FORECAST OF THE KAMISHAK HERRING STOCK IN 1997

by

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ABSTRACT

The 1997 abundance of Pacific herring *Clupea pallasi* in the Kamishak Bay District of Lower Cook Inlet, Alaska, was forecast using an age-structured-analysis model. This model estimates values of survival, age-specific maturity, fishery selectivity, and initial population abundances that minimize differences between predicted and observed run and catch age composition and run biomass estimates. Estimated parameters were used to project 1997 abundance. The recent five-year average (1991-1996) was used to predict herring weight-at-age in 1997.

A biomass of 25,302 tons (22,954 tonnes) of herring is expected to return to the Kamishak Bay District in 1997. Herring mean weight is predicted to be 227 g. The 1988 year class is forecast to represent 39% of the run biomass (30% of the population abundance) as age-9 herring. Samples collected in mid-May 1996, after the commercial fishery, suggested strong recruitment from the 1992 and 1993 cohort classes, which should result in increased age 4 and 5 returns in 1997. The total allowable herring harvest for 1997 is projected to be 3,800 tons (3,447 tonnes) based on an exploitation rate of 15% of the forecast. The harvest allocation is 3,420 tons (3,103 tonnes) for the 1997 Kamishak spring sac roe fishery and 380 tons (345 tonnes) for the 1996 Shelikof Strait fall food and bait fishery.

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

INTRODUCTION

The Kamishak Bay Pacific herring *Clupea pallasi* stock supports a spring sac roe fishery in the Kamishak Bay District of the Lower Cook Inlet Management Area and a fall food and bait fishery in Shelikof Strait of the 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 Kamishak Bay. Herring observed from mid-April to June were considered recruited to the fishery and available to the sac roe fishing fleet even though fleet efficiency and harvest guidelines typically limit the fishery to one or a series of short openings in late-April (Bucher and Hammarstrom 1995).

Stock assessment information such as total run age composition, commercial catch age composition, mean weight-at-age, and aerial survey indices of run biomass have been collected for the Kamishak Bay herring population since 1972. Similar to previous years, aerial surveys to monitor relative biomass, distribution, and spawning of the 1996 herring population began in early April. Daily biomass indices were derived from the number and size of observed herring schools. Run biomass indices for each year was either: (1) the sum of "peak" estimates from a time series of aerial observations if the surveyor believed observed herring resided in the surveyed area more than one day; (2) the sum of multiple surveys if residence time was only one day, or (3) the sum of all surveys plus linearly interpolated estimates of biomass for days not surveyed. The third method was developed because adverse weather conditions during some years reduced the frequency with which aerial surveys could safely be flown. Because herring migration to and from the spawning grounds is likely a continuous process, and water visibility in Kamishak Bay is consistently low, aerial survey results were considered to be conservative and were used primarily as indices of relative abundance.

Run estimates have historically been derived from the preseason forecast or from run timing proportions (Yuen *in preparation*). The exponential decay models used until 1993 depended on the prior year escapement estimates, calculated as the estimated total run minus the harvested biomass. However, escapement estimates derived from preseason forecasts are not appropriate as input data for exponential decay models, and run biomass estimates based on run timing proportions have not gained universal acceptance. Thus, age-structured analysis (ASA) was adopted as the forecast method for Kamishak Bay herring because it relied more on multiple years of data to back-calculate estimates of age-3 herring and was less dependent on annual aerial survey estimates of run biomass (Yuen et. al. 1994, Yuen and Brannian 1994, Bechtol and Brannian 1996).

ASA minimized differences between predicted and observed age composition as well as total run biomass. Because the conversion of herring school surface area to biomass was undocumented for Kamishak Bay prior to 1989, only surveys occurring after 1989 were considered for inclusion in the model. To forecast the 1997 return, the predicted run biomass was scaled to aerial survey estimates of run biomass from 1990 and 1992 because they had the best overall aerial survey condition ratings during the past 7 years. This approach removed much of the bias in abundance estimates by excluding aerial survey estimates made during years having poor weather or inadequate geographic and temporal coverage. The ASA model may have still underestimated true herring abundance because the residence time of herring on the spawning grounds was unknown and, even during years with good survey conditions, not all herring were observed. The qualitative exclusion of some survey years ignores years when large biomass aggregations were observed but the temporal coverage for the season was restricted (Yuen *in preparation*). In addition, these exclusions largely fail to incorporate calibrated survey techniques used since 1989 (Lebida and Whitmore 1985). In developing the 1997 forecast we attempted to examine model sensitivity by varying the emphasis placed on survey years, including 1992, which had poor temporal coverage but involved calibrated estimates under reasonable survey conditions that were expanded through a run timing model (Yuen *in preparation*).

Specific objectives of this report are to (1) document data sources and methodology used for the 1997 forecast, (2) formally present the 1997 forecast, and (3) through application of the Kamishak Bay Herring Management Plan (5 AAC 27.465), propose a harvest guideline for the 1997 commercial fishing season.

KAMISHAK BAY HARVEST AREA

The Kamishak Bay District is defined in state regulation 5 AAC 21.200 as all waters enclosed by a line from 59°46'12" N. lat., 153°00'30" W. long., then east to 59°46'12" N. lat., 152°20' W. long., then south to 59°03'25" N. lat., 152°20' W. long., then southwesterly to Cape Douglas at 58°52' N. lat. (Figure 1). In practice, fishing is restricted to the waters defined as the territorial seas. The Kamishak District is typically a foul weather area with tidal fluctuations in excess of 8 meters and marine habitat typified by shallow rocky reefs separated by muddy, silty substrate. Several glaciers on the shores surrounding the Kamishak District result in a substantial influx of glacial silt into the marine environment. This glacial silt complicates both aerial survey assessment and the commercial herring fishery.

Management strategies and fishing patterns for sac roe herring in the Kamishak Bay District have been relatively consistent over the past seven seasons. Purse seine fishing generally occurred in nearshore waters at the southern end of the district between the Douglas River mouth and Contact Point at the mouth of Bruin Bay. Although protection from the weather was severely limited, Nordyke Island served as one of very few suitable anchorages in the Kamishak District. Of the 74 limited entry permits issued for herring in Lower Cook Inlet, approximately 90 to 95 percent of the permit holders have participated in the Kamishak fishery in a given year. Fishing often focused immediately south or west of Nordyke Island (Figure 1), and depending on fish distribution, the entire fleet often fished in an area of 1.3-2.6 km^2. Fish value depended upon roe content as a percent of body weight. Because the mature fish with the highest roe content were often found in close proximity to the beach, purse seining frequently occurred in intertidal areas of 0-12 m in depth.

METHODS

Database

Kamishak herring harvest abundance by age, commercial catch and total run age compositions, and mean weights through 1995 were forwarded from last year's ASA model (Bechtol and Brannian 1996, Appendix A-C). Harvest and age composition data for 1996 were obtained from catch sampling, test fishing, and fish ticket data. Revisions were made to the total run age composition data used in the model (Appendix B). Because a shift in age composition has been shown to occur in the past (Yuen 1994), we only included data from years where late season (i.e. May) samples were included in the total run age composition data set (i.e. 1986, 1988, 1990, and 1996). Age composition data from 1987, 1989, 1992, 1994, and 1995 were dropped from the model because they were comprised of samples collected only in April. The years 1991 and 1993 were also removed from the model because they were, in part, derived, and not estimated soley from catch samples.

Aerial survey indices of run biomass (Appendix D) were obtained from the most recent annual management report (Bucher and Hammarstrom 1997) with the exceptions of 1989 where 27,855 tons was used instead of 35,701 tons (Yuen et al. 1990) and 1992 where 30,660 tons was used instead of 24,077 tons (Yuen and Bucher 1994). During herring aerial surveys, observers estimated 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 Togiak Bay calibration samples in which estimated herring schools were captured by purse seines (Lebida and Whitmore 1985). Aerial surveys in 1996 were hampered by poor survey conditions for the fourth consecutive year (Table 1); inclement weather prevented aerial surveys between 6 and 13 May and again between 16 and 28 May.

Age-Structured-Model

In our conceptual model of the annual cycle of events affecting the Kamishak Bay herring stock (Figure 2), ages increment at the end of winter to coincide with the approximate time of annulus formation. The population model begins accounting for herring at age 3, the age when Kamishak

Bay herring first appear in the purse seine sac roe fishery. Although age-1 and -2 herring have been captured with a trawl on the spawning grounds in April, these fish rarely appear in the commercial harvest and are not considered recruited into the fishery. Prior to spring, the conceptual model splits the "total" herring population into two components: an "immature" portion that does not return to spawn or does not otherwise recruit to the fishery, and a "run" biomass that returns to spawn. Deducting removals by the purse seine sac roe fishery leaves the "escapement" biomass that actually spawns. In this conceptual model, harvests by the Shelikof Strait fall food and bait fishery are not specifically identified but 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, further evaluation is needed to determine if Shelikof fishery data will 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 with heterogeneous auxiliary data from a variety of sources. The ASA was developed in a computer spreadsheet containing a nonlinear optimization function which minimized sums of squares values.

ASA models which incorporate heterogeneous 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 1997, the model also updated estimates of maturity and historical abundance for 1979-1996, and also the fishery selectivity curve for the purse seine fishery. Information supplied to the ASA model included estimates of the commercial harvest abundance by age (Appendix A), age composition of the run biomass (Appendix B), weight-at-age (Appendix C), and the aerial survey run biomass (Appendix D). Final values of fishery selectivity, a maturity curve, and the number of age-3 herring for each cohort from the 1996 forecast (Bechtol and Brannian 1996) were used as initial parameter values for the 1997 forecast. The 1997 mean weight-at-age was estimated as the five-year mean weight for the previous 5 years. The abundance of age-3 herring in 1997 was forecast as the median of age-3 abundance estimates since 1978.

In previous years, the forecast model was allowed to estimate annual survival (S). Because we removed several years from the total run age composition time-series to generate the 1997 forecast, the authors felt that insufficient age-composition data were available for the model to estimate S. Accordingly, we reduced the parameters the model had to estimate by fixing S at 0.67 (equivalent to an instantaneous rate of natural mortality [M] of 0.4).

Model Assumptions

The following assumptions are incorporated into the model:

1. Purse seine fishery selectivity for all years can be described by a logistic function whose shape is determined by two parameters estimated by the model.
2. The availability of herring to the gear used to sample the spawning populations in all years can be described by a logistic function whose shape is determined by two parameters estimated by the model.
3. Cohorts older than age 12 are a minor component of the population and can be pooled and adequately represented by a single age class, age 13+.
4. All age classes, from age 3 to 13+, are present in the forecast population.
5. The proportion of herring dying from causes other than the commercial sac roe fishery is constant among years.
6. Maturity-at-age is assumed to be constant among years.
7. Measurement errors in each of the three data sources are independent.
8. The model is correctly specified with respect to the amount and type of available data such that parameter estimates are not correlated and differences between model estimates and observed values are caused by measurement error, not errors in correctly specifying mathematical forms of the underlying processes.
9. Simultaneously minimizing the squared measurement errors from all three data sources provides the best estimate of the true parameter values when all catch age compositions and survey age compositions are arc sine transformed and error terms are scaled and weighted.
10. Mortality is assumed to be constant among years and cohorts.

Assumptions 1-2 control the type and degree of curvature in relationships among model values. Assumptions 3-7 are required for assumption 8 to hold. Assumption 9 is the basis for the ASA model. Assumption 10 is a function of our fixing S at 0.67 for this year's forecast in order to reduce the number of parameters the model estimates and hasten individual model runs. The ASA model fits a variety of data measured in different units and of varying utility in identifying true parameter values. Unlike least squares linear regression, there is not a rigid statistical theory underlying the parameter estimation procedure in the ASA model. The rationale for assumption 8 is that the best estimates of the model parameters should provide a reasonable fit to all available data. In some cases, observed data are transformed to achieve symmetric and approximately normal error distributions, although the robustness of the parameter estimates to departures from normality is unknown (Funk 1994).

Survival

Our ASA model used a reduction equation to describe the number of herring (N) in a cohort aged a

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

in year y:

where S is the annual survival rate, fixed at 0.67 which is an instantaneous natural mortality rate of 0.4, and $C_{a,y}$ is the catch-at-age from the spring purse seine sac roe fishery. The annual survival rate of 0.67 was chosen for 3 reasons: (1) age structured analyses using a lengthy time series of Prince William Sound herring data indicate 0.67 is an average survivability rate for Central Alaska herring, (2) 0.67 is well within the published survivability range and (3) 0.67 is a relatively conservative estimate of survivability (Funk and Sandone 1990, Funk 1993). The number of herring in a cohort (N) was defined as the total spring population after annulus formation and includes both the mature and immature herring present before the spawning migration and spring fishery occurs (Figure 2). The model starts accounting for herring at age 3 and ends by grouping all herring age 13 and older as age 13+.

Selectivity Functions

Fishery Selectivity. The age composition of the purse seine commercial catch for each year, $\hat{p}_{a,y}$, was estimated from a model incorporating an age-specific fishery selectivity function, s_a, and the estimated cohort abundance, $N_{a,y}$, from equation (1):

$$\hat{p}_{a,y} = \frac{s_a \hat{N}_{a,y}}{\sum_{a=3}^{13} (s_a \hat{N}_{a,y})}. \tag{2}$$

For our model, fishery selectivity was defined as the proportion of the total population susceptible to capture by the commercial fishery 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 herring size classes during the fishery or sample collection (Schroeder 1989; Yuen 1994). Functions to describe the relationship between fishery 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 used in the commercial fishery was assumed to have an asymptotic selectivity represented by the 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.

Maturity. The ASA model calculated a maturity curve to estimate the proportion of each age class which returned to spawn each year. This maturity function was used to compare abundance estimates 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:

$$\rho_a = \frac{1}{1 + e^{\phi(a-\tau)}} , \tag{4}$$

where τ is the age at which 50% of a cohort reach maturity, and ϕ is a steepness parameter. The maturity-at-age relationship was assumed to be constant over the range of years examined by the model. Maturity estimates 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 (Schroeder 1989). Having reactivated late season sampling in 1996, we hope to continue it in the future so our total run age composition better represents true maturity.

SSQ Calculations

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:

$$SSQ_{agecomp:catch} = \sum_{y} \sum_{a} \left(\frac{C_{a,y}}{\sum_{a=3}^{13} C_{a,y}} - \hat{p}_{a,y} \right)^2 , \tag{5}$$

where $(\hat{p}_{a,y})$ was the estimated age composition of the catch from equation (2). To stabilize the variance, the observed and estimated age compositions were transformed by taking the arc sine of the square root of the composition proportion. Commercial catch age composition was fit across ages 3 to 13+ and years 1985 through 1995.

SSQ Biomass Estimates. Another measure of ASA model fit was obtained by comparing model estimates of biomass with aerial survey estimates of biomass. The sum of squares measuring the goodness of fit of the model's biomass estimates was based on the differences between ASA and

$$SSQ_{biomass} = \sum_{y_1}^{y_n} [\log_e(B_y^{survey}) - \log_e(\sum_{a=3}^{13} \rho_a w_{a,y} \hat{N}_{a,y})]^2 , \quad (6)$$

aerial survey estimates of run biomass:

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 of age a fish that are mature and are available to our survey (equation 5), $N_{a,y}$ is the ASA estimate of total abundance at age a in year y (equation 1), and y_1 and y_n are the first and last of an array of years included in a model variation. We used a log transformation in our model because a lognormal error structure is commonly found when dealing with abundance data. Though there were too few abundance estimates to evaluate the appropriateness of the log transformation in equation (6), fits with and without log transformation indicate ASA models are not sensitive to this assumption (Funk et al. 1992).

SSQ Run Age Composition. In addition to the time series of catch-by-age, a time series of age composition estimates of the run biomass are available for 1986-1990, 1992, and 1994-1996 (Appendix B). However, during 7 of the past 11 years, age composition samples were only collected prior to and during the commercial fishery which is generally prosecuted early in the run (i.e. late-April). During the years when late-run (i.e. May) samples were collected (1986, 1988, 1990, and 1996), it was apparent that April's samples alone under-represented the true composition of age-3 and -4 herring for the total run. Whereas total run age compositions for the previous 5 years were based on April samples alone, this year we had the opportunity to also collect samples in mid-May. Accordingly, we elected to adjust the Observed Total Run Age Composition (OTRAC) component of the model to incorporate only those sample years that included May samples. We felt this time series of age composition data best represented the entire run biomass.

A measure of how well the ASA model fit actual data was obtained by comparing age compositions estimated by the model with compositions based on samples. The sum of squares measuring the

$$SSQ_{agecomp:run} = \sum_y \sum_a [p_{a,y}^{run} - \frac{\rho_a \hat{N}_{a,y}}{\sum_{a=3}^{13} (\rho_a \hat{N}_{a,y})}]^2 , \quad (7)$$

goodness of fit of the age composition of the run biomass was computed as:

where $p_{a,y}^{run}$ is the observed total run age composition estimated for age a and year y. Arc sine square root transformation was applied to observed and estimated age composition proportions to stabilize their variance. Only samples from the years 1986, 1988, 1990, and 1996 were used in the SSQ of equation 7.

Aerial Surveys

The ASA model minimizes the sums of squares between ASA and aerial survey estimates of run biomass. The ability of aerial surveyors to estimate annual run biomass varied with weather conditions, survey conditions (e.g. water turbidity, tidal stage), and spatial and temporal coverage. A qualitative rating of geographic and temporal coverage was applied to aerial surveys for the years 1985-1989. A quantitative method for rating survey effort and survey conditions was adopted in 1996 and retroactively applied to surveys conducted from 1990 to present. (Table 1). Aerial survey biomass estimates from the years 1985 to 1989 were not well documented and were not used in the forecast model. In 1990, aerial surveyors began using published standards to convert herring school surface areas to estimates of biomass (Lebida and Whitmore 1985). Adoption of these standards, as well as the quantitative method for rating survey effort and conditions within seasons, enabled us to evaluate the relative quality of aerial survey biomass estimates between years. Survey years 1990 and 1992 had the highest relative values since 1990 and were used in the observed aerial survey biomass component of the model.

Annually estimating the total run biomass in Kamishak Bay based on aerial surveys is problematic; survey conditions are often poor, residency time of fish on the grounds is not precisely known, and frequently poor weather often leaves temporal and spatial gaps between surveys. Yuen *(in preparation)* attempted to overcome some of these factors by developing a migratory run timing model to adjust estimates of biomass; this model was used to generate the 1992 aerial survey biomass estimate used in the 1997 forecast.. For the past 2 years, linear interpolation was used to estimate biomass on the grounds during gaps in survey coverage and consecutive days totals were summed for the season. Appropriate criteria to estimate the total annual biomass for Kamishak Bay are still under development.

Forecasting Methods

The forecast of the herring run biomass for 1997 ($B_{1997}^{Forecast}$) was projected from total abundance with the survival model (equation 1) modified by the ASA estimated proportion of mature herring

$$B_{1997}^{Forecast} = \sum_a \rho_a \hat{w}_{a,1997} \hat{N}_{a,1997}, \qquad (8)$$

expected for each age:

where ρ_a is the proportion mature and available to our surveys at age a from equation (5); $w_{a,1997}$ is the individual fish weight at age a from the recent 5-year average (1992-1996; Appendix C); and $N_{a,1997}$ is the ASA estimate of age-a herring for 1997 from equation (1). The above model was used to forecast the 1997 herring abundance for all herring aged 3 and older. Lacking an adequate method to predict age-3 year class strength, we used the median ASA estimate of age-3 abundance from years 1978-1996 to generate $N_{3,1997}$. The median was thought to be more representative of recruitment than the mean because of the influence of a small number of large year classes (Appendices A and B).

$$\hat{p}_{a,1997} = \frac{\hat{N}_{a,1997}\rho_a}{\sum_a \hat{N}_{a,1997}\rho_a} \tag{9}$$

The age composition ($p_{a,1997}$), of $B_{1997}^{Forecast}$, was estimated using the maturity schedule (ρ_a of equation 5) as:

Parameter Estimation

$$\begin{aligned} SSQ_{Total} = \; & SSQ_{agecomp:catch}\lambda_{agecomp:catch} \; + \\ & SSQ_{biomass}\lambda_{biomass} \; + \\ & SSQ_{agecomp:run}\lambda_{agecomp:run} \end{aligned} \tag{10}$$

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

where the λ's are weights assigned to each sum of squares component. Theoretically, each sum of squares component should be scaled to a similar order of magnitude, so each contributes similarly to the total SSQ when λ's were equal. The λ's would then be 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 did not feel we could differentially weight age composition data sources at this time, so we set those λ's equal to 1.0. Weights for the 1997 biomass SSQ were chosen empirically. With the catch and the run age compositions weighted equally at 1.0, the weight given aerial surveys was varied from 0.0001 to 50 to examine model sensitivity to aerial survey weighting while letting the age composition SSQs be very close to their minima.

Minimization Methods. The ASA model estimated a total of 26 parameters: 22 initial cohort sizes, two fishery 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 178 data observations with 152 degrees of freedom and a data to parameter ratio of approximately 6.8:1.

The Microsoft Excel Solver[1] 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, central differencing for estimates of partial derivatives, and a quasi-Newton method for computing the search direction (Microsoft 1992). The precision level for minimizing the SSQ_{Total} was set at 0.00001. Population sizes for all cohorts forecast to return in 1997 were constrained to be greater than or equal to zero because negative population values were unrealistic.

Goodness of Fit

The goodness of fit for our ASA model was assessed through evaluation of model residuals, similar to the techniques in applied regression analysis (Draper and Smith 1981). Model fit was rated "good" if the residuals were small relative to alternative models. In addition, model residuals should be normally distributed with a mean of zero. The functional form of the model was rated "good" if the residuals appeared evenly distributed about zero and did not form a trend when plotted as a function of age, year, year class, or estimated values. For example, to evaluate the catch age composition, we graphed residuals for commercial catch age composition against age to see if the residuals were distributed about the zero axis. A trend in residuals may have indicated that the functional structure of the data changed over time or by age and that a time- or age-specific function was needed.

Harvest Strategy

The Kamishak Bay Herring Management Plan (regulation 5 AAC 27.465) stipulates the Kamishak Bay sac roe fishery and the Shelikof Strait food and bait fishery will both be closed if the biomass forecast for the Kamishak Bay herring run is less than 8,000 tons. If the projected biomass is more

[1] Vendor and product names are provided to document methods and do not represent an endorsement by ADF&G.

than 8,000 tons but less than 20,000 tons, maximum 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 maximum total exploitation rate of 10%. For a forecast of 20,000 to 30,000 tons, the total exploitation rate may increase to a maximum of 15%. If the forecast exceeds 30,000 tons, the total exploitation rate may increase to 20%. However, the relative allocation between the two fisheries remains the same with 10% of any allowable harvest allocated to Shelikof and 90% allocated to Kamishak. In season, the Kamishak Bay sac roe fishery is managed to avoid harvesting younger fish and to maximize economic benefit to the fishing industry by targeting fish of the greatest roe quality.

RESULTS

We ran a series of seven to eight weighting trials on each of four ASA model scenarios to evaluate different uses of the data available to us (Table 2). Survival was fixed at 0.67 for all 29 trials, and 1990 and 1992 were the only survey years contributing estimates of total run biomass. We pooled our April and May age-composition samples to represent OTRAC for three scenarios and used April samples to represent OTRAC for one scenario. The structure of the latter scenario closely resembled the 1996 forecast when late season samples were not available for inclusion in the model's OTRAC component. Forecast biomasses resulting from the 29 total trials ranged from 4,189 to 54,681 short tons; the average forecast biomass was 26,712 short tons (Table 2). The final parameter estimates and maturity curve for the 1997 forecast exhibited trends similar to the previous year's forecast (Table 3, Figure 3; Bechtol and Brannian 1996).

Our final choice of a weighting schedule was based on a graphical display of the influence that aerial survey λ had on the forecast and the scaled total SSQ. Generally, each increase in aerial survey λ resulted in an increase in the scaled total SSQ. The preferred aerial survey λ occurred at a level just prior to the point where incremental aerial survey λ increases resulted in proportionally greater increases in the scaled total SSQ. We concluded that beyond this point of inflection the model was overly sensitive to increased aerial survey λ's. Under these criteria, we selected an aerial survey λ of 0.1 which resulted in a scaled total SSQ of 0.6113. Of the 29 model trials we ran this year to evaluate sensitivity to various data sets and λ's, 0.6113 was the fourth lowest scaled total SSQ.

Pooled residuals of the total run age composition (TRAC) exhibited some variability, but were relatively evenly distributed about zero when displayed as a function of age (Figure 4). Residuals typically were less than 10% of the observed values and the largest residuals were for age-3 herring. There was a trend in residuals for some years. For instance, the 1988 TRAC had negative residuals for age-5 and older herring. Considering the residual calculation of observed minus predicted, this probably indicated that the ASA model overestimated the abundance-at-age of herring age-5 and older. Nevertheless, ASA estimates of the age compositions of the run biomass agreed moderately well with observed compositions, particularly in tracking the annual progression of the 1988 year class (Figure 5). Survey year 1996 had the widest residuals of the four year time series. A greater abundance of young herring was observed in 1996 as a result of sample collections extending into May. This simultaneously increased their own percent composition (age-3 and age-4) while lowering the percent composition of the dominant age-8 cohort. The wide residuals exhibited for the 1996 total run age composition will likely be reduced as a longer and more consistent time series of full season sampling is developed.

Residuals of the purse seine catch age composition from the ASA model were typically less than 10% of the observed values and again the largest residuals occurred in age-3 herring. Although residuals centered around zero, there appeared to be a slight tendency for negative residuals in age-6 and -7 herring and positive residuals in age-8 through age-11 herring (Figure 4). No strong trend was seen in residuals plotted by age for each year, however, residuals in 1992 tended to be negative. The age composition of the purse seine catch estimated from the ASA model generally agreed well with the observed age. The reliance of the Kamishak Bay catch on the 1988 year class continued in 1996, but with slightly less dominance (Figure 6).

Run biomass estimates obtained from the ASA model compared moderately well with the aerial surveys used as auxiliary data (Figure 7). The poorest fit was in 1985 and the best from 1987 to 1990, and 1992 and 1993. The trends in ASA estimates generally agreed with the trends in survey estimates, although the ASA model tended to “centralize” biomass relative to survey estimates.

Forecast

A biomass of 25,302 tons (22,954 tonnes) of herring is expected to return to the Kamishak Bay District in 1997 (Table 4; Figure 8). Depending upon the use of individual total run age composition data sets and weighting of specific λ applied in model runs, model forecasts ranged from 4,189 to 54,681 tons ($\bar{x}$ = 26,712; Table 2).

Herring mean weight in 1997 is predicted to be 227 g. The 1988 year class, returning as age-9 herring in 1997, is forecast to represent 39% of the run biomass and 30% of the total abundance (Table 4; Figure 9). Recruitment by age-4 and age-5 herring, as indicated by 1996 test fish samples, resulted in these cohorts comprising about 23% of the biomass and over 33% of the total abundance predicted to return in 1997 (Figure 9).

Projected Harvest

The total allowable harvest is projected to be 3,800 tons (3,447 tonnes) based on an exploitation rate of 15% of the estimated spawning biomass. The harvest allocation is 3,420 tons (3,103 tonnes) for the Kamishak spring sac roe fishery and 380 tons (345 tonnes) for the Shelikof Strait fall food and bait fishery (Table 5).

DISCUSSION

Both the exponential decay (Yuen et al. 1994) and ASA methods required an estimate of initial population size. For the exponential decay model, this estimate was the spawning population from the previous year. With 1996 being the fourth successive year of aerial surveys being hampered by weather, the 1997 forecast would have relied on an extension of a previous forecast. We would have adjusted the 1996 estimated age composition to match the observed 1996 age composition but could not have adjusted the magnitude of the 1996 biomass estimate or updated our mortality and recruitment rates in the exponential decay model. This would have essentially extended to 5-years, the biomass forecasts based primarily on the 1992 escapement data, the last year with a comprehensive aerial survey estimate.

In contrast, the ASA model relies on the estimated initial cohort abundance for age-3 herring. ASA was designed to use all available observed age composition data to adjust the initial abundance estimates of age-3 herring except for the current year. As a predictive tool, the ASA model is much more responsive to adjusting cohort strength, through changes to initial cohort abundance, than could be expected from the exponential decay model. For this, and the problem of missing escapement data, we changed our forecast methods.

The forecast variability we observed within and between model scenarios illustrates the model's sensitivity to the use of individual weighting schedules and data sets respectively (Table 2). This sensitivity indicates the need to keep weighting schedules within their ranges of relative stability and to use available data in the most appropriate manner. For instance, scenarios 1 and 2 experimented with using different data sets to represent OTRAC in the model. Scenario 1 used only pre-commercial fishery test fish data (April) and under-represented the contribution of age-3 and age-4 fish to the total run. While scenario 2 better represented the true age composition of the total run by pooling samples collected during April and May, it computed total run age composition residuals for most years and treated OTRAC's similarly regardless of the period during which their samples were collected. This seemed inappropriate because differences could reflect shifts in sampling schedules and not real changes in the age composition of the total run.

Accordingly, we ran trials for scenario 3, which only computed total run age composition residuals for those years where May samples were collected. This reduced the potential for a temporally-based sampling bias and better represented the true age composition of the total run by incorporating the later returning recruit classes. While this approach limited the time series of OTRAC data available to the model, we decided it was the most appropriate use of the available data. This conclusion was made with the expectation that late season samples would continue to be collected for model use in future years. Availability of these samples is pertinent to our timely assessment of recruitment; without them, we have little indication of year class strength until a cohort recruits to the commercial fishery at around age-4 or age-5. We intend to investigate the application of age composition data from several northern districts of Kodiak's winter food and bait fishery to provide more timely predictions of recruitment strength of age-3 herring returning to Kamishak Bay. These Kodiak districts are generally considered to consist largely of Kamishak herring and catch samples may provide indications of the relative strength of young herring (Johnson et. al. 1988).

Scenario four was similar to the accepted forecast scenario (scenario 3, trial C), except maturity was constrained at age 8 to be = 1.0. While that constraint appeared biologically appropriate, albeit conservative, it slightly increased the $SSQ_{age\ comp:run}$. This likely reflected our temporally limited age composition data. Because the model's maturity curve relies on ADF&G samples to represent OTRAC, the model curve is likely skewed to older ages due to the early curtailment of our sampling prior to the spawning run of younger fish (Table 3, Figure 3; Schroeder 1989). Although we attempted to overcome that sampling bias this year by collecting samples in May and constraining the OTRAC data set to similarly collected samples from previous years, a longer time series of late season samples is probably needed to mitigate the model's tendency to underestimate biological maturity in the younger age classes.

ASA hindcasted previous year's biomasses based on the current year's inputs and by minimizing the total sums of squares. The resulting trend suggests that the herring biomass in Kamishak Bay peaked in 1987, and again in 1995, with a minor valley centered around 1990 (Figure 8). The ASA model also indicated that the 1997 forecasted biomass continues a downward trend very similar to that of 1988 to 1990. The recruitment of the 1988 cohort to the fishery as age-3 fish in 1991 reversed the late 1980's downward trend in biomass. While the recruitment of age-3 to age-5 herring indicated by this year's survey samples is less than the 1988 cohort, we expect relatively strong returns of age-4 to age-6 fish next year as more individuals within these cohorts mature. Because the 1988 cohort will dominate the returning biomass as age-9 fish, we anticipate that the 15% exploitation rate will have minimal impact on the later returning component of younger fish that will provide the brood stock for future fisheries (Table 4). This expectation is based on our consistent observation that older fish generally dominate the commercial catch due to its early occurrence.

The ASA model treats aerial surveys as true abundance estimates. However, given the uncertainty about survey accuracy and the difficulties with spatial and temporal survey coverage in the Kamishak Bay area, aerial surveys should be regarded as an index. Future research will focus on developing a more comprehensive rating system for aerial survey quality. Without an appropriate rating system to facilitate standardized biomass estimates among years, the utility of aerial surveys in the ASA model is substantially less than size-sex-age samples of the herring run. However, it is also apparent that aerial survey data act as important waypoints to guide the ASA model's biomass forecasts into a realistic regime. Without them, the model attempts to reduce SSQ_{Total} by reducing the overall population size.

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Table 1. Summary of aerial surveys to assess herring in the Kamishak Bay District during 1985 to 1996.

Harvest Year	Months Surveyed	Longest Period Without Survey Coverage: Number of Days	Longest Period Without Survey Coverage: Unsurveyed Dates	Overall Survey Conditions[a]	Survey Estimate: Biomass (tons)	Survey Estimate: Estimate Derivation
1985	April - May	9	5/25-6/2	Fair	13,320	Observation
1986	April - May	8	5/19-5/26	Fair	26,001	Observation
1987	April - May	7	5/17-5/23	Good	35,332	Observation
1988	April - June	4	4/24-27, 5/3-5/6, 5/27-5/30	Good	29,548	Observation
1989	April - May	4	5/13-5/16	Good	27,855	Observation
1990	April - June	6	5/23-5/29	2.1	19,650	Observation
1991	April - June	20	4/25-5/14	3.2	18,163	Observation
1992	April - June	17	5/2-20	1.9	30,660	Run Timing
1993	April - June	12	4/28-5/9	2.5	32,439	Run Timing
1994	April - June	10	5/16-5/25	3.1	23,778	Interpolation
1995	April - June	15	5/3-5/15, 5/17-6/1	2.3	NA	
1996	April - June	11	5/7-5/12, 5/17- 5/27	2.4	18,138	Interpolation

[a] A quantitative method for documenting survey conditions was adopted in 1990. The data reported here is the mean survey condition from all surveys flown that year. Criteria for quantifying survey conditions are: 1= Excellent (calm, no glare); 2= Good (light ripple, uneven lighting, easy to spot schools); 3= Fair (light chop, some glare or shadows, relatively easy to spot schools); 4= Poor (rough seas, strong glare, difficult to spot schools); 5= Unsatisfactory.

Table 2. Index of ASA model runs used to evaluate model sensitivity to the various options for weighting data inputs.

Scenario	Run #	OTRAC[1]	Lamda weighting Catch	Aerials	Run	Aerial Survey Years[2] (lamda)	Total SSQ	Forecast	Comments
1	1	test fish	1	0.0001	1	90+92 (1.0)	0.766	15,781	TRAC residuals computed for most years (as done previously)
	2	test fish	1	0.001	1	90+92 (1.0)	0.766	14,472	TRAC residuals computed for most years (as done previously)
	3	test fish	1	0.01	1	90+92 (1.0)	0.767	12,763	TRAC residuals computed for most years (as done previously)
	4	test fish	1	0.1	1	90+92 (1.0)	0.774	14,059	TRAC residuals computed for most years (as done previously)
	5	test fish	1	1	1	90+92 (1.0)	0.802	26,984	TRAC residuals computed for most years (as done previously)
	6	test fish	1	10	1	90+92 (1.0)	0.817	39,865	TRAC residuals computed for most years (as done previously)
	7	test fish	1	50	1	90+92 (1.0)	0.819	41,741	TRAC residuals computed for most years (as done previously)
2	8	all (pooled)	1	0.0001	1	90+92 (1.0)	0.861	4,170	TRAC residuals computed for most years (as done previously)
	9	all (pooled)	1	0.001	1	90+92 (1.0)	0.861	4,189	TRAC residuals computed for most years (as done previously)
	10	all (pooled)	1	0.01	1	90+92 (1.0)	0.864	4,590	TRAC residuals computed for most years (as done previously)
	11	all (pooled)	1	0.1	1	90+92 (1.0)	0.875	11,862	TRAC residuals computed for most years (as done previously)
	12	all (pooled)	1	1	1	90+92 (1.0)	0.915	28,495	TRAC residuals computed for most years (as done previously)
	13	all (pooled)	1	1	1	90+92 (1.0)	0.915	28,495	Increased Excel Solver precision to see if it would change forecast
	14	all (pooled)	1	10	1	90+92 (1.0)	0.934	43,709	TRAC residuals computed for most years (as done previously)
	15	all (pooled)	1	50	1	90+92 (1.0)	0.937	45,948	TRAC residuals computed for most years (as done previously)
3	16	all (pooled)	1	0.0001	1	90+92 (1.0)	0.605	39,688	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	17	all (pooled)	1	0.001	1	90+92 (1.0)	0.605	33,604	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	18	all (pooled)	1	0.01	1	90+92 (1.0)	0.606	25,500	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	19	all (pooled)	1	0.1	1	90+92 (1.0)	0.611	25,302	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	20	all (pooled)	1	1	1	90+92 (1.0)	0.63	40,736	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	21	all (pooled)	1	10	1	90+92 (1.0)	0.64	53,879	Only computed TRAC resids for yrs with late samples (86,88,90,96)
	22	all (pooled)	1	50	1	90+92 (1.0)	0.66	54,681	Only computed TRAC resids for yrs with late samples (86,88,90,96)
4	23	all (pooled)	1	0.0001	1	90+92 (1.0)	0.653	50,681	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	24	all (pooled)	1	0.001	1	90+92 (1.0)	0.654	29,747	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	25	all (pooled)	1	0.01	1	90+92 (1.0)	0.658	15,563	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	26	all (pooled)	1	0.1	1	90+92 (1.0)	0.669	10,985	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	27	all (pooled)	1	1	1	90+92 (1.0)	0.725	14,369	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	28	all (pooled)	1	10	1	90+92 (1.0)	0.784	20,456	Same as runs 16-22, but maturity constrained at 1.0 by age 8
	29	all (pooled)	1	50	1	90+92 (1.0)	0.793	22,334	Same as runs 16-22, but maturity constrained at 1.0 by age 8
						Min. Total SSQ	0.605	4,189	Min. Forecast Biomass
						Max. Total SSQ	0.937	54,681	Max. Forecast Biomass
						Avg. Total SSQ	0.757	26,712	Avg. Forecast Biomass

[1] OTRAC= Observed total run age composition: all (pooled) indicates all 1996 samples (April and May test/sampling fisheries) were pooled to represent the total run; test fish indicates only April's (pre-commercial fishery) test fish samples were used (as has been the case in most previous years).

[2] Survey years 1990 and 1992 were weighted at 1.0 and were the only survey years considered good enough to include in the model.

Table 3. Final parameter estimates from the ASA model for the 1996 and the 1997 forecasts of herring returning to Kamishak Bay, Alaska.

Parameter	Estimated Parameter Value		Remarks
	1996 Forecast[a]	1997 Forecast[b]	
S	0.64	0.67	Estimated in 1996, fixed in 1997, Equation 1
β	1.181	1.324	Fishery selectivity steepness parameter, Eq. 3
α	5.601	5.452	Age of 50% fishery selectivity, Equation 3
ϕ	0.785	0.998	Maturity curve parameter, Equation 5
τ	6.227	5.588	Age at 50% maturity
	Initial cohort abundance by year class (x 1 million herring)		
1978 age-3	193.17	131.21	
" " age-4	94.34	61.87	
" " age-5	3.11	15.10	
" " age-6	0.18	0.17	
1979 age-3	240.96	164.97	
1980 age-3	384.16	274.56	
1981 age-3	203.71	144.85	
1982 age-3	221.98	161.21	
1983 age-3	151.66	110.42	
1984 age-3	195.43	144.37	
1985 age-3	40.72	29.36	
1986 age-3	227.69	167.00	
1987 age-3	370.61	273.61	
1988 age-3	78.96	60.38	
1989 age-3	65.66	55.04	
1990 age-3	136.45	107.05	
1991 age-3	625.77	507.96	
1992 age-3	57.79	62.21	
1993 age-3	48.11	57.57	
1994 age-3	14.47	50.86	
1995 age-3	4.89	129.26	
1996 age-3	172.41	152.01	Calculated as a median for the 1996 forecast.
1997 age-3		131.21	Calculated as a median for the 1997 forecast.

[a] From Bechtol and Brannian 1996

[b] Represents initial parameter values for the 1998 forecast.

Table 4. Forecast age compositions of herring run abundance and harvest biomass for the Kamishak Bay District in 1997.

	1997 Forecast					1997 Projected Harvest	
Age	Inshore Run Abundance (million fish)	Age Composition	Mean Weight (g)	Biomass (tons)	Harvest Rate	Allowable Harvest (tons)	Proportion by Weight
3	9.22	8.2%	80	807	0.15	121	3.2%
4	17.32	15.4%	127	2,425	0.15	364	9.6%
5	20.56	18.3%	162	3,671	0.15	551	14.5%
6	8.67	7.7%	198	1,892	0.15	284	7.5%
7	8.49	7.6%	226	2,116	0.15	317	8.4%
8	6.36	5.7%	247	1,731	0.15	260	6.8%
9	33.32	29.7%	267	9,807	0.15	1471	38.8%
10	4.08	3.6%	295	1,327	0.15	199	5.2%
11	1.09	1.0%	303	362	0.15	54	1.4%
12	0.61	0.5%	309	207	0.15	31	0.8%
13+	2.56	2.3%	339	956	0.15	143	3.8%
Total			227	25,302		3,800[a]	

[a] Total projected 1997 harvest was rounded up.

Table 5. Allocation of the projected 1997 Kamishak Bay herring harvest.

	Exploitation Rate	Allowable Harvest (tons)
Kamishak Bay Sac Roe Fishery	0.135	3,420
Shelikof Strait Food-and-Bait Fishery	0.015	380
Total	0.150	3,800

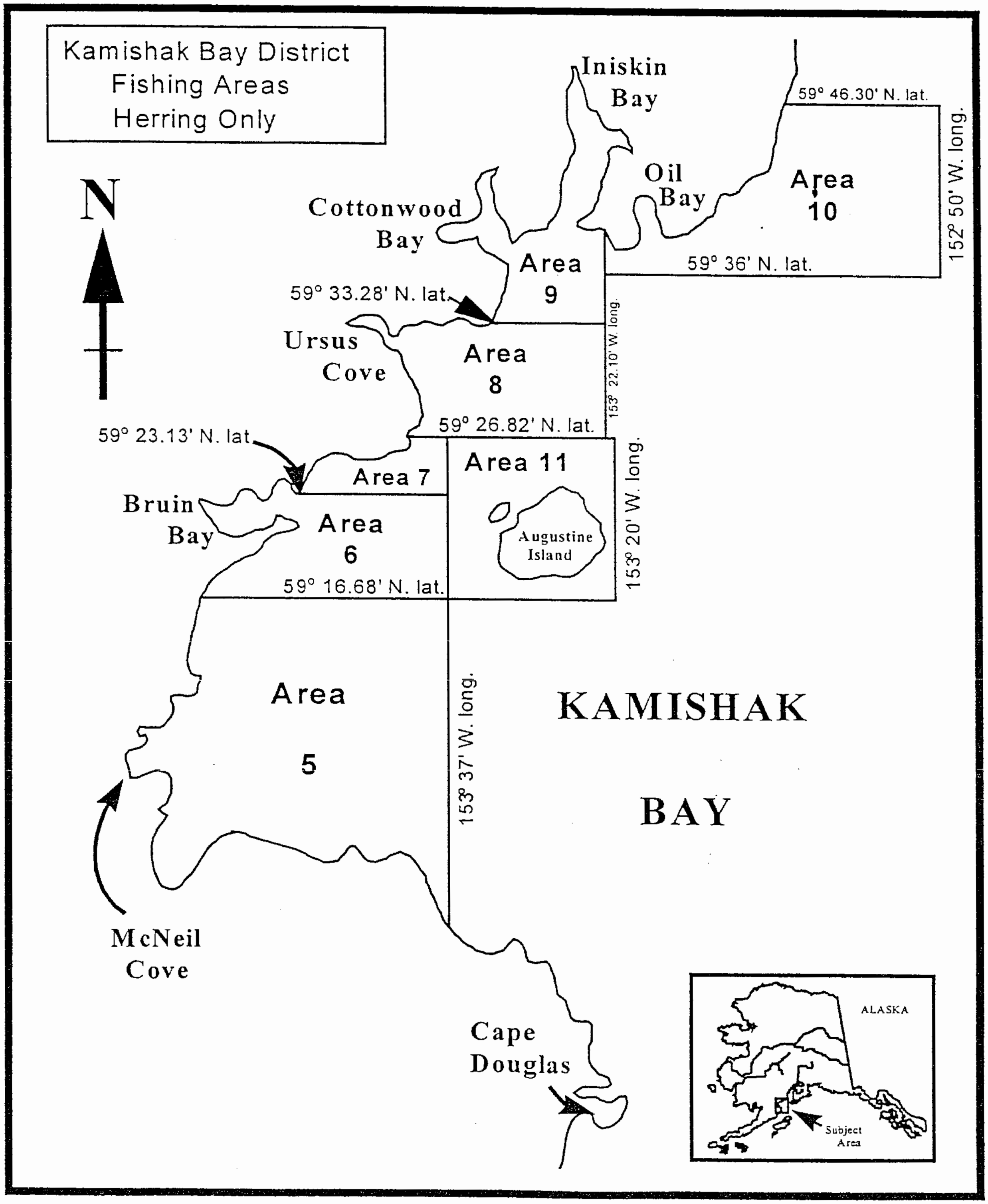


Figure 1. Commercial herring fishing areas in Kamishak Bay District, Alaska.

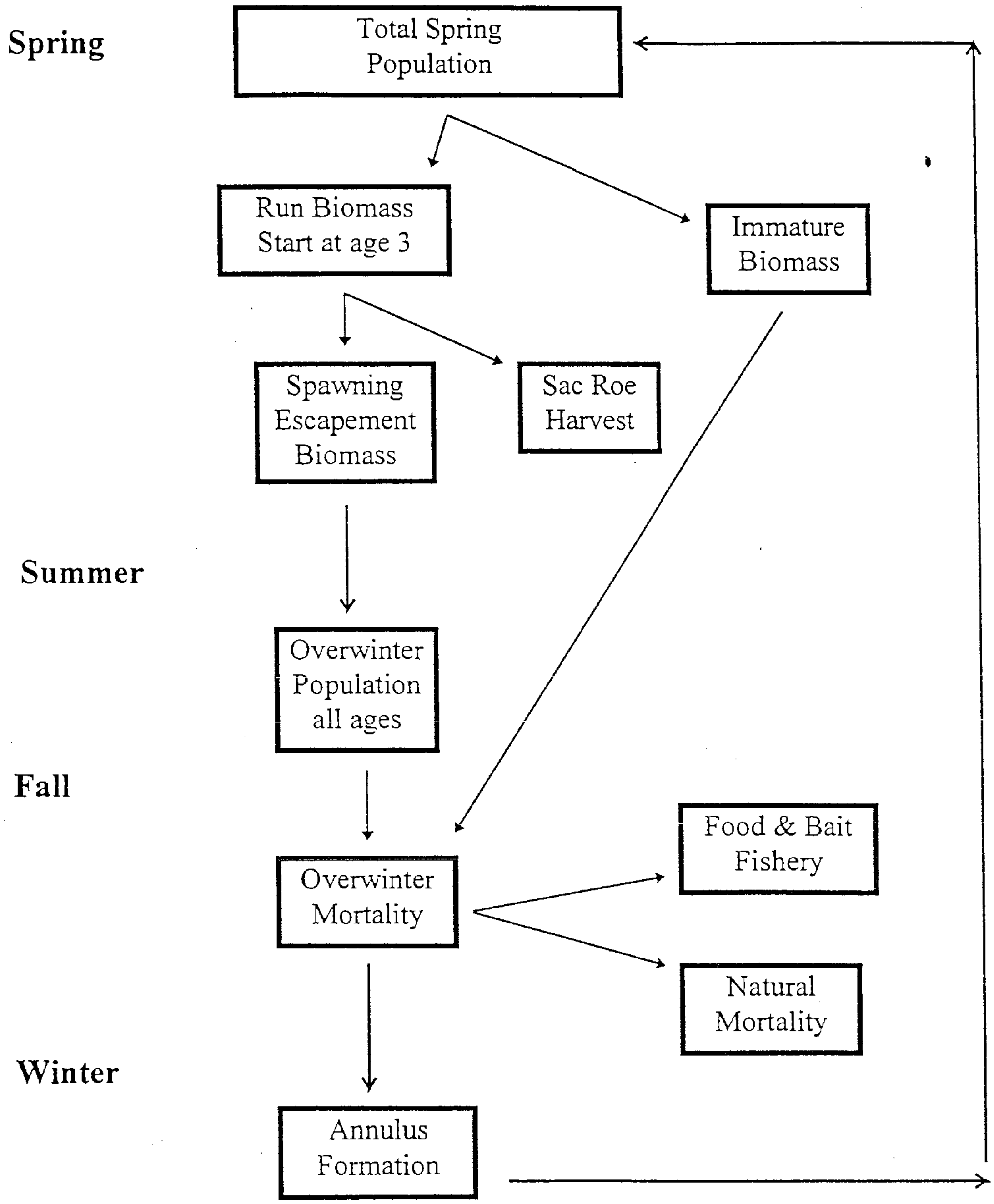
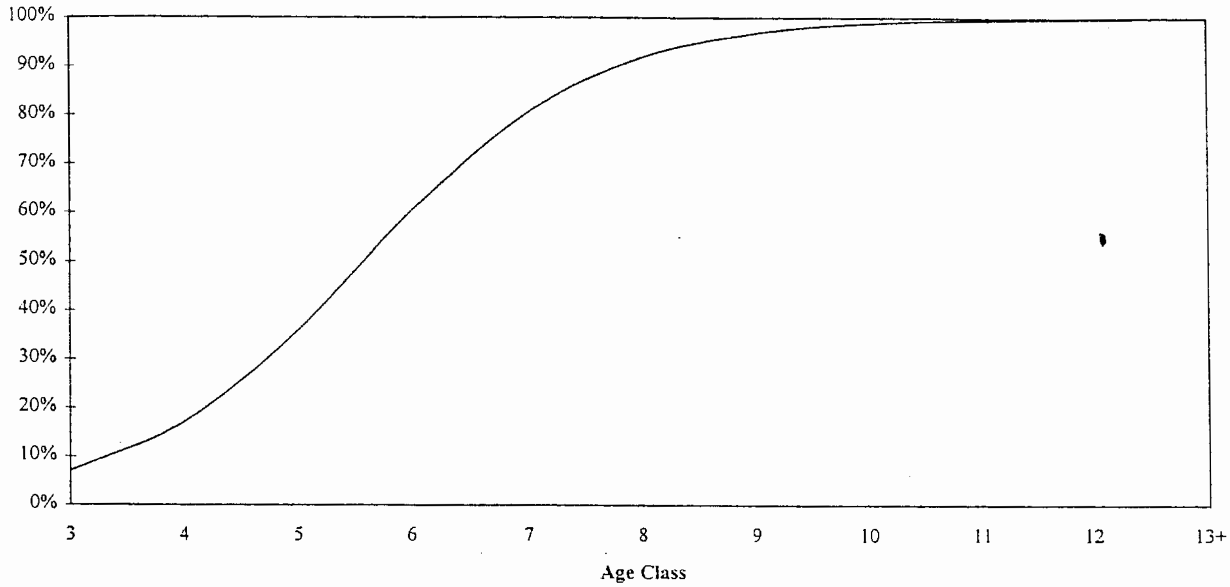


Figure 2. Conceptual model of the annual cycle of events affecting the Kamishak herring population.

A. Sexual Maturity.



B. Fishery Selectivity

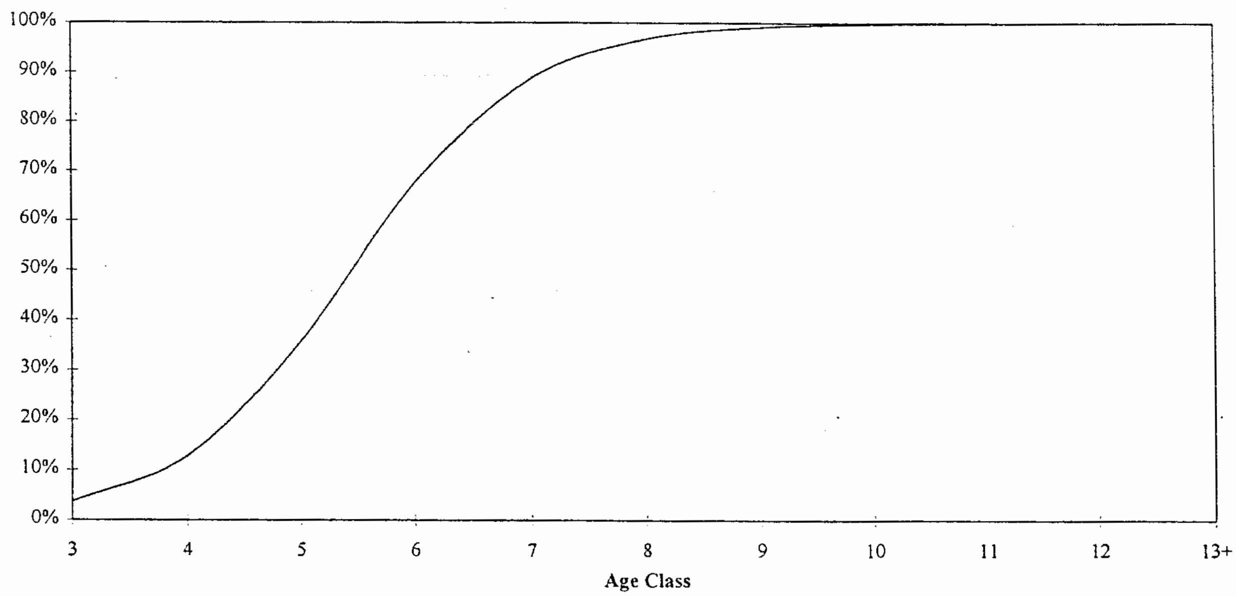
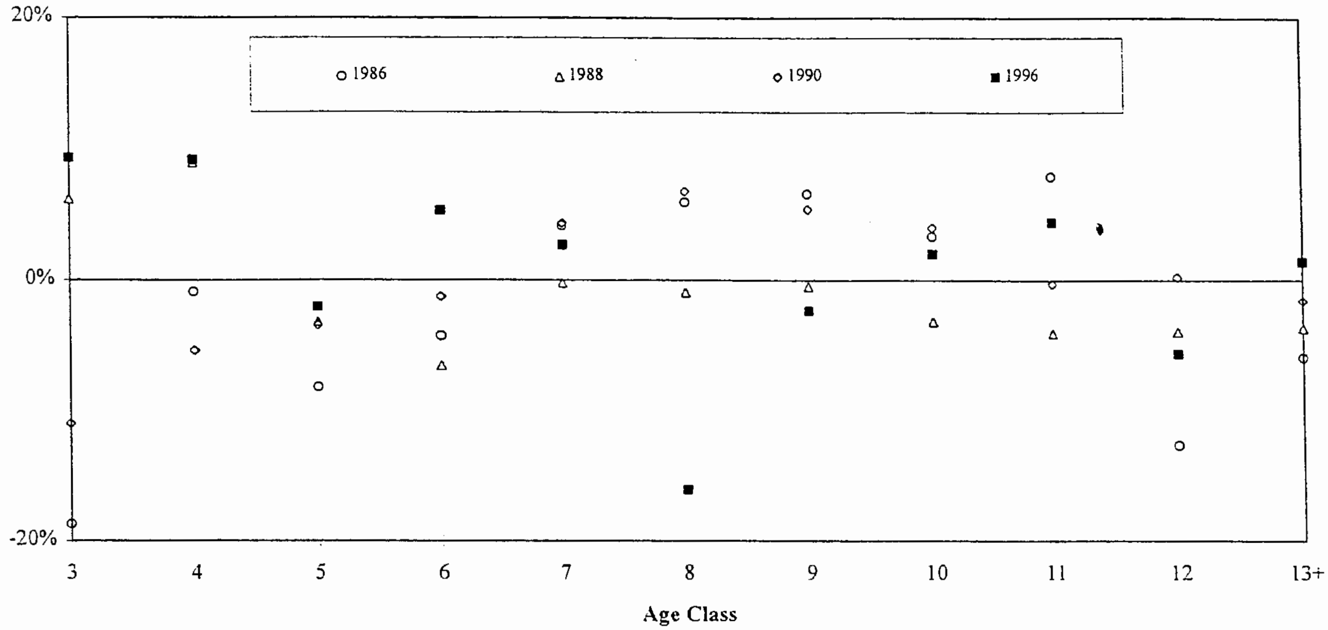


Figure 3. Maturity (A) and fishery selectivity (B) curves estimated by the ASA model for the Kamishak Bay herring run.

A. Total run age composition residuals (transformed)



B. Catch age composition residuals (transformed)

Figure 4. Residual differences between transformed estimated and observed age composition values for the (A) total run biomass and the (B) commercial catch of Kamishak Bay herring returns during 1985 to 1996.

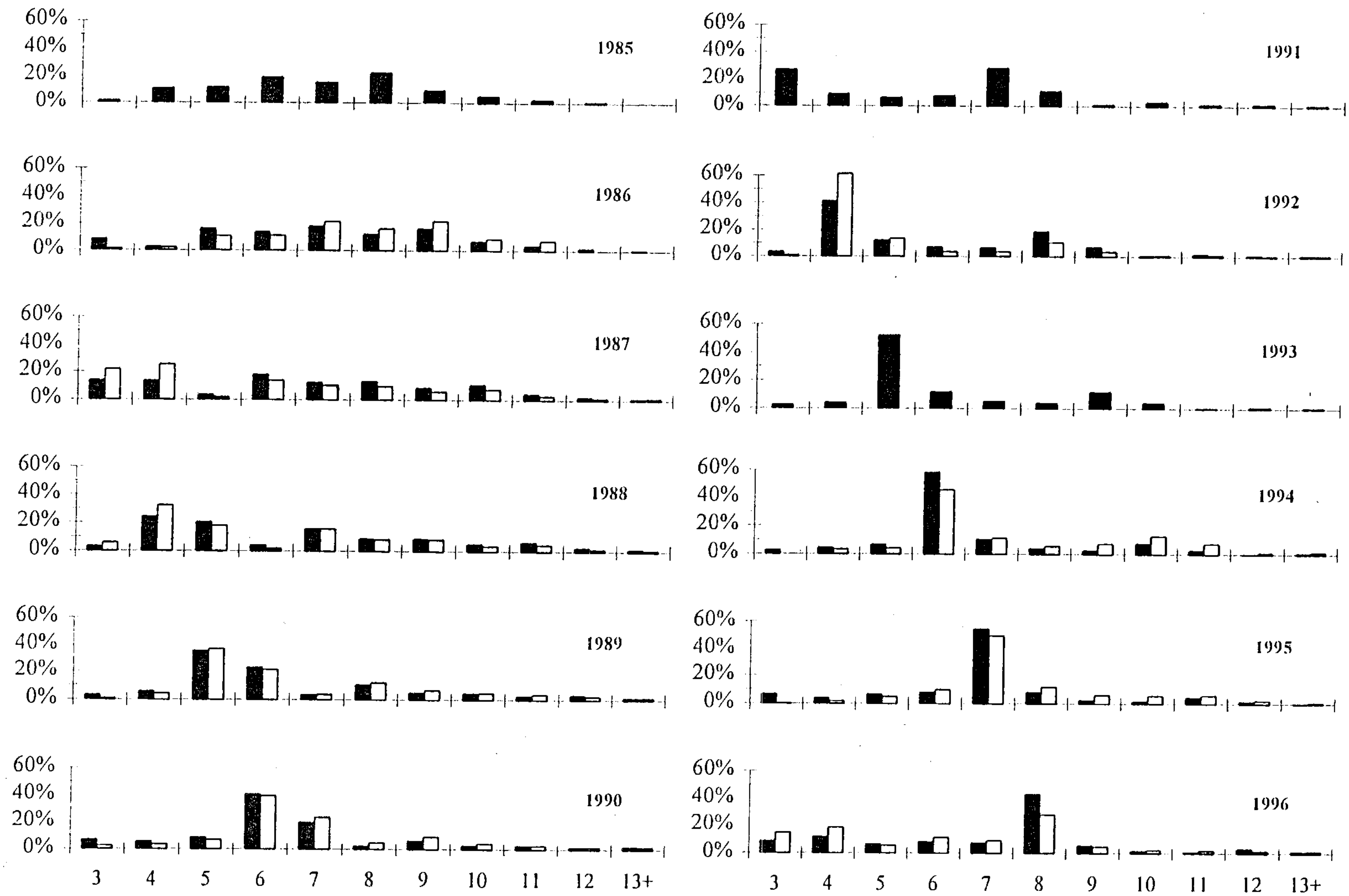


Figure 5. Total run age composition as estimated by the ASA model (black bars) and observed by sampling (white bars) for Kamishak Bay herring during 1985-1996 (sampling did not occur in 1985, 1991, or 1993).

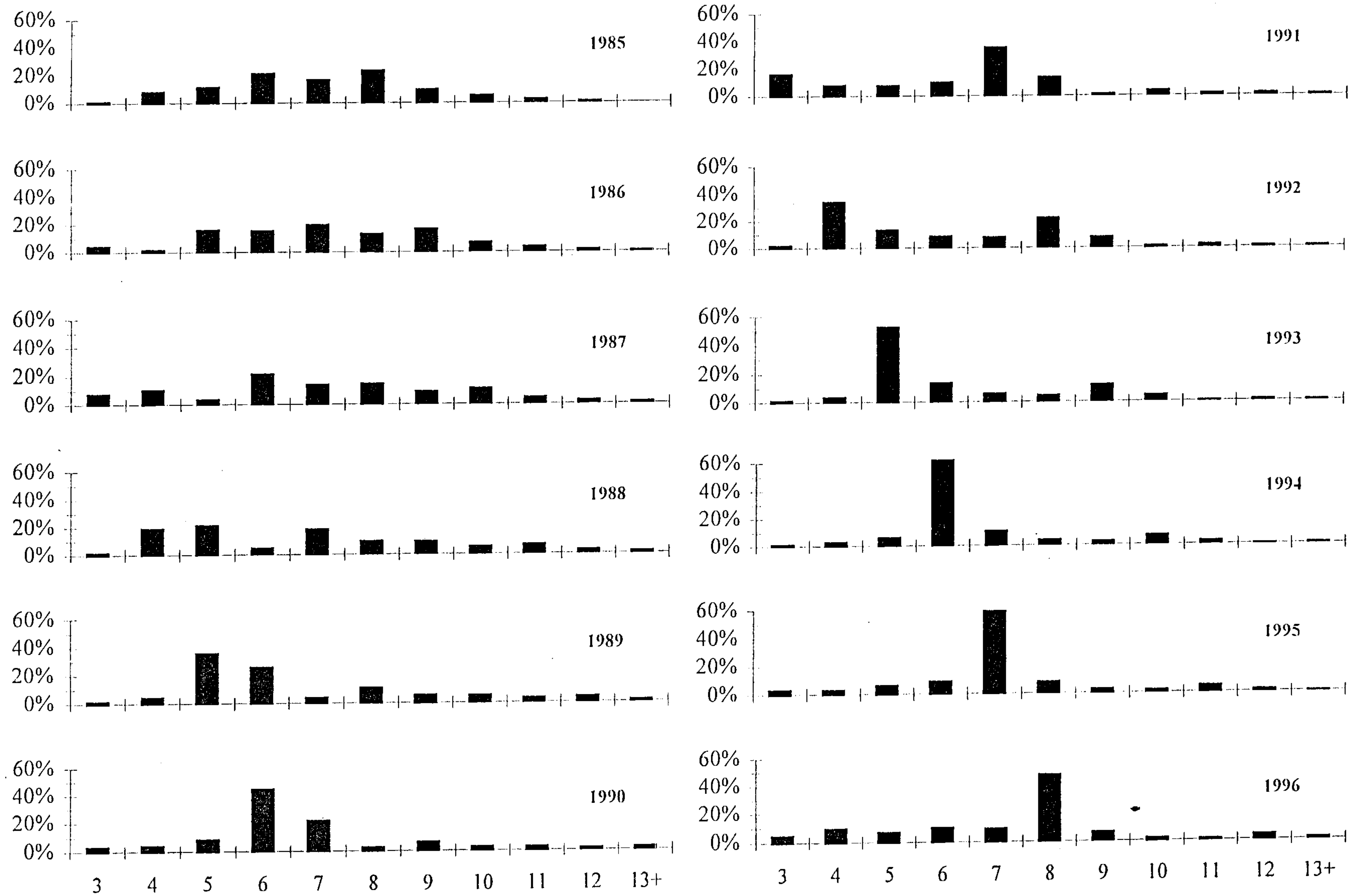


Figure 6. Commercial catch age composition estimated by the ASA model for Kamishak Bay herring during 1985-1996.

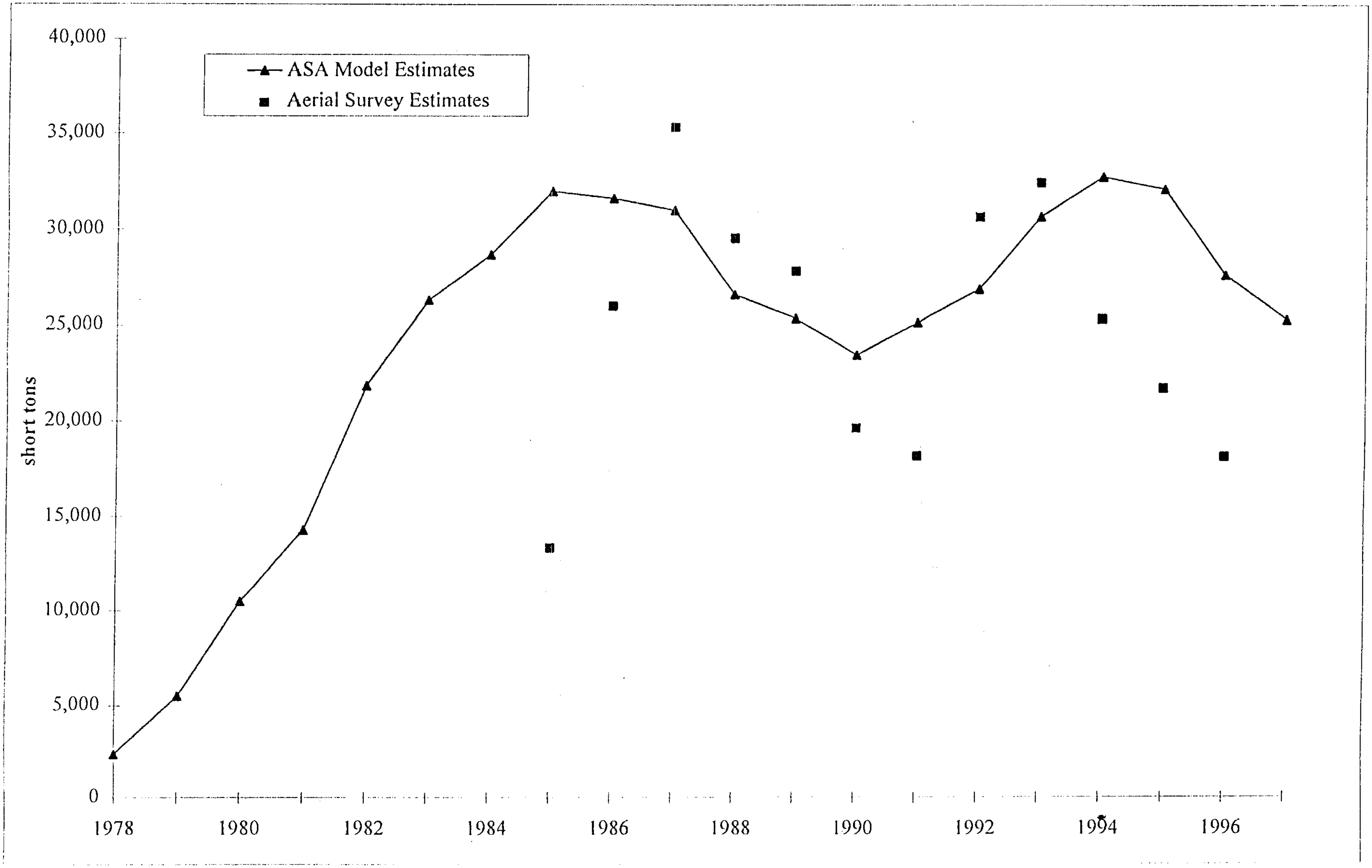


Figure 7. Kamishak Bay herring run biomass estimated by the ASA model for 1978 to 1995 and observed by aerial surveys during 1985 to 1994.

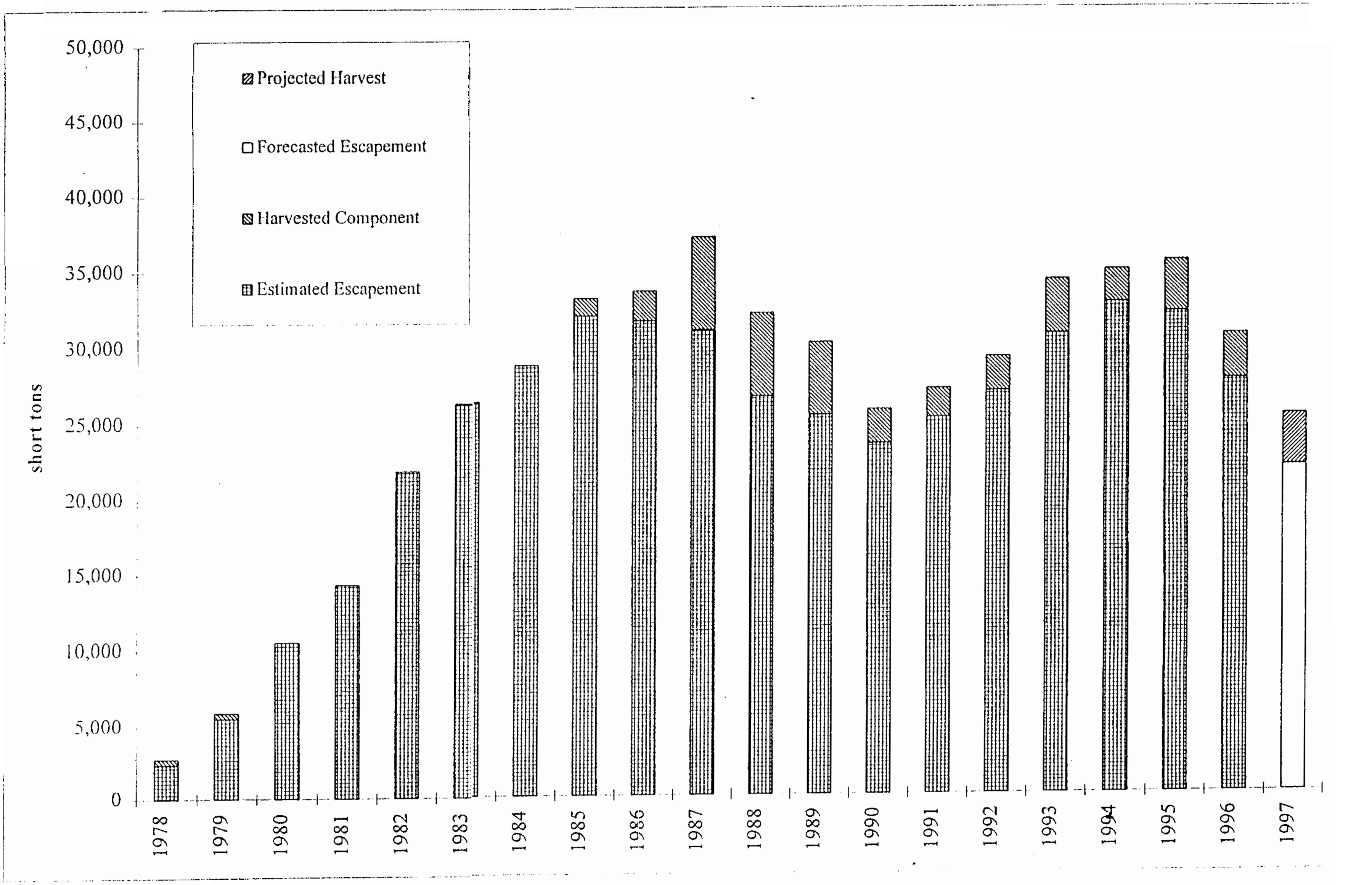


Figure 8. Kamishak Bay District herring catch and estimated escapement during 1978 to 1996 and as forecast for 1997

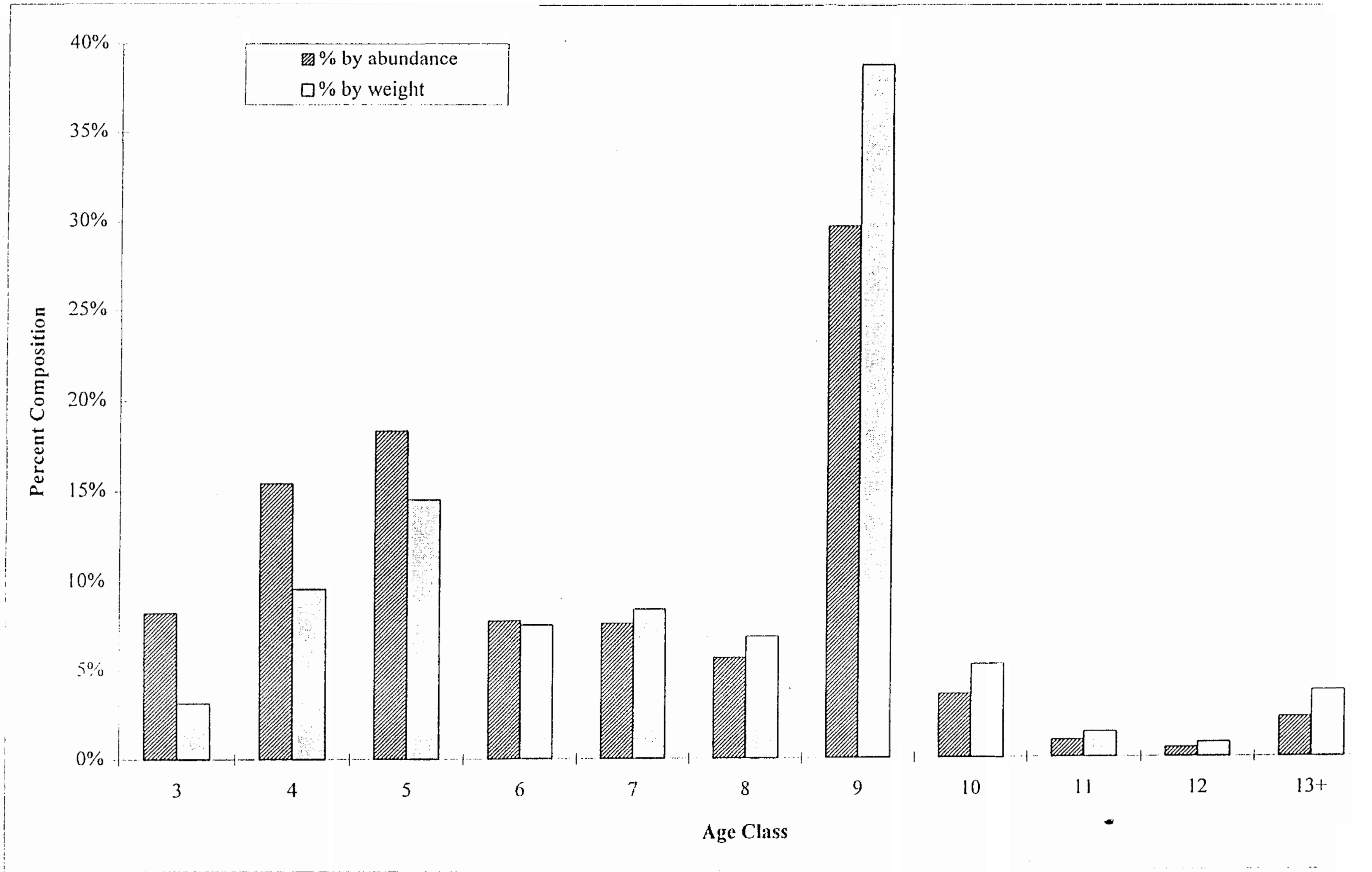


Figure 9. Kamishak Bay District herring age composition as a percentage of the total forecast (by abundance and by weight) to return in 1997.

Appendix A. Kamishak Bay District herring catch by age and harvest year during 1978 to 1996.

	Age Class Abundance (X 1,000 fish)										
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13+**
Year											
1978	400	1,353	915	93	88	131	110	110	440	11	
1979	618	533	1,012	725	53	32	43	21	21	21	
1980											
1981											
1982				Fishery	Closed						
1983											
1984											
1985	10	569	700	1,124	739	1,177	433	253	204	49	0
1986	1,093	227	1,028	889	1,586	1,190	1,609	647	250	196	66
1988	120	5,593	5,338	592	5,160	2,687	2,743	1,231	1,485	481	209
1989	12	388	7,599	4,704	825	2,796	1,615	1,168	938	662	379
1990	154	364	603	4,327	2,333	647	789	444	211	94	77
1991	1,102	697	787	945	3,690	1,462	45	270	112	22	22
1992	87	8,344	1,848	520	491	1,415	491	115	173	29	87
1993	26	367	10,007	2,362	945	945	1,916	630	105	52	52
1994	0	180	334	4,453	923	633	481	947	492	76	140
1995	49	346	673	1,035	6,959	1,366	756	724	756	312	66
1996	49	687	1,079	1,006	1,227	5,691	1,006	393	245	196	148

Appendix B. Observed age composition of the herring run biomass in the Kamishak Bay District during harvest years 1986 to 1995.

	Age Class										
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13+**
Year	Percent of the Total Run Biomass for the Return Year										
1986[1]	1.10	2.10	10.70	11.10	21.30	16.50	21.60	8.50	7.10	0.00	0.00
1987	21.70	25.40	1.90	13.50	9.90	9.30	5.60	7.30	2.90	1.20	1.30
1988[1]	5.89	32.38	17.87	1.82	15.66	8.07	8.16	3.67	4.40	1.40	0.68
1989	1.22	4.55	37.21	21.52	3.91	11.83	6.79	4.84	3.90	2.70	1.53
1990[1]	2.40	3.50	6.90	39.50	23.40	5.00	9.10	4.20	2.60	1.60	1.80
1991											
1992	0.60	61.50	13.60	3.80	3.60	10.40	3.60	0.80	1.30	0.20	0.60
1993											
1994	0.10	3.23	4.04	45.80	11.21	5.56	7.17	12.83	7.37	1.01	1.72
1995	0.24	2.01	5.13	9.71	49.76	11.66	6.29	5.86	6.04	2.38	0.92
1996[1]	14.80	18.80	5.70	11.50	9.20	28.10	4.70	2.20	2.00	1.60	1.40

[1]Only data from years 1986, 1988, 1990, and 1996 were used in the ASA model to forecast the 1997 return.

Appendix C. Kamishak Bay District herring mean weight by age and year of harvest during 1978 to 1996.

	Age										
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13+**
Year	Mean Weight (grams)										
1978	61	85	121	168	170	188	204	217	212	247	
1979	68	98	128	156	170	197	210	221	272	265	
1980[a]	69	107	136	155	186	204	219	229	260	270	
1981	70	88	124	121	186	204	219	229	260	270	
1982[a]	69	107	136	155	186	204	219	229	260	270	
1983	74	118	137	160	182	196	210	218	253	270	
1984[a]	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
1987	91	134	162	198	218	241	251	267	276	275	288
1988	84	123	163	196	218	236	248	261	266	280	298
1989	98	131	158	199	228	245	254	268	285	288	298
1990	90	135	162	182	220	245	256	273	289	303	310
1991	79	118	172	208	214	259	267	288	280	229	413
1992	99	116	156	210	229	234	266	304	303	279	333
1993	88	131	152	193	230	245	260	293	302	317	382
1994	55	147	174	190	223	256	261	283	300	315	325
1995	76	124	168	200	223	258	282	295	310	325	327
1996	81	119	162	199	224	241	264	299	298	311	326
1997[b]	80	127	162	198	226	247	267	295	303	309	339

[a] Mean weights for 1980, 1982, and 1984 were calculated as averages across available values from 1979 to 1985.

[b] The five-year average from 1992 to 1996 was used to predict mean weights in 1997.

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

Year	Estimated Run Biomass (tons)
1990	19,650
1992	30,660

Appendix E. Data files used to forecast the herring biomass returning to Kamishak Bay in 1997.

Data File	Data Format	Description
97HERFOR.XLS	Excel 5.0	Spreadsheet containing commercial catch and total run age compositions, biomass estimates, and maturity and fishery selectivity curves used by the ASA model to forecast the 1997 return of herring to Kamishak Bay. Also includes a table summarizing pertinent data to go into the annual management and forecast reports; documents data sources and procedures.
ASAINDEX.XLS	Excel 5.0	Spreadsheet indexing all ASA model runs used to evaluate the sensitivity of the model to various data input weighting options.
SSQSUM97.XLS	Excel 5.0	Summary of pertinent results of sensitivity analyses described above.