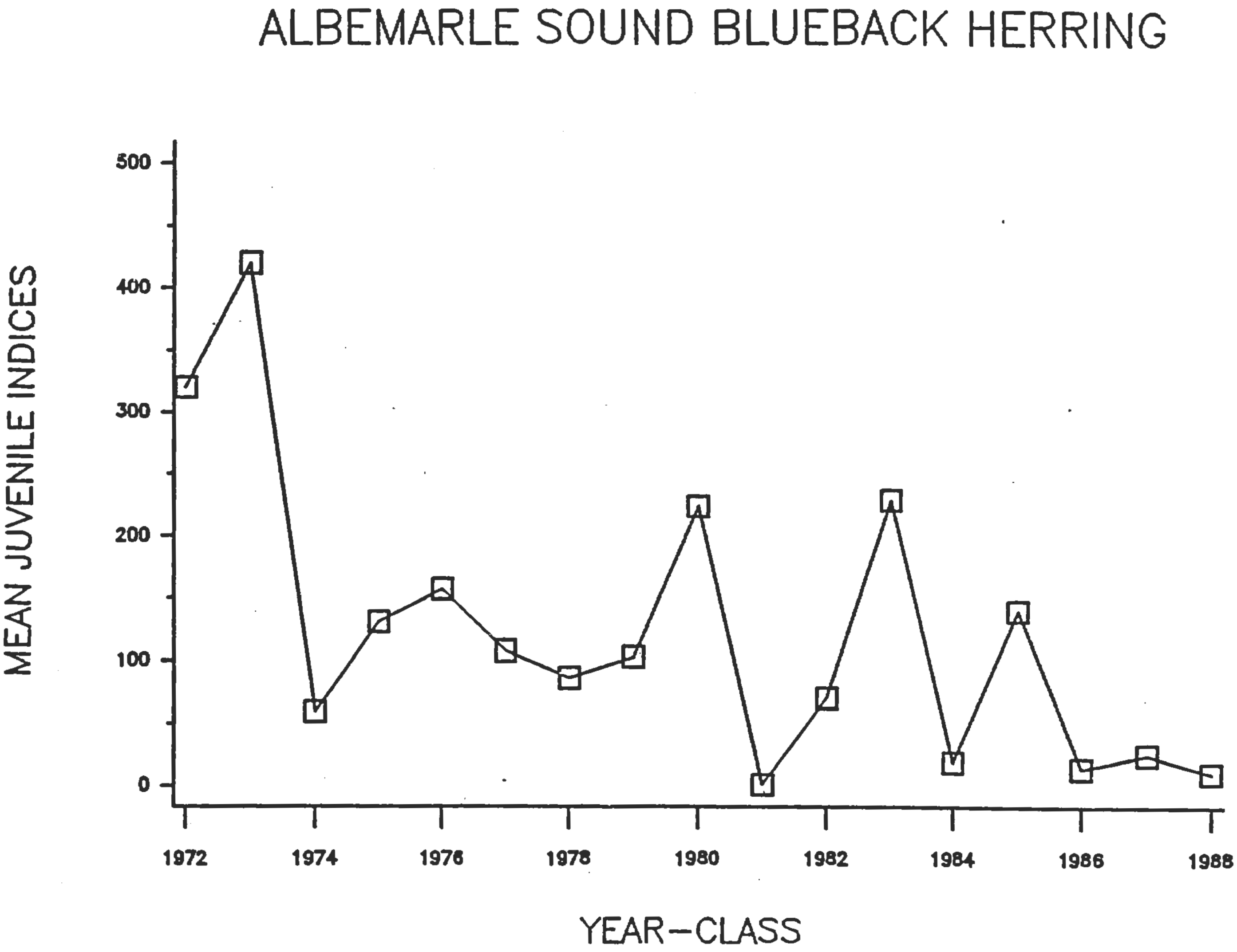


FIGURE 15 TREND IN MEAN JUVENILE INDEX FOR BLUEBACK HERRING IN ALBEMARLE SOUND FOR TH 1972 TO 1988 YEAR–CLASSES (NCDMR 1988)

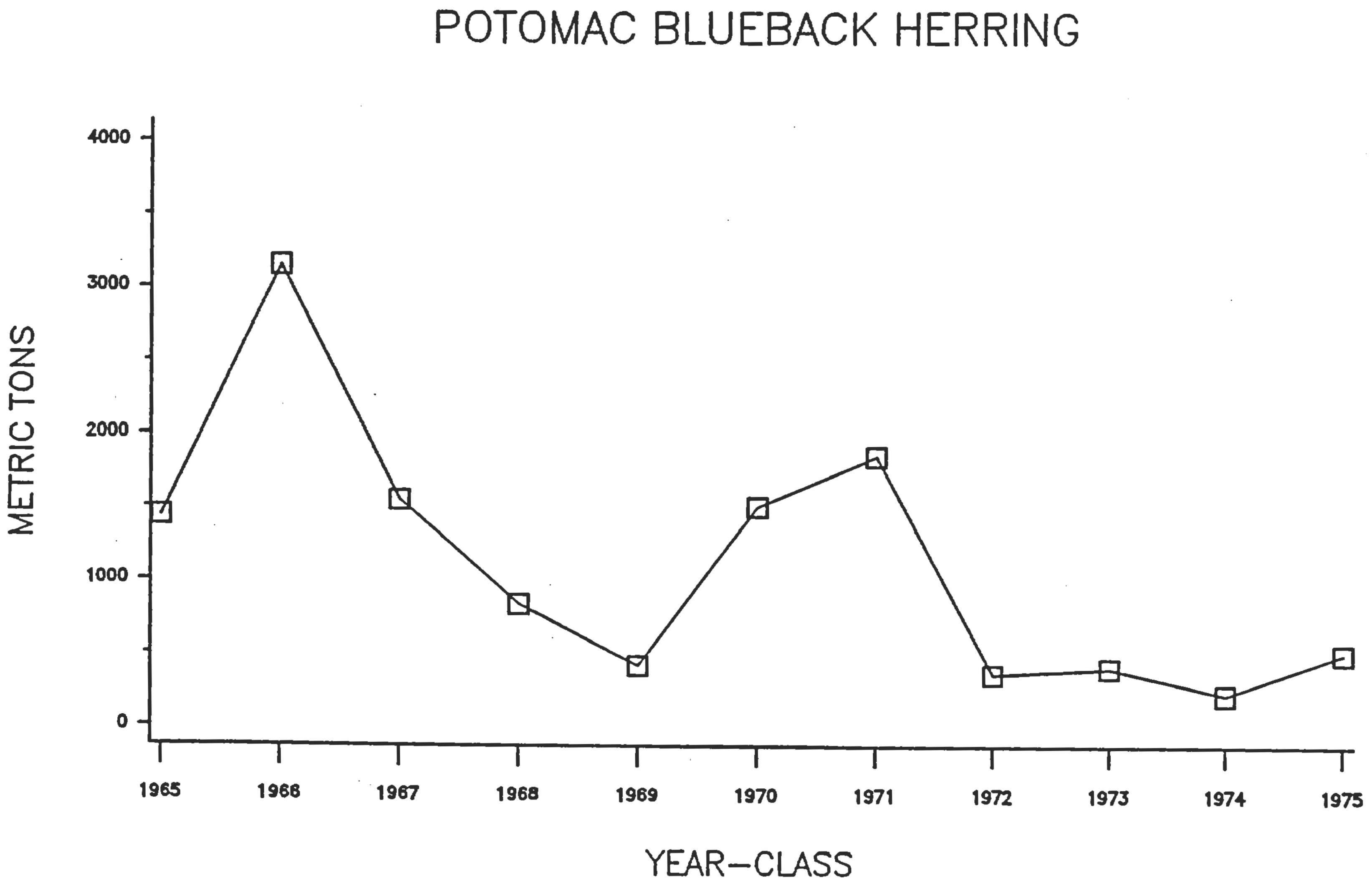
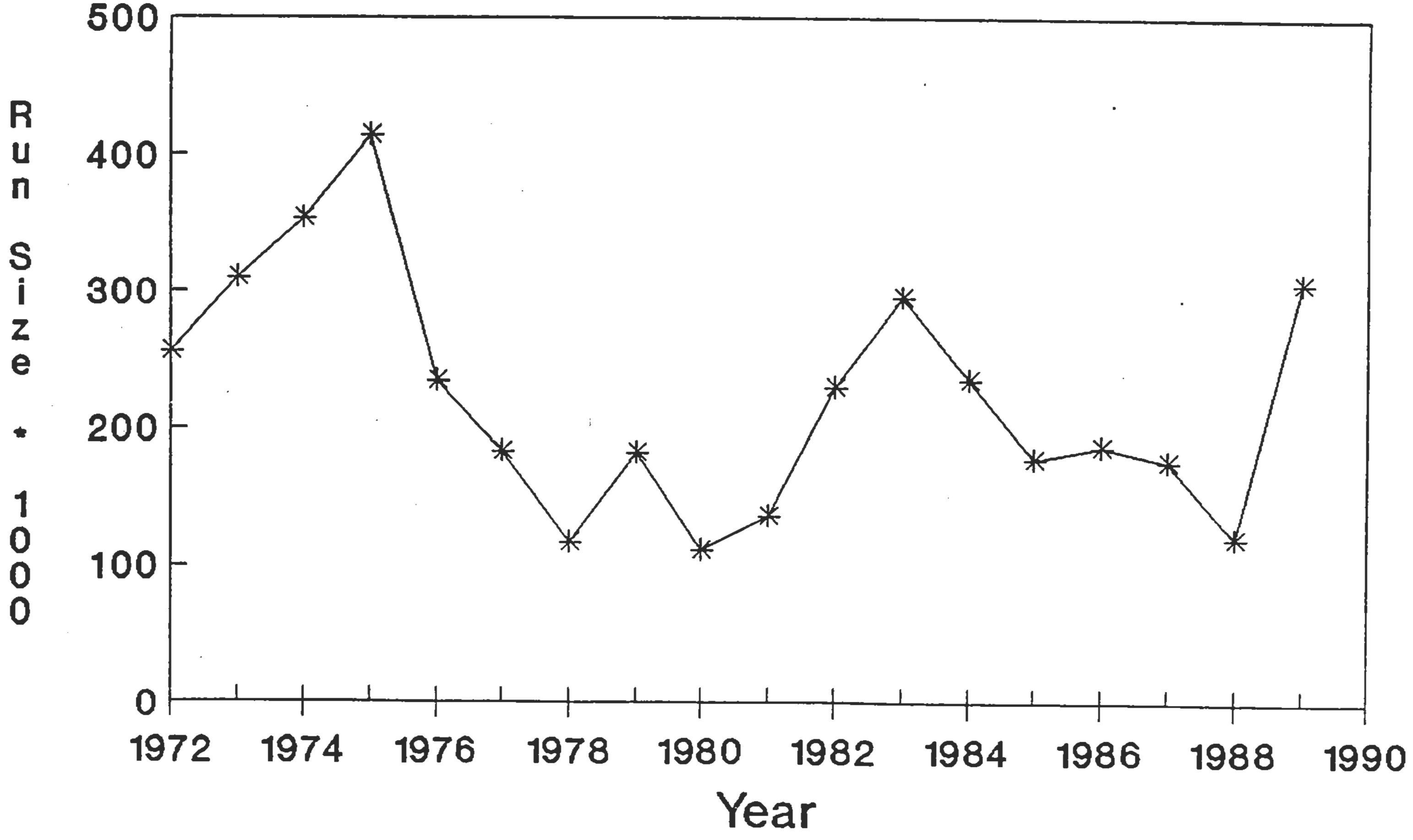


FIGURE 16 ABUNDANCE OF THE 1965—1975 YEAR—CLASSES IN THE 1969—1981 BLUEBACK HERRING POPULATION IN THE POTOMAC RIVER (ASMFC 1985)

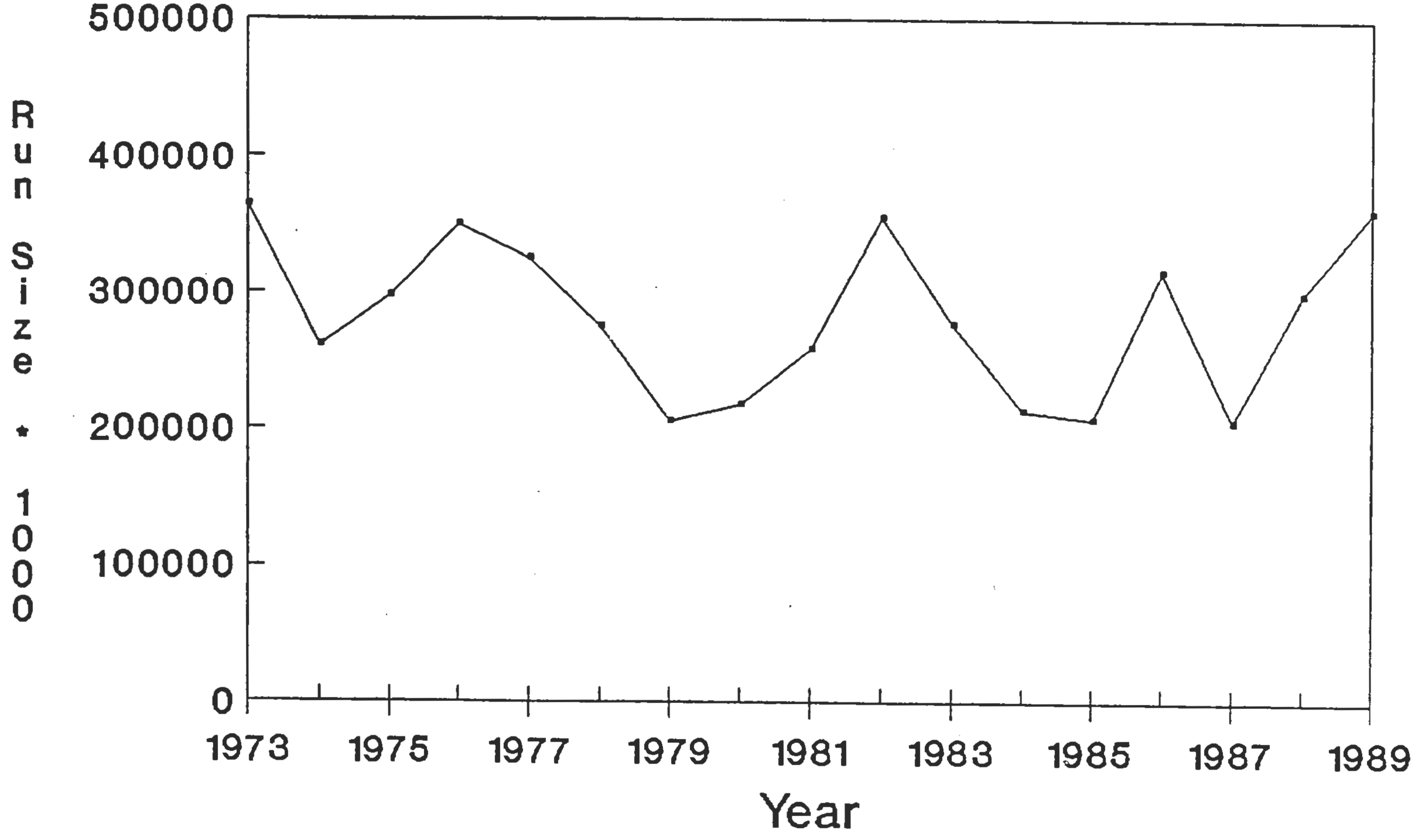
Fig.17- Herring R. Alewife/ Blueback Trends, 1972-1989



Data MA Div. Mar. Fish, Bournedale DNR

Fig.18-Alewife Population

Trend Annaquatucket River, 1973-89



Data from RI Fish and Wild.

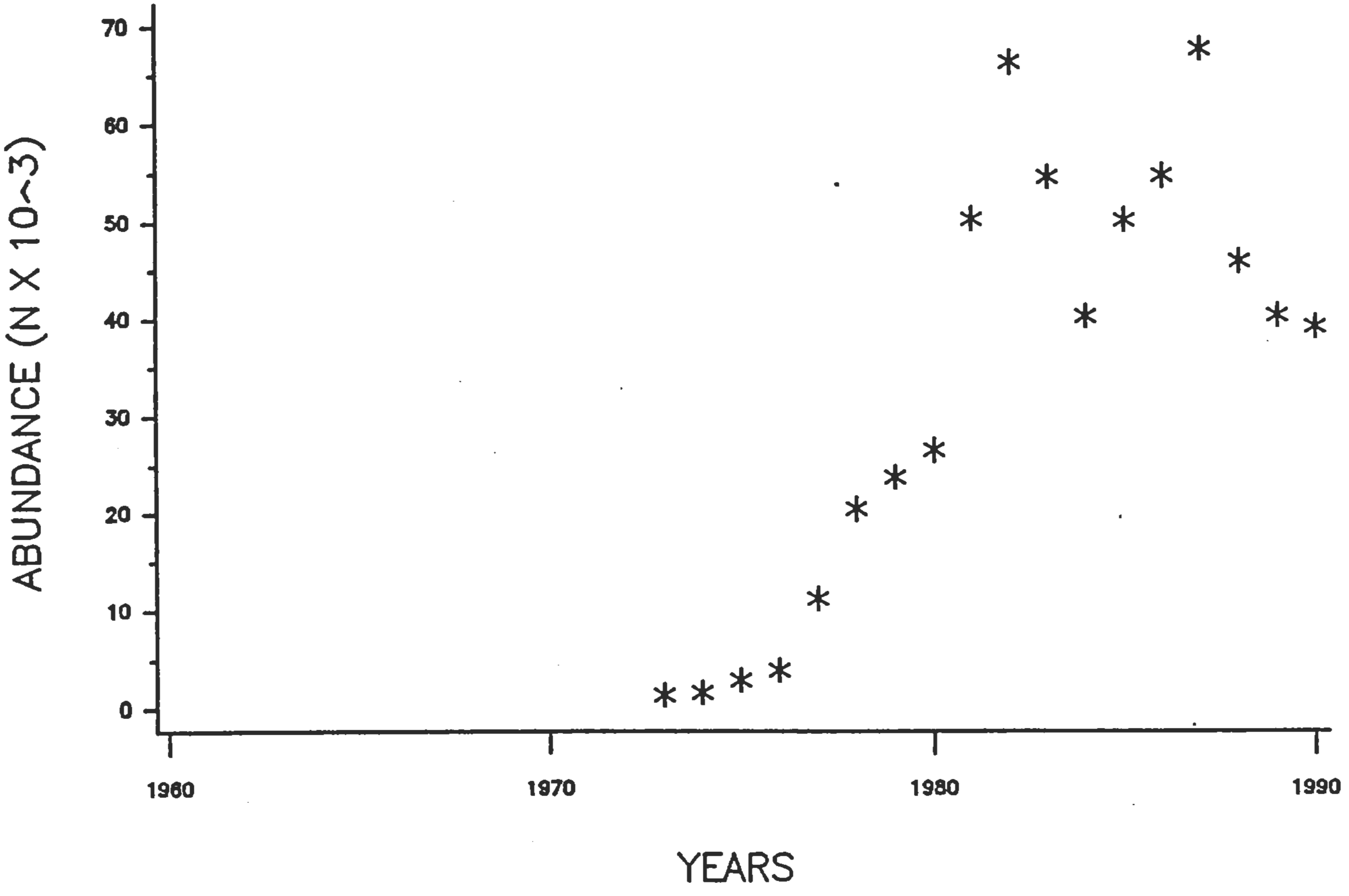


FIGURE 19 ABUNDANCE OF ADULT ALEWIFE PASSED AT THE LAMPREY RIVER FISHLIFT FROM 1973 TO 1990.

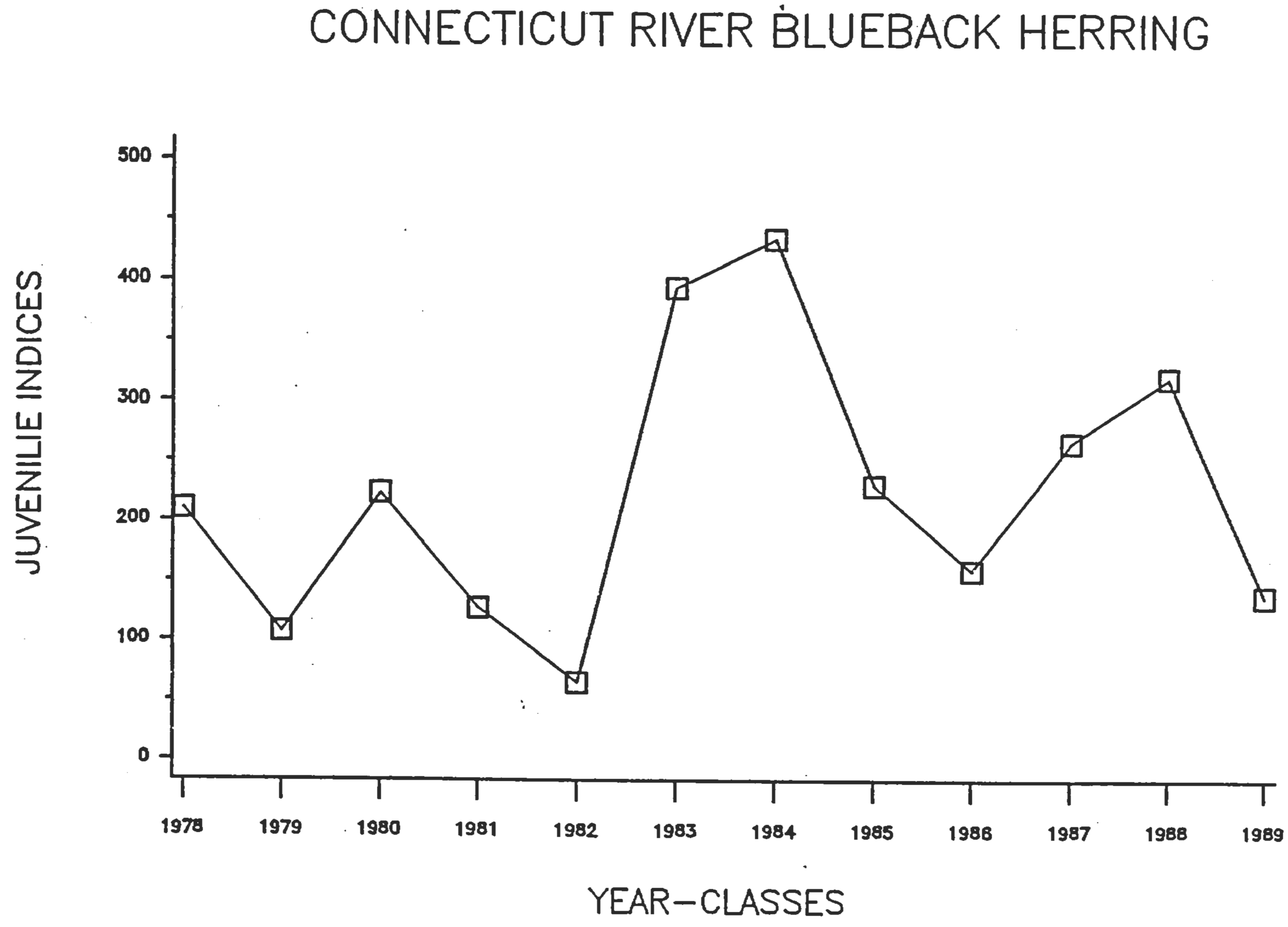


FIGURE 20 TREND IN JUVENILE INDICES FOR BLUEBACK HERRING IN THE CONNECTICUT RIVER FOR THE 1978–89 YEAR–CLASSES (THOMAS SAVOY PERS. COMM.)

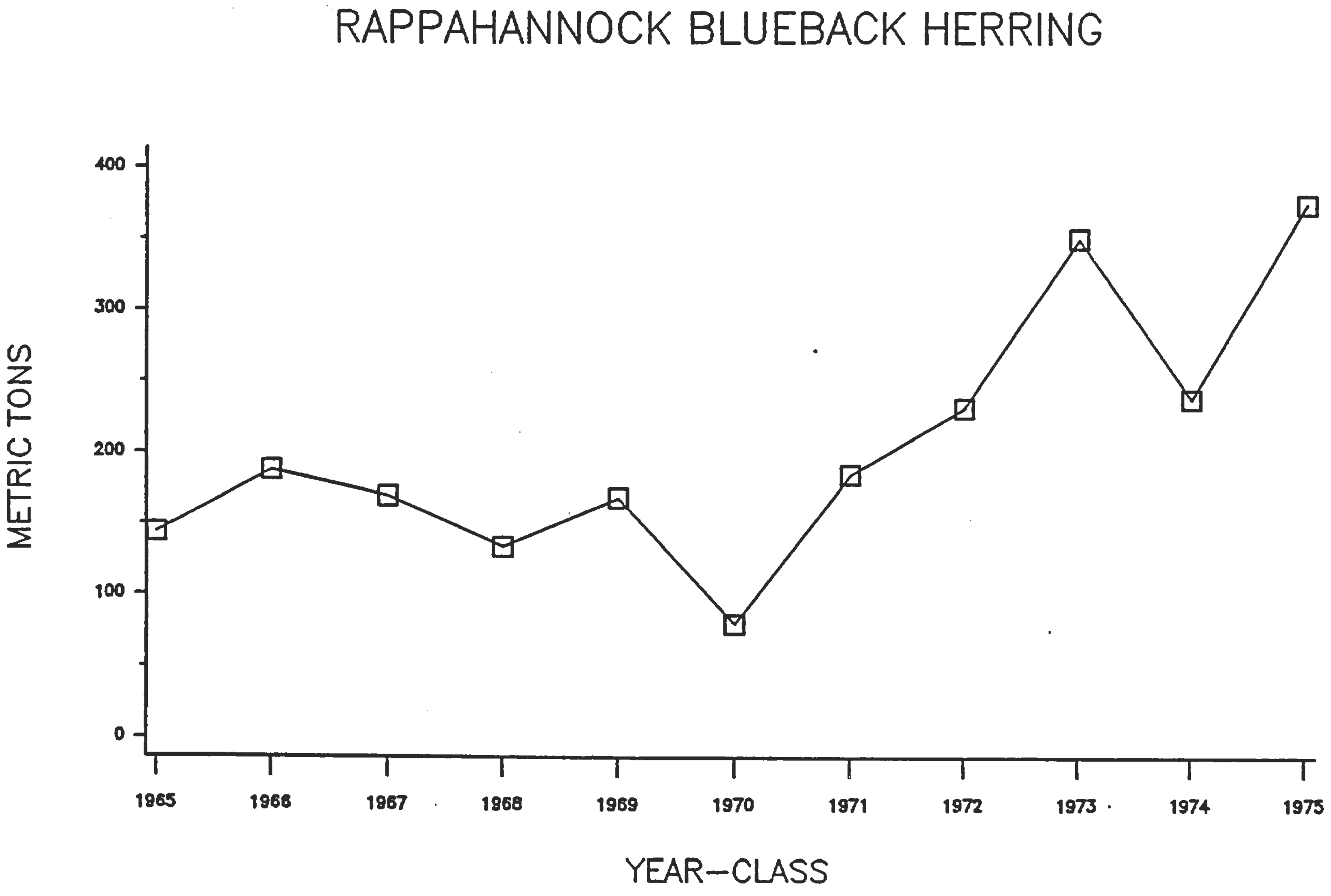


FIGURE 21 ABUNDANCE OF THE 1965–1975 YEAR–CLASSES IN THE 1969–1981 BLUEBACK HERRING POPULATION IN THE RAPPAHANNOCK RIVER (ASMFC 1985)

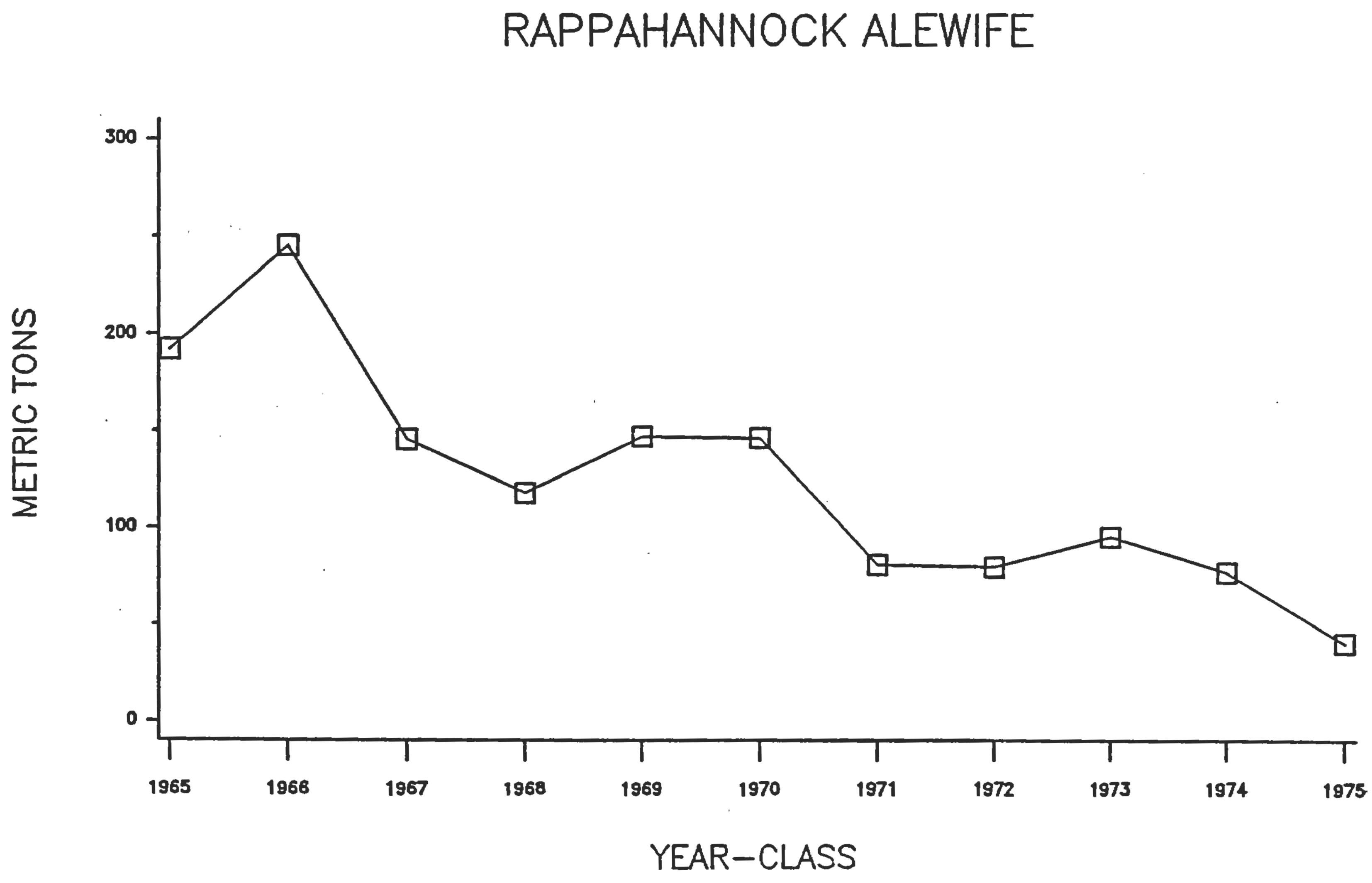


FIGURE 22 ABUNDANCE OF THE 1965—1975 YEAR—CLASSES IN THE 1969—1981 ALEWIFE POPULATION IN THE RAPPAHANNOCK RIVER (ASMFC 1985)

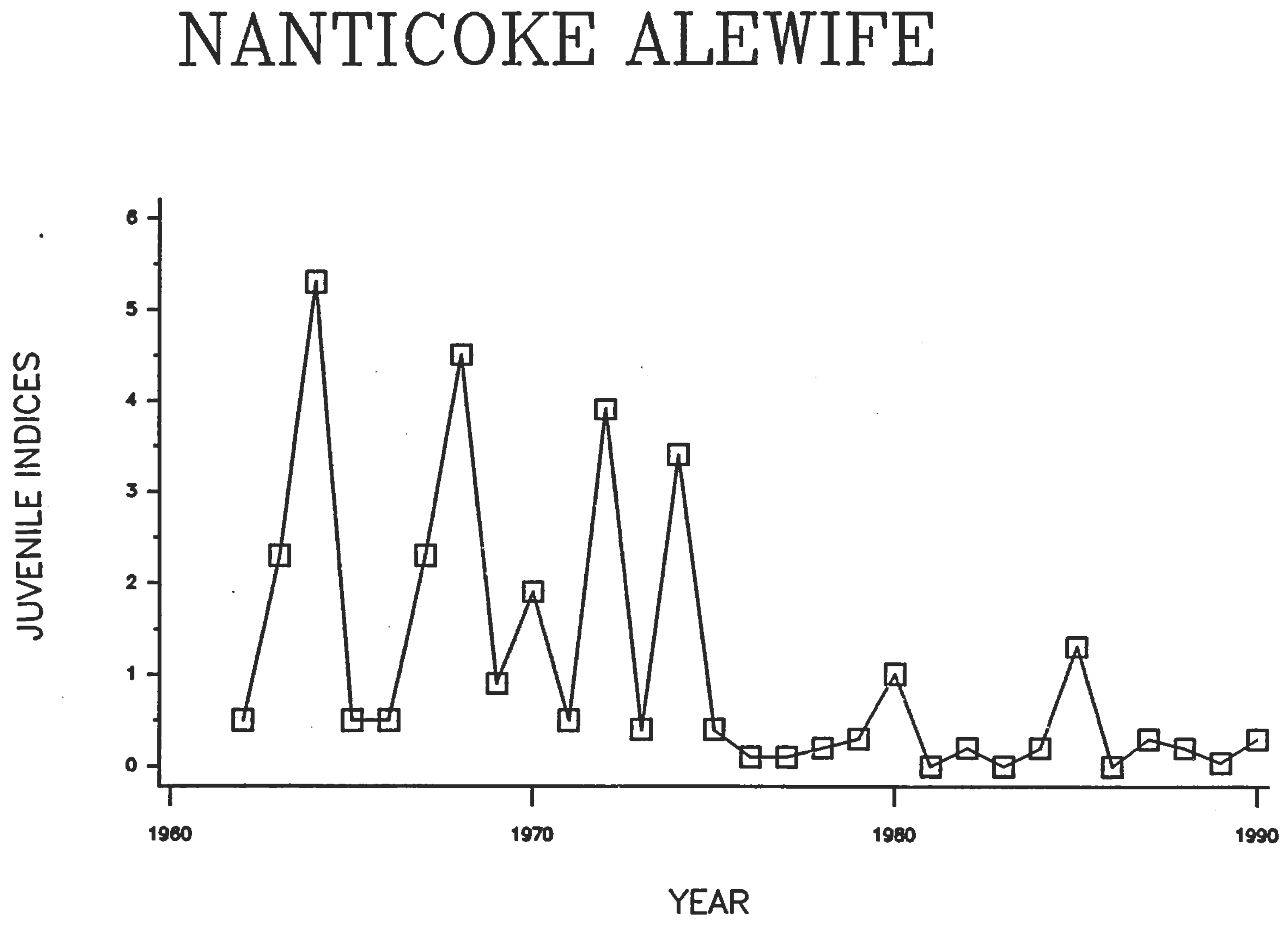


FIGURE 23. CHANGES IN THE MEAN JUVENILE INDICES OF ALEWIFE IN THE NANTICOKE RIVER FORM 1962 THROUGH 1990 (WEINRICH, PERS. COMM.).

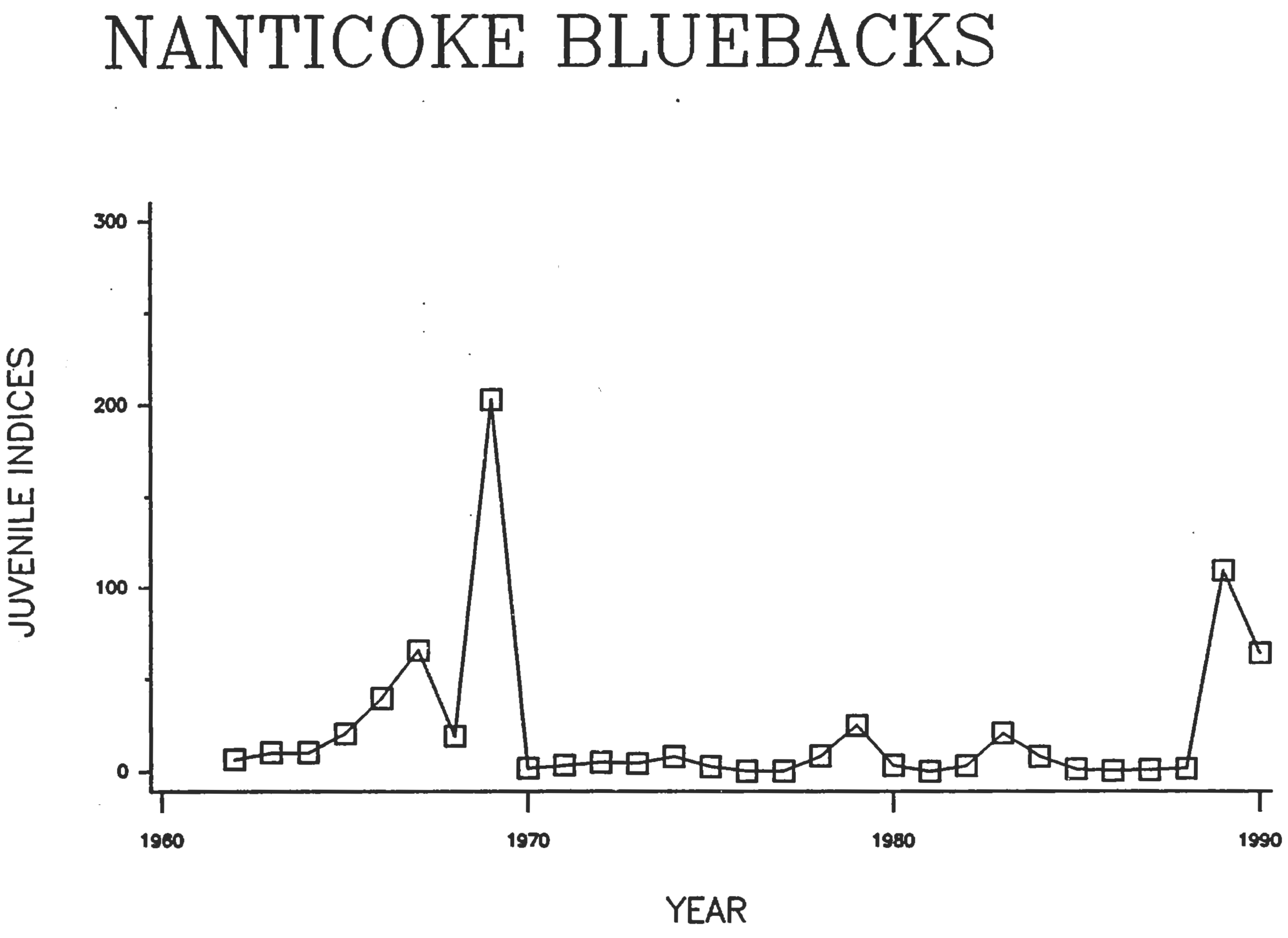


FIGURE 2A. CHANGES IN THE MEAN JUVENILE INDICES OF BLUEBACK HERRING IN THE NANTICOKE RIVER FORM 1962 THROUGH 1990 (WEINRICH, PERS. COMM.).

Appendix 1

River systems used in the stock assessment of river herring along the Atlantic coast. The availability of input data is represented by a yes or no response for each river and species

River	Species	Stock Recruitment Data?	Absolute stock size from start of restoration?	Fishing mortality Data?
St. John, NB	Alewife	Yes	Yes	Yes
	Blueback	Yes	Yes	Yes
Damariscotta, ME	Alewife	Yes	No	Yes
Androscoggin, ME	Alewife	No	Yes	No
St. Croix, ME	Alewife	No	Yes	No
Royal, ME	Alewife	No	Yes	No
Union, ME	Alewife	No	Yes	No
Lamprey, NH	Alewife	No	Yes	Yes
Oyster, NH	Alewife	No	Yes	No
Herring, MA	Alewife Blueback	No	No	Yes
Annaquatucket, RI	Alewife	Yes	Yes	Yes
Connecticut, CT	Blueback	Yes	Yes	Yes
Nanticoke, MD	Alewife	No	No	Yes
	Blueback	No	No	Yes
Potomac, VA	Alewife	No	No	Yes
	Blueback	No	No	Yes
Rappahannock, VA	Alewife	No	No	Yes
	Blueback	No	No	Yes
Chowan, NC	Alewife	No	No	Yes
	Blueback	Yes	No	Yes

Appendix 1

Parent stock (lbs x 10^3) and recruitment (N x 10^3) data for seven river herring stocks along the Atlantic coast.

Year	Connecticut River, CT		Chowan River, NC	
	P	R	P	Adj 1/
	Parents	Recruits	Parent	Recruits
1971	0.062	3.31	----	-----
1972	0.058	12.57	8668	21004
1973	0.094	28.80	6014	67679
1974	0.156	37.60	4694	17030
1975	0.496	87.00	4118	34117
1976	1.457	233.00	4692	35778
1977	10.230	426.60	5155	27411
1978	11.780	415.10	3902	27852
1979	12.400	211.70	1911	27852
1980	61.380	440.80	3161	24355
1981	130.200	230.40	1633	27852
1982	182.900	132.20	3197	84220
1983	139.500	325.60	1629	41385
1984	149.700	352.09	1688	10107
1985	195.300	439.40	2958	12128
1986	160.400	374.70	1922	21891
1987	110.600	675.60	753	18582
1988	106.400	612.85	885	3655
1989	88.660	265.88	----	-----

1/ Recruitment was adjusted for average April, May and June river flow.

Appendix 1

Parent stock (lbs x 10^3) and recruitment (N x 10^3) data for seven river herring stocks along the Atlantic coast.

Year	Damariscotta River		Year	Annaquatucket River	
	P Parents	R Recruits		P Parents	R Recruits
1949	304.1	2236.1	1945	20.8	221.3
1950	401.0	1516.2	1946	21.2	392.5
1951	428.3	2124.4	1947	31.4	302.9
1952	442.2	2840.7	1948	27.8	334.5
1953	321.9	2366.4	1949	17.6	330.5
1954	283.1	1695.0	1950	17.1	330.3
1955	94.0	1539.2	1951	38.0	445.0
1956	322.6	1759.2	1952	37.2	412.1
1957	343.6	1494.2	1953	35.4	473.7
1958	228.3	995.0	1954	38.0	324.1
1959	147.8	961.4	1955	38.0	356.6
1960	151.4	1356.3	1956	89.6	350.5
1961	189.8	1199.0	1957	29.4	236.0
1962	118.7	1035.6	1958	33.4	177.3
1963	65.0	1286.0	1959	27.9	182.3
1964	78.6	1329.1	1960	54.3	234.9
1965	128.3	1210.2	1961	36.4	345.4
1966	67.3	1221.1	1962	66.2	299.6
1967	68.9	1341.1	1963	28.7	301.6
1968	92.5	1459.1	1964	31.7	299.8
1969	76.1	1666.8	1965	39.1	208.9
1970	63.0	1412.9	1966	21.5	119.4
1971	50.6	1418.8	1967	19.2	120.3
1972	72.5	1335.1	1968	35.7	117.0
1973	78.2	1031.6	1969	38.5	65.8
1974	66.4	855.3	1970	34.3	59.8
1975	19.7	822.8	1971	33.3	49.9
1976	41.0	840.4	1972	30.0	34.4
1977	15.3	549.6	1973	21.5	35.7
1978	30.9	218.6	1974	8.3	28.2
1979	12.6	187.4	1975	7.7	27.2
1980	24.5	161.2	1976	16.2	19.7
1981	55.4	125.0	1977	14.9	34.2
1982	34.1	176.4	1978	8.8	33.2
1983	11.4	261.8	1979	9.3	24.1
1984	21.3		1980	10.4	19.8
1985	12.1		1981	12.3	25.3
1986	18.6		1982	0.4	70.8
1987	48.7		1983	0.4	70.8
1988	64.8		1984	1.1	108.8
1989	72.9		1985	1.2	118.2
			1986	1.3	102.7
			1987	9.2	103.2
			1988	12.8	135.6
			1989	29.3	121.9

Appendix 1

Parent stock (lbs x 10^3) and recruitment (N x 10^3) data for seven river herring stocks along the Atlantic coast.

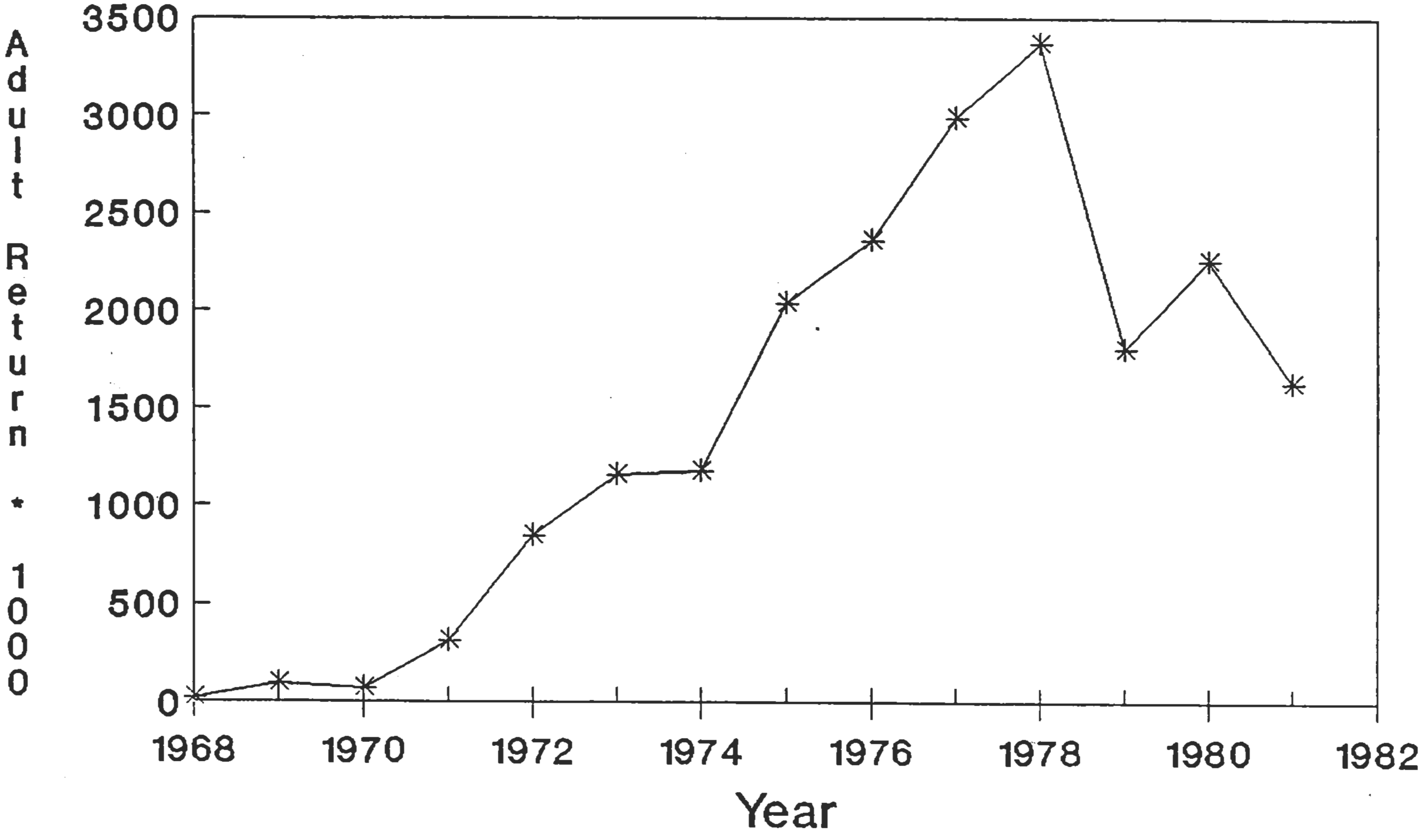
Year	St. John River			
	Alewife		Blueback	
	P Parents	R Recruits	P Parents	R Recruits
1968	12.06	848.00	.95	365.50
1969	55.68	1158.00	6.75	286.60
1970	42.24	1175.50	7.05	168.40
1971	187.92	2037.00	40.65	363.70
1972	508.80	2359.10	178.25	1081.50
1973	694.80	2991.60	143.30	1221.80
1974	358.38	3367.30	68.05	1076.50
1975	470.04	1803.20	87.35	1258.70
1976	369.06	2257.40	80.30	1540.70
1977	179.58	1631.50	92.65	710.50
1978	239.58	902.90	33.80	772.80
1979	200.22	698.00	133.05	764.00
1980	240.00	899.40	162.50	793.40
1981	195.00	814.60	226.81	1002.00
1982	318.00	1500.00	------	-------

Appendix 1

Parent stock (lbs x 10^3) and recruitment (N x 10^3) data for seven river herring stocks along the Atlantic coast.

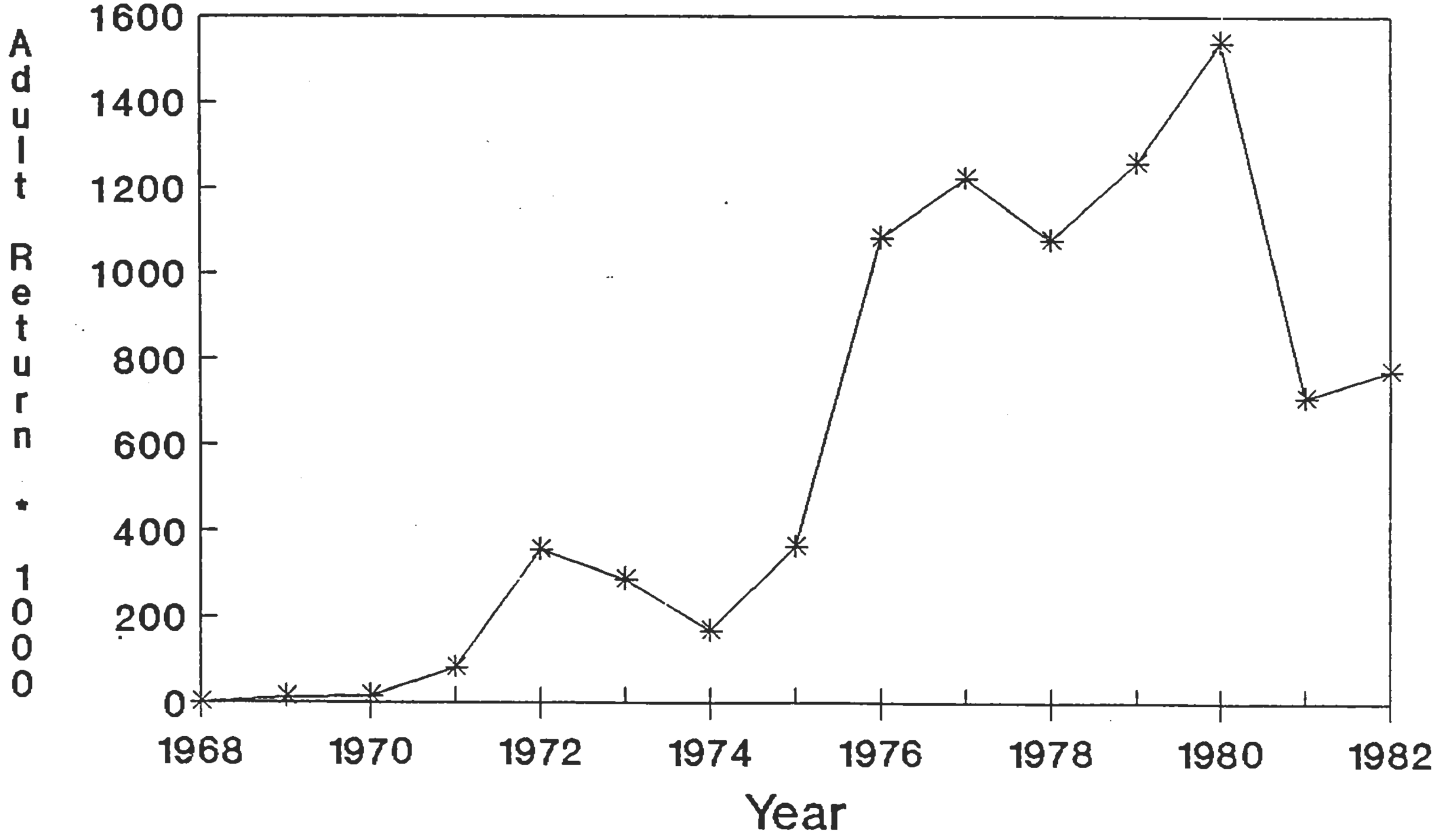
Year	Lamprey River P Parents	 R Recruits
1972	1.13	9.57
1973	.62	11.25
1974	.73	20.46
1975	1.29	23.74
1976	1.77	26.51
1977	5.06	50.22
1978	9.20	56.17
1979	10.68	48.10
1980	11.93	48.08
1981	22.60	53.19
1982	29.79	59.84
1983	24.55	52.77
1984	18.10	44.64
1985	22.58	40.32

Fig.A1-Alewife Population
Growth St. John R., 1968-1981



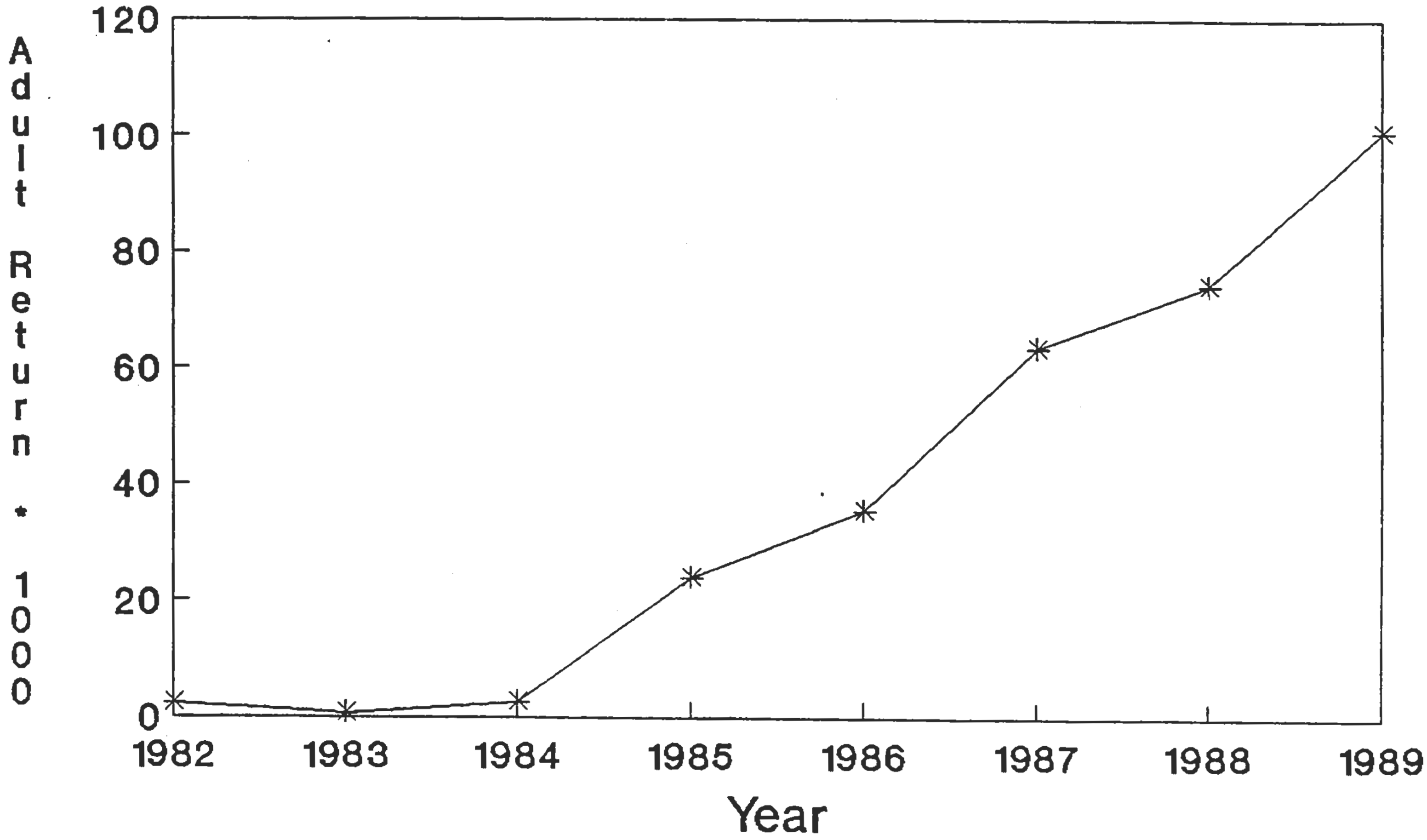
Data from Jessop (1986)

Fig.A2-Blueback Herring
Population Growth, St. John R.1968-82



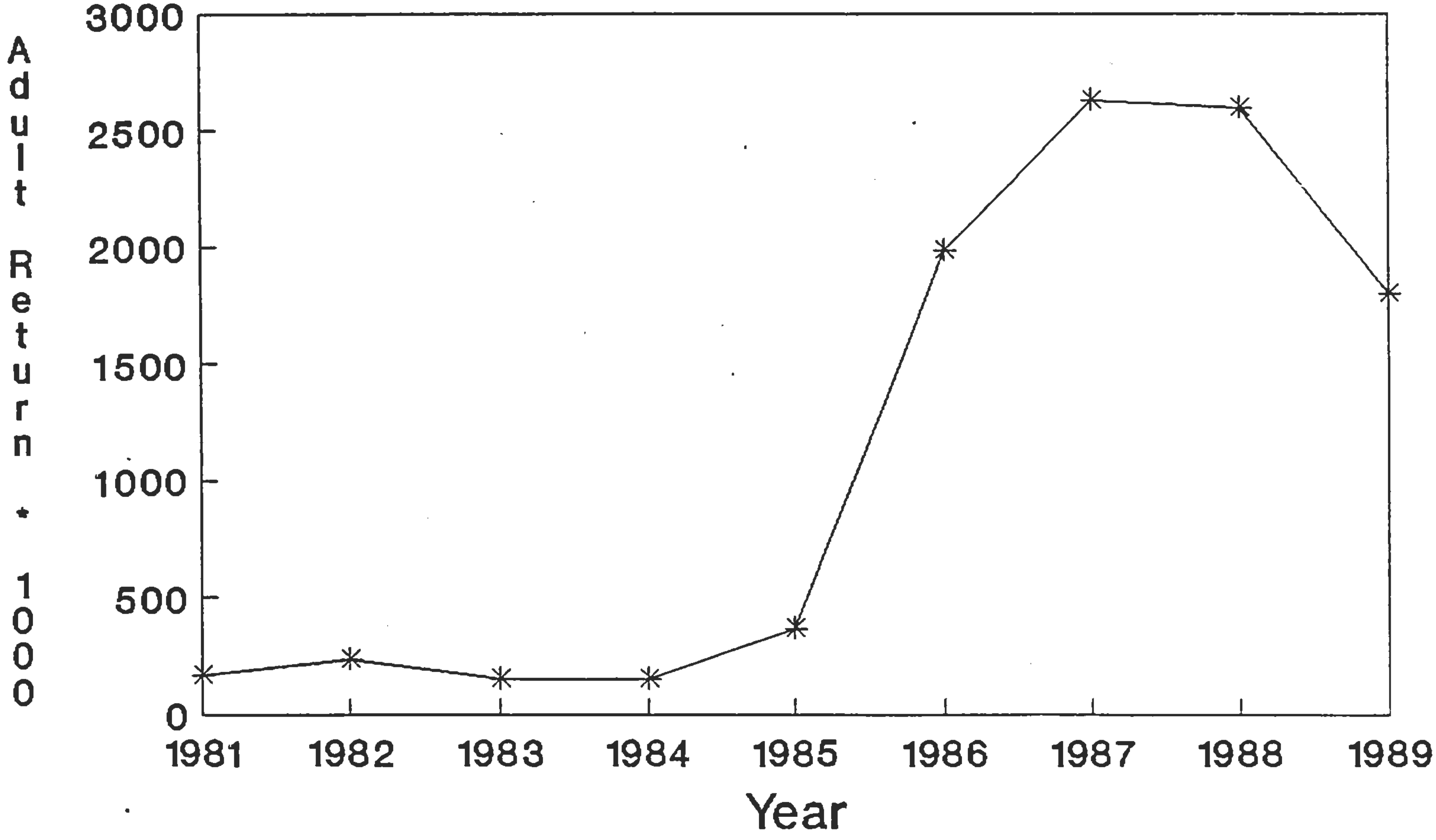
Data from Jessop (1986)

Fig. A3-Alewife Population
Growth Androscoggin R., 1982-1989



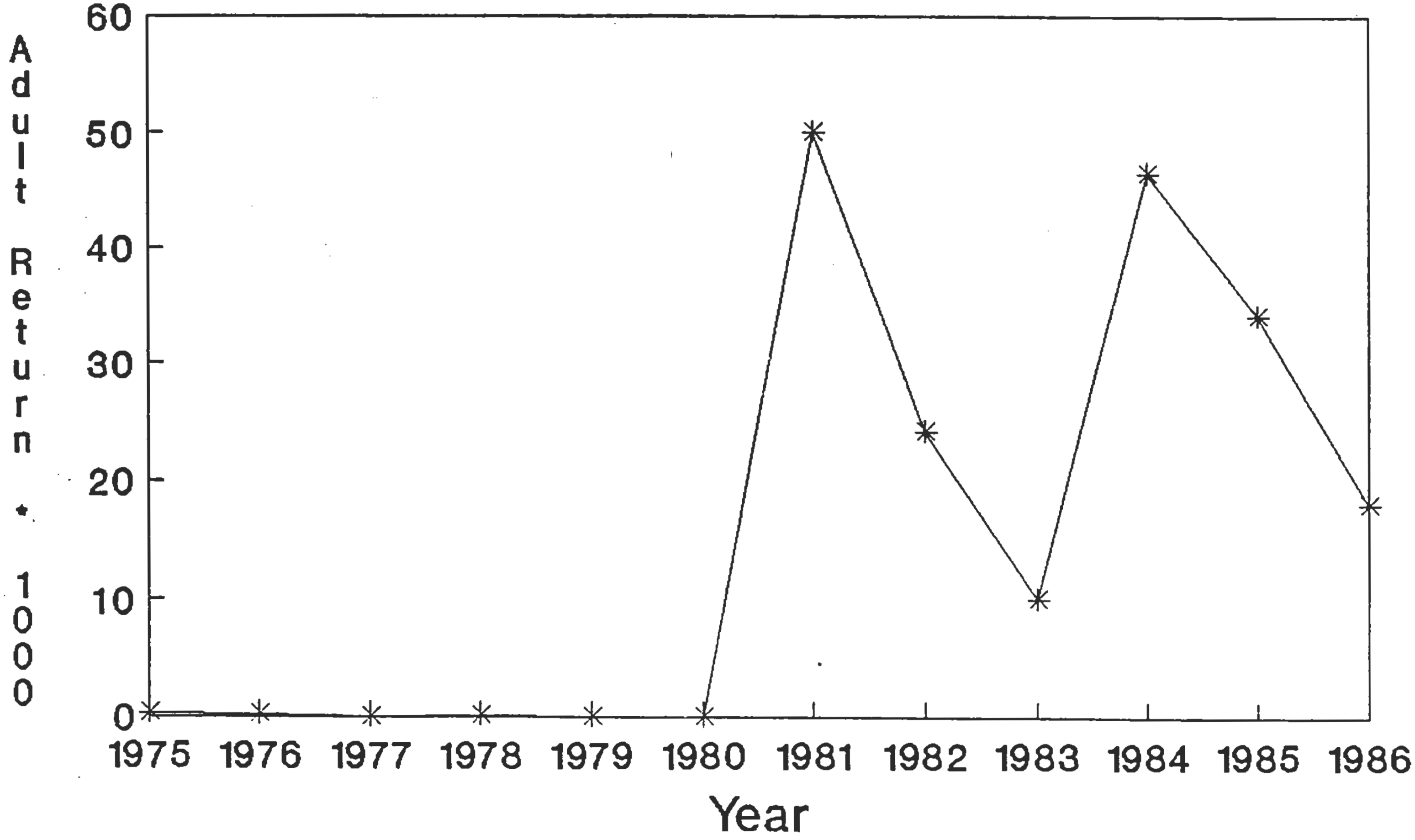
Data from ME Dept. Mar. Res.

Fig.A4-Alewife Population
Growth St. Croix River, 1981-1989



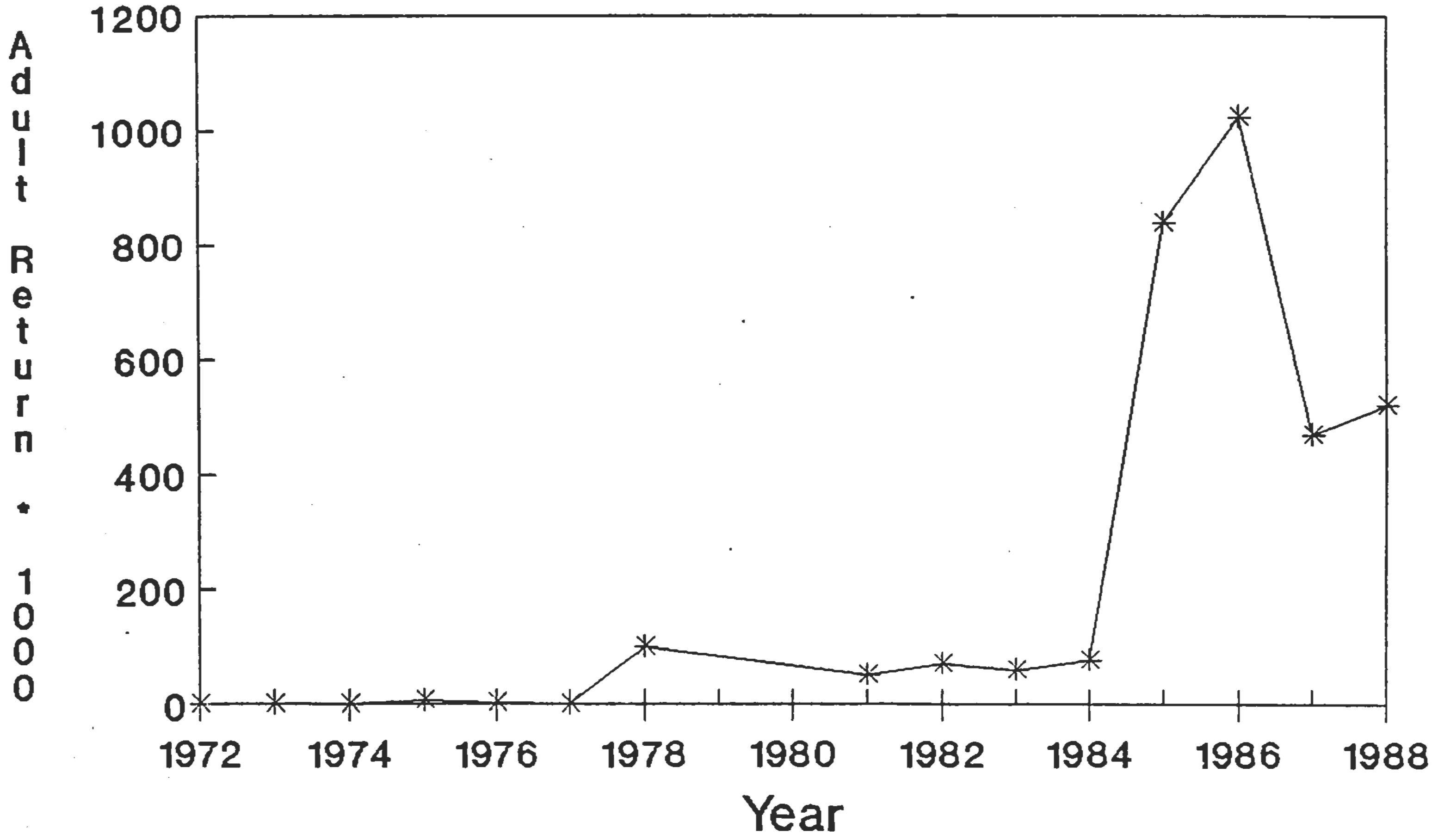
Data from Canada DFO, Halifax

Fig.A5-Alewife Population
Growth Royal River, ME 1975-1986



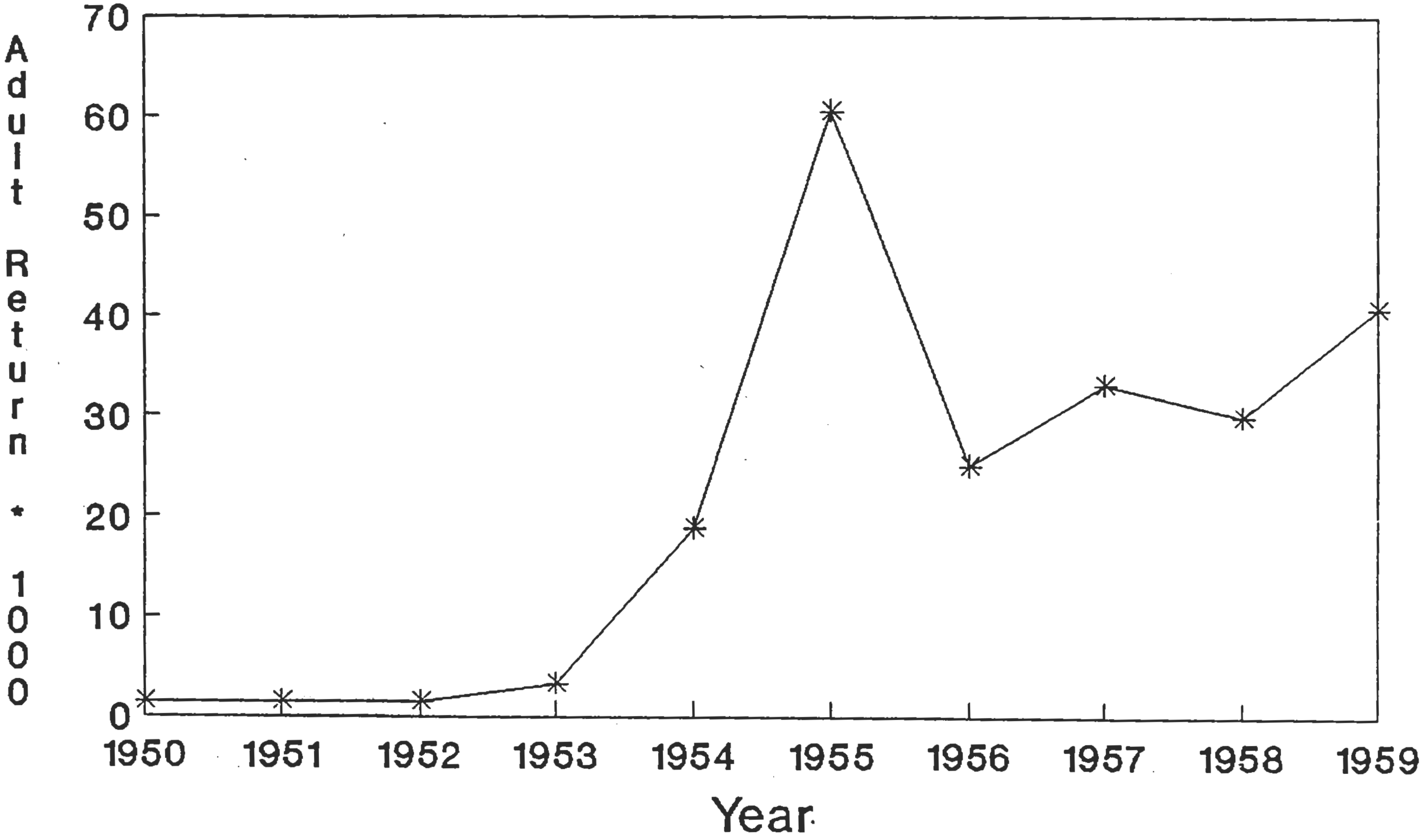
Data from ME Dept. Mar. Res.

Fig.A6-Alewife Population
Growth Union River ME, 1972-1988



Data from ME Dept. Mar. Res.

Fig.A7-Alewife Population
Growth Long Pond, ME 1950-1959



Data from Havey (1961)

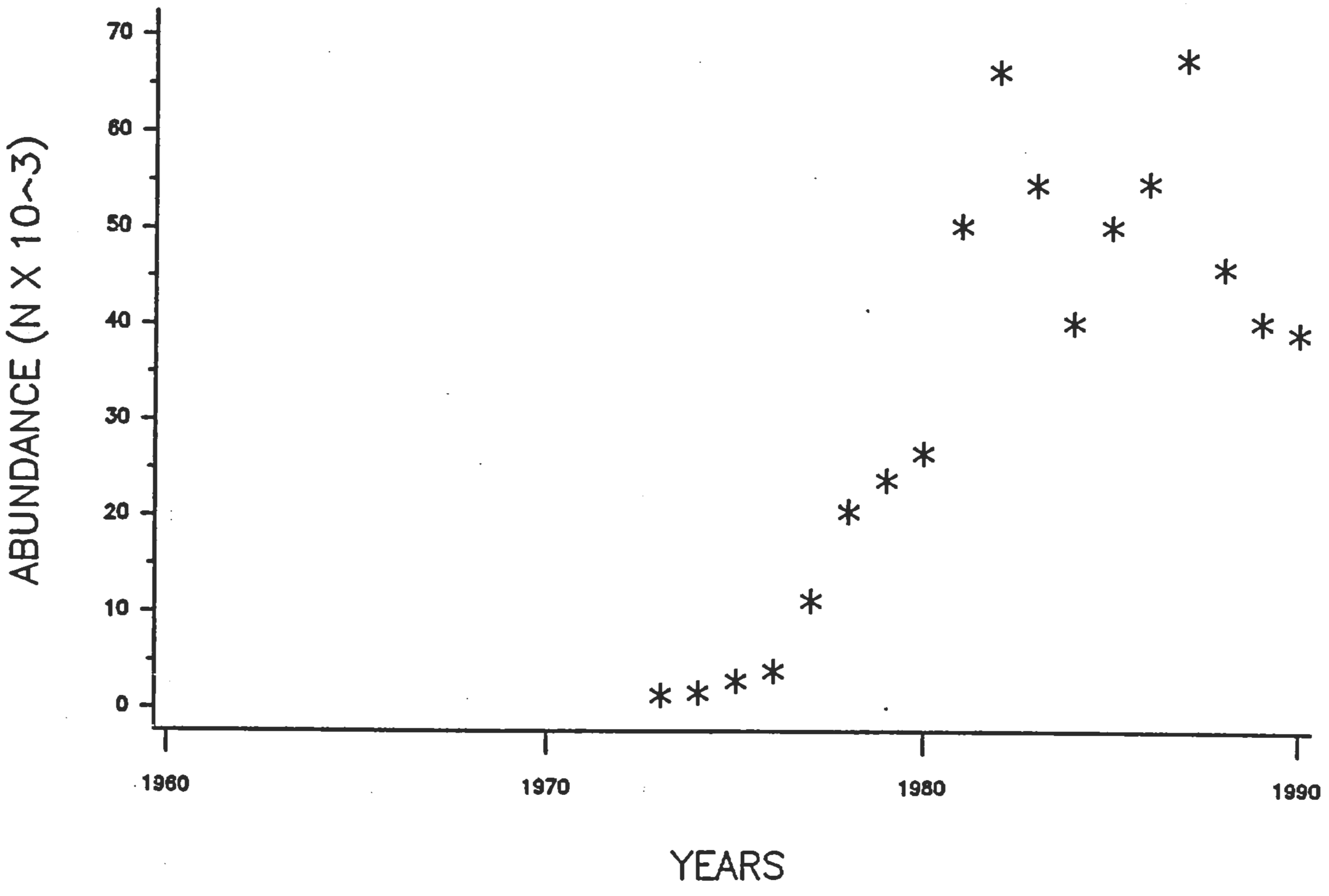


FIGURE A8 ABUNDANCE OF ADULT ALEWIFE PASSED AT THE LAMPREY RIVER FISHLIFT FROM 1973 TO 1990.

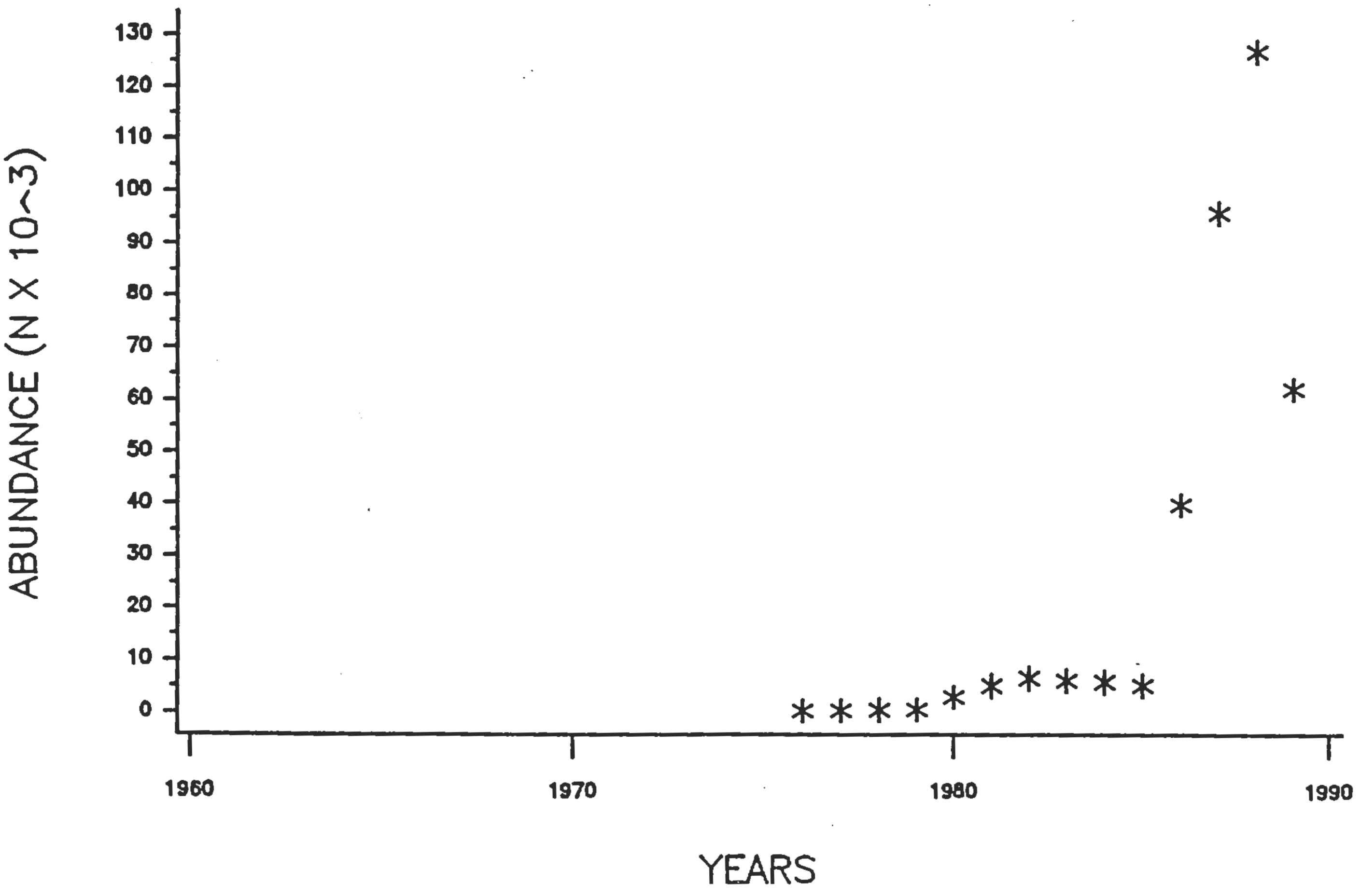
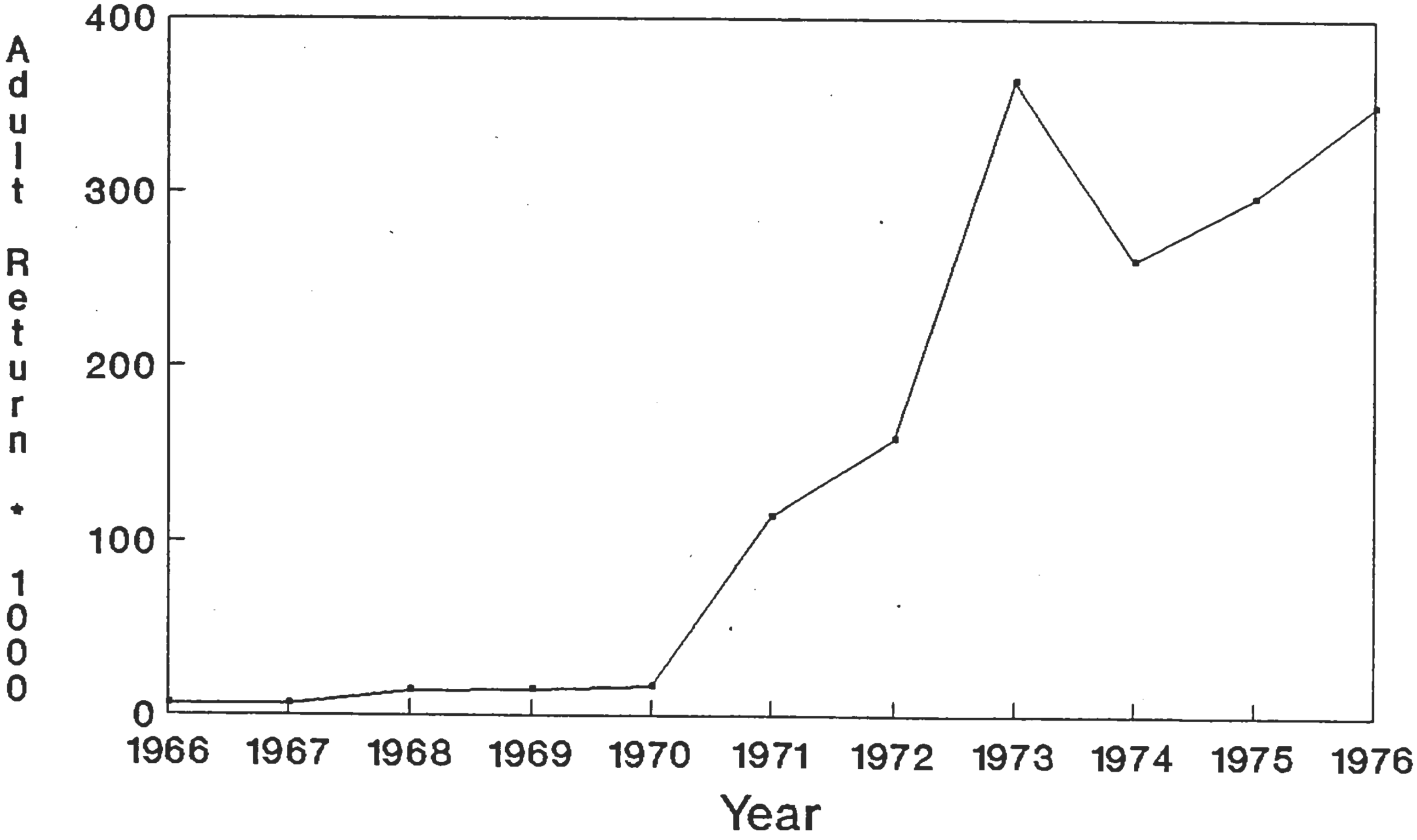


FIGURE A9 ABUNDANCE OF ADULT ALEWIFE PASSED AT THE OYSTER RIVER FISHLIFT FROM 1976 TO 1989.

Fig.A10-Alewife Population
Growth Annaquatucket R., RI 1966-197



Data from RI Div. Fish and Wild.

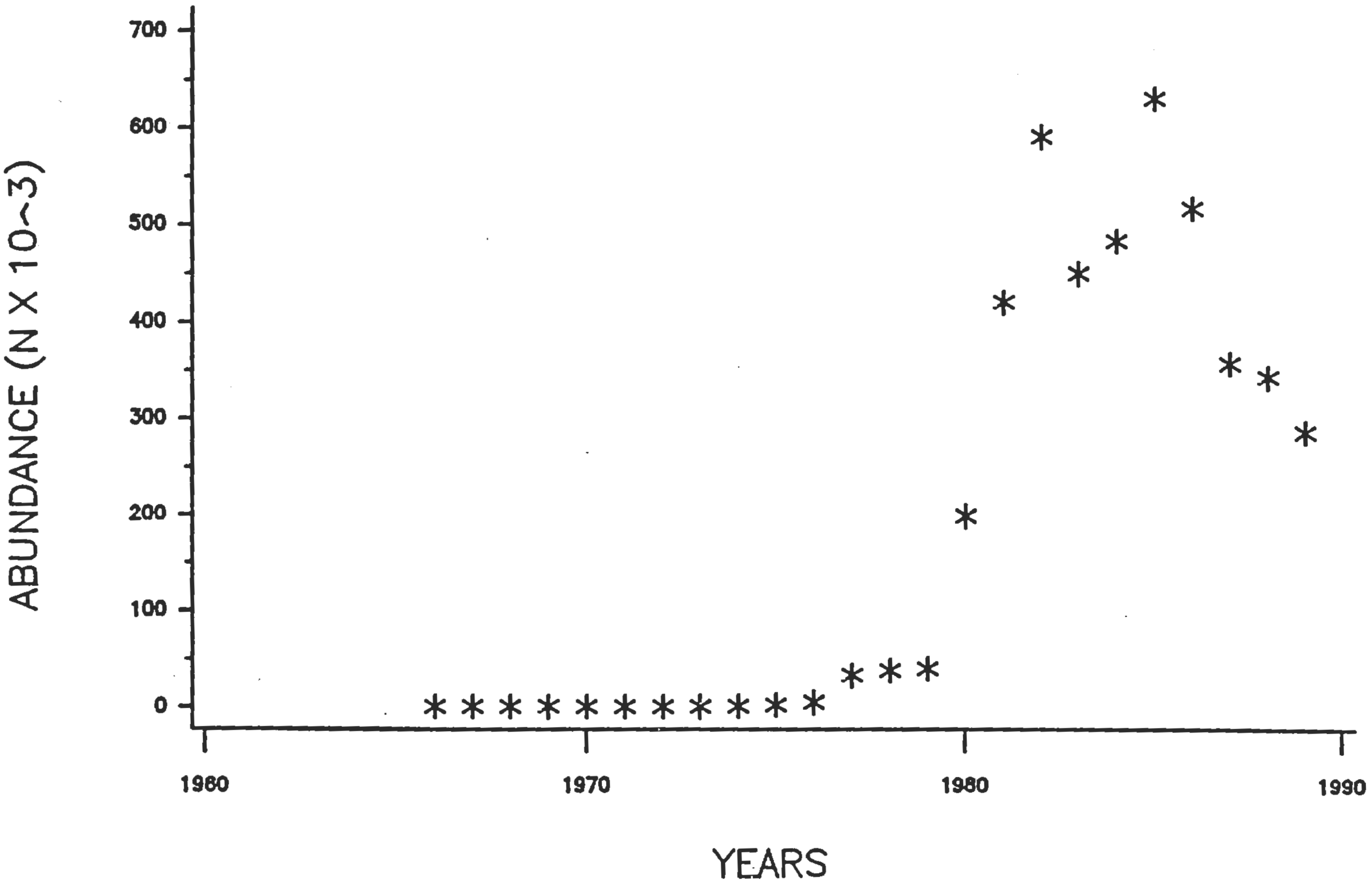


FIGURE A11 ABUNDANCE OF ADULT BLUEBACK HERRING TRANSPORTED OVER THE HOLYOKE DAM FROM 1966–89.

Appendix 2

Estimate of instantaneous total (Z), fishing (F) and rate of exploitation (u) of blueback herring in the Connecticut River, CT based on catch curve analysis. The age frequency data were from Marcy (1969). A natural mortality rate (M) of 1.0 was assumed.

Years	Age Groups	Z	SE_Z	F	u^1
1968	5-8	1.30	0.14	0.30	0.26

1/ u = 1-exp(-F)

Appendix 2

Estimates of instantaneous total (Z), fishing (F) mortality and rate of exploitation (u) for several Atlantic coast river herring populations based on the fractional harvest method. A natural mortality of 1.0 was used.

River and Species	Years	u[1]	SEu	F[2]	Z[3]
St. John, NB Alewife	1975-82	0.755	0.057	1.406	2.406
St. John, NB Blueback	1975-82	0.717	0.058	1.262	2.262
Damariscotta, MD Alewife	1971-87	0.891	0.024	2.220	3.220
Herring R., MA Alewife/Blueback	1980-87	0.441	0.107	0.582	1.582

1/ u = Harvest/(Escapement + Harvest)

2/ $F = -\ln(1-u)$

3/ $Z = F + M$

Appendix 2

Estimates of instantaneous total (Z), fishing (F) mortality and rate of exploitation of alewife in Gilbert Stuart Brook, RI based on catch-curve analysis. The age frequency and population size data are from Mark Gibson (pers comm). A natural mortality rate (M) of 1.0 was used.

Yearclass	Ages	Z	SE^Z	F	$u^{1/}$
1975	5-8	1.139	0.248	0.139	0.130
1976	5-8	1.268	0.184	0.268	0.235
1977	5-8	1.945	0.051	0.945	0.611
1978	5-8	2.129	0.075	1.129	0.677
1979	5-8	1.472	0.529	0.472	0.376
1980	5-8	0.903	0.442	0.000	0.000
1981	5-8	0.948	0.167	0.000	0.000
Pooled	5-8	1.183	0.086	0.183	0.167

1/ u = 1-exp(-F)

Table Estimates of instananeous total (Z), fishing (F) and rate of exploitation (u) of alewife in the Lamprey River, NH based on catch curve analysis. The age frequency data were from Bob Fawcett (pers. comm.). A natural mortality rate (M) of 1.0 was assumed.

Years	Age groups	Z	SE_Z	F	u[1/]
1976-1978	5-8	1.26	0.12	0.26	0.23
1983-1986	5-8	1.48	0.19	0.48	0.38

[1/] u=1-exp(-F)

Appendix 2

Estimates of instantaneous total (Z), fishing (F) mortality and exploitation (u) rates for bluebacks and alewife in the Chowan River, NC based on catch curve analysis of age frequency data (Street and Davis 1976; Street et al. 1975; Johnson et al. 1978; Winslow et al. 1985, 1987.) A natural mortality (M) of 1.0 was assumed for both.

Years	Age groups	Z	SE_z[1]	F	u[2]
Blueback					
1972-1974	5-8	1.63	0.13	0.63	0.47
1977-1981	5-8	1.71	0.18	0.71	0.51
1983-1987	5-8	2.13	0.10	1.13	0.68
Alewife					
1972-1974	5-8	1.25	0.17	0.25	0.22
1977-1981	5-8	1.78	0.21	0.78	0.54
1983-1987	5-8	2.16	0.16	1.16	0.69

[1] SE_z is the standard error about the total mortality (z) estimate.

[2] $u=1-\exp(-F)$

Appendix 2

Estimates of instantaneous total (Z), fishing (F) mortality and the rate of exploitation (u) for bluebacks and alewife in the Potomac River based on catch curve analysis. The age frequencies are from Loesch and Kriete (1980). A natural mortality rate (M) of 1.0 was assumed.

Year-class	Ages	Z	F	u[1]
		Alewife		
1965	5-8	0.90	-	-
1966	5-7	1.15	0.15	0.14
1967	5-7	1.25	0.25	0.22
1968	5-7	1.62	0.62	0.46
1969	5-6	2.71	1.71	0.82
1970	6-7	2.90	1.90	0.85
1971	6-7	1.50	0.50	0.39
1972	6-7	1.41	0.41	0.34
1973		no estimate possible		
1974	5-6	2.63	1.63	0.80
	mean	1.79	0.90	0.59
	SE	0.24	0.22	0.14
		Blueback		
1965	5-8	0.86	-	-
1966	5-8	1.50	0.50	0.39
1967	5-8	1.78	0.78	0.54
1968	5-8	1.83	0.83	0.56
1969	5-6	2.41	1.41	0.76
1970	6-7	2.17	1.17	0.69
1971	6-8	2.41	1.41	0.76
1972	6-7	3.97	2.97	0.95
1973	6-7	1.65	0.65	0.48
1974	5-6	1.15	0.15	0.14
	mean	1.97	1.10	0.67
	SE	0.26	0.24	0.15

[1] $u=1-\exp(-F)$

Table Estimates of instantaneous total (Z), fishing mortality (F) and exploitation rates (u) based on catch curve analysis on blueback herring and alewife in the Rappahannock River, Virginia. Data are from Loesch et al. (1986). A natural mortality rate of 1.0 was assumed.

Species	Year-class	Z	F	u
Alewife				
	1969	2.06	1.06	0.65
	1970	1.38	0.38	0.32
	1971	1.21	0.21	0.19
	1972	1.65	0.65	0.48
	1973	-[1/]	-	-
	1974	1.32	0.32	0.27
	1975	1.20	0.20	0.18
	1976	1.58	0.58	0.44
	1977	1.42	0.42	0.34
	1978	1.40	0.40	0.33
	Mean	1.47	0.47	0.37
	SE	0.08	0.08	0.06
Blueback				
	1969	2.22	1.22	0.70
	1970	1.72	0.72	0.51
	1971	1.90	0.90	0.59
	1972	1.74	0.74	0.52
	1973	1.47	0.47	0.37
	1974	1.11	0.11	0.10
	1975	1.65	0.65	0.48
	1976	1.31	0.31	0.27
	1977	1.72	0.72	0.51
	Mean	1.65	0.65	0.48
	SE	0.102	0.10	0.07

[1/] Estimate of Z for the 1973 year-class was considered an outlier.

Appendix 2

Estimates of instantaneous total (Z), fishing mortality (F) and exploitation rates (u) based on the 1989-90 catch curve analysis on blueback herring and alewife in the Nanticoke River, Maryland. Data are from Dale Weinrich, Maryland DNR. A natural mortality rate of 1.0 was assumed.

Species	Year	Age Groups	Z	F	u
Alewife	1989	6 - 8	1.76	0.76	0.53
	1990	6 - 9	1.57	0.57	0.43
	Average		1.67	0.67	0.49
Blueback	1989	6 - 8	1.29	0.29	0.25
	1990	6 -10	1.25	0.25	0.22
	Average		1.27	0.27	0.24