FORECAST OF THE KAMISHAK HERRING STOCK IN 1996

by

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ABSTRACT

The 1996 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, 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 1996 abundance. A recent five-year average (1991-1995) was used to predict herring weight at age in 1996.

A biomass of 20,925 tons (18,983 tonnes) of herring is expected to return to the Kamishak Bay District in 1996. Herring mean weight is predicted to be 223 g. The 1988 year class is forecast to represent 59% of the run biomass (53% of the population abundance) as age-8 herring. Due to an apparently weak 1992 year class, few age-3 herring were observed in 1995 catch samples and few age-4 returns are expected in 1996. The total allowable herring harvest for 1996 is projected to be 2,500 tons (2,268 tonnes) based on an exploitation rate of 12% of the forecast. The harvest allocation is 2,250 tons (2,042 tonnes) for the Kamishak spring sac roe fishery and 250 tons (227 tonnes) for the Shelikof Strait fall food and bait fishery.

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

INTRODUCTION

This report presents the forecast for the 1996 Kamishak Bay herring run biomass. This herring 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 limits typically limit the fishery to a series of short openings from late-April to early-May (Bucher and Hammarstrom 1995).

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 began in early April when the herring spawning grounds in the nearshore areas of Kamishak Bay were surveyed from small aircraft to monitor relative biomass, distribution, and spawning of the herring population. Daily biomass estimates were derived from the number and size of observed herring schools. Run biomass estimates for each year was either: (1) the sum of "peak" estimates from this time series of aerial observations if the surveyor believed observed herring resided in the surveyed area more than one day; or (2) the sum of all surveys if residence time was only one day. Because herring migration to and from the spawning grounds was likely a continuous process, aerial surveys were considered to be conservative biomass estimates.

Run estimates have historically been derived from the preseason forecast or from run timing proportions (Yuen *in press*). 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-caulculate estimates of age-3 herring and was less dependent on annual aerial survey estimates of run biomass (Yuen et al. 1994).

Both old and new forecast methods minimized differences between predicted and observed age composition as well as total run biomass. ASA sought a simultaneous solution while the exponential decay model progressed in a step wise manner. In the ASA forecast of the 1995 return, the predicted run biomass was scaled to aerial survey estimates of run biomass from years 1986 through 1990 which were rated as having "fair" or "good" survey coverage. 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. However, the herring run occurs from April to June with the rating reflecting a cumulative assessment of the aerial survey coverage. 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 press*). In addition, these exclusions largely fail to incorporate calibrated survey techniques used since 1989 (Lebida and Whitmore 1985). Such techniques only partially corrected the tendency for aerial surveys to be conservative. The development of the 1996 forecast attempted to examine model sensitivity by varying the emphasis placed on survey years, including some years in the 1990s which had poor temporal coverage but involved calibrated estimates under reasonable survey conditions and were expanded through a run timing model (Yuen *in press*).

Specific objectives of this report are to (1) document data sources and methodology used for the 1996 forecast, (2) present the 1996 forecast, and (3) through application of the Kamishak Bay Herring Management Plan (5 AAC 27.465), propose a harvest guideline for the 1996 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. In reality, 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 six seasons. Purse seine fishing generally occured 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, 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 occured in intertidal areas of 0-12 m in depth.

METHODS

Database

Kamishak herring harvest abundance by age, harvest and run age composition and mean weights through 1994 were forwarded from last year's ASA model (Yuen and Brannian 1994, Appendix A-C). Preliminary 1995 data were obtained from age-sex-size sampling and fish ticket data (Appendix A-C). Revisions were also made to the total run age composition data used in the model (Appendix B). Data for 1986 (Schroeder 1989), 1992 (Yuen and Bucher 1994*a*), and 1994 (Yuen and Bucher 1994b) were added. For the 1991 run age composition, estimates which incorporated younger age herring were substituted for historical data in ASA forecast of the 1995 return (Yuen et al. 1994). We chose to remove these estimates because actual samples from the same year classes in 1992 were available.

Aerial survey estimates of run biomass (Appendix D) were obtained from the most recent annual management report (Bucher and Hammarstrom 1995) 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*a*). During herring aerial surveys, observers estimated the surface area of herring schools arriving on the spawning grounds. The conversion of herring school surface area to biomass was undocumented for Kamishak Bay prior to 1989. 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 1995 were hampered by bad weather and turbidity for the fifth consecutive year (Table 1). A 'poor' aerial survey rating for 1995 resulted from weather preventing aerial surveys between 3 and 15 May and again from 17 May through 1 June.

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 1996, the model also updated estimates of natural mortality, maturity, and historical abundance for 1979-1995, and also the gear 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 survival, gear selectivity, a maturity curve, and the number of age-3 herring for each cohort from the 1995 forecast (Yuen and Brannian 1994) were used as initial parameter values for the 1996 forecast. The 1996 mean weight-at-age was estimated as the five-year mean weight for the years 1991 to 1995. The biomass of age-3 herring in 1996 was forecast as the median of age-3 biomass estimates since 1978.

Model Assumptions

The following assumptions are incorporated into the model:

1. Purse seine gear 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 age compositions catch and.survey age compositions are arc sine transformed and error terms are scaled and weighted.

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. 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 in year y:

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

where S is the annual survival rate, and $C_{a,y}$ is the catch from the spring purse seine sac roe fishery. The annual survival rate of 67% was used to forecast the 1995 return but became an estimated parameter for the 1996 forecast. 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+.

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 incorporating an age-specific gear selectivity function, s_a, and the estimated abundance, $N_{a,y}$, from equation (1):

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

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 herring size classes during the fishery or sample collection (Schroeder 1989; Yuen 1994). Functions 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 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.

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:

$$SSQ_{agecomp:catch} = \sum_y \sum_a \left(\frac{C_{a,y}}{\sum_{a=3}^{13} C_{a,y}} - \hat{p}_{a,y} \right)^2 , \tag{4}$$

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. Purse seine age composition was fit across ages 3 to 13+ and years 1985 through 1995.

Maturity

The ASA model calculates a maturity curve to estimate the proportion of each age class which returned to spawn each year. The 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:

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

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. 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 (Schroeder 1989).

SSQ Biomass Estimates

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, and spatial and temporal coverage. A qualitative rating of geographic and temporal coverage was applied to aerial surveys for the years 1985-1995 (Table 1).

Aerial surveys from the years 1986 to 1990 were rated 'OK' and initially used in the ASA model. Beginning with the 1995 forecast, aerial estimates developed from both observations and migratory run timing were also included. Because of the dominance of the 1988 year class in recent returns, our goal was to choose the model that best represented this cohort. One measure of ASA model fit was obtained by comparing model run biomass estimates with estimates from 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:

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

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) , $N_{a,y}$ 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).

To examine model sensitivity to various aerial survey weighting schemes and to incorporate confidence in the repeatability of surveys for individual years using calibrated survey techniques, the model was run under the following weighting schemes applied to individual survey years:

(1) survey years 1986-1990 given an equal weighting of 1.0 and other aerial surveys excluded from the model;
(2) survey years 1987-1990 and 1992 given an equal weighting of 1.0 and other aerial surveys excluded from the model;
(3) survey years 1990 and 1992 given an equal weighting of 1.0 and other aerial surveys excluded from the model

(4) survey year 1990 given a weighting of 1.0, year 1992 given a weighting of 0.5, and other aerial surveys excluded from the model.

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, 1994-1995 (Appendix B). The age composition of the run biomass was estimated using herring sampled from the commercial fishery and also from herring concentrations observed in Kamishak Bay by aerial surveys or with vessel sonar during fishery closures. Vessel operators volunteered during commercial closures to make purse seine sets to capture herring (referred to as test fishing). 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. Samples were pooled whenever possible to obtain sample sizes large enough to represent the estimated biomass within time and area strata.

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

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

where $p_{a,y}^{run}$ is the observed run age composition estimated for age a and year y. The arc sine square root transformation was applied to observed and estimated age composition proportions to stabilize their variance. Only the samples mentioned above were used in the SSQ of equation 7. Though catch sampling began in 1985, and some sampling has occured every year, sampling before and after the fishery was inconsistent among years and not thought to be representative of the entire run biomass.

Forecasting Methods

The forecast of herring run biomass for 1996 ($B_{1996}^{Forecast}$) was projected from total abundance with the survival model (equation 1) modified by the ASA estimated proportion of mature herring expected for each age:

$$B_{1996}^{Forecast} = \sum_{a} \rho_a \hat{w}_{a,1996} \hat{N}_{a,1996}, \tag{8}$$

where ρ_a is the proportion mature at age a from equation (5); $w_{a,1996}$ is the individual fish weight at age a from the recent 5-year average (1991-1995; Appendix C); and $N_{a,1996}$ is the ASA estimate of age-a herring for 1996 from equation (1). The above model was used to forecast the 1996 herring abundance for all ages except age 3. Lacking an adequate method to predict age-3 year class strength, we used the median ASA estimate of age-3 abundance from years 1978-1995 to generate $N_{3,1996}$. The median was thought to be more representative of recruitment than the mean because of the skew in the distribution of age-3 abundances.

The age composition ($p_{a,1996}$), of $B_{1996}^{Forecast}$, was estimated using the maturity schedule (ρ_a of equation 5) as:

$$\hat{p}_{a,1996} = \frac{\hat{N}_{a,1996}\rho_a}{\sum_a \hat{N}_{a,1996}\rho_a} \tag{9}$$

Parameter Estimation

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

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

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 and set those λ's equal to 1.0. Weights for the 1996 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 0.001 to 1,000 to examine model sensitivity to aerial survey weighting while letting the age composition SSQs be very close to their minimum. Our choice of weights was based on a graphical display of the influence that aerial survey weighting had on the forecast. Based on preliminary analysis, model runs included in the final forecast were limited to aerial survey weighting of $\lambda_{biomass}$=0.1 or $\lambda_{biomass}$=1.0. This restriction reduced what appeared to be forecast outliers. Given this restriction, we had difficulty in choosing a particular model run because the total SSQ was generally quite similar bewteen most model runs, and model forecasts fell within 30 percent of the mean forecast. Therefore, results from the different model runs were averaged to provide a final forecast.

Minimization Methods. The ASA model estimated a total of 26 parameters: 21 initial cohort sizes, two gear selectivity function parameters (α and β), and two maturity function parameters (φ and τ), and the survival rate parameter (S). The three SSQ equations referred to 215 data observations with 189 degrees of freedom and a data to parameter ratio of approximately 8:1. However, the information available from the data was less than if all observations were independent.

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 was set at 0.00001. Population sizes for all cohorts forecast to return in 1996 were constrained to be greater than or equal to zero because negative population values were unrealistic and negative residuals could not be arc sine transformed.

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, when choosing the purse seine selectivity function, we graphed residuals for purse seine age composition against year or 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.

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

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 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%. If the forecast is more than 20,000 tons but less than 30,000 tons, the total exploitation rate may increase to a maximum of 15%. If the forecast is more than 30,000 tons, the total exploitation rate may increase to 20%. The relative allocation between the two fisheries remains the same with 10% of any allowable exploitation allocated to Shelikof and the remainder allocated to Kamishak. Inseason, 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

Several ASA models were tested. The first model was similar to the forecast of the 1995 return where maturity was constrained to only accept parameter values estimating the percent mature at age 6 to be ≥ 0.98. Subsequent models did not constrain the maturity curve. Removing the constraints on maturity reduced $SSQ_{age\ comp:run}$ and improved the distribution of run age composition residuals, leading us to accept an unconstrained maturity curve for the 1996 forecast (Table 2; Figure 3). Subsequent model runs involved changes in aerial survey weights. SSQ_{total} appeared to be fairly stable after elimination of some model runs as apparent outliers.

Pooled residuals of the run biomass age composition appeared to be evenly distributed about zero when displayed as a function of age (Figure 4). The largest residuals were for age-3 and -4 herring. There was also a trend in residuals for some years, such as the 1987 run biomass which had negative residuals for age-5 and older herring. Based on the residual calculation of observed minus predicted, this indicated that the ASA model tended to underestimate what was observed in test fish samples. 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).

Residuals of the purse seine catch age composition from the ASA model did not form a distinct horizontal band centered around zero when displayed as a function of age (Figure 4). The variability seemed greatest for older herring with a tendency for negative residuals in age-5 to -8 herring and positive residuals in age-11 and older fish. However, no strong trend was seen in residuals plotted by age for each year, and the age composition of the purse seine catch estimated from the ASA model generally agreed well with the observed age. The increasing reliance of the Kamishak Bay catch on the 1988 year class was evident (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 1986 and the best from 1987 to 1990. 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 20,925 tons (18,983 tonnes) of herring is expected to return to the Kamishak Bay District in 1996 (Table 3; Figure 8). Depending upon the weighting of individual aerial survey years and also the specific λ applied in model runs, model forecasts ranged from 16,469 to 27,290 tons.

Herring mean weight in 1996 is predicted to be 223 g. The 1988 year class, returning as age-8 herring in 1996, is forecast to represent 59% of the run biomass and 53% of the total abundance (Table 3; Figure 9). The forecast of few age-4 herring in 1996 follows observations of few age 3 in the 1995 commercial catch samples (Figure 6).

Projected Harvest

The total allowable harvest is projected to be 2,500 tons (2,268 tonnes) based on an exploitation rate of 12% of the forecast. The harvest allocation is 2,250 tons (2,042 tonnes) for the Kamishak spring sac roe fishery and 250 tons (227 tonnes) for the Shelikof Strait fall food and bait fishery (Table 4).

DISCUSSION

In some year's ASA models, age-6 herring were assumed to be the age of full recruitment for the Kamishak stock and therefore age-6 maturity was constrained to be at least 0.98. Removal of this constraint for the 1996 forecast allowed the age of full recruitment to be as late as age 9 (Figure 3). This model also estimated the 1995 biomass at 25,115 tons, almost unchanged from the preseason 1995 forecast of 25,344 tons. If the constraint was left in place, the 1996 forecast would have declined by up to 4,000 tons.

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 1995 being the fifth successive year of aerial surveys being hampered by weather, the 1996 forecast would have relied on an extension of a previous forecast. We would have adjusted the 1995 forecast age composition to match the observed 1995 age composition but could not have adjusted the magnitude of the 1995 run biomass estimate or updated our mortality and recruitment rates in the exponential decay model. This would have essentially resulted in a 6-year forecast from the 1990 escapement data, the last year with a comprehensive aerial survey estimate.

On the other hand, estimates of initial cohort size for the ASA models were age-3 herring. ASA was designed to use the observed 1995 age composition, along with all other observed age compositions, to adjust the initial abundance estimates of age-3 herring except the age-3 forecast for 1996. 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 between 1985 and 1987 with a downturn in the late 1980s (Figure 8). 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 1996 biomass may continue a downward trend. The 1996 forecast is for more than half of the abundance to be age 8 with very little age 4-7 recruitment based on the 1995 age composition samples. The forecast of age-3 recruitment was simply a median and not reliable. This increasing reliance of the Kamishak return on the 1988 year class, appearing as age-8 herring in 1996, is disconcerting because recruitment of younger fish is needed to support future fisheries. A further research emphasis should be to examine the potential of juvenile herring fom Shelikof Strait food and bait fisheries as a predictor of subsequent Kamishak Bay abundance, particularly for age-3 fish in Kamishak.

Field data for the 1985 and 1986 aerial surveys was missing during preparation of last year's forecast. Although this data has since been located, there remains uncertainty about a qualitative rating for these and other survey years. 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 must be regarded as an important index. Future research should focus on developing a more comprehensive rating system for aerial survey quality. If aerial survey data cannot be developed into a better estimator with an appropriate rating system, the utility of aerial surveys in the Kamishak ASA model may be substantially less than size-sex-age samples of the herring run.

We are concerned about the ASA trying to estimate the 1988 year class which is forecast to represent 59% of the run biomass and 53% of the total abundance in the 1996 return (Table 3). This year class has previously presented difficulties for the model. This was the first major year class for which we have limited to poor aerial survey data to verify the forecasts, and ASA models in previous years have generated large residuals for this year class (Yuen and Brannian 1994). Consequently, we have reduced confidence in the 1996 forecast. The management plan compounds the forecast error by allowing an increase in the maximum harvest rate from 10% to 15% exploitation if the run biomass is greater than 20,000 tons. Based on our uncertainty in the 1996 forecast of 20,925 tons, a somewhat reduced exploitation level of 12% is recommended as appropriate.

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Table 1. Summary of aerial surveys to assess herring in the Kamishak Bay District during 1985 to 1995.

		Longest Period Without Survey Coverage		Overall	Survey Estimate	
Harvest Year	Months Surveyed	Number of Days	Unsurveyed Dates	Survey Conditions	Biomass (tons)	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	Good	19,650	Observation
1991	April - June	20	4/25-5/14	Poor	18,163	Observation
1992	April - June	17	5/2-20	Poor	30,660	Run Timing
1993	April - June	12	4/28-5/9	Poor	32,439	Run Timing
1994	April - June	10	5/16-5/25	Poor	23,778	Interpolation
1995	April - June	15	5/3-5/15, 5/17-6/1	Poor	NA	

Table 2. Final parameter estimates from ASA model forecasts of the 1995 and the 1996 run biomasses of herring to Kamishak Bay, Alaska.

Parameter	Estimated Parameter Value 1995 Forecast	1996 Forecast[a]	Remarks
S	0.67	0.64	Fixed in 1995, estimated in 1996, Equation 1
β	1.135	1.181	Gear selectivity steepness parameter, Eq. 3
α	5.562	5.601	Age of 50% gear selectivity, Equation 3
ϕ	0.902	0.785	Maturity curve parameter, Equation 5
τ	4.896	6.227	Age at 50% maturity
Initial cohort abundance by year class (x 1 million herring)			
1978 age-3	67.43	193.17	
" " age-4	64.38	94.34	
" " age-5	14.22	3.11	
" " age-6	3.65	0.18	
1979 age-3	116.36	240.96	
1980 age-3	198.55	384.16	
1981 age-3	121.99	203.71	
1982 age-3	138.70	221.98	
1983 age-3	106.35	151.66	
1984 age-3	132.30	195.43	
1985 age-3	26.25	40.72	
1986 age-3	149.08	227.69	
1987 age-3	209.81	370.61	
1988 age-3	41.27	78.96	
1989 age-3	40.59	65.66	
1990age-3	74.24	136.45	
1991 age-3	370.84	625.77	
1992 age-3	23.98	57.79	
1993 age-3	15.36	48.11	
1994 age-3	0.00	14.47	
1995 age-3	106.35	4.89	Calculated as a median for the 1995 forecast.
1996-age3	NA	172.41	Calculated as a median for the 1996 forecast.

[a] Represents initial parameter values for the 1997 forecast.

Table 3. Forecast age compositions of herring run abundance and harvest biomass for the Kamishak Bay District in 1996.

	1996 Forecast					1996 Projected Harvest	
Age	Inshore Run Abundance (million fish)	Age Composition	Mean Weight (g)	Biomass (tons)	Harvest Rate	Allowable Harvest (tons)	Proportion by Weight
3	13.1	15.4%	79	1,146	0.12	137	5.5%
4	0.5	0.6%	127	66	0.12	8	0.3%
5	1.5	1.8%	164	278	0.12	33	1.3%
6	5.2	6.1%	200	1,153	0.12	138	5.5%
7	5.5	6.4%	224	1,348	0.12	162	6.4%
8	44.7	52.6%	250	12,327	0.12	1,479	58.9%
9	6.4	7.6%	267	1,891	0.12	227	9.0%
10	1.7	2.0%	293	537	0.12	64	2.6%
11	1.1	1.3%	299	363	0.12	44	1.7%
12	4.0	4.7%	293	1,296	0.12	156	6.2%
13+	1.3	1.6%	356	520	0.12	62	2.5%
Total	85.0		223	20,925		2,500[a]	

[a] Total projected 1996 harvest is rounded.

Table 4. Allocation of the projected 1996 Kamishak Bay herring harvest.

	Exploitation Rate	Allowable Harvest (tons)
Kamishak Bay Sac Roe Fishery	0.108	2,250
Shelikof Strait Food-and-Bait Fishery	0.012	250
Total	0.120	2,500

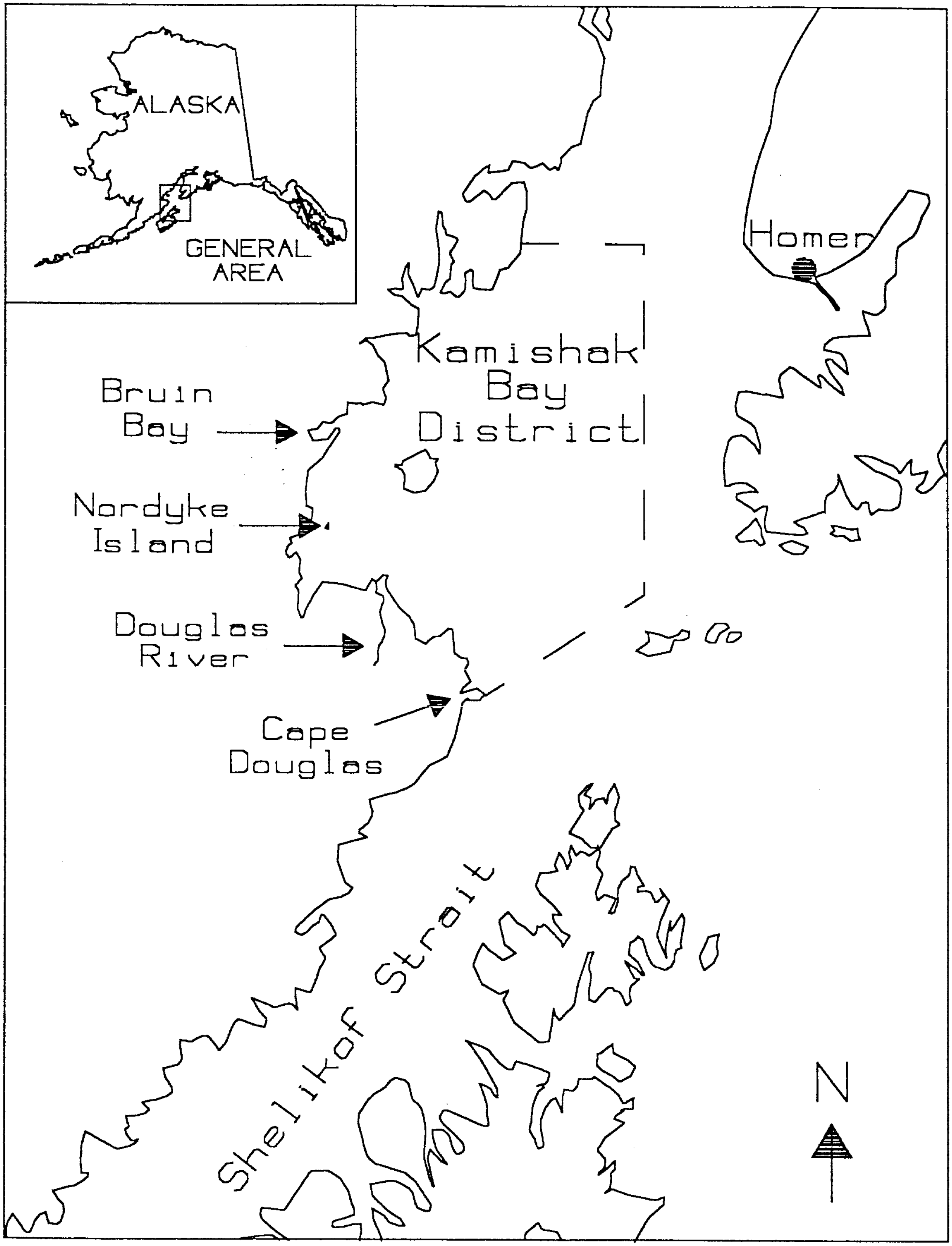

Figure 1. Kamishak Bay and Shelikof Strait, Alaska.

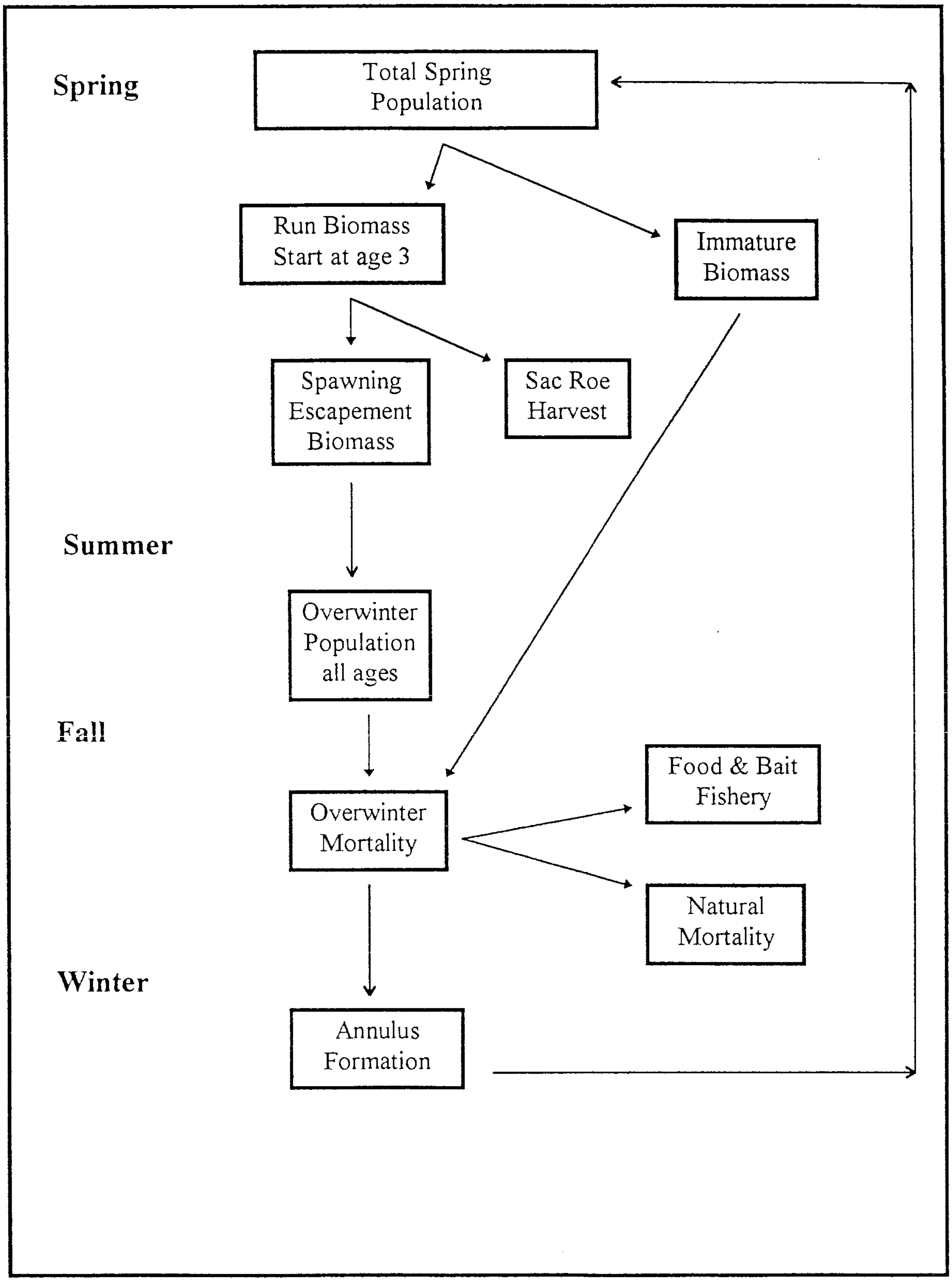

Figure 2. Conceptual model of the annual cycle of events affecting the Kamishak herring population.

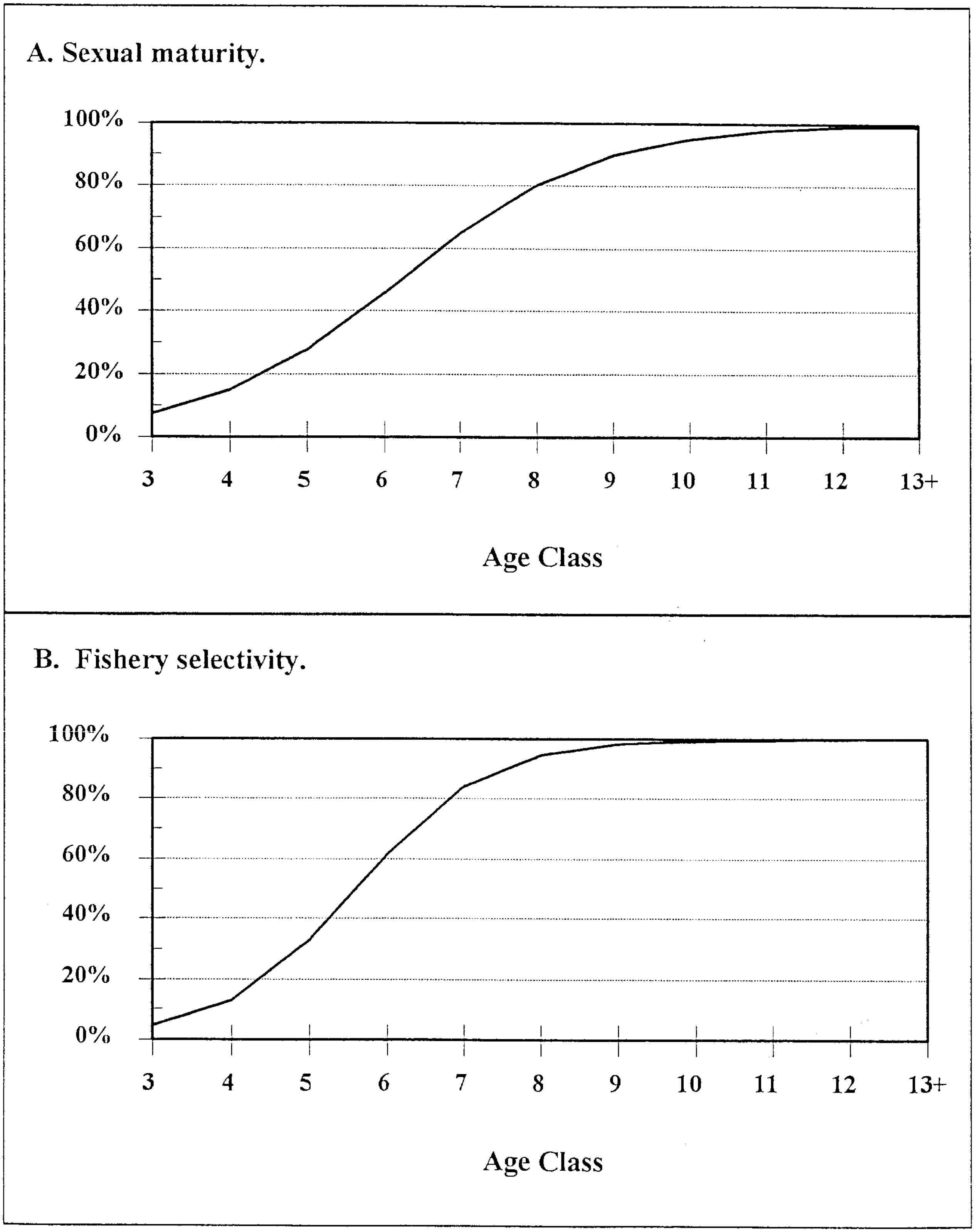

Figure 3. Maturity (A) and selectivity (B) curves estimated by the ASA model for the Kamishak Bay herring run.

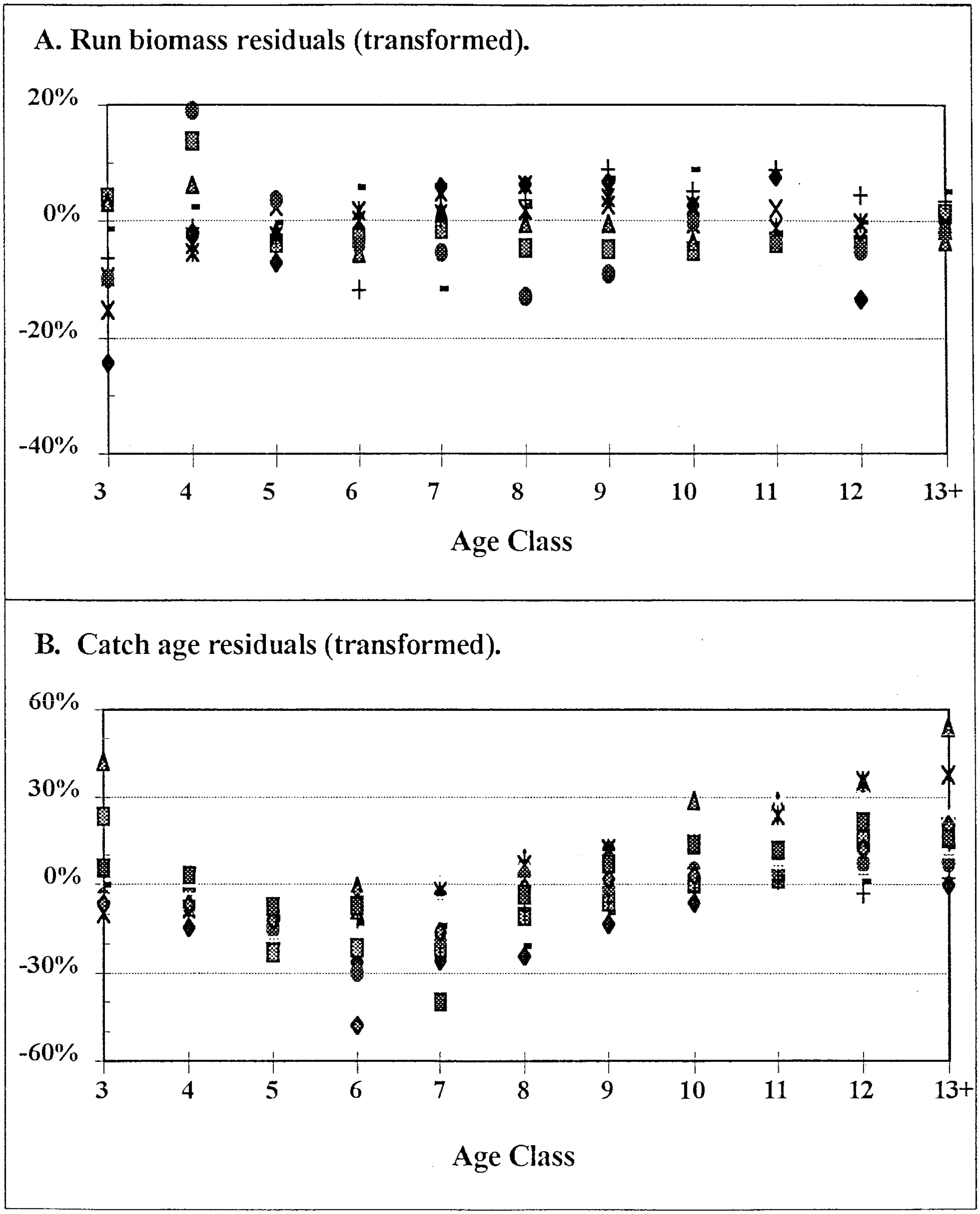

Figure 4. Residual differences between transformed estimated and observed age composition values for the (A) run biomass and the (B) catch of Kamishak Bay herring returns during 1985 to 1995.

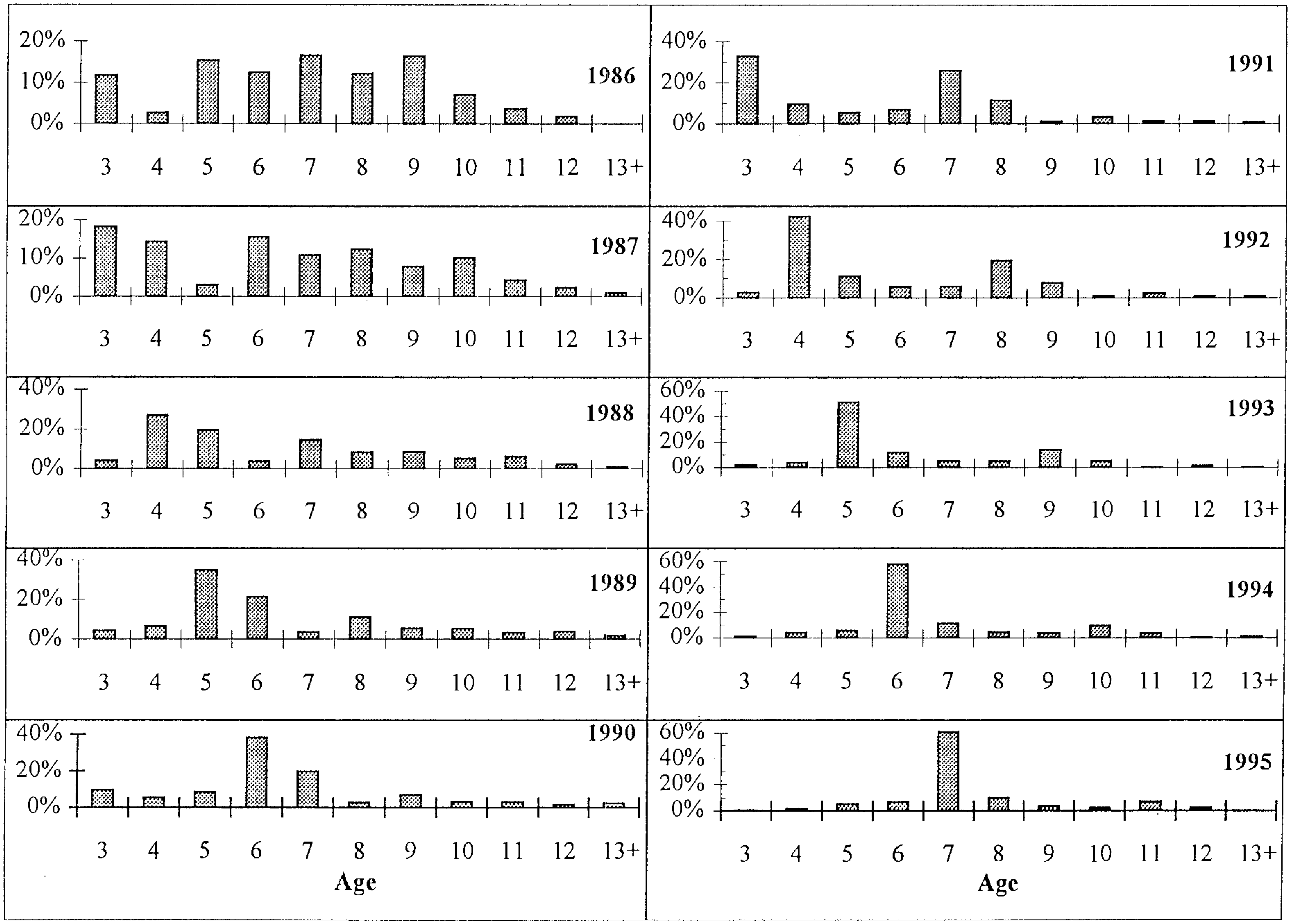

Figure 5. Run biomass age composition estimated by the ASA model for Kamishak Bay herring during 1986 to 1995.

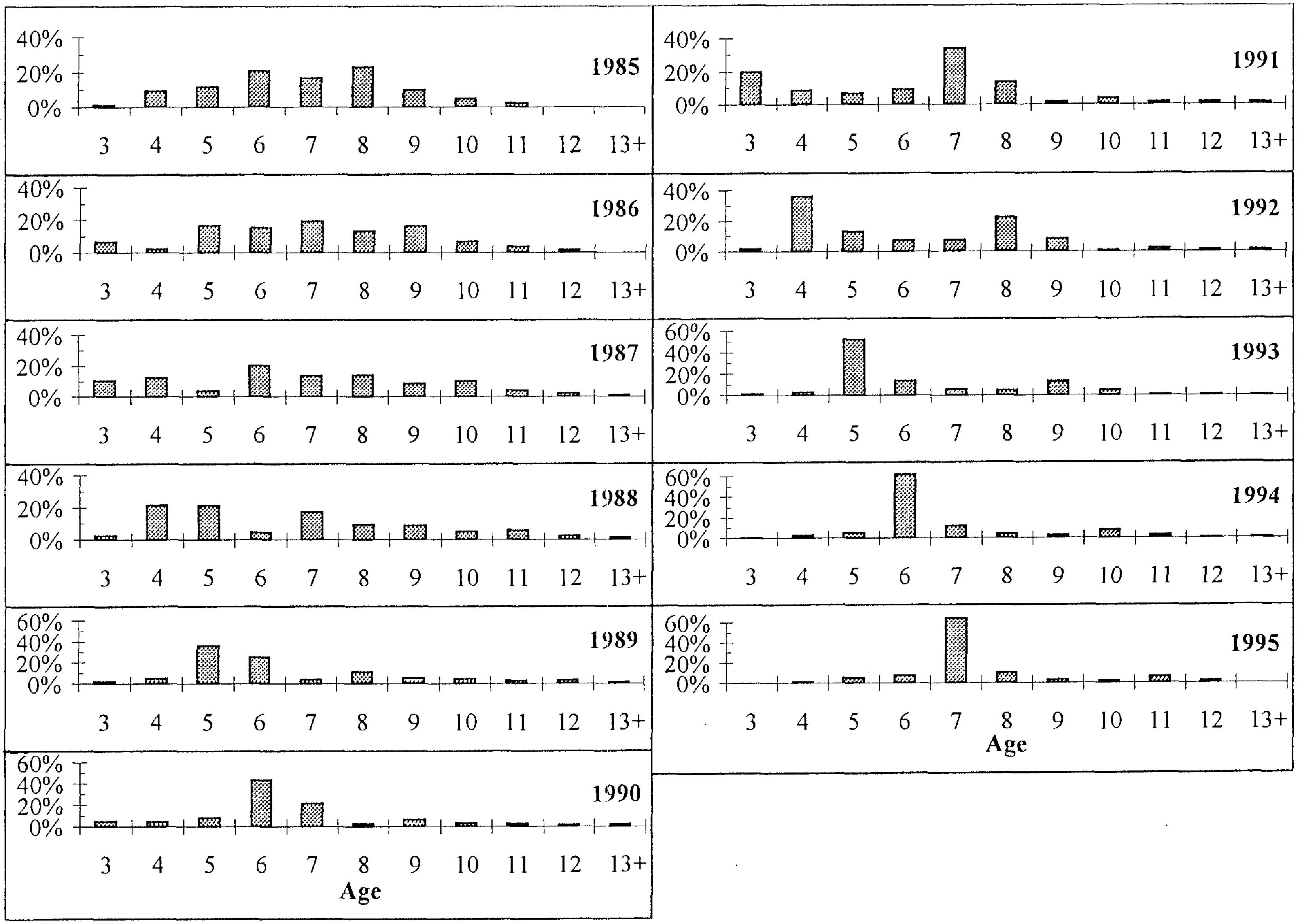

Figure 6. Catch age composition estimated by the ASA model for Kamishak Bay herring during 1985 to 1995.

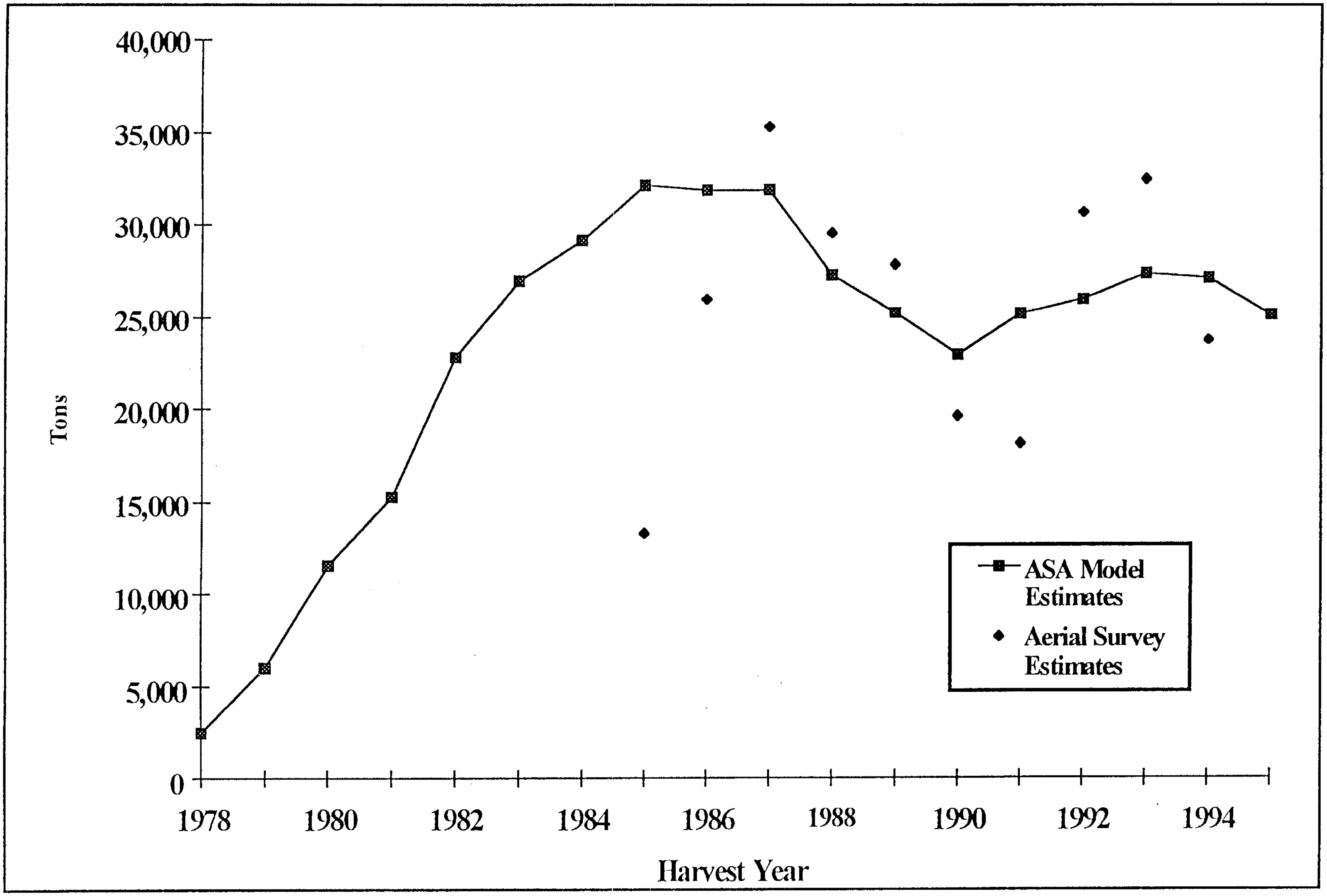

Figure 7. Kamishak Bay herring run biomass estimated by the ASA model for 1978 to 1995 and observed by aerial surveys during 1985 to 1994.

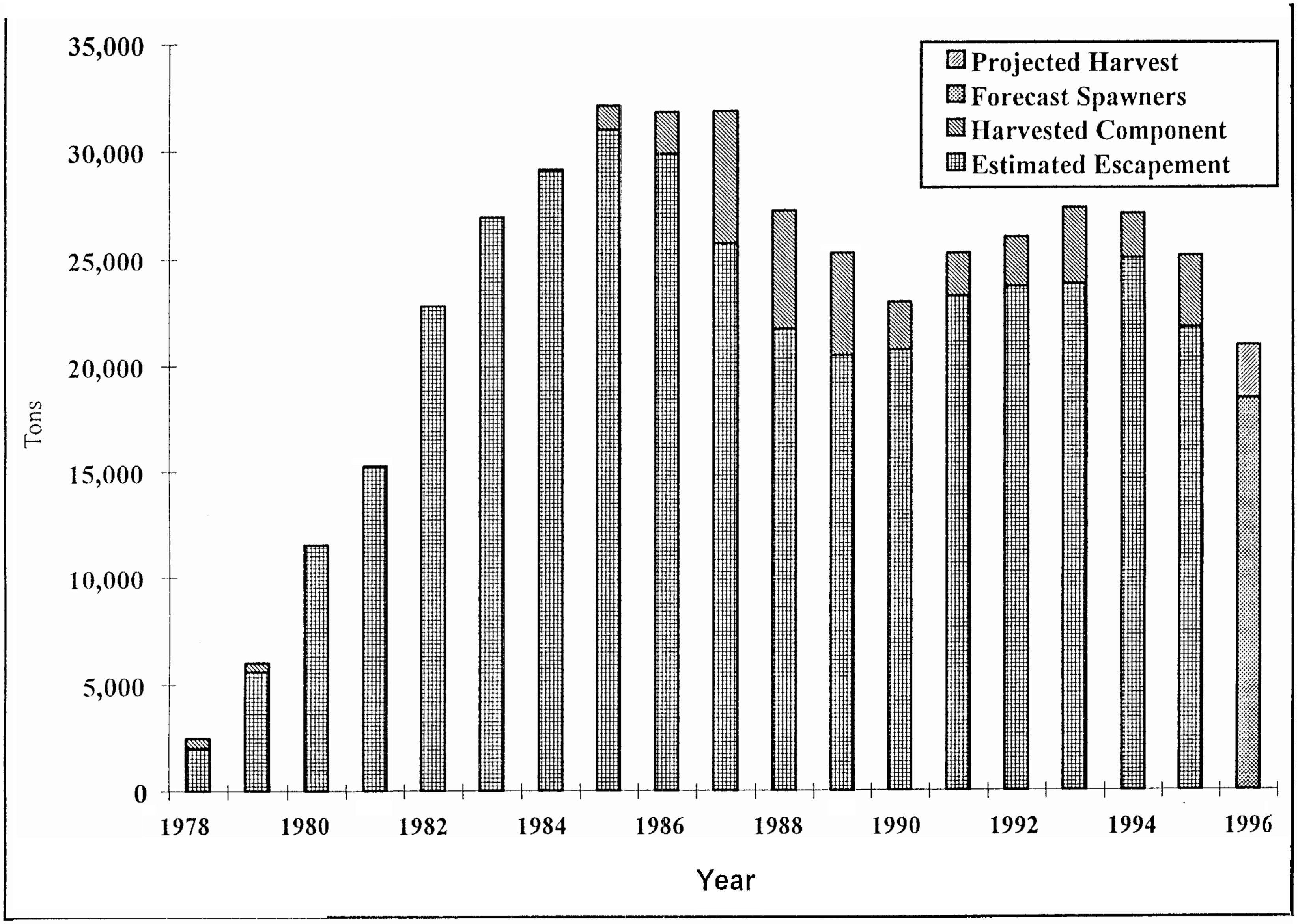

Figure 8. Kamishak Bay District herring catch and estimated escapement during 1978 to 1995 and as forecast for 1996.

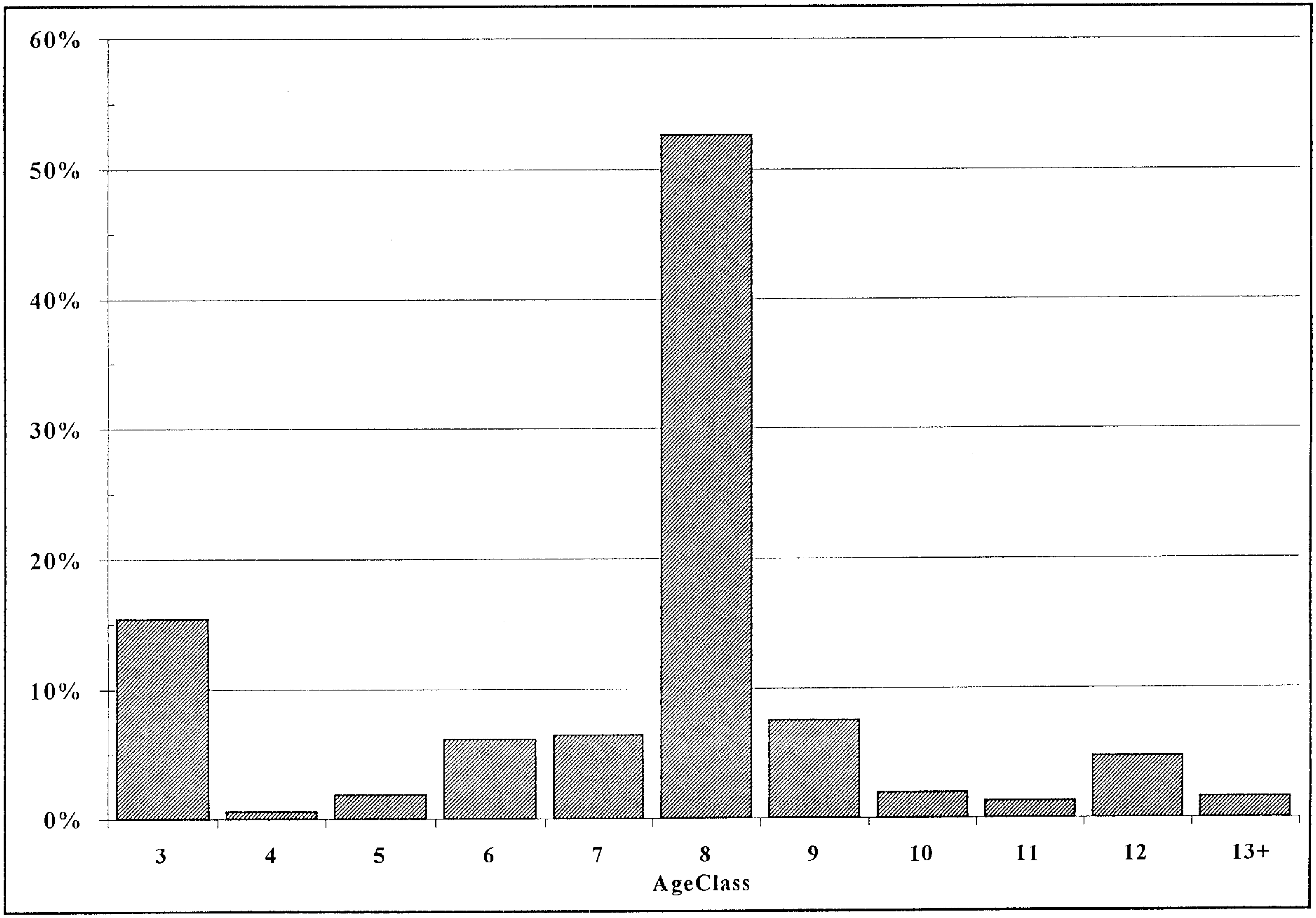

Figure 9. Kamishak Bay District herring age composition as a percentage of the total abundance forecast to return in 1996.

Appendix A. Kamishak Bay District herring catch by age and harvest year during 1979 to 1995.

	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											
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
1987	2,342	3,098	476	5,133	3,612	3,696	2,454	3,182	1,335	579	597
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

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	1.10	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	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	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

Appendix C. Kamishak Bay District herring mean weight by age and year of harvest during 1978 to1995.

	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[b]	79	127	164	200	224	250	267	293	299	293	356

[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 1991 to 1995 was used to predict mean weights in 1996.