2A94-37

FORECAST OF THE KAMISHAK HERRING STOCK IN 1995

by

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Regional Information Report[1] No. 2A94-37

Alaska Department of Fish and Game
Division of Commercial Fisheries Management and Development
333 Raspberry Road
Anchorage, Alaska 99518-1599

December 1994

[1] Contribution 94-37 from the Lower Cook Inlet area office. The Regional Information Report Series was established in 1987 to provide an information access system for all unpublished divisional reports. These reports frequently serve diverse ad hoc informational purposes or archive basic uninterpreted data. To accommodate timely reporting of recently collected information, reports in this series may contain preliminary data; this information may be subsequently finalized and published in the formal literature. Consequently, these reports should not be cited without prior approval of the author or the Division of Commercial Fisheries Management and Development.

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ACKNOWLEDGMENTS

Stephen Fried, Regional Research Biologist, and Wesley Bucher, LCI Area Management Biologist, reviewed the manuscript and provided many valuable comments. Wesley Bucher and Lee Hammarstrom, LCI Assistant Area Management Biologist, flew aerial surveys in 1994. Fritz Funk, statewide herring biometrician, developed the ASA model as a spreadsheet application.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The 1995 abundance of Pacific Herring *Clupea pallasi* in the Kamishak Bay District of Lower Cook Inlet, Alaska, was forecasted from an age-structured-analysis model. This model estimates values of survival, maturity, gear selectivity, and initial population abundance that minimize differences between predicted and observed run and catch age composition and run biomass estimates. Estimated parameters were used to project the 1995 abundances. A 10 year running average was used to predict 1995 weight at age.

A biomass of 21,989 tons (19,948 tonnes) of herring is expected to return to the Kamishak Bay District in 1995. Herring mean weight is predicted to be 202 g. The 1988 year class is forecast to represent 62% of the run biomass (57% of the population in numbers) as age-7 herring. The forecast model, however, exhibited large residuals when fitting the 1988 year class data: -12% at age-3, +24% at age-4, and -17% at age-6. This difficultly in predicting the 1988 year class coupled with no aerial survey observations to verify 1994 spawning biomass suggest a low confidence in the 1995 forecast. There are almost no age-4 herring in the 1995 forecast as virtually no age-3 were seen in the 1994 commercial catch samples. Total allowable harvest is projected to be 3,300 tons (3,000 tonnes) based on an exploitation rate of 15% of the forecast. Harvest allocation is 2,970 tons (2,700 tonnes) for the Kamishak spring sac roe fishery and 330 tons (300 tonnes) for the Shelikof Strait fall food and bait fishery.

KEY WORDS: *Clupea pallasi*, herring, forecast, Lower Cook Inlet.

INTRODUCTION

This report presents the forecast for the 1995 Kamishak Bay herring run biomass. This herring stock supports a spring sac roe fishery in the Kamishak Bay District (Lower Cook Inlet Management Area) and a fall food and bait fishery in Shelikof Strait (Kodiak Management Area; Figure 1). Run biomass was defined as the segment of the herring population participating in the spring spawning migration and observed by aerial surveyors in the Kamishak Bay District between mid-April and June. Observed herring are considered recruited into the fishery and available to the sac roe fishing fleet even though harvest limits are typically achieved by mid-May.

Stock assessment information such as age composition, mean weight-at-age, and aerial survey estimates of run biomass have been collected for the Kamishak Bay herring population since 1972. Aerial survey estimates of biomass begin in early April when the nearshore area of Kamishak Bay District is surveyed daily from small aircraft to monitor relative biomass, distribution, and spawning of the herring population. Daily biomass estimates are derived from the number and size of herring schools observed. Run biomass estimates for each year is either (1) sum of "peak" estimates from this time series of biomass observations if the aerial surveyor believes residence time of herring in the surveyed area is more than one day or (2) sum of all surveys if residence time is only one day. Because immigration to and emigration from the herring spawning grounds is likely a continuous process, aerial surveys tend to be conservative estimates of biomass.

Stock assessment activities, however, were hampered in 1994 by bad weather and turbidity for the fourth consecutive year of 'poor' aerial survey coverage when aerial surveyors were grounded for 11 consecutive days between 15 and 26 May (Table 1). Consequently, run estimates are derived from either run timing proportions (Yuen 1994) or the preseason forecast. The exponential decay models in use until 1993, depended on the prior year escapement estimate, i.e., the difference between the total run and harvest biomass. Unfortunately, escapement estimates derived from the preseason forecast are not appropriate as input data for exponential decay models and run biomass estimates based on run timing proportions appear reasonable in only half of the trials. Thus, age-structured analysis (ASA) was adopted as the forecast method for Kamishak Bay herring because its forecast is based on the estimated initial cohort size of age-3 herring.

Both old and new forecast methods work by minimizing differences between predicted and observed age composition as well as total run biomass. ASA seeks a simultaneous solution while the exponential decay model progressed in a step wise manner. In the case of run biomass, the predicted run biomass was scaled by ASA only to the observed aerial survey estimates of run biomass from years with "good" survey coverage. While this approach removes much bias in abundance estimates by excluding aerial survey biomass estimates made during years having poor weather or inadequate geographic and temporal coverage, it only partially corrects the tendency for aerial surveys to be conservative. ASA estimates will still tend to underestimate true herring abundance since residence time of herring on the spawning grounds is not known and not all herring are observed, even during years with good survey conditions.

Specific objectives of this report are (1) to document data sources and methodology used for the 1995 forecast, (2) present the 1995 forecast, and through application of the Kamishak Bay Herring Management Plan (5 AAC 27.465), (3) propose a harvest guideline for the 1995 commercial fishing season.

METHODS

Database

Kamishak herring harvest abundance by age, harvest and run age composition and mean weights were obtained from the most recent catch sampling report (Yuen and Bucher *in press*, Appendix A-C). Aerial survey estimates of run biomass were obtained from the most recent annual management report (Bucher and Hammarstrom 1993) with the sole exception of 1989 where 27,855 tons was used instead of 35,701 tons (Yuen et al. 1990, Appendix D). During herring aerial surveys, observers estimate the surface area of herring schools arriving on the spawning grounds. Since 1989 surface areas have been converted to biomass estimates based on results of calibration samples from Togiak Bay in which entire herring schools were captured by purse seines after observers had estimated their surface area (Lebida and Whitmore 1985). Prior to 1989 the conversion of herring school surface area to biomass is undocumented.

Age-Structured-Analysis

In our conceptual model of the annual cycle of events affecting the Kamishak Bay herring stock (Figure 2), we increment ages at the end of winter, coinciding with the approximate time of annulus formation. The population model begins accounting for herring at age 3, when Kamishak Bay herring first appear in the purse seine catch of sac roe herring. Although, age-1 and 2 herring have been captured with a trawl on the spawning grounds during the month of April, they are not considered recruited into the fishery as they rarely appear in the commercial harvest. Prior to spring, the conceptual model splits the "total" herring population into two components: an "immature" portion that will not return to spawn, and a "run" biomass that will return to inshore areas to spawn. Removals by the purse seine sac roe fishery are then deducted which leaves the "escapement" biomass that actually spawns. In this model configuration, we do not account for removals by the Shelikof Strait fall food and bait fishery, but these harvests are reflected in the survival rate estimate. The removals in the food and bait fishery could be explicitly made when catch by age becomes available. However, because selectivity in Shelikof Strait may be highly variable and these harvests occur on mixed stocks, catch information from that fishery may not provide useful "tuning" information for Kamishak ASA models.

The Kamishak Bay ASA model incorporates auxiliary information, similar to models developed by Deriso et al. (1985). Nonlinear least squares techniques are used to minimize a sum of squares constructed from heterogeneous types of auxiliary information which may incorporate many different sources of data. The ASA was developed in an Excel spreadsheet with a vendor (Microsoft[1]) supplied nonlinear optimization function named SOLVER.

ASA models which incorporate heterogenous data have been reviewed by Hilborn and Walters (1992) and Megrey (1989). Whereas our primary goal was to generate a one-year-ahead forecast of herring abundance for 1995, the model also updated estimates of historical abundances for 1979-1994, provided estimates of natural mortality, maturity, and estimated gear selectivity for the purse seine fishery. Information supplied to the ASA model included estimates of the commercial harvest abundance by age (Appendix A), run biomass (Appendix D), age composition of the run biomass (Appendix B) and harvest (calculated from Appendix A), and weight-at-age (Appendix C). Initial parameter values for survival, gear selectivity curve, maturity curve, and the number of age-3 herring for each cohort were the final values from the 1994 forecast.

Survival

Our ASA model used a difference equation to describe the number of herring (N) in a cohort aged a in year y:

$$\hat{N}_{a+1,y+1} = S\ (N_{a,y}-C_{a,y}) \qquad (1)$$

where S is the annual survival rate, constrained at 0.67 which is an instantaneous mortality rate of 0.4, and $C_{a,y}$ is the catch from the spring purse seine sac roe fishery. The annual survival rate of 67% is the same value used to prepare the 1994 forecast. The number of herring in a cohort (N) includes both mature and immature herring present after annulus formation but before the spawning migration or spring roe fisheries occur (the "total population of all ages" in Figure 2). The model starts accounting for herring at age 3 and ends at age 16.

[1]Vendor names are provided to document methods but do not constitute an endorsement by ADF&G

Estimated Catch Age Composition

Gear Selectivity. An estimated age composition of the purse seine catch for each year ($\hat{p}_{a,y}$) was computed from a model which incorporated an age-specific gear selectivity function s_a and the estimated abundance $N_{a,y}$ from equation (1):

$$\hat{p}_{a,y} = \frac{s_a \hat{N}_{a,y}}{\sum_{a=3}^{16} [s_a \hat{N}_{a,y}]} . \tag{2}$$

For our model, selectivity was defined as the proportion of the total population susceptible to capture by the fishing gear and includes the effect of immature herring not being present on the fishing grounds (partial recruitment or maturity), as well as active selection or avoidance of certain size classes of herring by the gear or fisher. Functions chosen to describe the relationship between gear selectivity and age were limited to two parameters because (1) it was desirable to minimize the number of parameters estimated by the model and (2) two parameters were the fewest that could adequately describe the age-selectivity relationship. The choice of a particular functional form represented an assumption which limited the possible range of selectivities. Purse seine gear was assumed to have an asymptotic selectivity and was represented by a logistic function:

$$s_a = \frac{1}{1 + e^{\beta(a-\alpha)}} , \tag{3}$$

where α is the age at which selectivity is equal to 50%, and β is a steepness parameter. Initial values for parameters were chosen to give selectivities similar to those reported by Funk and Sandone (1990) for Prince William Sound.

SSQ Catch Age Composition. One measure of how well the ASA model fit actual data was obtained by comparing model age composition estimates for the commercial catch with actual estimates based on catch samples. The sum of squares, SSQ, measuring the goodness of fit of the age composition of the catch was computed as:

$$SSQ_{agecomp:catch} = \sum_{y} \sum_{a} \left(\frac{C_{a,y}}{\sum_{a=3}^{16} C_{a,y}} - \hat{p}_{a,y} \right)^2 , \tag{4}$$

where $(\hat{p}_{a,y})$ was the estimated age composition of the catch from equation (2). A transformation, $\sin^{-1}$(square root), was applied to observed and estimated age composition proportions to stabilize the variance. Purse seine age composition was fit across all age groups (age 3 to 16) and years 1985 through 1994.

Maturity

Maturity was estimated for each age by the ASA model to estimate the proportion of the population which returned to spawn each year. The maturity function was applied when comparing abundances determined from equation (1) with aerial survey biomass estimates and run biomass age compositions. Because maturity is expected to be an asymptotic function, a logistic expression was used:

$$\rho_a = \frac{1}{1 + e^{\phi (a-\tau)}} , \tag{5}$$

where τ is the age at which 50% of a cohort reach maturity, and ϕ is a steepness parameter. The maturity-age relationship was assumed to be constant over the range of years examined by the model. Initial values supplied for maturity parameters set a 50% maturity at age 4 increasing to 100% maturity at age 7. Maturity based on ADF&G run age composition sampling is likely older than biological maturity because sampling tends to be curtailed at the end of the fishery which is before the late spawning run of younger fish.

SSQ Biomass Estimates

Aerial survey data from 1985-1994 were rated based on coverage which included survey frequency, survey spatial and temporal coverage, and weather conditions (Table 1). Aerial surveys rated 'OK' (1987-1990) were considered for use in the ASA model plus one of the surveys rated '?' (1986). One measure of how well the ASA model fit actual data was obtained by comparing model run biomass estimates with actual estimates based on aerial surveys. The sum of squares measuring the goodness of fit of the run biomass was based on the differences between ASA and aerial survey estimates of run biomass:

$$SSQ_{biomass} = \sum_{y=1986}^{1990} \{ \log_e (B_y^{survey}) - \log_e [\sum_{a=3}^{16} \rho_a w_{a,y} \hat{N}_{a,y}] \}^2 , \tag{6}$$

where B_y^{survey} is the aerial survey biomass estimate in year y, $w_{a,y}$ is the weight at age a in year y (Appendix C), ρ_a is the proportion mature at age a (equation 5) , and $N_{a,y}$ is the ASA estimate of total abundance at age a in year y (equation 1). Though there were too few abundance estimates to evaluate the appropriateness of the log transformation in equation (6), ASA models have been fit with and without the log transformation, with the results not being sensitive to this assumption (Funk et al. 1992). We chose to use a log transformation in our model because a lognormal error structure is commonly found when dealing with abundance data.

SSQ Run Age Composition

In addition to the time series of the catch by age, a time series of age composition estimates of the run biomass are available for 1987-1991 (Appendix B). The age composition of the run biomass was estimated using herring sampled from commercial fishery harvests as well as from areas where large concentrations of herring were sighted during aerial surveys or with vessel sonar. During fishery closures, commercial vessels volunteered to make multiple purse seine sets to capture herring (hereafter referred to as test fishing). Samples were pooled whenever possible, in order to obtain sample sizes large enough to represent the estimated biomass within area and time strata. For commercial harvests, samples were collected from tenders and fishing boats at the close of each fishing period. Both test fishing and commercial harvest samples were used to obtain data on herring age and size.

A measure of how well the ASA model fit actual data was obtained by comparing model run biomass age composition estimates with actual estimates based on samples. The sum of squares measuring the goodness of fit of the age composition of the run biomass was computed as:

$$SSQ_{agecomp:run} = \sum_y \sum_a [p_{a,y}^{run} - \frac{\rho_a \hat{N}_{a,y}}{\sum_{a=3}^{16} (\rho_a \hat{N}_{a,y})}]^2 , \tag{7}$$

where $p^{run}_{a,y}$ is the observed run age composition estimated for age *a* and year *y*. The $\sin^{-1}$(square root) transformation, was applied to observed and estimated age composition proportions to stabilize their variance. Only samples from 1987 through 1991 were used in the SSQ of equation 7. Though catch sampling began in 1985, sampling for age composition before and after the fishery did not begin until 1987.

Forecast Methodology

The forecast of herring run biomass for 1995 ($B^{Forecast}_{1995}$) was based on projecting total abundance with the survival model (equation 1) modified by the ASA estimates of the proportion of mature herring expected for each age:

$$B^{Forecast}_{1995} = \sum_a \rho_a \, \hat{w}_{a,1995} \, \hat{N}_{a,1995} \, , \tag{8}$$

where ρ_a is the proportion mature at age *a* from equation (5); $w_{a,1995}$ is weight at age *a* from the running 10-year average (i.e., 1984-1994; Appendix C) obtained from samples of herring from purse seine catches (Yuen and Bucher *in press*); and $N_{a,1995}$ is the ASA estimate of age-*a* herring for 1995 from equation (1). The above model was used to forecast the abundance of herring of all ages except age-3, since we have no method to predict year class strength as measured by age-3 abundance. We used the median ASA estimate of age-3 abundance, i.e., 1978-1994 year classes, to generate $N_{3,1995}$. The median was thought to be more representative of recruitment in typical years than the mean, since the distribution of year class abundance at age 3 was very skewed.

The age composition ($p_{a,1995}$), of $B^{Forecast}_{1995}$, was estimated using the maturity schedule (ρ_a of equation 5) as :

$$\hat{p}_{a,1995} = \frac{\hat{N}_{a,1995}\rho_a}{\sum_a \hat{N}_{a,1995}\rho_a} \tag{9}$$

Parameter Estimation

Total SSQ. A total sum of squares was computed by adding the adjusted sum of squares for each of the components (equations 4, 6, 7):

$$SSQ_{Total} = SSQ^{adjusted}_{agecomp:catch}\ \lambda_{agecomp:catch} + SSQ^{adjusted}_{biomass}\ \lambda_{biomass} + SSQ^{adjusted}_{agecomp:run}\ \lambda_{agecomp:run}\quad, \tag{10}$$

where the λ's are weights assigned to each sum of squares component. Each sum of squares component was scaled to a similar order of magnitude, so to contribute similarly to the total SSQ when λ's were equal. The method for adjusting the value of SSQ_j (from equations 4, 6, or 7) for the j sources of auxiliary information; (j=1) catch age composition, (j=2) aerial survey run biomass, and (j=3) run age composition was suggested by J. Bromaghim (ADF&G, Anchorage personal communication) as:

$$SSQ_j^{adjusted} = \frac{SSQ_j - Min(SSQ_{j,k}\ across\ all\ k)}{Max(SSQ_{j,k}\ across\ all\ k) - Min(SSQ_{j,k}\ across\ all\ k)}\quad, \tag{11}$$

where $SSQ_{j,k}$ is the estimated sum of squares for data source k when SSQ_{total} (equation 10) is estimated and λ is set equal to zero for all data sources except data source j. The λ's were used to assign ad hoc weights to each SSQ component reflecting our confidence in each component. An inverse variance weighting scheme could not be used, because the variance of the aerial survey abundance estimator was unknown. We felt we could not differentially weight data sources at this time and set λ equal to one for all data sources.

Minimization Methods. The ASA model estimated a total of 25 parameters: 21 initial cohort sizes, two gear selectivity function parameters (α and β), and two maturity function parameters (ϕ and τ). The survival rate parameter (S) was fixed at 0.67. The three SSQ equations referred to 208 data observations with 183 degrees of freedom and a data to parameter ratio of approximately 8. However, not all observations were independent, so the amount of information contained in the data was considerably less than one could obtain from completely independent observations.

The Microsoft Excel[2] spreadsheet solver was used to estimate parameter values which minimized the total weighted sums of squares (equation 10). Parameter values manipulated by the solver were all scaled to a similar order of magnitude, as recommended by the software manufacturer. The solver obtained estimates of the variables in each one-dimensional search using linear extrapolation from a tangent vector (Tangent option), central differencing for estimates of partial derivatives, and a quasi-Newton method for computing the search direction (Microsoft 1992). The precision level was set at 0.00001. Population sizes for all age groups being forecast in 1995 were constrained to be greater than or equal to zero as negative population values were impossible and negative residuals cannot be $\sin^{-1}$ transformed.

Goodness of Fit

The goodness of fit for our ASA model was assessed through evaluation of model residuals. A model's fit was rated as "good" if the residuals were small. The choice of model, i.e. it's functional form, was rated "good" if the residuals were randomly distributed about zero and did not form a pattern when plotted as a function of age, year, year class, or estimated values. For example, to choose a function to describe purse seine selectivity we examined residuals for purse seine age composition displayed against year or age to see if the function resulted in residuals distributed as a horizontal band. Another pattern or trend in residuals might indicate that the functional structure of the data changed through time or by age which would necessitate the use of a time period or age-specific function. Ideally, model residuals should have a normal distribution with zero mean. Essentially, we applied the same principles of goodness of fit used in applied regression analysis and examination of residuals (Draper and Smith 1981).

Projected Harvest

The Kamishak Bay Herring Management Plan (5 AAC 27.465) stipulates both fisheries will be closed if the Kamishak Bay herring run biomass forecast is less than 8,000 tons. If the projected biomass is more than 8,000 tons but less than 20,000 tons, harvest rates will be 9% of the forecast for the spring Kamishak sac roe fishery and 1% for the Shelikof Strait fall food and bait fishery for a total exploitation rate of 10%. If the forecast is more than 20,000 tons but less than 30,000 tons, total exploitation rate increases to 15%. If the forecast is more than 30,000 tons,

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[2] Company names are listed only for archival purposes and do not represent an endorsement of any kind by ADF&G.

total exploitation rate is 20%. The relative allocation between the two fisheries remains the same.

RESULTS

Two ASA models were tested. Both accounted for herring through age 16. The first was a model similar to that used to prepare the 1994 forecast, i.e., maturity was constrained to accept only those parameter values (Table 2) estimating the percent mature at age 6 to be ≥ 0.98. The other model had no constraints on the maturity curve. Accounting through age 16 increased the number of data observations and removing the constraints on maturity reduced $SSQ_{age\ comp:run}$ from 0.1541 to 0.1207 and improved the distribution of run age composition residuals leading us to accept this model for the 1995 forecast (Table 3).

Pooled residuals of the run biomass age composition did not form a horizontal band when displayed as a function of age (Figure 3). While residuals for ages 3-8 were almost evenly distributed, residuals for ages 9-16 were predominately positive. Nevertheless, the age compositions of the run biomass estimated from the ASA model agreed fairly well with that observed (Figure 4).

Residuals of the purse seine catch age composition from the ASA model formed a fairly horizontal band centered close to zero when displayed as a function of age (Figure 3). The variability seems greater for age-4 herring and perhaps more negative residuals for the oldest and youngest ages. No strong trend was seen in residuals plotted by age for each year. The age composition of the purse seine catch estimated from the ASA model agreed well with the observed age composition of catch samples except for the 1988 year class which was poorly estimated in 1991 as age 3, in 1992 as age 4, and 1994 as age 6 (Figure 5). We are disturbed because the 1988 year class is also forecast to contribute 57% of the biomass as age 7 (Figure 6).

Run biomass estimates obtained from the ASA model compared well with the five aerial surveys used as auxiliary data (Figure 3). The poorest fit was through 1986 and the best through 1988.

Forecast

A biomass of 21,998 tons (19,998 tonnes) of herring is expected to return to the Kamishak Bay District in 1995 (Table 3). Herring mean weight is predicted to be 202 g. The 1988 year class is forecast to represent 57% of the run biomass as age-7 herring (Figure 6). There are almost no age-4 herring in the 1995 forecast as virtually no age-3 were present in the 1994 commercial catch samples.

Projected Harvest

Total allowable harvest is projected to be 3,300 tons (3,000 tonnes) based on an exploitation rate of 15% of the forecast. Harvest allocation is 2,970 tons (2,700 tonnes) for the Kamishak spring sac roe fishery and 330 tons (300 tonnes) for the Shelikof Strait fall food and bait fishery (Table 4).

DISCUSSION

The preliminary harvest estimate of 2,104.4 tons (1,909.1 tonnes) was used in the ASA because a final harvest estimate was not available when the forecast was being prepared. The difference between preliminary and final harvest estimate, if any, is not expected to exceed 1% of the preliminary estimate.

In last year's ASA model, we assumed age-6 herring to be the age of full recruitment for the Kamishak stock and therefore constrained age-6 maturity to be greater than or equal to 0.98. This constraint was removed in this year's model which allowed age of full recruitment to be as late as age-8. Historically, Kamishak age of full recruitment has been later than that reported in PWS and Togiak and removal of the constraint did not conflict with observed Kamishak data.

This model also estimates the 1994 biomass at 25,364 tons, almost unchanged from the preseason 1994 forecast of 25,344 tons. If the constraint was left in place, the 1995 forecast would have been only 15,738 tons. It would have also revised the 1994 biomass estimate downward to 19,884 tons. Unfortunately, 1994 aerial surveys were limited by adverse weather and the 1994 preseason forecast can not be verified. Although the 1994 Kamishak catch/unit of effort (CPUE) was less than expected this year, harvest rates may have been affected by spawning migration and maturity delayed by low water temperatures. Post fishery spawning as measured in observed-miles-of-spawn, however, were greater this year than in previous years.

Both the exponential decay (Yuen et al. 1994) and ASA methods required an estimate of initial population size. For the exponential decay model this was the spawning population from the previous year. However, without a successful aerial survey of run biomass in 1994, and therefore without an 1994 escapement estimate, the 1995 forecast would have been an extension of a previous forecast. We would, of course, adjust the 1994 forecast age composition to match the observed 1994 age composition but we could not adjust the magnitude of the 1994 run biomass estimate or update our mortality and recruitment rates in the model. Because 1994 was the fourth year of frustrated aerial surveys, we were essentially making a 5-year forecast from the 1990 escapement data, the last year with a successful aerial survey program.

On the other hand, estimates of initial cohort size for the ASA models were age-3 herring. ASA was designed to use the observed 1994 age composition, along with all other observed age compositions, to adjust the initial abundance estimates of age-3 herring except that estimated for 1995. Because year class abundances would change, survival rates would also change as we tried to minimize the difference between observed and predicted run biomass and age composition. That chain of events would revise the 1995 forecast in a manner that the old method could not easily do. For this and the problem of missing escapement data, we changed our forecast methods.

Kamishak herring abundance and biomass peaked in 1987 with a downturn in 1990 (Figure 7). However, aerial surveys were not able to discern a trend since 1991. The ASA model suggests a smaller peak may have occurred in 1993 and that the 1995 biomass may be on the order of magnitude as the 1990 downturn. The 1995 forecast is for more than half of the abundance to be age-7 with very little age 4-6 recruitment based on the 1994 age composition samples. The forecast of age-3 recruitment was simply a median and not reliable.

An inconsistency was detected after the 1995 forecast was completed and should be resolved before the 1996 forecast is prepared. One of the two aerial surveys rated "?" in Table 1, i.e. 1985 and 1986, was used to estimate $SSQ_{biomass}$ in equation (6). Either 1985 and 1986 be included or 1986 be excluded. The option to include catch age residuals for 1978 and 1979 should also be tested.

We are concerned about the residuals (Figure 3) resulting from the ASA trying to estimate the 1988 year class which is expected to represent 57% of the run biomass (Figure 6). This year class presented unusual difficulties for the model. The model estimated catch age compositions for age 3, 4, and 6 to be 21.2%, 37.9%,, and 64.8% when the observed catch age compositions were 12.0%, 61.4%, and 51.4%. This equates to $\sin^{-1}$(square root) transformed residuals of -12% at age-3, +24% at age-4, and -17% at age-6. This year class is also the first major year class for which we have no aerial survey observations to verify the forecasts. The last aerial survey in the model was conducted in 1990 before this year class was recruited into the spawning biomass. Consequently, we have a low confidence in the 1995 forecast. The management plan compounds the forecast error as it calls for an increase in the harvest rate from 10% to 15% exploitation rate if the run biomass is greater than 20,000 tons.

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Table 1. Rating of aerial surveys for use in Kamishak herring ASA models.

Harvest[a] Year	Months Surveyed	Longest Period Without Aerial Survey (days)	Date(s) of Longest Period Without Data	Coverage
85				?
86				?
87	April May	7	5/17-5/23	OK
88	April May June	4	4/24-27, 5/3-5/6, 5/27-5/30	OK
89	April May	4	5/13-5/16	OK
90	April May June	6	5/23-5/29	OK
91	April May June	20	4/25-5/14	poor
92	April May June	17	5/2-20	poor
93	April May June	12	4/28-5/9	poor
94	April May June	11	5/16-5/25	poor

[a] original aerial survey data forms for 1985 and 1986 were not available.

Table 2. Final parameter estimates for ASA model used to forecast 1995 run biomass.

Parameter	Value	Remarks
S	0.67	constrained to be 0.67, Equation 1
β	1.135	gear selectivity,
α	5.562	Equation 3
ϕ	0.902	maturity,
τ	4.896	Equation 5
initial cohort size by year class (x 1,000 herring)		
78	67.43	age 3
	64.38	age 4
79	116.36	age 3
80	198.55	age 3
81	121.99	age 3
82	138.7	age 3
83	106.35	age 3
84	132.3	age 3
85	26.25	age 3
86	149.08	age 3
87	209.81	age 3
88	41.27	age 3
89	40.59	age 3
90	74.24	age 3
91	370.84	age 3
92	23.98	age 3

Table 3. Forecast of 1995 Kamishak Bay District herring abundance and projected harvest by year class.

	1995 Forecast					1995 Projected Harvest	
Age	Inshore Run Abundance (millions)	Age Composition	Mean Wt (g)	Biomass (short tons	Harvest Rate	Total Allowable Harvest (short tons	Proportion by Weight
3	16.3	0.16	84	1,506	0.15	226	0.07
4	0.0	0.00	126	0	0.15	0	0.00
5	3.5	0.04	161	628	0.15	94	0.03
6	5.0	0.05	195	1,067	0.15	160	0.05
7	56.1	0.57	220	13,607	0.15	2,042	0.62
8	7.2	0.07	241	1,911	0.15	287	0.09
9	2.4	0.02	255	675	0.15	101	0.03
10	1.3	0.01	275	387	0.15	58	0.02
11	4.1	0.04	283	1,289	0.15	193	0.06
12	1.8	0.02	284	556	0.15	83	0.03
13	0.1	0.00	327	40	0.15	6	0.00
14	0.5	0.01	306	179	0.15	27	0.01
15	0.2	0.00	293	77	0.15	12	0.00
16	0.2	0.00	297	69	0.15	10	0.00
Total	98.8		202	21,989		3,300	

Table 4. Allocation of the projected 1995 Kamishak Bay herring harvest.

	Exploitation Rate	Harvest (short tons)
Kamishak Bay Sac Roe Fishery	0.135	2,970
Shelikof Straits Bait Fishery	0.015	330
Total	0.150	3,300

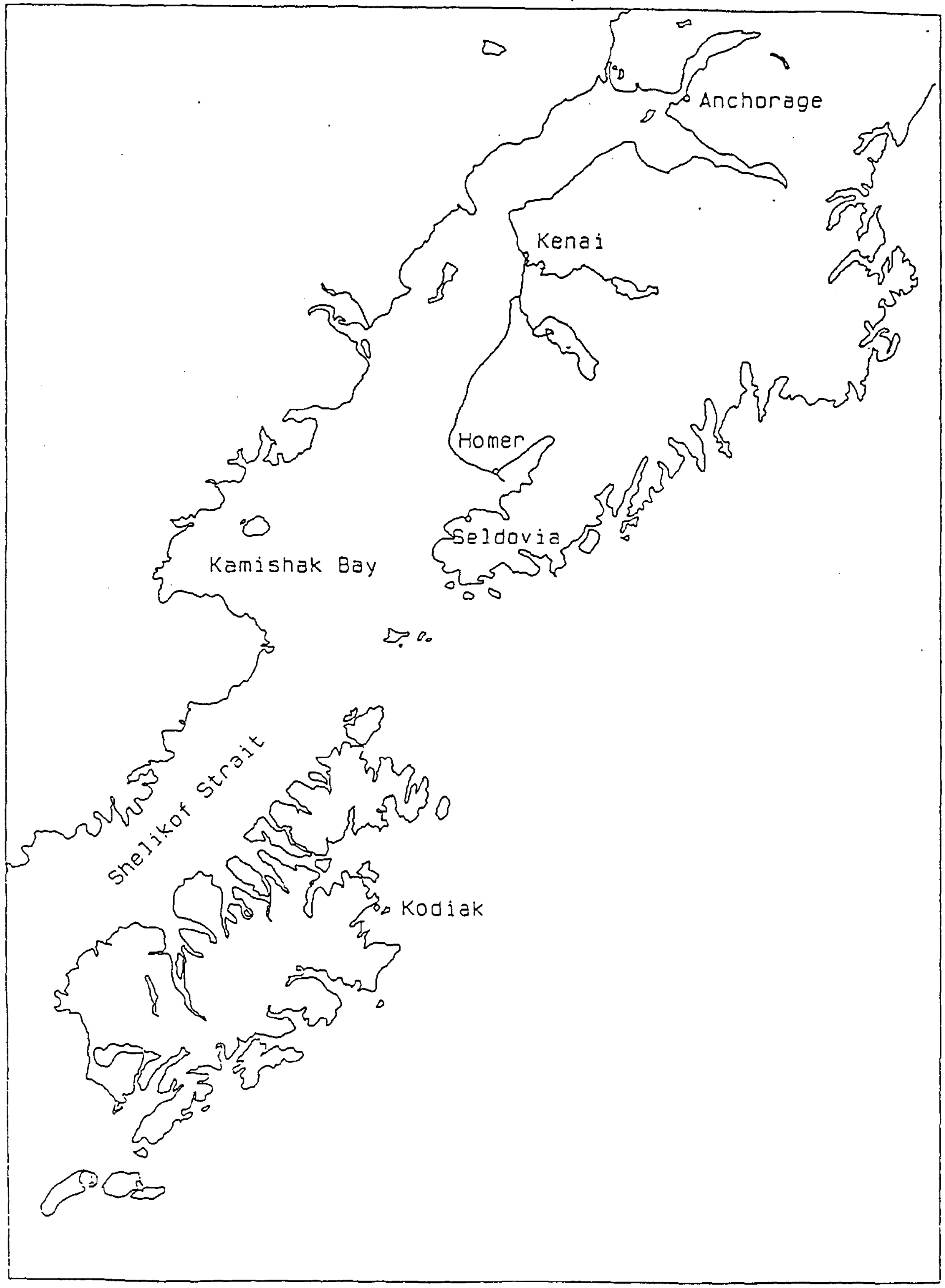


Figure 1. Kamishak Bay and Shelikof Strait, Alaska.

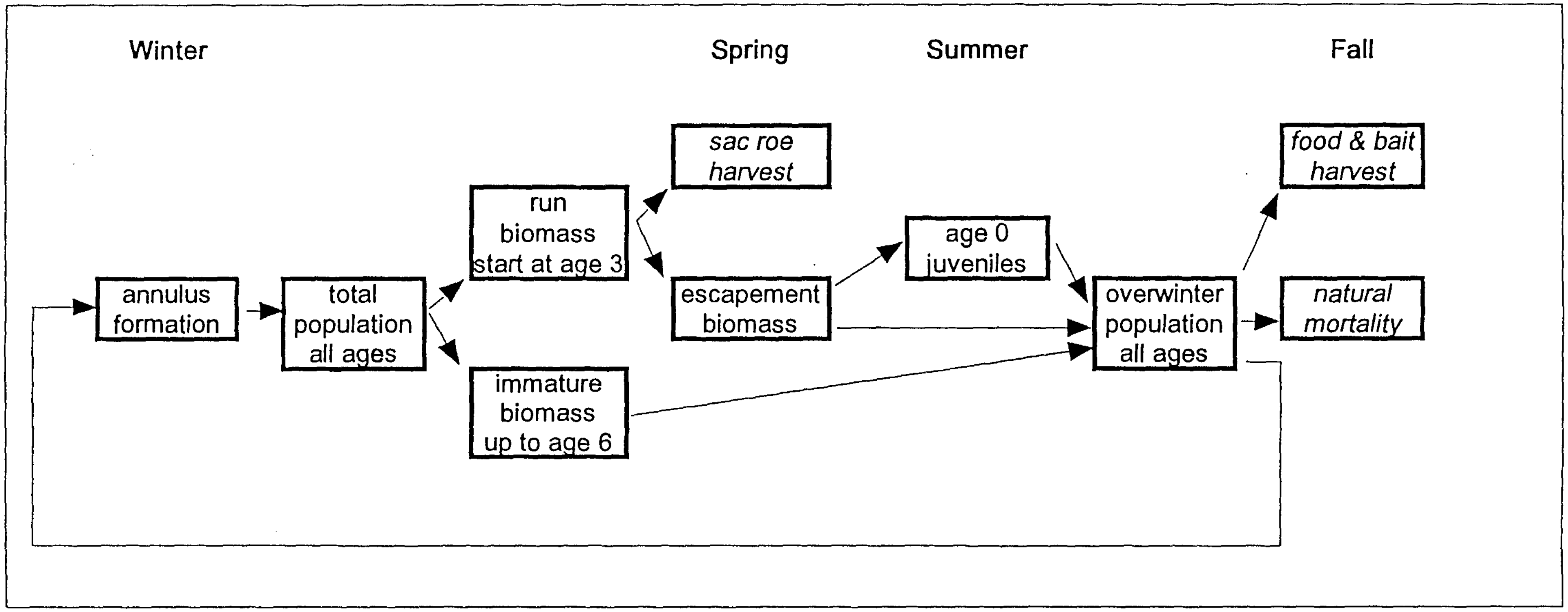
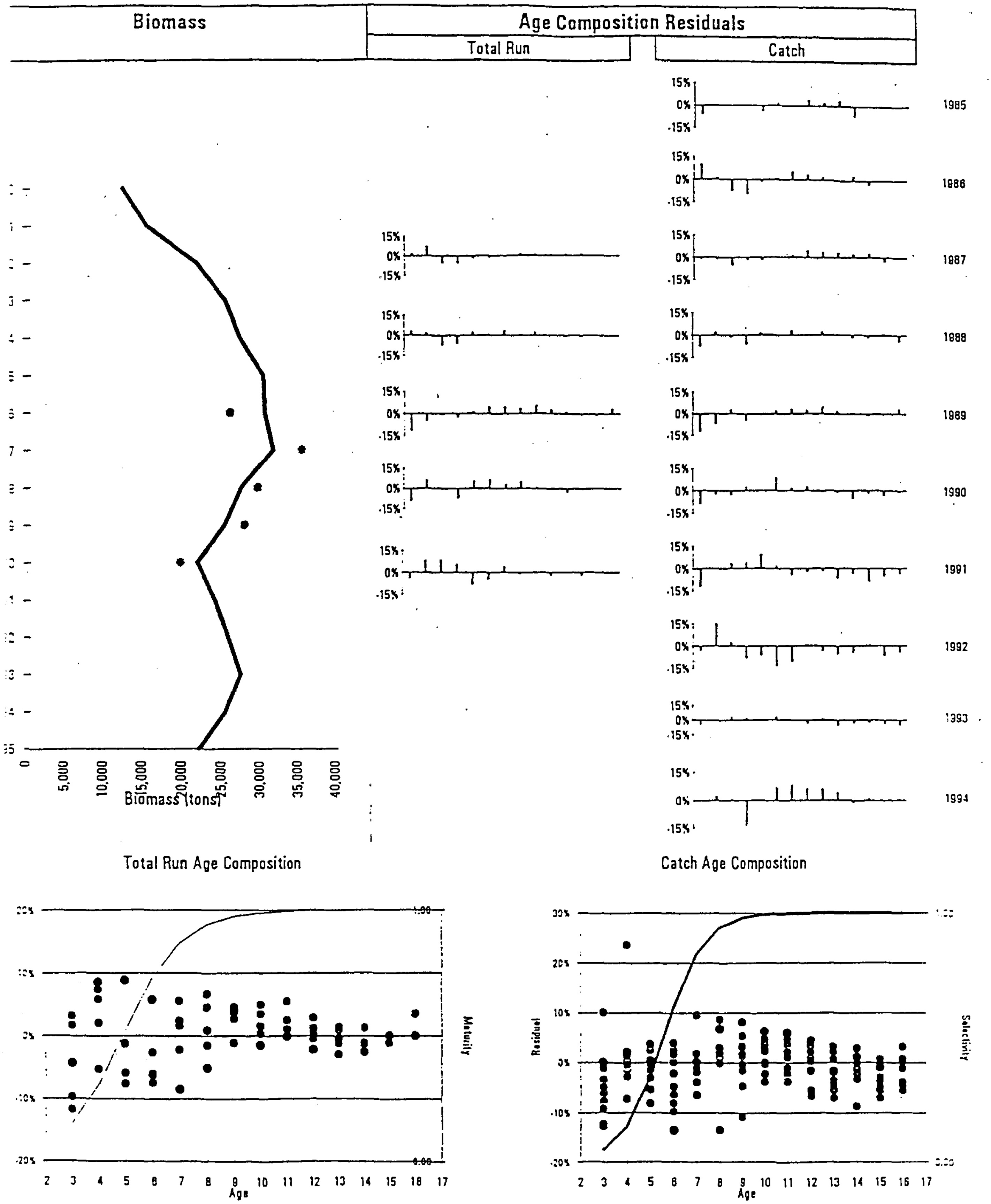


Figure 2. Conceptual model of the annual cycle of events affecting the Kamishak herring population.



jure 3. **Observed versus estimated run biomass, run and catch age composition residuals, maturity and selectivity curves for ASA model for Kamishak herring.**

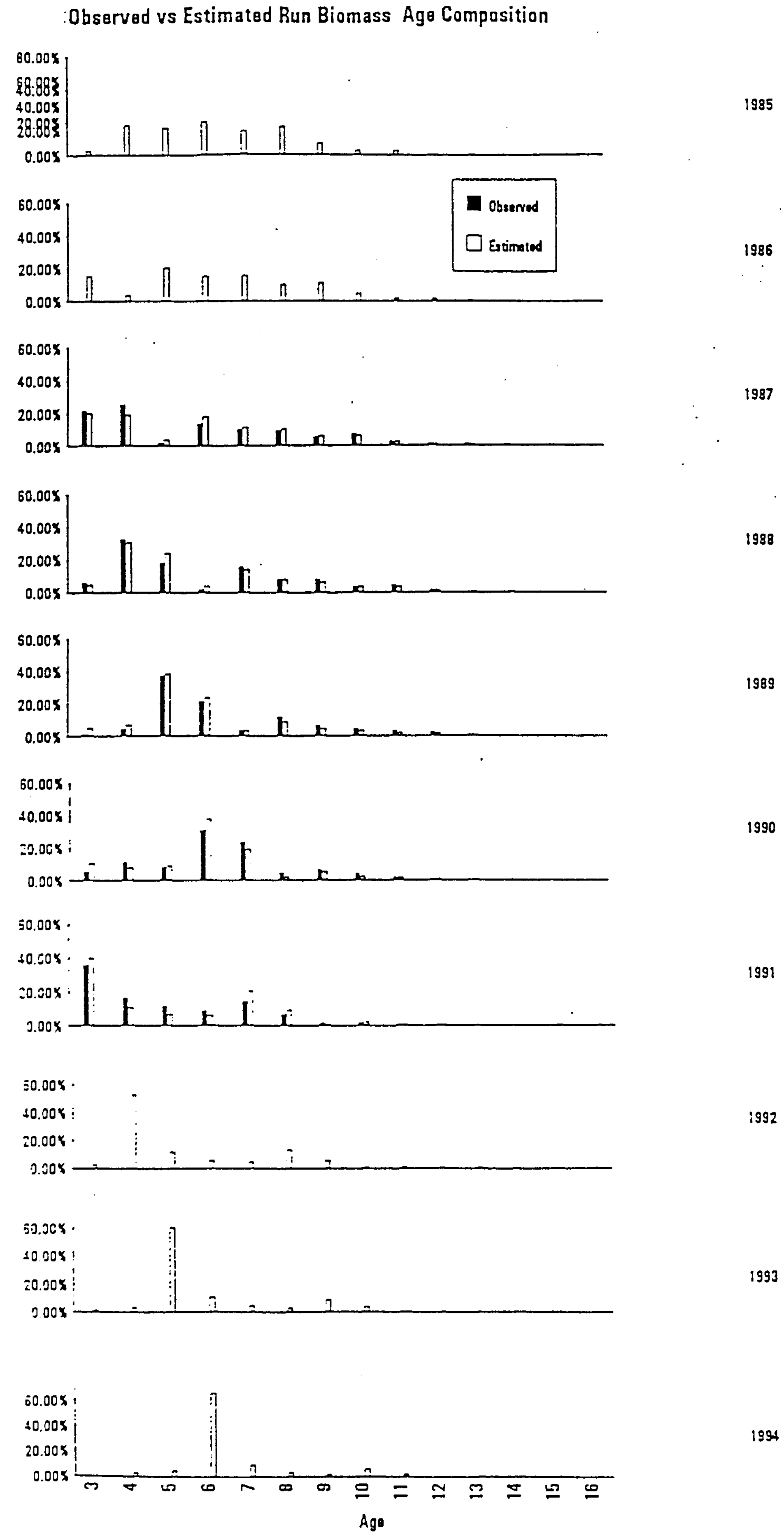


Figure 4. Observed age compostion of the run biomass versus that estimated to be available by the ASA model for Kamishak herring.

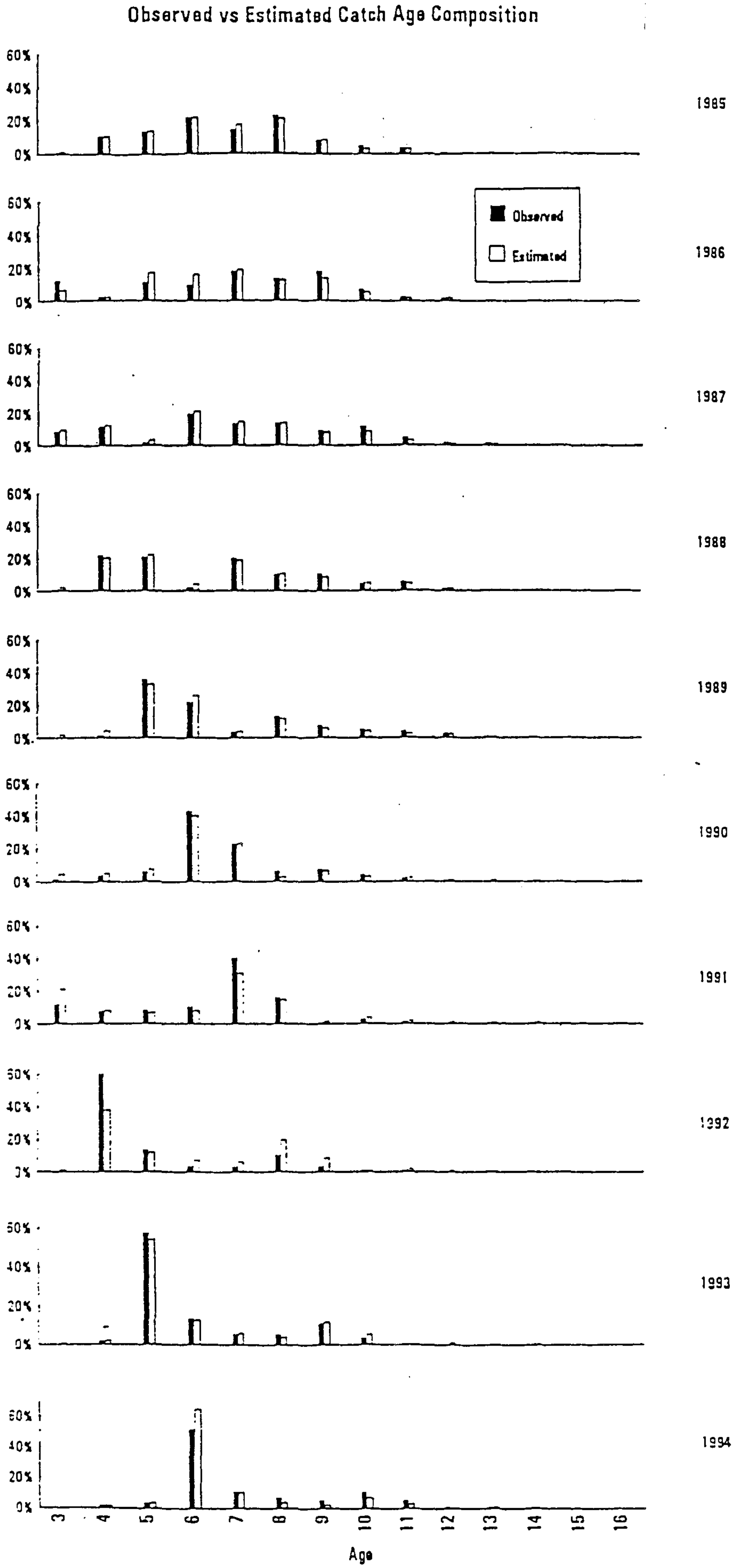


Figure 5. Observed age compostion of the purse seine catch versus that estimated to be available by the ASA model for Kamishak herring.

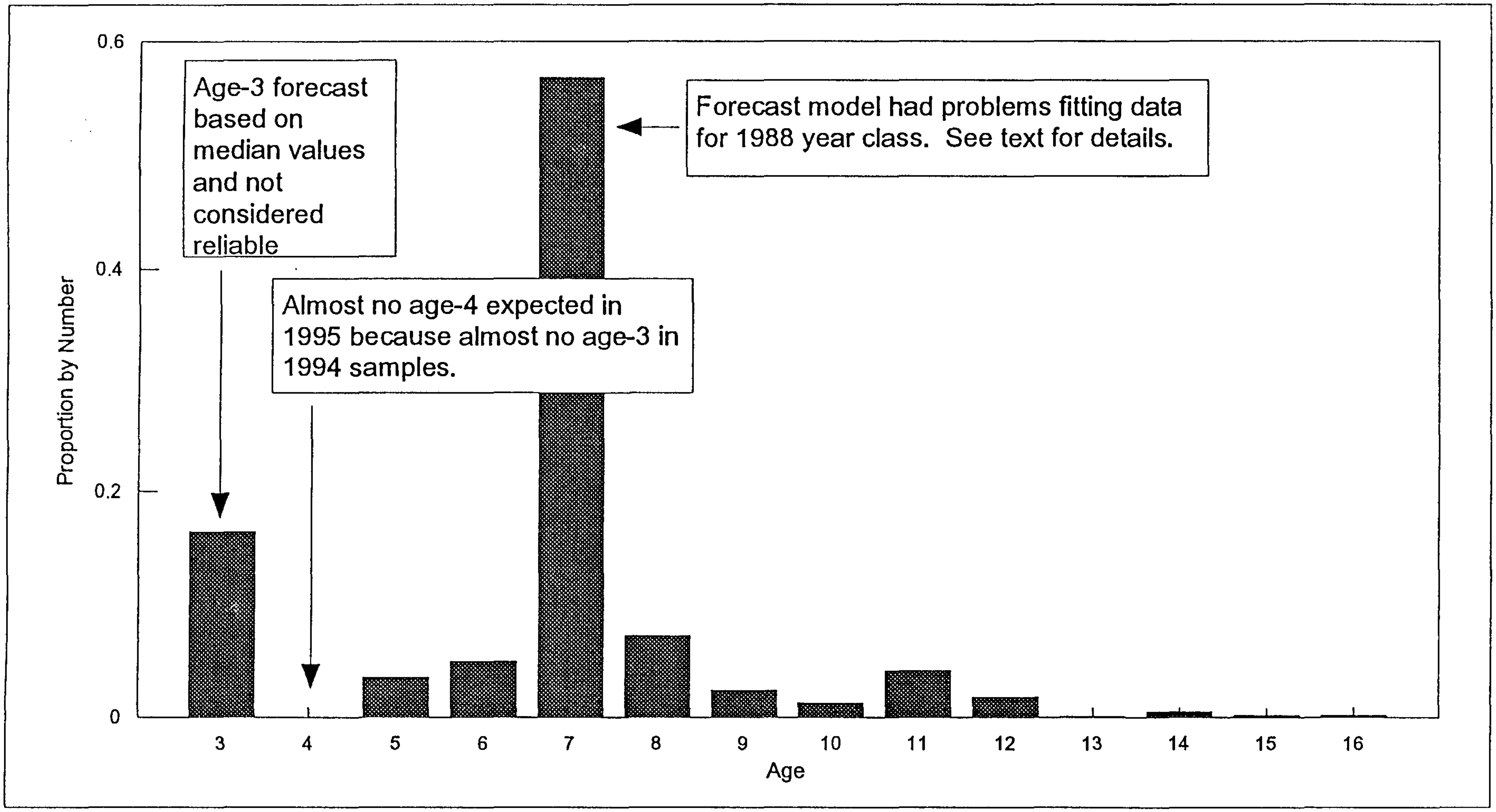


Figure 6. Kamishak Bay District age composition by number forecast for 1995.

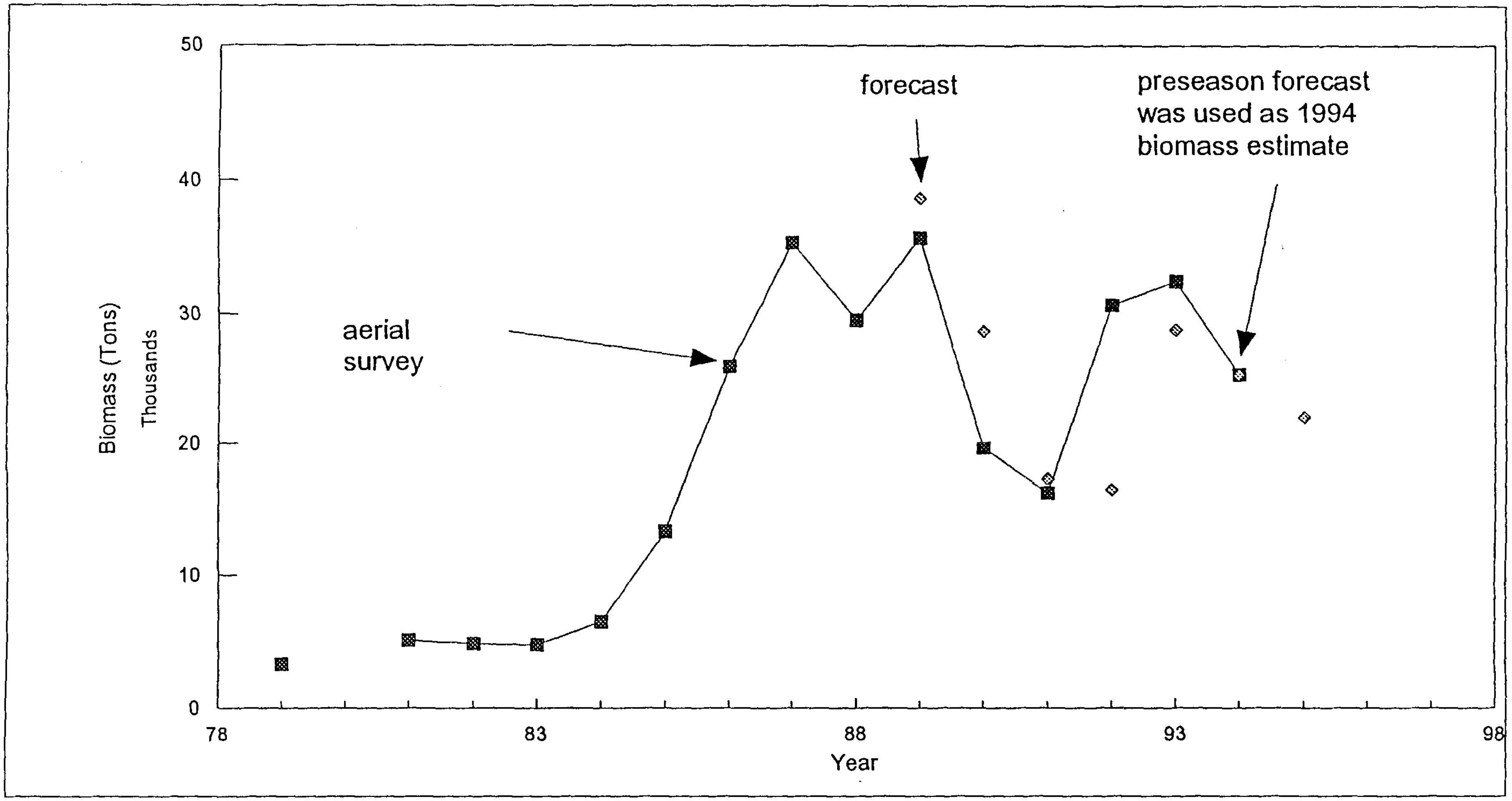


Figure 7. Kamishak Bay District herring biomass by year, 1979-1994, and forecast by year 1989-1994.

Appendix A. Kamishak Bay District herring catch (x 1,000) by age and year of harvest, 1979-1994.

YEAR	AGE													
	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1979	618	533	1,012	725	53	32	43	21	21	21				
1981														
1983														
1985	10	569	700	1,124	739	1,177	433	253	204	49	0	0	0	0
1986	1,093	227	1,028	889	1,586	1,190	1,609	647	250	196	58	8	0	0
1987	2,342	3,098	476	5,133	3,612	3,696	2,454	3,182	1,335	579	476	112	9	0
1988	120	5,593	5,338	592	5,160	2,687	2,743	1,231	1,485	481	92	103	14	0
1989	12	388	7,599	4,704	825	2,796	1,615	1,168	938	662	234	51	57	37
1990	154	364	603	4,327	2,333	647	789	444	211	94	34	26	2	15
1991	1,102	697	787	945	3,690	1,462	45	270	112	22	22	0	0	0
1992	87	8,344	1,848	520	491	1,415	491	115	173	29	29	58	0	0
1993	26	367	10,007	2,362	945	945	1,916	630	105	52	26	26	0	0
1994	0	180	334	4,453	923	633	481	947	492	76	50	50	21	19

Appendix B. Kamishak Bay District herring observed age composition (%) of the run biomass by year of harvest, 1987-1991.

	AGE													
YEAR	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1987	21.70	25.40	1.90	13.50	9.90	9.30	5.60	7.30	2.90	1.20	1.10	0.20		
1988	5.89	32.38	17.87	1.82	15.66	8.07	8.16	3.67	4.40	1.40	0.30	0.30		
1989	1.22	4.55	37.21	21.52	3.91	11.83	6.79	4.84	3.90	2.70	1.00	0.20	0.20	0.20
1990	5.54	11.38	8.37	30.87	23.78	4.66	6.83	4.44	2.20	0.90	0.50	0.30	0.20	
1991	35.80	16.60	11.70	9.10	14.30	6.60	1.80	2.00	1.10	0.50	0.40	0.20		

Appendix C. Kamishak Bay District herring mean weight[a] (g) by age and year of harvest, 1978-1994.

	AGE													
YEAR	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1978	61	85	121	168	170	188	204	217	212	247				
1979	68	98	128	156	170	197	210	221	272	265				
1980	69	107	136	155	186	204	219	229	260	270				
1981	70	88	124	121	186	204	219	229	260	270				
1982	69	107	136	155	186	204	219	229	260	270				
1983	74	118	137	160	182	196	210	218	253	270				
1984	69	107	136	155	186	204	219	229	260	270				
1985	64	125	155	182	205	220	238	248	255	275				
1986	88	104	155	189	215	233	249	261	272	281	292	295		
1987	91	134	162	198	218	241	251	267	276	275	288	288	287	
1988	84	123	163	196	218	236	248	261	266	280	298	262	282	
1989	98	131	158	199	228	245	254	268	285	288	298	293	313	296
1990	90	135	162	182	220	245	256	273	289	303	310	333	269	299
1991	79	118	172	208	214	259	267	288	280	229	413			
1992	99	116	156	210	229	234	266	304	303	279	333	349		
1993	88	131	152	193	230	245	260	293	302	317	382	318		
1994	55	147	174	190	223	256	261	283	300	315	325	309	312	296
mean[b]	84	126	161	195	220	241	255	275	283	284	327	306	293	297

[a] shaded mean weights are interpolated from 1979, 1981 (when available), 1983 (when available) and 1985 data.

[b] 10-year running average.

Appendix D. Kamishak Bay herring run biomass estimated from aerial survey used to 'tune' ASA model.

Year	Run Biomass (tons)
1986	26,001
1987	35,332
1988	29,548
1989	27,855
1990	19,650