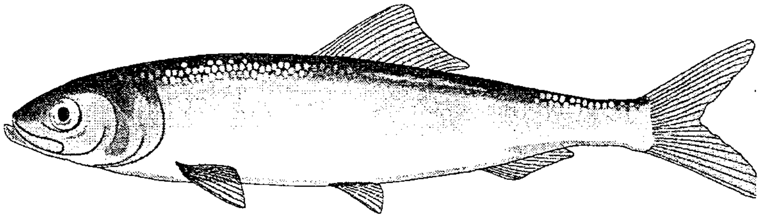
FORECAST OF THE KAMISHAK HERRING STOCK IN 2000



by

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ABSTRACT

The 2000 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 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. For the first time, I did not use the recent five-year average to predict herring weight-at-age in 2000. Estimates of herring weight-at-age were instead based on a year-ahead projection of a linear trend line plotted through the weights-at-age from the previous 5 years. This approach was used with the expectation that the recent trend of reduced weights will continue.

A biomass of 6,330 tons (5,742 tonnes) of herring is expected to return to the Kamishak Bay District in 2000. Herring mean weight is predicted to be 161 g. The 1993 and 1994 year classes are forecast to represent 27.7% and 20.3% of the run biomass (23.2% and 18.8% of the population abundance) as age-7 and age-6 herring, respectively. Samples collected in mid-May 1999, during the late season herring return, suggested relatively strong recruitment from the 1996 year class, which should result in increased age-4 returns in 2000 (21.5% of the population abundance). However, due to the low overall biomass expected to return, the sac roe fishery will not open in 2000.

KEY WORDS: age-structured-analysis, *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 (Figure 1) and a fall food and bait fishery in Shelikof Strait of the Kodiak Management Area. Run biomass is 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 1999).

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 1978 (Otis et al. 1998). Similar to previous years, aerial surveys to monitor relative biomass, distribution, and spawning of the 1999 herring population began in mid-April. Daily biomass indices were derived from the number and size of observed herring schools. Run biomass indices for each year were 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 the surveyor believed observed herring had not previously been counted, 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 effectively be flown. Because herring migration to and from the spawning grounds is likely a continuous process, and water clarity in Kamishak Bay is consistently poor, 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. 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; Otis et al. 1998).

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 1990, only surveys occurring after 1989 were included in the model (Otis and Bechtol 1999). To forecast the 2000 return, the predicted run biomass was scaled to aerial survey estimates of run biomass from 1990, 1992, and 1999 because they had the best overall aerial survey condition ratings since 1990. This approach is intended to remove much of the bias in abundance estimates by excluding aerial survey estimates made during years having poor weather or inadequate geographic and temporal coverage (Otis et al. 1998). The qualitative exclusion of some survey years occasionally ignores years, such as 1995, when a large biomass was observed but the temporal coverage for the season was restricted. In developing the 2000 forecast I 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.

Specific objectives of this report are to (1) document data sources and methodology used for the 2000 forecast, (2) formally present the 2000 forecast, and (3) through application of the Kamishak Bay Herring Management Plan (5 AAC 27.465), propose a harvest guideline for the 2000 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°46.13' N. lat., 153°00.70' W. long., then east to 59°46.14' N. lat., 152°20.00' W. long., then south to 59°03.42' N. lat., 152°20.00' W. long., then southwesterly to Cape Douglas at 58°51.10' N. lat. For management purposes, herring fishing is restricted to seven areas within the territorial seas (Figure 1). 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 introduce glacial silt into the marine environment. This glacial silt, in combination with typically poor weather, 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 since 1990. 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 is severely limited, Nordyke Island serves as one of very few suitable anchorages in the Kamishak District. Of the 73 limited entry permits issued for herring in Lower Cook Inlet, approximately 90 to 95 percent of the permit holders participate in the Kamishak fishery in a typical year. Fishing effort is often focused immediately south or west of Nordyke Island, centrally located in Area 5 (Figure 1). Depending on fish distribution, the entire fleet may fish in an area of 1.3-2.6 km^2. Fish value generally depends 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 occurs in intertidal areas 1-12 m deep.

METHODS

Database

Kamishak herring harvest abundance by age, commercial catch and total run age compositions, and mean weights through 1998 were forwarded from last year's final ASA model (Otis, unpublished data). Because no commercial fishery occurred in 1999, this year's catch data inputs to the model consisted of ADF&G cost recovery harvests only. Beginning with the 1997 forecast, revisions were made to the total run age composition data used in the model (Appendix B). In most years, the age composition shifts from older to younger fish as the spawning season progresses (Yuen 1994, Otis et al. 1998). Therefore, I only included data from years where late season (i.e., May) samples were included in the total run age composition data set- 1986, 1988, 1990, and 1996-1999. Total run 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 solely from catch samples.

During herring aerial surveys, observers estimated the surface area of herring schools present on the spawning grounds. Since 1990, 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; Otis and Bechtol 1999). Aerial survey conditions in 1999, particularly through mid-May, were generally much better than during the previous 6 years (Table 1). However, inclement weather prevented aerial surveys from 20-25 May, 27 May to 1 June, and 3-10 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 begin to appear in the purse seine sac-roe fishery. Although age-1 and -2 herring occasionally 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 from the “run” biomass 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. Shelikof Strait’s fall food and bait fishery must be considered in Kamishak Bay’s herring assessment because the stocks appear to intermix for much of the year in eastern Shelikof Strait (Johnson et al. 1988). The removals in the food and bait fishery could be explicitly made using that fishery's catch sampling data. 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 that minimizes sums of squares values. ASA models that 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 2000, the model also updated estimates of maturity and historical abundance for 1979-1999, and also the fishery selectivity curve for the purse seine fishery. New information supplied to the ASA model included 1999 estimates of the cost recovery 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 1999 forecast (Otis, unpublished data) were used as initial parameter values for the 2000 forecast. The 2000 mean weight-at-age was not estimated as the five-year mean weight for the previous 5 years, as had been done in previous forecasts. Instead, a linear trend line was plotted through the previous five year's weights-at-age and projected one year ahead to estimate the 2000 weights-at-age. This method was used with the assumption that the current 5-year trend of decreasing herring weights will continue into next year. The abundance of age-3 herring in 2000 was estimated as the median of hindcasted age-3 abundance estimates since 1978.

Because a limited and discontinuous time series of total run age composition data are available to the model, I don't believe sufficient age-composition data were available for the model to estimate survival (S). Accordingly, I fixed S at 0.67 (equivalent to an instantaneous rate of natural mortality [M] of 0.4). As the time series of total run age-composition data continues to expand, I will reevaluate the ability of the model to estimate S.

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 and cohorts.
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.

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, fixed at 0.67, which corresponds to 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 North Gulf of 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 1994; Williams and Quinn 1997). 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 included 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 that limited the possible range of selectivity. 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 that 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.

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 proportions. Commercial catch age compositions were fit across ages 3 to 13+ and years 1987 through 1999.

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 aerial survey estimates of run biomass:

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

where B_y^{survey} is the aerial survey biomass estimate in year y, $w_{a,y}$ is the weight at age a in year y (Appendix C), ρ_a is the proportion 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. I 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 1994-1999 (Appendix B). However, during 7 of the past 14 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 1996-1999), it was apparent that April's samples alone under-represented the true composition of age-3 and -4 herring for the total run (Yuen 1994; Otis et al. 1998). Therefore, I reinstated late season age composition sampling in 1996 and adjusted the Observed Total Run Age Composition (OTRAC) component of the model to incorporate only those years that included May samples. I believe 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 goodness of fit of the age composition of the run biomass was computed as:

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

where $p^{run}_{a,y}$ 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 1996-1999 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 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 (e.g., good, fair, poor). A quantitative method for rating survey effort and survey conditions was adopted in 1990 (Table 1). Aerial survey biomass estimates from the years 1985 to 1989 were not well documented and were not used in the forecast model. Beginning in 1990, aerial surveyors standardized their methods to convert herring school surface areas to estimates of biomass (Lebida and Whitmore 1985; Otis and Bechtol 1999). Adoption of these standards, as well as the quantitative method for rating survey effort and conditions within seasons, enabled me to evaluate the relative quality of aerial survey biomass estimates between years. Survey years 1990 and 1992 had the best relative values since 1990 and were used again this year, along with the 1999 survey results, to represent 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 *(unpublished manuscript)* attempted to overcome some of these factors by developing a migratory run timing model to estimate the relative proportion of the run biomass that might be expected to be present on the spawning grounds at a given time in the spawning season. This approach was used to generate the 1992 aerial survey biomass estimate used in the 1996-1998 forecasts. In 1996 and 1997, linear interpolation was used to estimate biomass on the grounds during gaps in survey coverage and consecutive days totals were summed for the season. This year, consecutive survey's totals were summed for the season, but, linear interpolation was not used to estimate biomass on the grounds during gaps in survey coverage. We also did not include over 6,000 tons of herring observed in McNeil Cove on June 24 because they did not reside in the area more than a few days and were not observed spawning. I used a conservative approach to estimate the total spawning biomass this year because the herring population is depressed and its recovery could be delayed by reopening the commercial fishery prematurely. Appropriate criteria to standardize the estimation of total annual biomass for Kamishak Bay herring are still under development.

Forecasting Methods

The forecast of the herring run biomass for 2000 ($B_{2000}^{Forecast}$) was projected from total abundance with the survival model (equation 1) modified by the ASA estimated proportion of mature herring expected for each age:

$$B_{2000}^{Forecast} = \sum_{a} \rho_a \hat{w}_{a,2000} \hat{N}_{a,2000}, \tag{8}$$

where ρ_a is the proportion mature and available to our surveys at age a from equation (5); $w_{a,2000}$ is the individual fish weight-at-age a estimated for 2000 based on the recent decline in weight-at-age (Appendix C); and $N_{a,2000}$ is the ASA estimate of age-a herring for 2000 from equation (1). The model forecasted the 2000 herring abundance for all herring aged 3 and older. Lacking an adequate method to predict age-3 year class strength, I used the median ASA estimate of age-3 abundance from years 1978-1999 to generate $N_{3,2000}$. 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). The age composition $p_{a,2000}$, of $B_{2000}^{Forecast}$, was estimated using the maturity schedule (ρ_a of equation 5) as:

$$\hat{p}_{a,2000} = \frac{\hat{N}_{a,2000}\,\rho_a}{\sum_a \hat{N}_{a,2000}\,\rho_a} \tag{9}$$

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 are then used to assign ad hoc weights to each SSQ component reflecting our confidence in that component. An inverse variance-weighting scheme was not used because the variance of the aerial survey abundance estimator was unknown. Weights for the 2000 biomass SSQ were chosen empirically. With the catch and the run age compositions weighted equally at either 1.0 or 0.5, the weight given aerial surveys was varied from 0.0001 to 5 to examine model sensitivity to aerial survey weighting.

Minimization Methods. The ASA model estimated a total of 29 parameters: 25 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 223 data observations with 194 degrees of freedom and a data to parameter ratio of approximately 7.7:1.

The Microsoft Excel Solver[1] was used to estimate parameter values that 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 Corporation 1992). The precision level for minimizing the SSQ_{Total} was set at 0.00001. Population sizes for all cohorts forecast to return in 2000 were constrained to be greater than or equal to zero because negative population values were unrealistic.

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

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, I 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, north of the latitude of Miner's Point, 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 allocated to the spring Kamishak sac roe fishery and 1% to 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 herring ≤ age-5 and to maximize economic benefit to the fishing industry by targeting fish of the greatest roe quality. Because of the age composition from older to younger fish as the spawning season progresses (Yuen 1994; Otis et al. 1998), the fishery targets the early portion of the spawning run.

RESULTS

Forecast Scenarios

To generate the 2000 forecast I ran a series of 6-8 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 30 trials, and 1990, 1992 and 1999 were the only aerial survey years contributing estimates of total run biomass. Once again, early and late run herring exhibited differences in age composition and size (Otis in press). Therefore, I again weighted and pooled our April and May age-composition samples to represent OTRAC for all four scenarios. The final parameter estimates and maturity curve for the 2000 forecast exhibited trends similar to previous forecasts (Table 3, Figure 3).

The first forecast scenario was very similar to the final forecast for 1999, except that the 1998 survey biomass was replaced by the 1999 survey biomass of 6,377 tons, a cumulative count of all the herring observed by air between April 20 and June 2. This survey biomass estimate excluded 6,078 tons of herring that were observed on June 24 in and around McNeil Cove. These herring did not remain in the district more than a few days and were not observed spawning. Because the possibility existed that this biomass was of non-Kamishak origin, and because insufficient age composition samples were collected to represent the biomass, I excluded this biomass from scenario 1. A weighting of 0.5 was assigned to the 1999 survey biomass observation while the 1990 and 1992 data were assigned λ's of 1.0. Catch and total run λ's were held at 1.0 while the overall survey biomass λ was incrementally increased through 8 trials. Scenario 1 produced forecast biomasses in the range of 4,543-7,850 tons (Table 2).

Scenario 2 was very similar to scenario 1, except the 1990 and 1992 survey biomass estimates were averaged and set at 22,000 tons each to reduce the model's tendency to set a biomass trend line through these two data points, when such a trend was not certain to exist. In the interest of evaluating what impact it would have on forecast results, I also increased the 1999 survey biomass to 11,535 tons. This new estimate included the 6,078 tons of herring seen on June 24, but excluded herring schools that observers believed may have been counted more than once on consecutive surveys. The individual λ's for each survey year were kept the same as in scenario 1, as were the catch and total run survey λ's. Once again, I incrementally increased the overall survey biomass λ to evaluate the model's sensitivity to those data. The 8 trials run during scenario 2 resulted in a range of forecasts from 4,547-14,577 tons (Table 2).

In scenario 3, I maintained the same basic foundation as in scenario 2, but reduced the 1999 survey biomass estimate to 5,456 tons. This again excluded the 6,078 tons observed in McNeil Cove on June 24th, and also excluded any herring schools that observers believed may have been counted more than once on consecutive surveys. Individual survey biomass λ's and catch and total run λ's were similar to scenario 2. By incrementally increasing the overall survey biomass λ during 8 trials, I generated forecasts in the range of 4,541-6,673 tons (Table 2).

After evaluating these results (e.g., goodness of fit, total SSQ, etc.), I decided to use the 1999 survey biomass estimate from scenario 1. However, I wanted to explore the effect of slightly modified survey biomass estimates and λ's for the 1990 and 1992 inputs. As a conservative approach, I set the 1990 and 1992 survey biomass estimates at 20,000 tons each. I also kept the 1990-survey biomass lambda at 1.0 but reduced the 1992 lambda to 0.5 to account for the greater uncertainty I had in the 1992-survey biomass estimate. Based on scenario 1 results, a survey biomass λ of 0.05 was preferred, so I varied the catch and total run survey λ's to see if I could further reduce the total SSQ (weighted). After a series of five trials, I settled on equal weighting of the catch and total run λ's (λ = 0.5). This resulted in a forecast biomass of 7,134 tons.

Before accepting 7,134 tons as the final 2000 forecast I re-evaluated all of the model inputs and formulas. It became apparent that the standard method for estimating the weight-at-age for the year ahead might not be the most appropriate for 2000. Normally, forecast weight-at-age was estimated as the recent 5-year average. However, 1999 continued a recent trend of declining weights-at-age. Therefore, for each age class, I plotted a linear trend line through mean weights from the previous five years and projected that line one year ahead (Figure 4). Age-4 herring were the only cohort that did not exhibit a prominent trend so I used their recent 5-year average weight. The final run of the ASA model, using these new data to represent the 2000 weights-at-age, resulted in a forecast of 6,330 tons.

Final Forecast

A biomass of 6,330 tons (5,742 tonnes) of herring is expected to return to the Kamishak Bay District in 2000 (Table 4). Depending upon the use of aerial survey biomass estimates and the weighting of specific λ's used for each trial, model forecasts ranged from 4,541 to 14,577 tons ($\bar{x}$ = 7,431 tons; Table 2).

Herring mean weight in 2000 is predicted to be 161 g. The 1993-year class, returning as age-7 herring in 2000, is forecast to represent 28% of the run biomass and 23% of the total abundance (Table 4; Figure 5). The 1994-year class, returning as age-6 herring, is forecast to represent 20% of the biomass and 19% of the total abundance of herring in 2000. Almost 82% of the biomass and 87% of the total abundance of herring forecast to return in 2000 are ≤ age-7 (Table 4; Figure 5).

Goodness of fit

The forecast results from each trial run were used to evaluate model fit to that use of the available data. This goodness of fit evaluation, along with the magnitude and relative stability of the total SSQ value, were used to select the final forecast. Overall, the model run selected to represent the 2000 forecast had a good fit to all the data. Pooled residuals of the total run age composition (TRAC) exhibited some variability, but were relatively evenly distributed about zero with no obvious trend as a function of age (Figure 6). Residuals based on 1999 data were all less than 10% of the observed values with the largest residual derived from age-11 herring. Age-7 through -10 herring exhibited small, but consistently positive residuals in 1999, while age-11 through –13+ fish exhibited negative residuals. When considering data among all years, the largest residuals occurred for age-3 herring. Overall, ASA estimates of the age compositions of the run biomass agreed moderately well with observed compositions, particularly in tracking the annual progression of dominant age classes (e.g., 1988 year class; Figure 7).

Residuals of the purse seine catch age composition, based on 1999 data, were also ≤10% of the observed values. Again, age-11 herring from the 1988 cohort contributed the largest residual. Although residuals centered around zero, there again appeared to be a slight tendency for positive residuals in age-7 through -10 herring and negative residuals in age-11 through age-13+ herring (Figure 6). No strong trend was seen in residuals plotted by age for each year, except in 1992 when residuals for herring greater than age-5 tended to be negative. Overall, the age composition of the purse seine catch estimated from the ASA model agreed well with the observed age. The 1993-year class continued to dominate the catch samples in 1999 as age-6 herring (Figure 8).

Run biomass estimates obtained from the ASA model were consistently less than the aerial surveys used as auxiliary data, which led to positive residuals of up to 25% of the observed values (Figure 9). The poorest fit was for 1992 survey data; the 1999 survey data fit best.

Projected Harvest

Because the forecasted biomass is less than the 8,000-ton threshold and the population contains a large component of recruit class fish, the Kamishak sac roe fishery will not be opened in 2000. According to the Kamishak District Herring Management Plan [Regulation 5 AAC 27.465.e.4], the Shelikof Strait food and bait fishery north of the latitude of Miners Point must also be closed.

DISCUSSION

The forecast variability I 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 illuminates the need to keep weighting schedules within their ranges of relative stability and to use available data in the most appropriate manner (i.e., goodness of fit). For instance, during many previous forecasts, only early-season samples (testfish and commercial fishery) were available to represent OTRAC in the model. Because a temporal shift in age composition frequently occurs around early-May (Otis et al. 1998), OTRAC's comprised solely of early-season samples tended to under-represent the contribution of age-3 and age-4 fish. Accordingly, I reinstituted late-season sampling with the addition of an annually chartered test-fishing vessel beginning in 1996. Including these surveys better represents the overall age composition and improves our assessment of the relative strength of incoming recruits.

My final choice of a weighting schedule was based on an evaluation of the influence that individual λ values 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 (Table 2). 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. I concluded that beyond this point of inflection, the model was overly sensitive to increased aerial survey λ's. Using this criterion, I selected an aerial survey λ of 0.05. I used similar techniques to determine appropriate λ's for catch and total-run age composition data, leading to λ values of 0.5 for each. These final λ values resulted in a scaled total SSQ of 0.3806 (Table 2). Of the 30 model trials I ran this year to evaluate sensitivity to various data sets and λ's, 0.3806 was the lowest scaled total SSQ.

While the catch and total run age composition residuals generally indicated a good model fit with the observed data, some minor trends stood out. For instance, when considering data among years, the largest residuals frequently occurred for age-3 herring. This trend is readily explained by the fact that herring first begin to recruit to our assessment program at this age. Thus, the model has no previous information on this cohort to base its abundance estimate on. Instead, age-3 cohort abundance for 2000 was forecast as the median of model hindcast age-3 abundances. Because there is considerable natural variability in the recruitment success of herring (Figure 10), there is often disparity between the model's estimates and our initial observation of the abundance of age-3 herring when they first appear in our assessment. While this disparity leads to consistently high residuals for forecasts of this one age group, these residuals are quickly brought back in line for succeeding age groups by the model's ability to increasingly track the annual abundance of herring as they recruit more fully to our assessment.

In 1992, all age groups greater than age-4 exhibited negative catch age composition residuals (Figure 6). The very large 1988-year class first appearing in force as age-4 herring in 1992 likely caused this distinctive trend. Their tremendous abundance effectively reduced the relative abundance of the other age classes leading to their negative residuals. To some extent, the effect this very large year class had on the model appears to have persisted. While it is now apparent that few herring from this cohort persist today, the model continued to expect a relatively abundant return of age-11 fish in 1999, as evidenced by a relatively large negative residual observed for age-11 herring in 1999. This relatively large negative residual may suggest that: 1) the natural mortality rate for this cohort was greater over the years than was estimated by the model's fixed rate of 0.4; or 2) this cohort's removal from the population through fishing was not accurately represented by our catch-at-age data, either due to aging error or because Kodiak food/bait harvests were greater than I expected. Herring age 7 through 10 exhibited small, but consistently positive residuals in 1999, while those age-11 and older exhibited negative residuals. However, this trend was minor and did not appear to be consistent across years.

It is more difficult to explain the trend for positive residuals associated with survey biomass estimates. The model hindcast estimates of herring biomass were consistently less than aerial surveyor's observations for the three years that survey biomass estimates were used as auxiliary data in the model (Figure 9). The greatest residuals occurred for the 1990 and 1992 survey biomass estimates and the least was for the 1999 estimate. It is difficult to accept that aerial survey biomass estimates were 20-25% higher than the actual biomass in 1990 and 1992, as the model suggests. For the 2000 forecast I used relatively conservative biomass estimates for 1990 and 1992 (20,000 tons). Aerial surveyors observed cumulative totals of 30,258 and 21,874 tons of herring in 1990 and 1992 respectively. When considering only the peak counts from successive spawning waves, 17,823 tons of herring were observed in 1990 and 11,394 tons were observed in 1992. However, it is extremely unlikely that aerial surveyors observed all available herring, particularly in 1992 when long (17 and 9 days) temporal gaps occurred in survey coverage due to poor weather. The observed biomass from 1992 is essentially just for the first spawning wave because aerial surveys were so ineffective the rest of the year.

However, even when survey coverage and conditions were very good, not all herring were observed by aerial surveyors. For instance, on April 22, 1990, under very good conditions, aerial surveyors observed 1,120 tons of herring. However, the commercial fleet harvested 1,437 tons in four hours of fishing soon after the survey was completed. Likewise, on April 24, 1992, under excellent conditions, aerial surveyors observed 1,438 tons of herring and the fleet harvested 2,281 tons in just 60 minutes of fishing. Similar examples abound in the historical database. The largest disparity between aerial surveyor's observations and a commercial harvest on the same date occurred on 24 April, 1996. Despite fair conditions, aerial surveyors were only able to document 657 tons of herring, while the fleet harvested 2,984 tons in just 30 minutes of fishing.

It is apparent from these examples that aerial survey does not provide a consistently accurate measure of herring abundance in Kamishak Bay. Poor survey conditions and temporal gaps in survey coverage exacerbate the problem. Unfortunately, most other accepted means for estimating population size (e.g., egg deposition surveys, compact airborne spectrographic imaging of herring schools) are also ill suited to Kamishak Bay (Otis et al. 1998). Techniques to reliably quantify herring biomass using hydroacoustics are under development in Prince William Sound. Once established, these techniques may be applicable to Kamishak Bay herring. However, some distinctions exist between the two areas that may hinder the transferability of this assessment tool. Kamishak Bay is very shallow and strewn with reefs that make navigation and hydroacoustic surveys problematic. Also, herring do not reside year round in Kamishak Bay, as they do in Prince William Sound. Thus, Kamishak Bay herring are only available to our assessment program for 6-8 weeks a year. Furthermore, individual schools of fish may only be present on the grounds for a few days before spawning and leaving the area. These factors would likely hinder hydroacoustic assessments in much the same way they have hindered aerial assessments.

The ASA model 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 1985 following successive strong year classes combined with a 5-year fishery closure, then decreased steadily until 1991 when the very large 1988 cohort first recruited to the fishery as age-3 fish. The biomass then rose slightly until 1993 when it began declining again. This most recent decline stabilized in 1997 and the biomass now appears to be slowly rebuilding (Figure 9).

This recent upturn may be related more to the lack of a significant harvest in the past 2 years than to a new strong cohort arriving on the scene. While age-5 and –6 herring were strong relative to the other age classes in 1999, their cohort abundances did not approach the 1988-year class strength (Figure 10). However, the past decade of relatively weak year classes may be over. Aerial surveyors observed over 6,000 tons of herring in and around McNeil Cove on June 24, 1999. This biomass showed up 3-4 weeks after the spawning season typically ends in Kamishak Bay. Though the fish were not observed to spawn, local pilots first observed this large biomass two days prior to our aerial survey. Salmon seiners in the area managed to capture a small number of these herring and reported they all were similar in size, around 130-150 mm. Fish of this size are generally age 2. This anecdotal observation corroborates information I received from federal researchers performing small mesh trawl surveys in Lower Cook Inlet. Alisa Abookire reported frequent and abundant captures of age-1 herring in 1998 (USGS-BRD-Anchorage, pers. comm.). These observations suggest that 1997 may have produced the first significant year class of herring in Lower Cook Inlet since 1988. If so, I will be better able to evaluate year class strength in 2000 when this cohort begins recruiting to our assessment program as age-3 fish.

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Table 1. Summary of aerial surveys to assess herring in the Kamishak Bay District during 1985 to 1999.

		Longest Period Without Survey Coverage		Overall	Survey Estimate	
Harvest Year	Months Surveyed	Number of Days	Unsurveyed Dates	Survey Conditions[a]	Biomass (tons)	Estimate Derivation
1985	April - May	9	5/25-6/2	Fair	13,320	Observation
1986	April - May	8	5/19-26	Fair	26,001	Observation
1987	April - May	7	5/17-23	Good	35,332	Observation
1988	April - June	4	4/24-27, 5/3-6, 5/27-30	Good	29,548	Observation
1989	April - May	4	5/13-16	Good	27,855	Observation
1990	April - June	6	5/23-29	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	5/16-25	3.1	23,778	Interpolation
1995	April - June	15	5/3-15, 5/17-6/1	2.3	NA	
1996	April - June	11	5/7-12, 5/17- 27	2.4	18,138	Interpolation
1997	April-June	11	4/23-30, 5/9-19, 5/23-6/1	2.1	NA	
1998	April-May	28	5/14-6/10	2.4	NA	
1999	April-June	6	5/20-25, 5/27-6/1, 6/3-9	2.4	6,377	Observation

[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.

			Lambda Values			Aerial Survey	Total SSQ	Forecast	
Scenario	Run #	OTRAC	Catch	Survey	Total Run	Year (tons) lambda	(weighted)	(tons)	Comments
1	1	all (pooled)	1	0.0001	1	1990 (20,000) 1.0; 1992 (24,000) 1.0; 1999 (6,377) 0.5	0.7458	4,543	Similar setup to 99's final forecast, but with
	2	all (pooled)	1	0.001	1	same as preceding	0.7464	4,595	updated survey biomass estimates (cut the
	3	all (pooled)	1	0.01	1	same as preceding	0.7516	5,101	98 estimate and used 6,377 tons for 99).
	4	all (pooled)	1	0.05	1	same as preceding	0.7658	6,677	
	5	all (pooled)	1	0.1	1	same as preceding	0.7756	7,451	
	6	all (pooled)	1	0.5	1	same as preceding	0.8071	7,850	
	7	all (pooled)	1	1	1	same as preceding	0.8277	7,766	
	8	all (pooled)	1	5	1	same as preceding	0.8871	7,808	
2	9	all (pooled)	1	0.0001	1	1990 (22,000) 1.0; 1992 (22,000) 1.0; 1999 (11,535) 0.5	0.7459	4,547	Same basic setup as trial 1 but with slightly modified
	10	all (pooled)	1	0.001	1	same as preceding	0.7469	4,645	survey biomass estimates. Made the 92
	11	all (pooled)	1	0.01	1	same as preceding	0.7554	5,744	and 94 estimates the same (22,000) and made
	12	all (pooled)	1	0.05	1	same as preceding	0.7709	11,566	the 99 estimate 11,535, which includes the 6000
	13	all (pooled)	1	0.1	1	same as preceding	0.7759	13,875	tons observed in McNeil Cove on June 24
	14	all (pooled)	1	0.5	1	same as preceding	0.7848	14,577	
	15	all (pooled)	1	1	1	same as preceding	0.7877	14,408	
	16	all (pooled)	1	5	1	same as preceding	0.7944	14,078	
3	17	all (pooled)	1	0.0001	1	1990 (22,000) 1.0; 1992 (22,000) 1.0; 1999 (5,456) 0.5	0.7458	4,541	Same basic setup as trial 3, but modified
	18	all (pooled)	1	0.001	1	same as preceding	0.7463	4,583	the 99 estimate to 5,456 tons, thereby
	19	all (pooled)	1	0.01	1	same as preceding	0.7508	4,957	excluding the anomalous late season
	20	all (pooled)	1	0.05	1	same as preceding	0.7633	5,978	biomass observed on June 24, as well as
	21	all (pooled)	1	0.1	1	same as preceding	0.7719	6,439	any schools that may have been counted
	22	all (pooled)	1	0.5	1	same as preceding	0.7924	6,673	the day before.
	23	all (pooled)	1	1	1	same as preceding	0.7998	6,619	
	24	all (pooled)	1	5	1	same as preceding	0.8152	6,555	
4	25	all (pooled)	1	0.05	1	1990 (20,000) 1.0; 1992 (20,000) 0.5; 1999 (6,377) 0.5	0.7566	6,422	same as Scenario 1, but lowered 92 survey est. to 20,000
	26	all (pooled)	0.5	0.05	1	same as preceding	0.4946	8,260	adjusted catch lambda
	27	all (pooled)	1	0.05	0.5	same as preceding	0.6254	5,500	adjusted total run lambda
	28	all (pooled)	0.5	0.05	0.75	same as preceding	0.4396	7,697	adjusted catch and total run lambda
	29	all (pooled)	0.5	0.05	0.5	same as preceding	0.3806	7,134	adjusted catch and total run lambda
	30	all (pooled)	0.5	0.05	0.5	same as preceding	0.3806	6,330	adjusted 2000 weight-at-age data
						Maximum Total SSQ:	0.8871	14,577	Maximum forecast biomass
						Minimum Total SSQ:	0.3806	4,541	Minimum forecast biomass
						Average Total SSQ:	0.7244	7,431	Average forecast biomass

Table 3. Final parameter estimates from the ASA model for the 1999 and the 2000 forecasts of herring returning to Kamishak Bay, Alaska.

	Estimated Parameter Value		
Parameter	1999 Forecast[a]	2000 Forecast[b]	Remarks
S	0.67	0.67	Estimated in 1996, fixed in 1997, Equation 1
β	1.426	1.386	Fishery selectivity steepness parameter, Eq. 3
α	5.206	5.193	Age of 50% fishery selectivity, Equation 3
ϕ	1.131	1.179	Maturity curve parameter, Equation 5
τ	5.048	4.943	Age at 50% maturity
Initial cohort abundance by year class (x 1 million herring)			
1978 age-3	127.12	127.16	
" " age-4	30.89	31.26	
" " age-5	2.81	2.81	
" " age-6	0.18	0.17	
1979 age-3	150.65	150.37	
1980 age-3	237.61	236.98	
1981 age-3	129.53	128.86	
1982 age-3	138.81	137.73	
1983 age-3	96.03	94.98	
1984 age-3	117.57	115.73	
1985 age-3	22.99	22.66	
1986 age-3	117.66	114.01	
1987 age-3	170.24	160.41	
1988 age-3	42.17	41.35	
1989 age-3	33.93	32.04	
1990 age-3	52.02	47.10	
1991 age-3	214.77	183.00	
1992 age-3	31.43	27.01	
1993 age-3	24.79	20.63	
1994 age-3	15.01	12.30	
1995 age-3	32.61	24.14	
1996 age-3	79.94	52.72	
1997 age-3	44.39	31.87	
1998 age-3	23.89	18.36	
1999 age-3	79.94	49.37	Calculated as a median for the 1999 forecast.
2000 age-3		51.04	Calculated as a median for the 2000 forecast.

[a] From Otis, unpublished data.

[b] Represents initial parameter values for the 2001 forecast.

Table 4. Forecast age compositions of herring run abundance and harvest biomass for the Kamishak Bay District in 2000.

	2000 Forecast					2000 Projected Harvest	
Age	Total Run Abundance (million fish)	Age Composition (by number)	Mean Weight (g)	Biomass (tons)	Harvest Rate	Allowable Harvest (tons)	Age Composition (by Weight)
3	4.69	12.32%	75	388	0.0	0	0.0%
4	8.18	21.47%	122	1,100	0.0	0	0.0%
5	4.23	11.10%	143	667	0.0	0	0.0%
6	7.18	18.84%	162	1,282	0.0	0	0.0%
7	8.82	23.17%	180	1,751	0.0	0	0.0%
8	2.56	6.73%	195	551	0.0	0	0.0%
9	0.61	1.61%	205	139	0.0	0	0.0%
10	0.55	1.45%	215	131	0.0	0	0.0%
11	0.32	0.84%	225	79	0.0	0	0.0%
12	0.86	2.27%	232	221	0.0	0	0.0%
13+	0.07	0.20%	270	22	0.0	0	0.0%
Totals	38.09	100.00%	161	6,330		0	0.0%

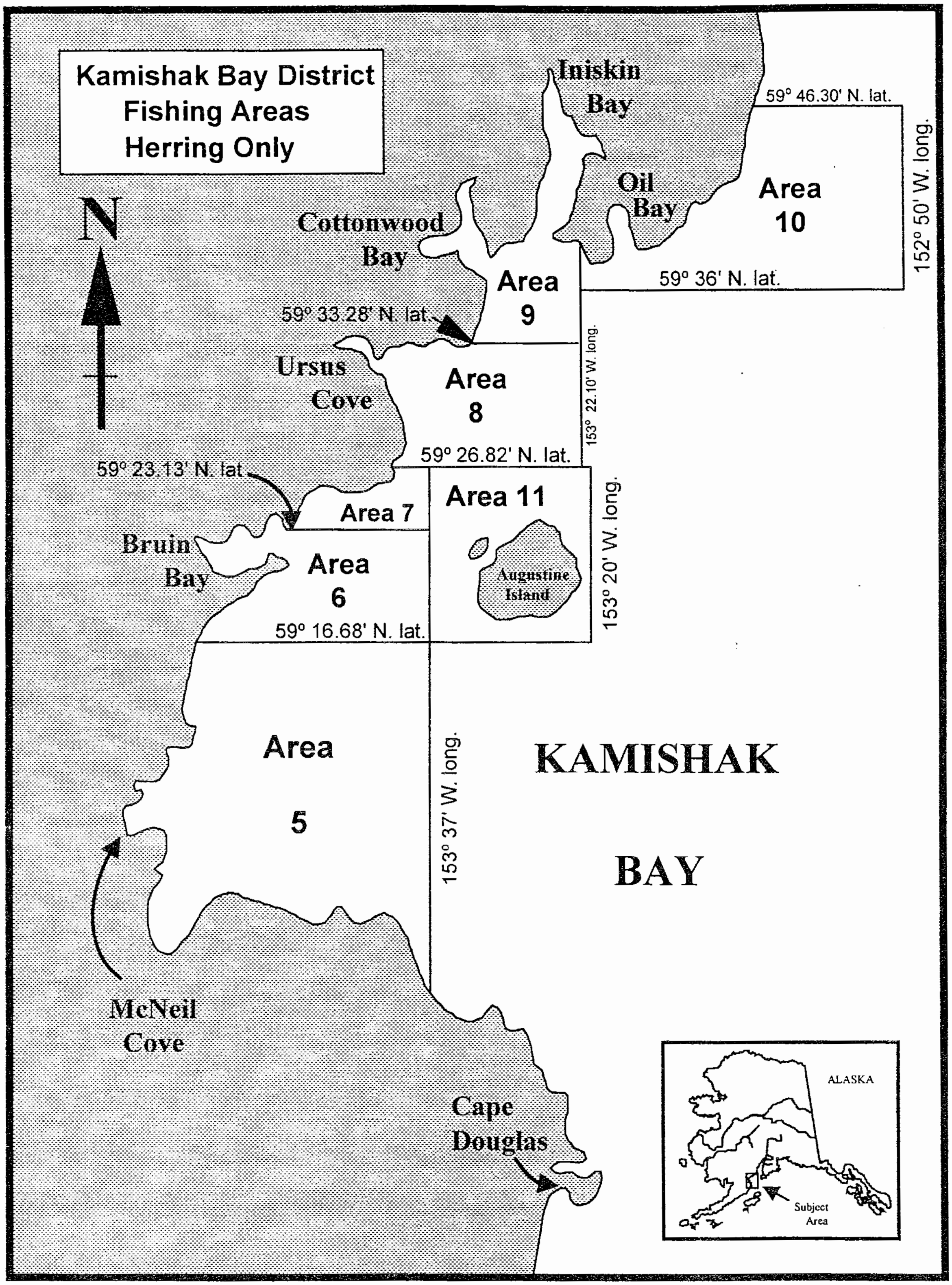


Figure 1. Commercial herring fishing areas in Kamishak Bay District, Alaska.

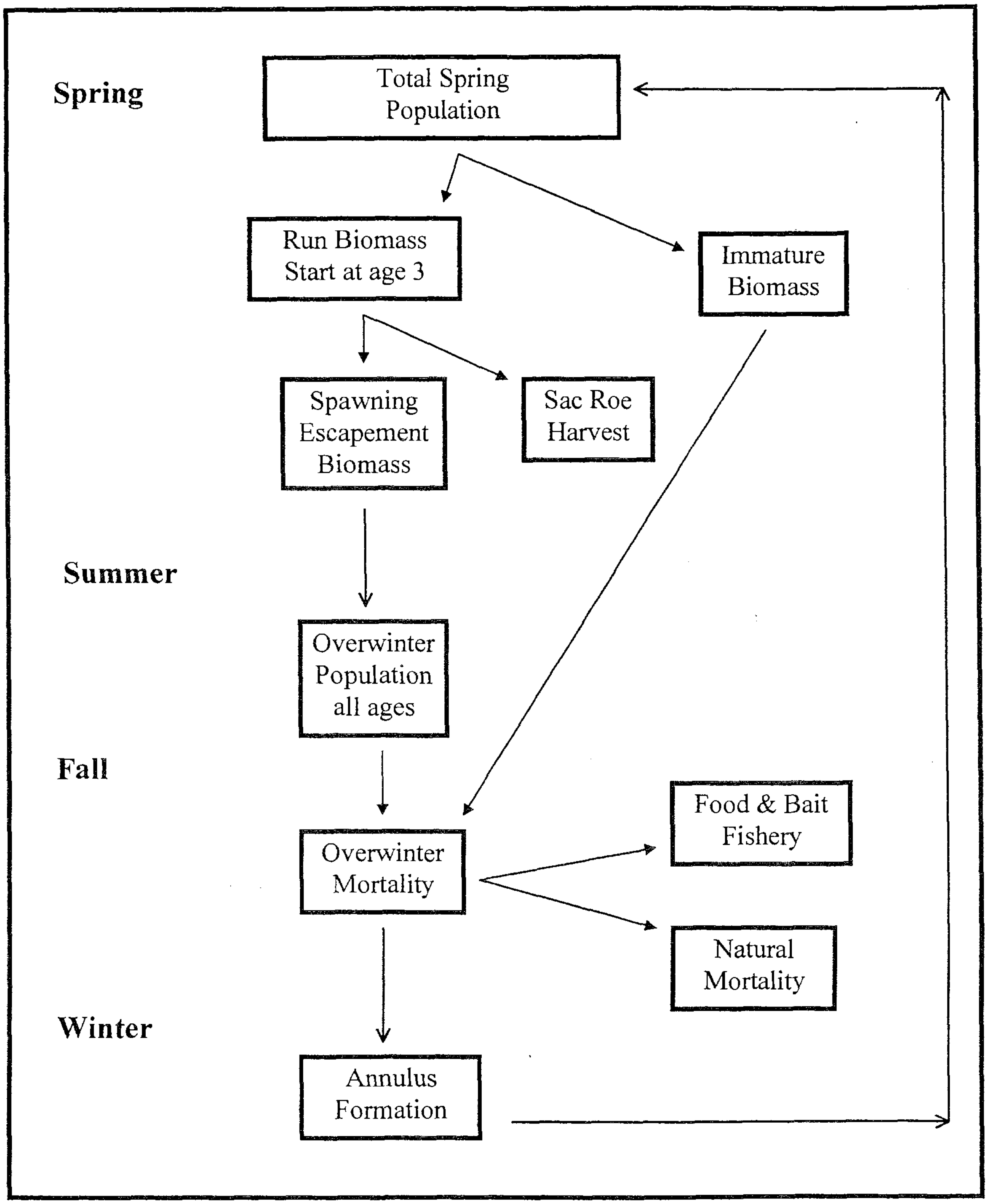


Figure 2. Conceptual model of the annual cycle of events affecting the Kamishak herring population.

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.

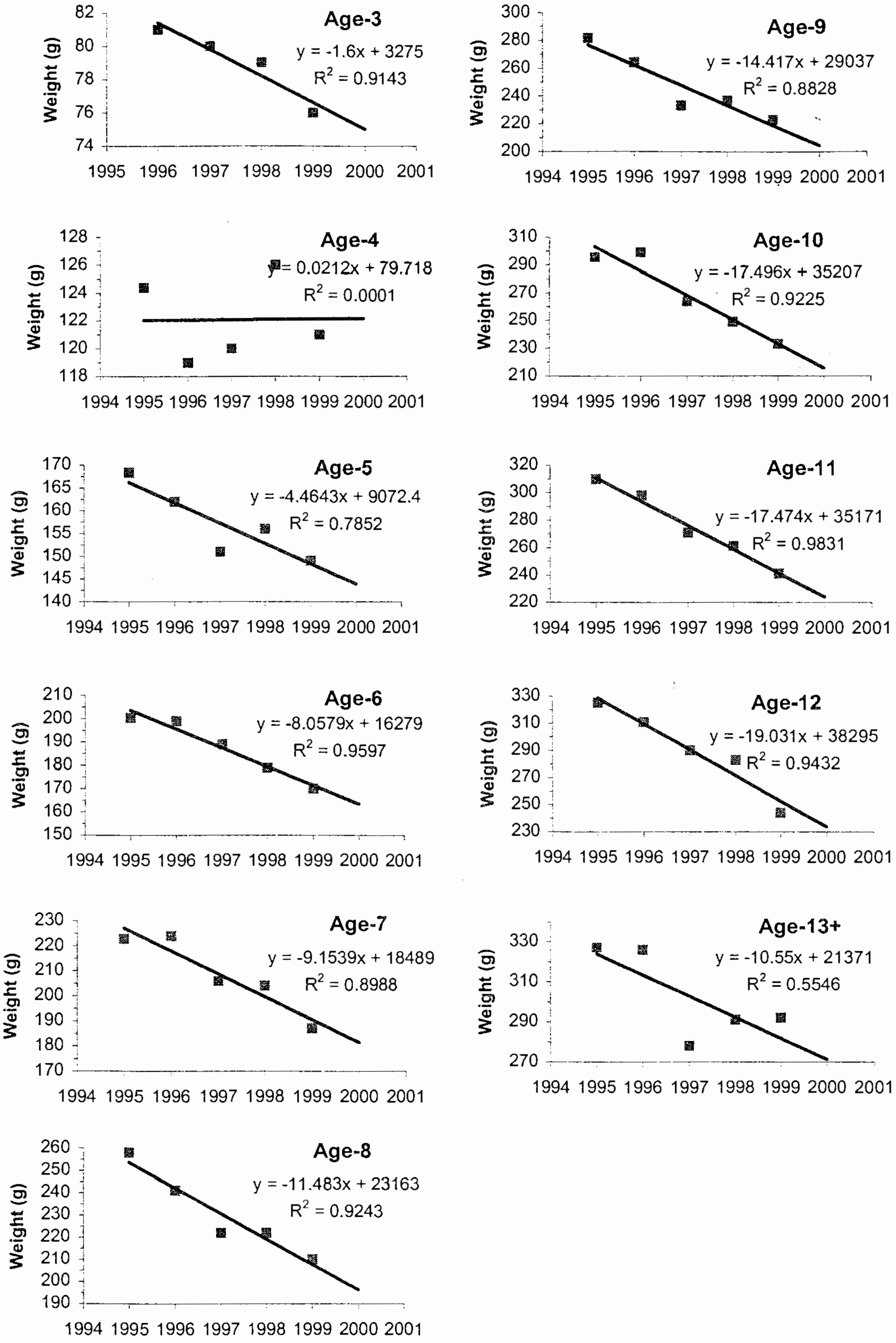
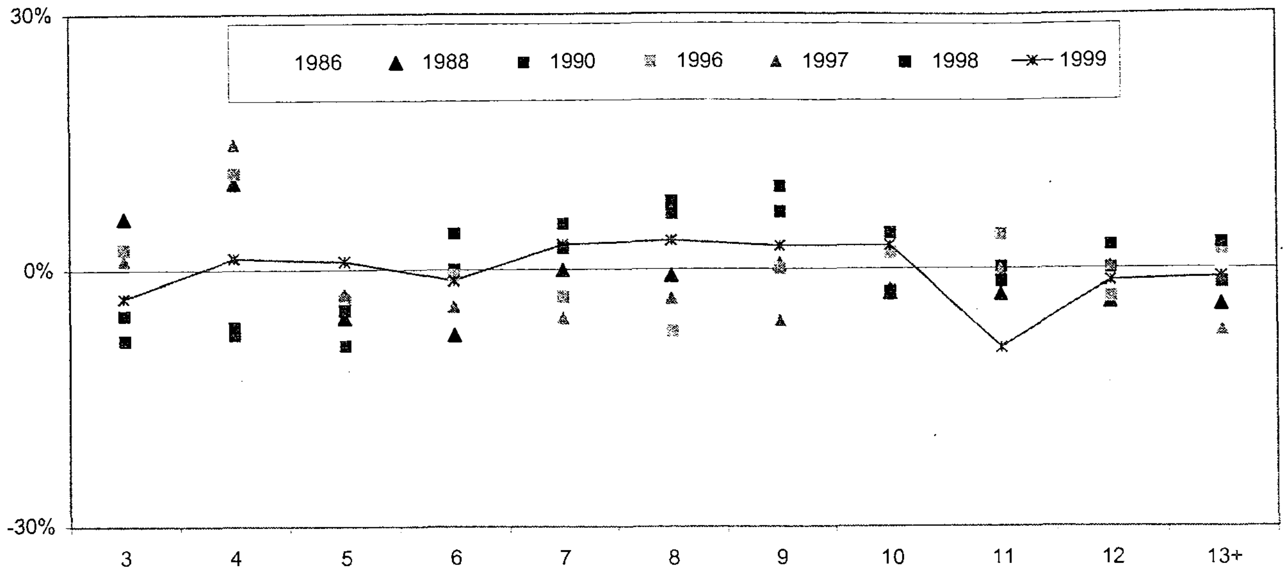


Figure 4. Linear trend line plotted through the recent weight-at-age trend for Kamishak herring; a one-year-ahead projection of the line was used to estimate the 2000 weights-at-age.

Figure 5. Kamishak Bay District herring age composition as a percentage of the total abundance and of herring forecasted to return in 2000.

A. Total run age composition residuals (transformed)



B. Catch age composition residuals (transformed)

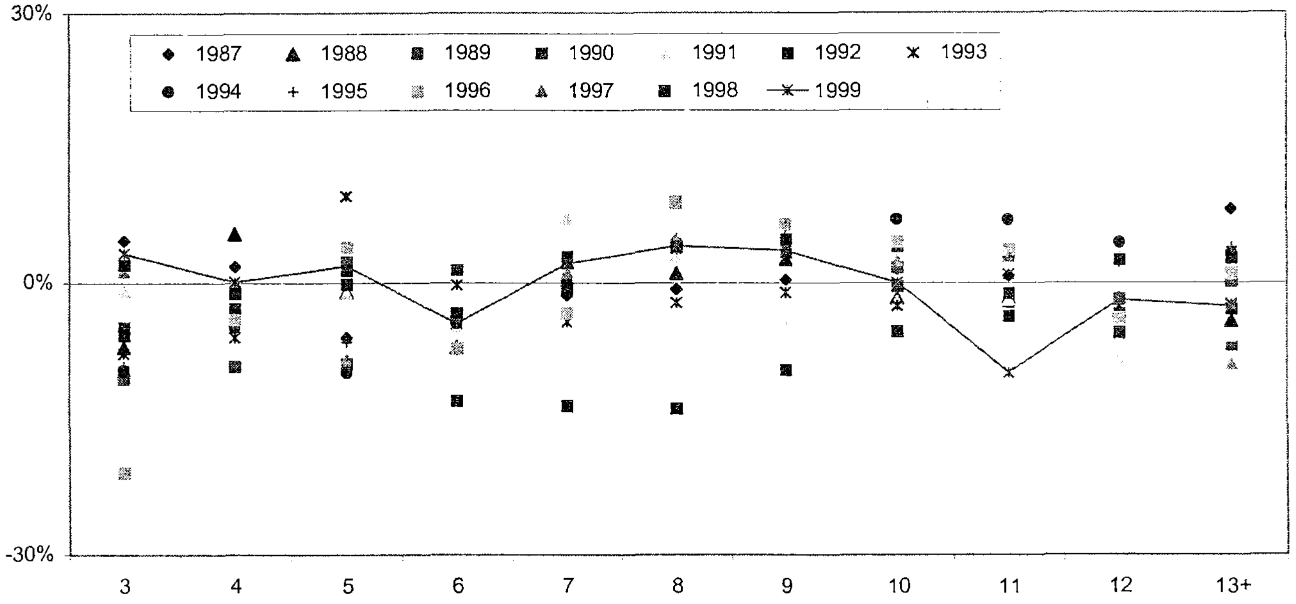


Figure 6. Residual differences between transformed estimated and observed age composition values for the (A) total run biomass and the (B) commercial catch of Kamishak Bay herring returns during 1985 to 1999.

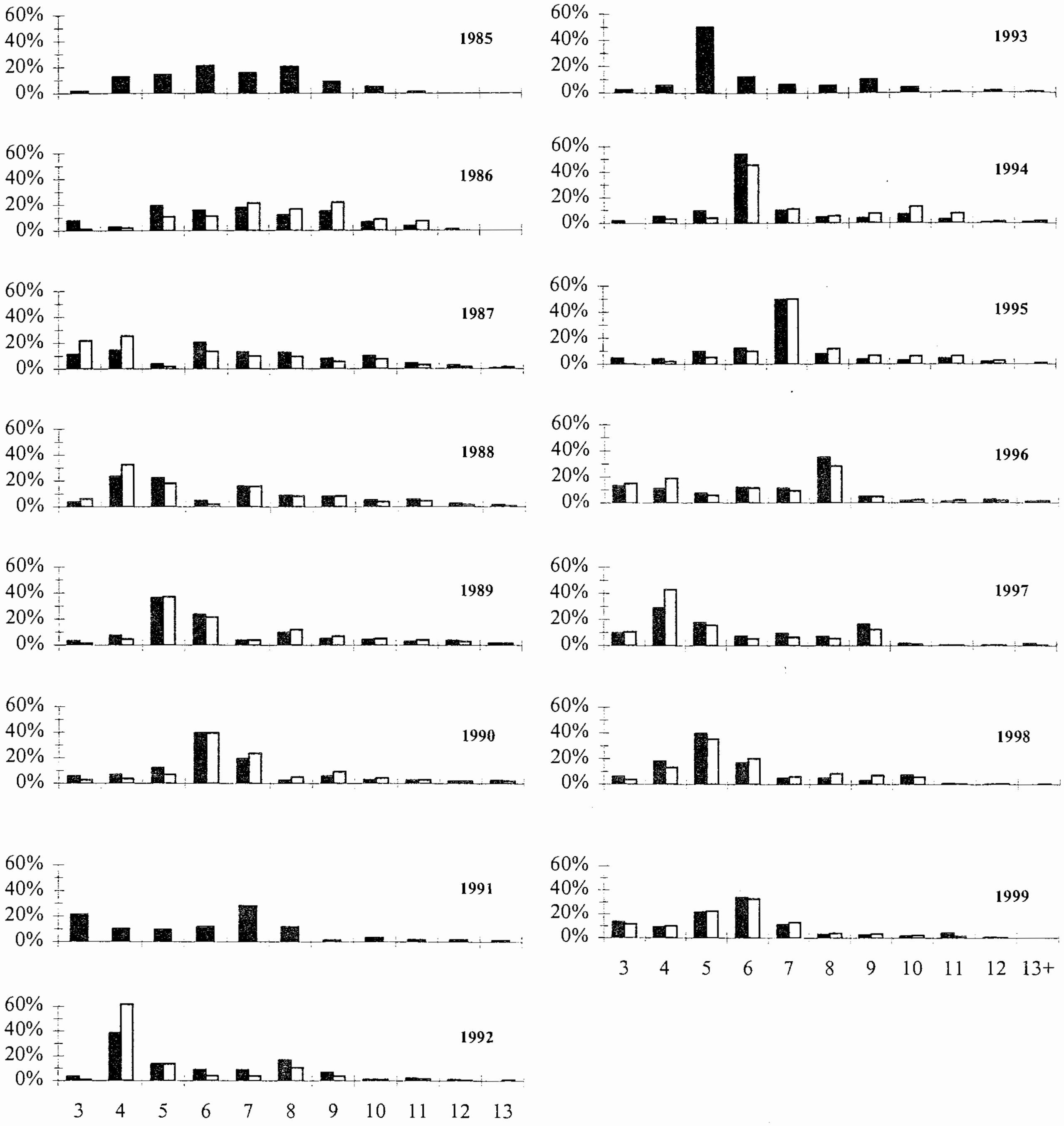


Figure 7. Total run age composition as estimated by the ASA model (black bars) and observed by sampling (white bars)for Kamishak Bay herring during 1985-1999 (sampling did not occur in 1985, 1991, or 1993).

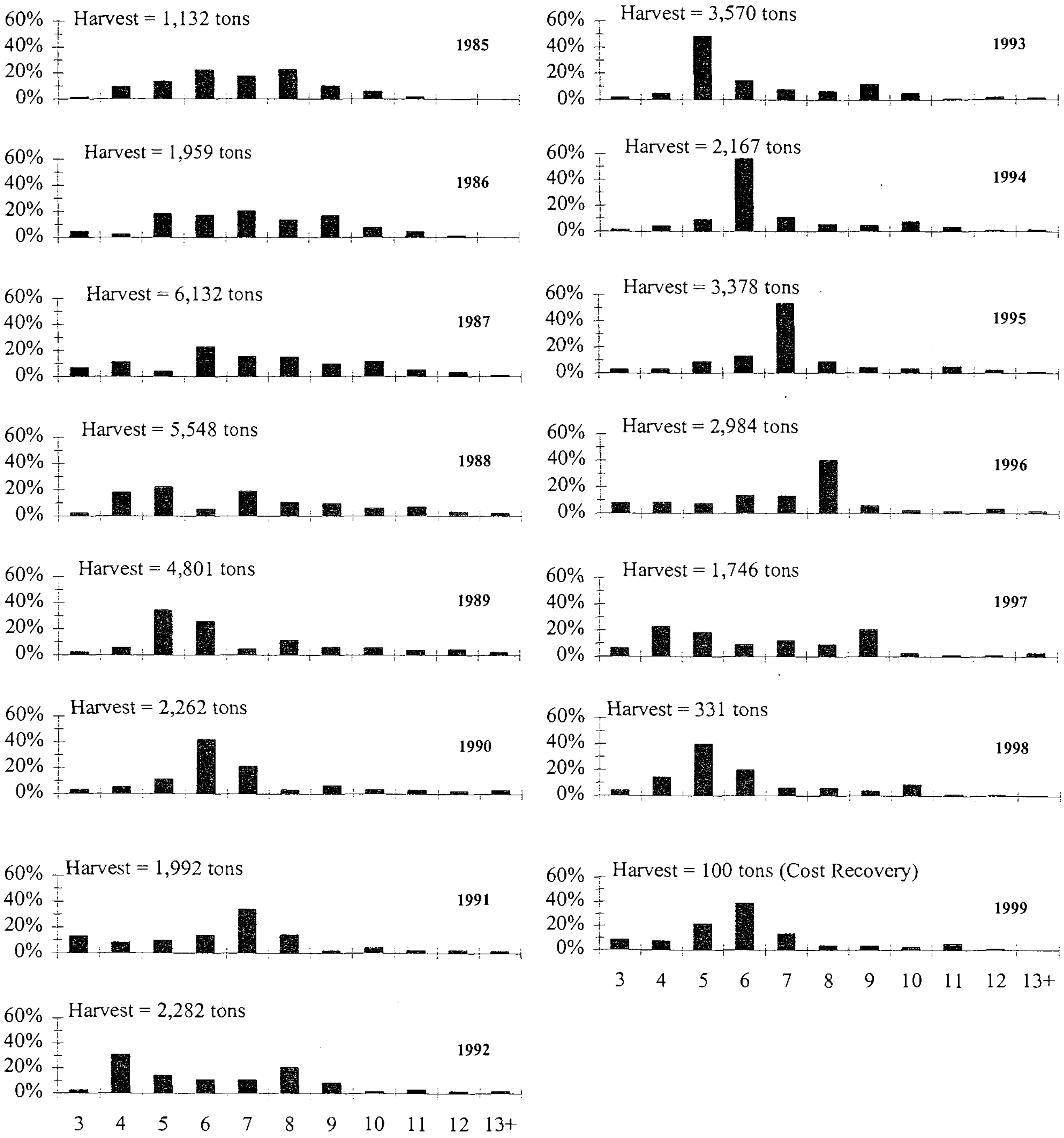


Figure 8. Commercial catch age composition estimated by the ASA model for Kamishak Bay herring during 1985-1999.

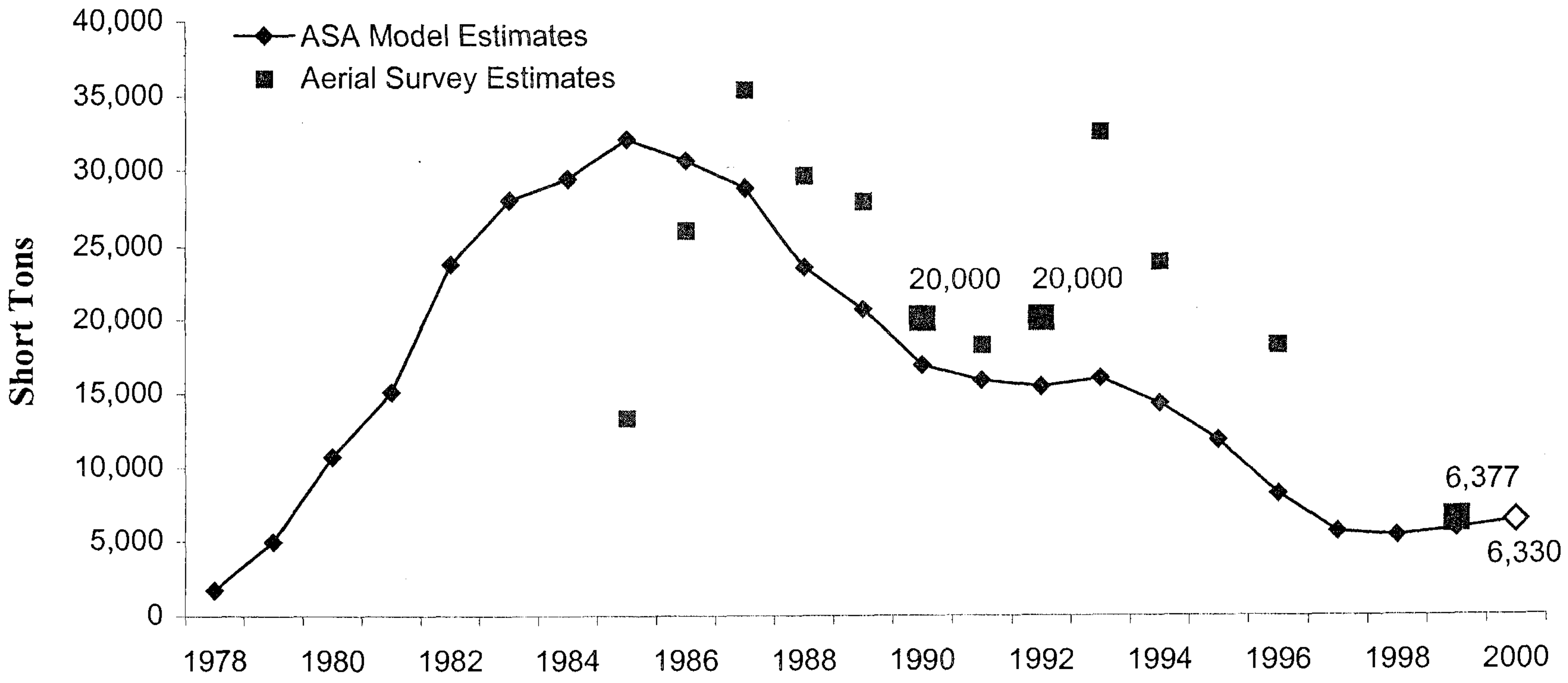
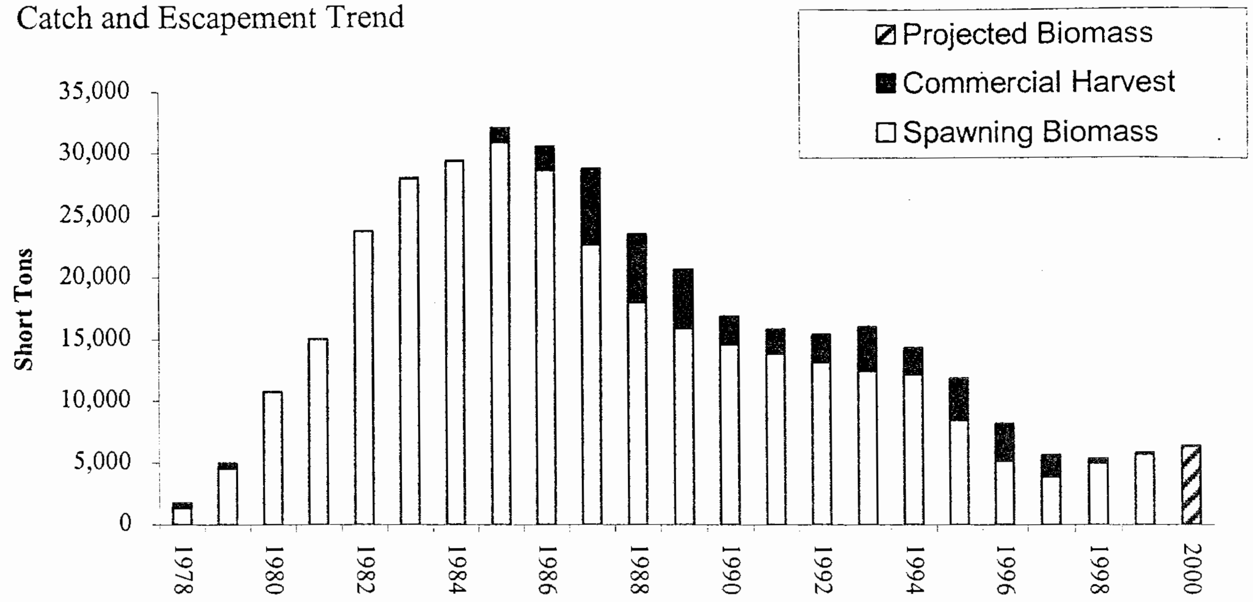


Figure 9. Kamishak Bay herring biomass estimated by the ASA model for 1978-2000 and observed by aerial surveys during 1985-1999. The larger aerial survey data labels with estimates shown next to them were used as auxiliary scaling information in the ASA model. The last ASA model estimate is the 2000 forecast.



A. Catch and Escapement Trend

B. Brood Year Strength

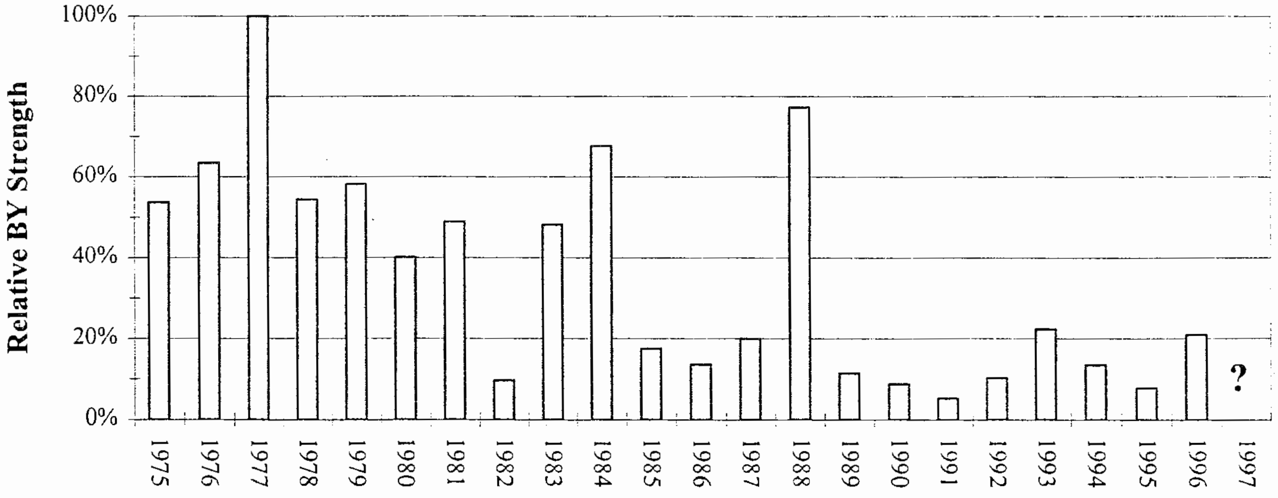


Figure 10. Kamishak Bay District herring catch and estimated escapement from 1978-1999 and as forecast for 2000 (A), and (B), the relative brood year strength for Kamishak Bay herring age classes from 1975-1996, scaled to the 1977 year class, the largest since our assessment began.

Appendix A. Kamishak Bay District herring catch by age and harvest year during 1978 to 1999.

	Age Class Abundance (X 1,000 fish)											
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13+**	**Total**
Year												
1978	400	1,353	915	93	88	131	110	110	440	11		3,651
1979	618	533	1,012	725	53	32	43	21	21	21		3,079
				Fishery	Closed	1980-84						
1985	10	569	700	1,124	739	1,177	433	253	204	49	0	5,258
1986	1,093	227	1,028	889	1,586	1,190	1,609	647	250	196	66	8,781
1987	2,342	3,098	476	5,133	3,612	3,696	2,454	3,182	1,335	579	597	26,504
1988	120	5,593	5,338	592	5,160	2,687	2,743	1,231	1,485	481	209	25,639
1989	12	388	7,599	4,704	825	2,796	1,615	1,168	938	662	379	21,086
1990	154	364	603	4,327	2,333	647	789	444	211	94	77	10,043
1991	1,102	697	787	945	3,690	1,462	45	270	112	22	22	9,154
1992	87	8,344	1,848	520	491	1,415	491	115	173	29	87	13,600
1993	26	367	10,007	2,362	945	945	1,916	630	105	52	52	17,407
1994	0	180	334	4,453	923	633	481	947	492	76	140	8,659
1995	49	346	673	1,035	6,959	1,366	756	724	756	312	66	13,040
1996	49	687	1,079	1,006	1,227	5,691	1,006	393	245	196	148	11,727
1997	543	1,911	1,006	564	1,036	961	2,004	229	98	66	21	8,439
1998	71	220	694	283	92	129	89	94	9	7	5	1,693
1999	52	37	121	181	77	26	23	9	7	1	0	534

Appendix B. Observed age composition of the herring run biomass in the Kamishak Bay District during harvest years 1986 to 1999.

	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
1997[1]	10.31	42.79	15.51	5.15	6.40	5.34	12.26	1.10	0.47	0.34	0.31
1998[1]	3.60	13.10	35.20	20.00	5.90	8.60	6.80	5.70	0.40	0.40	0.30
1999[1]	11.44	9.88	22.32	32.57	12.88	3.98	3.43	2.16	1.12	0.19	0.02

[1] These data were used in the ASA model to forecast the 2000 return; late season samples were not available to represent the total return from the other year

Appendix C. Kamishak Bay District herring mean weight by age and year of harvest during 1978 to 1999.

	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	80	127	162	198	226	247	267	295	303	309	339
1998	79	126	156	179	204	222	237	249	261	283	291
1999[b]	76	121	149	170	187	210	223	233	241	244	292
2000[b]	75	122	143	162	180	195	205	215	225	232	270

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

[b] Due to the recent trend of reduced weights, linear regression was used to predict mean weights-at-age in 2000.

Appendix D. Kamishak Bay herring run biomass estimates used to ‘tune’ ASA model.

Year	Estimated Run Biomass (tons)
1990	20,000
1992	20,000
1999	6,377

Appendix E. Data files used to forecast the herring biomass returning to Kamishak Bay in 1998.

Data File	Data Format	Description
00HerForecast.XLS	Excel 97	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 97	Spreadsheet indexing all ASA model runs used to evaluate the sensitivity of the model to various data input weighting options.
00SSQSUM.XLS	Excel 97	Summary of pertinent results of sensitivity analyses described above.

Appendix F. Final ASA Model spreadsheet for the 2000 Kamishak Bay District herring return.

ASA.XLS - Age Structured Analysis

FILENAME: 00HerFcstxls

Forecast: 6,330

Catch Lamda: 0.5
Survey Lamda: 0.05
Total Run Lamda: 0.5

Total SSQ: 0.381

Kamishak

Last year examined:	1999
Max age examined:	13+

Performs age-structured analysis, tuning to catch and total run age compositions and aerial survey estimate of abundance.

Survival constrained at 67%.

OBSERVED CATCH (millions of fish):

YEAR	3	4	5	6	7	8	9	10	11	12	13+	Total #
1978	0.400	1.353	0.915	0.093	0.088	0.131	0.110	0.110	0.440	0.011		3.651
1979	0.618	0.533	1.012	0.725	0.053	0.032	0.043	0.021	0.021	0.021		3.070
1980												
1981												
1982												
1983												
1984												
1985	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1986	1.093	0.227	1.028	0.889	1.586	1.190	1.009	0.647	0.250	0.198	0.066	8.781
1987	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.504
1988	0.120	5.593	5.338	0.592	5.160	2.687	2.743	1.231	1.485	0.481	0.209	25.839
1989	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1990	0.154	0.364	0.503	4.327	2.333	0.647	0.789	0.444	0.211	0.094	0.077	10.043
1991	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1992	0.087	8.344	1.848	0.520	0.491	1.415	0.491	0.115	0.173	0.029	0.087	13.600
1993	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.407
1994	0.000	0.160	0.334	4.453	0.923	0.633	0.481	0.847	0.492	0.076	0.140	8.659
1995	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.040
1996	0.049	0.687	1.078	1.000	1.227	5.691	1.008	0.393	0.245	0.196	0.148	11.727
1997	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1998	0.071	0.220	0.594	0.283	0.092	0.129	0.089	0.094	0.009	0.007	0.005	1.693
1999	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% by #	9.7%	6.9%	22.7%	33.9%	14.4%	4.9%	4.3%	1.7%	1.3%	0.2%	0.0%	100.0%

Estimated Age Composition of the Catch

YEAR	3	4	5	6	7	8	9	10	11	12	13+	Total %
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985	0.73%	8.81%	13.07%	22.08%	16.97%	22.17%	8.15%	6.30%	1.20%	0.03%	0.00%	
1986	4.07%	1.90%	17.47%	16.55%	19.50%	12.94%	16.05%	0.86%	3.86%	0.79%	0.00%	
1987	[illegible]	10.54%	3.27%	22.15%	14.62%	[illegible]	[illegible]	11.03%	4.73%	2.79%	[illegible]	
1988	1.94%	17.47%	21.65%	4.95%	18.28%	9.86%	9.13%	5.55%	6.59%	2.83%	1.77%	
1989	1.70%	5.74%	33.76%	26.34%	4.17%	10.72%	6.49%	4.80%	3.24%	[illegible]	1.77%	
1990	2.98%	4.77%	10.96%	41.69%	20.83%	2.78%	6.13%	2.92%	2.76%	1.73%	2.45%	
1991	12.88%	7.84%	9.27%	13.46%	18.34%	33.54%	1.42%	3.71%	1.88%	1.61%	1.17%	
1992	1.89%	30.01%	13.70%	10.33%	10.33%	20.30%	8.05%	0.92%	2.24%	1.03%	1.21%	
1993	1.37%	4.21%	47.89%	15.76%	7.59%	8.48%	11.71%	4.88%	0.37%	1.28%	0.83%	
1994	0.94%	3.72%	8.61%	55.93%	10.60%	5.17%	4.03%	6.94%	2.89%	0.25%	0.91%	
1995	2.36%	2.83%	8.47%	12.44%	52.77%	8.31%	3.59%	2.27%	4.89%	1.77%	0.10%	
1996	7.37%	7.94%	7.02%	13.08%	12.66%	39.63%	5.30%	1.90%	1.18%	2.65%	1.06%	100.0%
1997	8.82%	22.56%	17.90%	8.51%	11.55%	[illegible]	20.04%	1.97%	0.82%	0.57%	1.07%	100.0%
1998	3.43%	13.78%	39.64%	19.30%	5.72%	5.60%	3.30%	8.29%	0.72%	0.15%	0.08%	100.0%
1999	7.80%	5.98%	21.10%	36.27%	12.95%	3.26%	2.06%	1.83%	4.54%	0.42%	0.07%	100.0%
Mean	4.36%	10.59%	18.76%	21.48%	16.57%	11.46%	8.94%	4.40%	2.79%	1.62%	1.05%	

Catch-Age Composition Residuals:

(Arc Sine Transformed)

YEAR	3	4	5	6	7	8	9	10	11	12	13+	Weight
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987	-0.067	0.015	-0.061	-0.034	-0.014	-0.006	0.003	0.018	0.001	-0.019	0.082	1.0
1988	-0.071	0.055	-0.010	-0.072	0.023	0.010	0.026	-0.017	-0.016	-0.032	-0.043	1.0
1989	-0.107	-0.031	0.024	0.036	-0.008	0.039	0.011	0.012	0.031	-0.019	0.001	1.0
1990	-0.049	-0.029	-0.090	0.014	0.029	0.089	0.034	0.040	-0.022	-0.035	-0.069	1.0
1991	-0.109	-0.001	-0.012	-0.049	0.072	-0.080	-0.049	-0.021	-0.019	-0.004	-0.088	1.0
1992	-0.058	0.320	-0.002	-0.130	-0.136	-0.139	-0.097	-0.004	-0.037	-0.055	-0.030	1.0
1993	-0.079	-0.061	0.080	-0.003	-0.044	-0.022	-0.011	-0.020	0.009	-0.058	-0.034	1.0
1994	-0.097	-0.049	-0.100	-0.045	0.001	0.044	0.036	0.070	0.070	0.044	0.032	1.0
1995	-0.091	-0.005	-0.066	-0.076	0.008	0.087	0.051	0.070	0.027	0.022	-0.030	1.0
1996	-0.210	-0.041	0.040	-0.073	-0.034	0.090	0.065	0.048	0.036	-0.040	0.010	1.0
1997	0.013	[illegible]	0.065	-0.039	0.011	-0.048	0.046	-0.028	0.029	0.027	-0.081	1.0
1998	0.020	-0.012	0.014	-0.034	-0.006	0.041	0.049	-0.054	-0.012	0.025	0.027	1.0
1999	0.033	0.001	0.019	-0.046	0.021	[illegible]	0.036	[illegible]	-0.100	-0.013	-0.027	1.0
Sum	-0.660	0.103	-0.233	-0.616	-0.077	0.300	0.233	0.161	0.004	-0.243	-0.154	

Estimated Pre-Fishery Total Abundance (millions of fish)

YEAR	3	4	5	6	7	8	9	10	11	12	13+	Total #
1978	127.18	31.26	2.81	0.17								
1979	150.37	84.83	20.04	1.27	0.05							
1980	238.98	100.34	54.55	12.75	0.38	0.00						
1981	128.86	158.77	67.22	37.89	8.54	0.24	0.00					
1982	137.73	86.33	108.38	45.04	25.36	5.72	0.18	0.00				
1983	94.98	92.28	57.84	71.27	30.18	17.01	3.83	0.11	0.00			
1984	115.73	63.63	61.83	38.76	47.75	20.22	11.39	2.57	0.07	0.00		
1985	22.66	77.54	42.64	41.42	25.97	31.99	13.55	7.63	1.72	0.05	0.00	
1986	114.01	15.18	51.57	28.10	27.00	16.90	20.65	8.79	4.95	1.02	0.00	288.15
1987	150.41	75.65	10.02	33.88	18.73	17.03	10.53	12.78	5.45	3.15	0.55	347.63
1988	41.35	105.91	48.61	6.39	19.25	9.79	8.93	5.41	8.41	2.76	1.72	256.54
1989	32.04	27.62	67.21	28.89	3.89	9.44	4.76	4.15	2.80	3.30	1.53	185.73
1990	47.10	21.46	16.25	39.94	16.27	2.05	4.45	2.11	2.00	1.25	1.77	156.65
1991	183.00	31.48	14.13	11.82	23.86	9.34	0.94	2.45	1.11	1.20	0.77	280.09
1992	27.01	121.87	20.61	8.94	7.29	13.51	5.28	0.60	1.48	0.67	0.79	208.03
1993	20.63	18.04	76.08	12.57	5.64	4.65	8.11	3.21	0.32	0.88	0.43	150.43
1994	12.30	13.81	11.84	44.28	6.84	3.15	2.42	4.15	1.73	0.15	0.54	101.17
1995	24.14	8.24	9.13	7.71	28.67	3.98	1.68	1.30	2.14	0.83	0.05	85.85
1996	52.72	16.14	5.79	5.67	4.47	13.21	1.74	0.62	0.38	0.93	0.35	101.51
1997	31.87	35.29	10.35	2.82	3.12	2.17	5.03	0.49	0.15	0.09	0.49	91.90
1998	18.36	20.99	22.38	6.28	1.51	1.40	0.81	2.03	0.18	0.04	0.02	73.88
1999	49.37	12.25	13.92	14.52	4.01	0.95	0.85	0.48	1.30	0.11	0.02	97.78
2000	51.04	33.04	8.18	9.24	9.81	2.83	0.82	0.55	0.32	0.86	0.07	118.18
Mean	81.73	54.44	34.91	22.16	14.36	8.82	5.29	3.13	1.81	1.02	0.57	169.44

OBSERVED WEIGHT AT AGE (grams)

shaded data is interpolated

YEAR	3	4	5	6	7	8	9	10	11	12	13	Mean
1978	61	85	121	168	170	186	204	217	212	247		
1979	66	98	128	156	170	197	210	221	272	265		
1980	88	107	138	155	186	204	219	229	280	270		
1981	70	88	124	121	186	204	219	229	280	270		
1982	88	107	136	155	186	204	219	229	280	270		
1983	74	118	137	160	182	196	210	218	253	270		
1984	88	107	138	155	186	204	219	229	280	270		
1985	84	125	155	182	205	220	238	248	255	275		
1986	88	104	155	189	215	233	249	261	272	281	292	213
1987	91	134	162	198	218	241	251	267	276	275	288	218
1988	84	123	163	196	218	238	248	261	266	280	298	216
1989	98	131	150	199	228	245	254	268	285	288	298	223
1990	90	135	162	182	220	245	256	273	289	303	310	224
1991	79	118	172	208	214	259	267	288	280	229	413	230
1992	99	116	156	210	229	234	266	304	303	279	333	230
1993	88	131	152	193	230	245	250	293	302	317	362	236
1994	91	147	174	190	223	256	251	283	300	315	325	233
1995	76	124	168	200	223	258	282	295	310	325	327	235
1996	81	119	162	199	224	241	264	299	298	311	320	229
1997	80	120	151	189	206	222	233	264	271	290	278	209
1998	79	126	156	179	204	222	237	249	261	283	291	208
1999	76	121	149	170	187	210	273	233	241	244	292	195
2000	75	122	143	182	180	195	205	215	225	232	270	5 yr avg.
Mean	79	118	150	179	204	224	239	255	270	278	315	

Survey Abundance & Residuals

YEAR	Cum. Count	Aerial Survey Biomass (tons) Observed	ASA	Residual	Weight	Obs. Est. Derivation
1978			1,729			
1979			4,946			
1980			10,729			
1981			15,056			
1982			23,761			
1983			28,002			
1984			29,404			
1985	13,320	13,320	32,055			Schroeder
1986	26,001	26,001	30,587			Schroeder
1987	35,332	35,332	28,755			Schroeder
1988	29,548	29,548	23,490			Schroeder
1989	27,855	27,855	20,643			Schroeder
1990	30,259	20,000	16,825	0.173	1.0	Qualitative
1991	3,666	18,163	15,782			Interpolation
1992	20,168	20,000	15,369	0.263	0.5	Qualitative
1993	4,918	32,439	15,930			Run Timing
1994	4,410	23,778	14,244			Interpolation
1995	6,833		11,762			
1996	5,331	18,138	8,115			Interpolation
1997	3,115		5,582			
1998	1,288		5,295			
1999	6,377	6,377	5,764	0.101	0.5	
2000			6,330			
Mean			16,094			

Removals

YEAR	Comm Harvest	Cost Recovery	Comments
1978	402		
1979	415		
1980	0		CLOSED
1981	0		CLOSED
1982	0		CLOSED
1983	0		CLOSED
1984	0		CLOSED
1985	1,132		
1986	1,959		
1987	6,132		
1988	5,548		
1989	4,801		
1990	2,264		
1991	1,992		
1992	2,282		
1993	3,570		
1994	2,167		
1995	3,378		
1996	2,984		
1997	1,746	54	
1998	331	33	
1999	100	100	CLOSED
2000	0		CLOSED

OBSERVED TOTAL RUN AGE COMPOSITION

YEAR	3	4	5	6	7	8	9	10	11	12	13+	Total %
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986	[illegible]	2.10%	10.70%	11.10%	21.10%	16.50%	21.00%	8.50%	7.50%	0.00%	0.00%	100.0%
1987	21.70%	25.40%	1.90%	13.50%	9.90%	9.30%	5.60%	7.30%	2.90%	1.20%	1.30%	
1988	[illegible]	32.50%	[illegible]	[illegible]	18.60%	8.07%	6.16%	9.87%	4.10%	1.40%	[illegible]	
1989	1.22%	4.55%	37.21%	21.52%	3.81%	11.83%	6.79%	4.84%	3.80%	2.70%	1.53%	
1990	2.40%	3.10%	8.90%	38.00%	21.40%	15.00%	6.10%	1.20%	3.80%	1.00%	1.40%	100.0%
1991												
1992	0.00%	61.80%	13.80%	3.80%	3.80%	10.40%	3.80%	0.90%	1.30%	0.20%	0.90%	100.0%
1993												
1994	0.10%	[illegible]	[illegible]	40.80%	11.21%	6.06%	7.17%	12.83%	7.87%	[illegible]	[illegible]	100.0%
1995	0.24%	2.01%	5.13%	8.71%	49.76%	11.86%	8.29%	5.86%	8.04%	2.38%	0.92%	
1996	16.80%	[illegible]	5.70%	11.80%	9.20%	28.50%	4.70%	2.20%	2.60%	1.60%	1.40%	100.0%
1997	10.31%	42.79%	15.51%	5.15%	6.40%	5.34%	12.26%	1.10%	0.47%	0.34%	0.31%	100.0%
1998	[illegible]	19.30%	[illegible]	20.00%	8.90%	[illegible]	[illegible]	5.20%	[illegible]	0.40%	[illegible]	100.0%
1999	11.44%	8.88%	22.32%	32.57%	12.88%	3.98%	3.43%	2.16%	1.12%	0.19%	0.02%	100.0%
2000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	6.12%	18.27%	14.67%	18.00%	14.43%	10.36%	7.96%	4.93%	3.30%	1.09%	0.88%	

ESTIMATED TOTAL RUN AGE COMPOSITION

YEAR	3	4	5	6	7	8	9	10	11	12	13	Total %
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985	1.36%	12.52%	14.37%	20.98%	15.56%	20.37%	8.76%	4.97%	1.12%	0.03%	0.00%	
1986	7.51%	2.70%	19.15%	[illegible]	17.82%	[illegible]	13.71%	6.40%	3.56%	0.73%	0.00%	100.00%
1987	11.29%	14.34%	3.96%	20.14%	12.82%	12.69%	8.00%	9.74%	4.17%	2.41%	0.42%	100.00%
1988	3.30%	23.31%	22.23%	3.41%	16.70%	8.48%	7.89%	4.60%	5.70%	2.48%	1.59%	100.00%
1989	3.06%	7.10%	38.07%	23.39%	3.71%	9.55%	4.90%	4.30%	2.91%	3.43%	1.59%	100.00%
1990	3.51%	8.76%	12.00%	39.48%	19.03%	2.14%	6.02%	2.90%	2.54%	1.60%	2.25%	100.00%
1991	21.41%	9.91%	9.30%	11.66%	27.90%	11.57%	1.19%	3.12%	1.42%	1.52%	0.98%	100.00%
1992	5.15%	48.22%	12.51%	6.55%	8.49%	15.69%	0.84%	0.76%	1.90%	[illegible]	1.00%	100.00%
1993	2.43%	5.73%	50.45%	17.53%	6.66%	5.69%	10.32%	4.11%	0.42%	1.11%	0.55%	100.00%
1994	1.79%	6.40%	8.65%	[illegible]	9.92%	4.84%	5.70%	6.83%	2.72%	0.23%	0.86%	100.00%
1995	4.50%	4.14%	9.57%	12.14%	49.60%	7.83%	3.39%	2.63%	4.35%	1.68%	0.10%	100.00%
1996	15.32%	10.81%	7.40%	11.91%	11.12%	[illegible]	4.67%	1.68%	1.04%	2.82%	0.93%	100.00%
1997	9.63%	28.72%	17.59%	7.20%	9.43%	6.96%	16.42%	1.61%	0.51%	0.31%	1.67%	100.00%
1998	5.90%	17.88%	39.89%	18.70%	4.77%	[illegible]	2.77%	[illegible]	0.61%	0.12%	[illegible]	100.00%
1999	13.59%	9.08%	21.53%	33.75%	11.02%	2.77%	2.52%	1.45%	3.88%	0.34%	0.06%	100.00%
2000	12.52%	27.47%	11.10%	15.84%	23.11%	6.75%	1.01%	1.45%	0.84%	2.27%	0.20%	100.00%
00 by#	4.69	8.18	4.23	7.18	8.82	2.56	0.61	0.55	0.32	0.86	0.07	38.09
00 by wt	367.9	1,099.9	656.5	1,281.7	1,750.8	550.9	139.0	131.0	79.0	221.1	27.2	6,330

Total Run Age Composition Residuals:

(Arc Sine Transformed)

YEAR	3	4	5	6	7	8	9	10	11	12	13	Weight
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986	-0.173	-0.020	-0.120	-0.087	0.044	0.067	0.090	-0.042	0.030	-0.068	0.000	1.0
1987												
1988	0.060	0.101	0.050	-0.078	-0.001	-0.007	0.005	-0.028	-0.030	0.019	-0.042	1.0
1989												
1990	-0.081	-0.075	0.068	0.000	0.054	0.066	0.067	-0.042	0.002	0.001	-0.010	1.0
1991												
1992												
1993												
1994												
1995												
1996	0.021	0.118	-0.034	0.000	-0.032	-0.072	-0.001	0.019	0.040	-0.028	0.022	1.0
1997	0.011	0.147	-0.028	-0.043	-0.056	-0.034	-0.059	-0.022	-0.003	0.003	-0.072	1.0
1998	-0.062	-0.068	-0.048	0.043	0.025	0.040	0.007	-0.028	-0.016	-0.027	0.030	1.0
1999	-0.032	0.014	0.010	-0.013	0.029	0.034	0.027	0.027	-0.092	-0.014	-0.011	1.0
2000												
Sum	-0.243	0.216	-0.363	-0.162	0.062	0.133	0.227	0.054	-0.017	-0.140	-0.089	

RESIDUAL SUMMARY AND WEIGHTING

		Current	SSQ at Min			Adjusted	Unadjust	Prior	Unadjusted SSQ was weighted Scaled & Weighted	
SSQ Source	N	SSQ's	CatchAge	Survey	RunAge	SSQ	SSQ	(λ)	SSQ	MSE
Catch Agecomp	143	0.5077	0.35	1.11	0.41	0.21	0.508	0.5	0.2538	0.0036
Survey Biomass	3	0.0897	0.10	0.00	0.56	0.124	0.070	0.05	0.0035	0.0232
Run AgeComp	77	0.2466	0.39	4.25	0.34	-0.024	0.247	0.5	0.1233	0.0032
Total	223								0.3806297	

CURRENT PARAMETER ESTIMATES

INITIAL COHORT SIZES

	AGE										
YEAR	3	4	5	6	7	8	9	10	11	12	13+
1978	127.16	31.26	2.81	0.17							
1979	150.37										
1980	236.98										
1981	128.86										
1982	137.73										
1983	94.90										
1984	115.73										
1985	22.66										
1986	114.01										
1987	160.41										
1988	41.35										
1989	32.04										
1990	47.10										
1991	183.00										
1992	27.01										
1993	20.63										
1994	12.30										
1995	24.14										
1996	52.72										
1997	31.87										
1998	18.38										
1999	49.37										
Mean	83.13										

SURVIVAL/MORTALITY RATES

	Survival		Inst. Mortality
S	67.00%	M	0.4005

GEAR VULNERABILITY FUNCTION COEFFICIENTS

	Function Parameters α	β	Type
Catch	5.193	1.386	*Logistic*
Total Run	4.943	1.179	*Logistic*

AGE-SPECIFIC GEAR VULNERABILITY FUNCTION VALUES

AGE	3	4	5	6	7	8	9	10	11	12	13
Catch (adjustment for catch being older than total run, if influx of younger aged fish occur after fishery)											
	0.046	0.161	0.434	0.754	0.925	0.980	0.995	0.999	1.000	1.000	1.000
Total Run (refers to maturity curve)											
	0.092	0.248	0.517	0.776	0.919	0.973	0.992	0.997	0.999	1.000	1.000

Forecast Biomass Summary

	Aerial	ASA
1991	18,183	15,782
1992	20,000	15,369
1993	32,439	15,930
1994	0	14,244
1995	0	11,762
1996	0	8,115
1997	0	5,582
1998	0	5,295
1999	6,377	5,764
2000	0	6,330

PARAMETER ESTIMATE SCALES

INITIAL COHORT SIZES

	AGE										
YEAR	3	4	5	6	7	8	9	10	11	12	13
1978	*0.9692*	*0.5052*	*0.1858*	*1.0000*							
1979	*0.9115*										
1980	*0.8631*										
1981	*0.8898*										
1982	*0.8543*										
1983	*0.8601*										
1984	*0.8017*										
1985	*0.7719*										
1986	*0.6327*										
1987	*0.5863*										
1988	*0.6848*										
1989	*0.5822*										
1990	*0.4400*										
1991	*0.3603*										
1992	*0.4341*										
1993	*0.3584*										
1994	*0.2418*										
1995	*0.1867*										
1996	*0.3468*										
1997	*0.2129*										
1998	*0.1494*										
1999	*0.6175*										
Mean	0.5834										

SURVIVAL/MORTALITY RATES

	Survival
S:	*1.0000*

change all parameter estimate scales (purple)
to 1 prior to each run of the solver (see step 8 below)

GEAR VULNERABILITY FUNCTION COEFFICIENTS

	Function Parameters α	β	Type
Catch	*0.9872*	*1.1369*	*Logistic*
Total Run	*0.9466*	*1.2762*	*Logistic*

Notes: Survival constrained at 67%

STORED INITIAL PARAMETER ESTIMATES

INITIAL COHORT SIZES

	AGE										
YEAR	3	4	5	6	7	8	9	10	11	12	13
1978	131.21	61.87	15.10	0.17							
1979	164.87										
1980	274.56										
1981	144.85										
1982	161.21										
1983	110.42										
1984	144.37										
1985	29.36										
1986	167.00										
1987	273.61										
1988	60.36										
1989	55.04										
1990	107.05										
1991	507.98										
1992	62.21										
1993	57.57										
1994	50.86										
1995	129.26										
1996	152.01										
1997	131.21										
1998	122.87										
1999	79.94										
Mean	141.72										

SURVIVAL/MORTALITY RATES

	Survival		Inst. Mortality
S:	67.0%	M	0.4256159

GEAR VULNERABILITY FUNCTION COEFFICIENTS

	Function Parameters α	β	Type
Catch	5.280	1.220	*Logistic*
Total Run	5.222	0.924	*Logistic*