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FORECAST OF PACIFIC HERRING BIOMASS IN THE TOGIAK DISTRICT, BRISTOL BAY, 1994

By

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and

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ABSTRACT

The 1993 Togiak District spawning migration consisted of 496 million Pacific herring *Clupea pallasi* weighing 193,847 tons. A total of 20,629 tons were harvested by the inshore sac roe fishery and the Dutch Harbor food and bait fishery. The 1994 forecast represents the second year an age-structured analysis, using fishery and run biomass age compositions with selected years of good aerial surveys, was used to generate abundance estimates. The 1994 spawning biomass of herring in the Togiak District is forecasted to be 142,498 tons. An estimated 72% of the individuals and 65% of the biomass will be age-6 and -7 herring. The average size of an individual is expected to be 298 g in the commercial fisheries and 286 g in the biomass.

The 1994 recommended total allowable harvest is 28,499 tons which represents 20% of the forecasted run biomass. In accordance with the Bristol Bay Herring Management Plan, the allocation would be 1,500 tons of herring for the Togiak spawn-on-kelp fishery, 1,890 tons for the Dutch Harbor food and bait fishery, and 25,109 tons for the Togiak sac roe fishery.

INTRODUCTION

The Togiak District of Bristol Bay, Alaska, extends from Cape Constantine to Cape Newenham (ADF&G 1992a) and supports the largest spawning population of Pacific herring *Clupea pallasi* in the eastern Bering Sea (Figure 1). Though studies have yet to demonstrate genetic variation among spawning populations of herring in the eastern Bering Sea, differences in growth and run timing are apparent. Herring that spawn in the Togiak District are most similar to herring from the Security Cove and Goodnews Bay Districts, but show significant differences in growth and run timing from herring which spawn along the Alaska Peninsula and north of Kuskokwim Bay (Barton 1978; Wespestad and Barton 1981; Walker and Schnepf 1982; Rogers et al. 1983, 1984; Schnepf 1984; Rogers and Schnepf 1985; Rowell et al. 1991). Herring move from their overwintering grounds near the Pribilof Islands into the Togiak District in the spring to spawn (Shaboneev 1965). After spawning, these herring undertake a feeding migration southward along the Alaska Peninsula, concentrate in the vicinity of Unalaska Island, and return to their overwintering grounds in the fall (Shaboneev 1965; Rumyantsev and Darda 1970; Funk 1990). These herring are harvested at various points during their migration. The primary harvest occurs in the Togiak District by a sac roe fishery during the spring (Table 1). Lesser harvests are taken during the summer months in the Dutch Harbor food and bait fishery and as bycatch from the domestic pollock trawl fishery.

Stock assessment information of various kinds has been collected for the Togiak herring population since 1977. These data include age composition estimates of commercial purse seine catches, commercial gillnet catches, testfish purse seine catches, and the mature run. Estimates of biomass are obtained by aerial survey estimates school size and abundance. Beginning in late April the nearshore area of the Togiak District is surveyed daily from small aircraft to monitor relative abundance, distribution, and spawning of the herring population. Daily biomass estimates are derived from the number and size of herring schools observed (Lebida and Whitmore 1985). Run biomass estimates for each year largely rely on summing "peak" estimates from this time series of abundance observations. Because immigration to and emigration from the herring spawning grounds is likely a continuous process, aerial surveys tend to be conservative estimates of abundance. Furthermore, in years when survey conditions are poor, aerial surveys likely underestimate biomass. Strong 1977 and 1978 year classes should have caused a very large pulse of biomass in the Togiak stock during the mid-1980's according to cohort analysis reconstructions (Baker 1991a, Wespestad 1991, Zheng et al. *in press*). This trend is not reflected in aerial survey estimates of biomass during this same time period which included years of varying survey conditions and data interpretations. Run biomass estimated from aerial surveys has ranged from 242,298 tons[1] in 1979 to 76,960 tons in 1980 (Figure 2).

Large numbers of herring collected in age-weight-length samples from the Togiak population likely provide precise estimates of age composition. These estimates reflect relative abundance trends such as the recruitment of the strong 1977 and 1978 year classes. Age-structured analysis

[1] Tons = 2,000 pounds and is often referred to as short tons. Tonnes = 2,204.62 pounds or 1,000 kg.

(ASA) provides a tool that can simultaneously incorporate age composition data and selected years of aerial surveys to generate abundance estimates rather than forecasting off the previous year's age composition and abundance estimate. The first ASA analysis applied to Togiak herring was the forecast of the 1993 run biomass. The ASA approach we used scales relative abundance trends from age composition estimates to the approximate magnitude of run biomass estimates from subsets of aerial surveys taken from years with "good" survey conditions. This ASA approach only partially corrects the tendency for aerial surveys to be conservative, but removes considerable bias in abundance estimates by excluding aerial survey biomass estimates made during years of poor weather or inadequate geographic and temporal coverage. The ASA model estimates will still tend to underestimate true herring abundance since residence time of herring on the spawning grounds is not known and not all herring are observed, even during years ahead with good survey conditions. The primary goal of the ASA model is to produce a one-year forecast which attempts to make maximum use of the information contained in age composition data and aerial survey years when it is likely that the "peak" abundances were at least observed under good aerial survey conditions, and aerial surveys were conducted throughout the run.

The purpose of this report is to provide a forecast of herring returning to spawn in the Togiak District, Bristol Bay in 1994. Specific objectives are (1) to document and evaluate the performance of the 1993 forecast, (2) to document data sources and methodology used for the 1994 forecast, and (3) to present the 1994 forecast, and through application of the Bristol Bay Herring Management Plan (ADF&G 1992a), propose a harvest guideline for the 1994 commercial fishing season.

METHODS

The Togiak ASA model incorporates auxiliary information, similar to models developed by Deriso et al. (1985). Nonlinear least squares techniques are used to minimize a sum of squares constructed from heterogeneous types of auxiliary information which may incorporate many different sources of data. ASA models which incorporate heterogenous data have been reviewed by Megrey (1989) and Hilborn and Walters (1992). Whereas our primary goal was to generate a one-year-ahead forecast of herring abundance for 1994, the model also updated estimates of historical abundances for 1978-1993, and provided estimates of natural mortality, maturity, and gear selectivities for purse seine, and gillnet fisheries.

In our conceptual model of the annual cycle of events affecting the Togiak herring stock (Figure 3), we increment ages at the end of winter, coinciding with the approximate time of annulus formation. The population model begins accounting for herring at age 4, the first year a measurable proportion of a cohort usually returns to spawn. Prior to spring, the conceptual model splits the "total" herring population into two components: an "immature" portion that will not return to spawn, and a "run" biomass that will return to inshore areas to spawn. Removals by purse seine and gillnet sac roe fisheries are then deducted which leaves the "escapement" biomass that actually spawns. In this model configuration, we do not account for removals by the Dutch Harbor food and bait fishery or groundfish trawl bycatches, but these harvests are reflected in the survival rate estimate. These removals could be explicitly made when catch by age becomes available from these fisheries. However, because selectivity in these fisheries may be highly variable and these harvests occur on mixed stocks, catch information from these fisheries may not provide useful "tuning" information for the Togiak ASA model.

The 1994 Togiak herring biomass was forecasted from the 1993 total population, adjusting for commercial removals, growth, mortality, maturity, and recruitment. Components used to prepare the forecast included estimates of: (1) the run biomass and commercial removals 2) age composition of the spawning biomass and commercial harvest, and (3) weight-at-age. Initial parameter values for natural mortality, selectivity, maturity, and the number of age-4 herring for each cohort were provided before initiating each model simulation.

Survival Model

The survival component of our model used a difference equation to describe the number of herring (*N*) in a cohort aged *a* in year *y*:

$$N_{a+1,y+1} = S\ (N_{a,y} - C^{seine}_{a,y} - C^{gillnet}_{a,y})\ , \qquad (1)$$

where S is the annual survival rate estimated by the ASA model, $C^{seine}_{a,y}$ is the catch from the spring purse seine sac roe fishery, and $C^{gillnet}_{a,y}$ is the catch in the spring gillnet sac roe fishery. The number of herring in a cohort (*N*) includes both mature and immature herring present after annulus formation but before the spawning migration or spring roe fisheries occur (the "total population biomass" of Figure 3). The model starts accounting for herring at age 4. Because herring age 9 and older were pooled in age composition data for 1978 and 1979, these fish were pooled into a single age-"9+" category for 1978 and 1979 estimates of abundance and age composition. Beginning in 1980, herring ages were recorded individually until age 15 and in 1988 have been recorded to age 18. In the model, the "9+" category of 1979 becomes the "10+" category of 1980, the "11+" category of 1982, etc. and eventually, the "15+" category of 1985. From 1985 forward, herring aged 15 and older are pooled into the "15+" category.

The starting values used to initiate the iterative process for solving the model corresponded to the final values generated by the 1993 forecast model (Brannian et al. 1993). The starting value for annual survival rate was 78.06%, which is equivalent to instantaneous natural mortality rate (M) of 0.26.

Catch at Age

Herring harvests by age for purse seine and gillnet fisheries were obtained from published sources for 1978-1991 (Tables 2 and 3). For 1978 and 1979, the age composition of the harvest was obtained from McBride et al. (1981) and Fried et al. (1983). Age composition estimates were converted to numbers of herring harvested in 1978 and 1979 using total catch weight for each gear (Skrade and Brookover 1991), and average weight at each age (Table 4). For 1980-1989, catches at age were obtained from Baker (1991b). For 1990-1993, this information was obtained using the catch weight at age distribution from the annual forecast report (Rowell 1992; Brannian et al. 1993; Rowell and Brannian 1993, *In Press*) and average weight at each age (Table 4).

Herring harvests by age were then entered in equation (1), as $C_{a,y}^{seine}$ and $C_{a,y}^{gillnet}$. Numbers of herring in the catch for only purse seine gear were also converted to age composition estimates (percent by age) so that they could be compared with age composition estimates obtained from the ASA model. Gillnet harvests were not converted to age composition or estimated by the ASA model for the 1994 forecast because 1) changes in prosecution of the fishery and changes in mesh size throughout the history of the fishery may affect the selectivity in the age structure of the harvest and 2) contribution of the harvest to the total fishery has historically been (no greater than 25%) which is considered relatively low in relation to the total estimated abundance.

Weight at Age

Estimates of weight at age were obtained from Baker (1991b) for 1981-1990 (Table 4). For 1978-1980 weight at age was obtained from Baker (1991a) who estimated values using Schnute's (1981) general growth model:

$$W_a = W_\infty e^{-e^{-g(a-a_o)}} \quad , \tag{2}$$

where W_a is the estimated weight at age a, W_∞ is asymptotic weight, g is a relative growth parameter and a_o is an initial age parameter. This relationship was fit using a non-linear least squares estimation procedure employing a modified Marquardt algorithm. Mean weight at age data from the 1980-1989 Togiak commercial purse seine fishery samples were used to estimate model parameters. The resulting weight-age relationship was:

$$W_a = 515 e^{-e^{-0.264(a-4.63)}} \; . \tag{3}$$

Mean weight at age was calculated from combined AWL samples collected from non-selective gear for years 1991-1993. For 1994, mean weight at age was estimated as the most recent five year average.

Estimation of the Age Composition of the Catch

Gear Selectivity

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

$$\hat{p}_{a,y} = \frac{s(a)N_{a,y}}{\sum_{a}[s(a) \cdot N_{a,y}]} \quad . \tag{4}$$

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

$$s(a) = \frac{1}{1 + e^{\beta(a-\alpha)}} \ , \tag{5}$$

where α is the age at which selectivity is equal to 50%, and β is a steepness parameter.

Comparing Actual and Model Estimates of Age Composition for Catches

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 measuring the goodness of fit of the age composition of the catch was computed as:

$$SSQ_{agecomp:catch} = \sum_{y} \sum_{a} \left(\frac{C_{a,y}}{\sum_{a} C_{a,y}} - \hat{p}_{a,y}\right)^2 \quad , \qquad (6)$$

where $(\hat{p}_{a,y})$ was the estimated age composition of the catch from equation (4). A transformation, $\sin^{-1}$(square root), was applied to observed and estimated age composition proportions to stabilize the variance. Purse seine age composition was fit across all age groups (age 4 to 15^{+}).

Maturity

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

$$\rho(a) = \frac{1}{1+e^{\phi(a-\tau)}} \quad , \qquad (7)$$

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. The validity of this assumption was investigated for the 1993 forecast (Brannian et al. 1993). Three scenarios were explored for the 1994 Togiak herring forecast. The first was to apply different maturity schedules for the total run age composition and for the aerial survey biomass where the total run age maturity schedule was further divided into early (1978-1987) and late components (1988 and later) reflective of historical differences in estimating the age composition and biomass found by Brannian et al. (1993). The second scenario was to force the aerial survey data and the run biomass data to share the same maturity schedule with no constraints other than the provision for early and late schedules. The third scenario was the same as the second except that maturity was constrained to be $\geq$ to 0.95 at age 12.

Aerial Survey Biomass Estimates

During herring aerial surveys, observers estimate the surface area of herring schools arriving on the spawning grounds. Surface areas are converted to biomass estimates based on results of calibration samples in which entire herring schools were captured by purse seines after observers had estimated their surface area (Lebida and Whitmore 1985). Calibration samples have been stratified by three depth zones. Biomass estimates from distinct spawning events are summed to obtain each annual run biomass. Distinct spawning events are defined as abundance peaks separated in space or time, having dissimilar age composition estimates, or showing differences in sexual maturity.

Biomass estimates derived from aerial survey data of past years were rated by criteria relating to survey conditions, duration and through VPA analysis (Brannian et al. 1993). Aerial survey biomass estimates are generally expected to underestimate actual herring biomass, particularly in years when aerial survey conditions are poor for the following reasons:

1) aerial surveyors may not see all the herring present,

2) surveys may not be flown during the time most herring are present on the spawning grounds, because of weather or logistical constraints, and

3) using only dates of maximum ("peak") biomass to calculate run biomass ignores effects of continuous immigration to and emigration from the spawning grounds.

All three of these problems may affect estimates differently each year and it is difficult to recognize years these problems were evident. Aerial survey data from 1980-1993 were given numerical ratings based on survey frequency, survey spatial and temporal coverage, and weather conditions (Table 5). Biomass estimates selected as representative of the biomass for the 1993 forecast model were estimates for 1981, 1988, and 1992 (Brannian et al. 1993). The inclusion of the 1993 aerial survey into the 1994 forecast model was evaluated with the same criteria as previous years, based on aerial survey conditions (Brannian et al. 1993). Three combinations of aerial survey estimates were used in model simulations to determine whether the data from the 1992 and 1993 seasons should be included in the model: 1) 1981, 1988, 1992; 2) 1981, 1988, 1993; and 3) 1981, 1988, 1992 and 1993.

The different subsets of these four years were evaluated using a goodness of fit statistic based on the differences between ASA and aerial survey estimates of run biomass:

$$SSQ_{aerialbiomass} = \sum_{y} \{ \log_e(B_y^{survey}) - \log_e[\sum_{a} \rho(a)\, w_{a,y} N_{a,y}] \}^2 , \qquad (8)$$

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 (Table 4), $\rho(a)$ is the proportion mature at age a, and $N_{a,y}$ is the ASA estimate of total abundance at age a in year y (equation 1). During an earlier attempt to construct a Togiak ASA model, Funk et al. (1992) noted that there were too few abundance estimates to evaluate the appropriateness of the log transformation in equation (8). The model was then fit with and without the log transformation, but results were not sensitive to this assumption. We chose to use a log transformation in our model because a lognormal error structure is commonly found when dealing with abundance data.

Age Composition of the Mature or Run Biomass

In addition to the time series of the catch by age, a time series of age composition estimates of the run biomass are available for 1978-1993 (Brannian and Rowell 1989; Baker 1991b; Rowell 1992; Brannian et al. 1993; Rowell and Brannian *In Press*; Table 6). The age composition of the 1993 run biomass was estimated using herring sampled from commercial fishery harvests as well as from areas where large concentrations of herring were observed during aerial surveys. During fishery closures, departmental and volunteered commercial vessels made multiple purse seine or variable mesh gillnet sets to capture herring (hereafter referred to as test fishing). Samples were pooled across periods of several days whenever possible, in order to obtain sample sizes large enough ($\geq$ 400) to represent the estimated biomass within each fishing section and time strata. For commercial harvests, samples were collected from tenders and fishing boats for each gear type and fishing section at the close of each fishing period. Both test fishing and commercial harvest samples were used to obtain data on herring age, size, and gonad condition.

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

$$SSQ_{agecomp:run} = \sum_{y}\sum_{a} [p_{a,y}^{run} - \frac{\rho_a N_{a,y}}{\sum_{a} (\rho_a N_{a,y})}]^2 , \tag{9}$$

where $p_{a,y}^{run}$ is the observed run age composition estimated for age a and year y. The $\sin^{-1}$ (square root) transformation, was applied to observed and estimated age composition proportions to stabilize their variance.

Forecast Methodology

The forecast of herring run biomass for 1994 ($B_{1994}^{Forecast}$) was based on projecting total abundance with the survival model (equation 1) modified by the ASA estimates of the proportion of mature herring expected for each age:

$$B_{1994}^{Forecast} = \sum_{a} \rho(a)\, w_{a,1994}\, N_{a,1994} , \tag{10}$$

where $\rho(a)$ is the proportion mature at age a from equation 7, $w_{a,1994}$ is weight at age a and represents an average of the most recent five years of data (1989-1993; Table 4), and $N_{a,1994}$ is the ASA estimate of age-a herring for 1994 from equation (1). The above model was used to forecast the abundance of herring other than age 4, since we have no method to predict year class strength. For age-4 herring we used the median observed abundance of this age class, based on ASA estimates for the 1974-1988 year classes, to generate a 1994 forecast, $N_{4,1994}$.

The median was thought to be more representative of recruitment in typical years than the mean year class strength, since the distribution of year class abundance at age 4 was very skewed.

The age composition of $B^{Forecast}_{1994}$, ($\hat{p}_{a,1994}$), was estimated using the maturity schedule for the recent years (1988-1994) of the run biomass age composition, $\rho_r(a)$, ($\rho(a)$ of equation 7), as:

$$\hat{p}_{a,1994} = \frac{N_{a,1994}\,\rho_r(a)}{\sum_a N_{a,1994}\,\rho_r(a)} \quad , \qquad (11)$$

and the biomass at age became:

$$B^{Forecast}_{a,1994} = \hat{p}_{a,1994}\, w_{a,1994} \frac{B^{Forecast}_{1994}}{\sum_a \hat{p}_{a,1994}\, w_{a,1994}} \quad . \qquad (12)$$

Equations 11 and 12 were used to forecast the biomass at age because age composition estimated by our sampling program will differ from that estimated from the maturity schedule of the run biomass since our samples do not span the duration of the entire spawning run. One of the few ways we can evaluate forecast accuracy during the season is to compare the age composition of the preseason forecast with that estimated during the season. Therefore, the maturity schedule estimated from our run biomass age composition ($\rho_r(a)$ of equation 11) was used.

Parameter Estimation

Total Sum of Squares

A total sum of squares was computed by adding the adjusted sum of squares for each of the components (equations 6, 8, 9):

$$\begin{aligned} SSQ_{Total} = {} & SSQ^{adjusted}_{agecomp:catch}\,\lambda_{agecomp:catch} + \\ & SSQ^{adjusted}_{aerialbiomass}\,\lambda_{aerialbiomass} + \\ & SSQ^{adjusted}_{agecomp:run}\,\lambda_{agecomp:run} \quad , \end{aligned} \qquad (13)$$

where the λ's are weights assigned to each sum of squares component. Each sum of squares component was scaled to a similar order of magnitude, to contribute similarly to the total SSQ when λ's were equal. The method for adjusting the value of SSQ_j (from equations 6, 8, or 9) for the j sources of auxiliary information; (j=1) catch age composition, (j=2) aerial survey run biomass, and (j=3) run age composition was suggested by J. Bromaghin (ADF&G, Anchorage personal communication) as:

$$SSQ_j^{adjusted} = \frac{SSQ_j - Min(SSQ_{j,k}\ across\ all\ k)}{Max(SSQ_{j,k}\ across\ all\ k) - Min(SSQ_{j,k}\ across\ all\ k)} \quad , \tag{14}$$

where $SSQ_{j,k}$ is the estimated sum of squares for data source k when SSQ_{total} (equation 13) is estimated and λ is set equal to zero for all data sources except data source j. The λ's were used to assign ad hoc weights to each SSQ component reflecting our confidence in each component. The two age composition data sources used were weighted relative to each other according to the sample sizes collected for each data source. Mature run age composition samples accounted for approximately 60%, purse seine samples accounted for 30-40%.

Minimization Methods

The ASA model estimated a total of 30 parameters: 21 initial cohort sizes, two gear selectivity function parameters (α, and β), six maturity function parameters (ϕ and τ, for run biomass, and early and late for both run biomass and age composition), and one survival rate parameter (S). When four aerial survey years were used, the four SSQ equations referred to 334 data observations with 304 degrees of freedom and a data to parameter ratio of approximately 10. However, not all observations were independent, so the amount of information contained in the data was considerably less than one could obtain from completely independent observations.

The Microsoft Excel[2] spreadsheet solver was used to estimate parameter values which minimized the combined weighted sums of squares (equation 13). Parameter values manipulated by the solver were all scaled to a similar order of magnitude, as recommended by the software manufacturer. The solver obtained estimates of the variables in each one-dimensional search using linear extrapolation from a tangent vector (Tangent option), forward 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. As the solver approached a solution, parameter values and SSQ_{total} were again rescaled to similar orders of magnitude, if necessary, to ensure that scaling problems did not influence the results. Population sizes for older herring ($\geq$ age 11) were constrained to be greater than or equal to zero as negative population values

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

were impossible and negative residuals cannot be $\sin^{-1}$ transformed.

Sensitivity Analysis

The sensitivity of the ASA model to model assumptions was investigated by Funk et al. (1992) and Brannian et al. (1993). Based on recommendations in these past modeling efforts, we have continued to include the 1981 and 1988 aerial surveys and the present data transformations and weights. The sensitivity of the ASA model to two assumptions was investigated for 1994. First the assumption of which aerial survey years to include in the analysis was somewhat subjective, so various combinations of the 1992 and 1993 aerial survey years were examined. Second the assumption inherent in our choice of maturity schedules was examined. Various combinations of maturity schedules estimated separately or combined for run age composition and aerial survey biomass were chosen to examine model sensitivity and determine what should be included in the final model.

Goodness of Fit

The goodness of fit for our ASA model was assessed through evaluation of model residuals. A model's fit was rated as "good" if the residuals were small. The choice of model, ie. it's functional form, was rated "good" if the residuals were randomly distributed about zero and did not form a pattern when plotted as a function of age or year. For example, to choose a function to describe purse seine selectivity we examined residuals for purse seine age composition displayed against year or age to see if the function resulted in residuals distributed as a horizontal band. Another pattern or trend in residuals might indicate that the functional structure of the data changed through time or by age which would require the use of a time period or age-specific function. Ideally, model residuals should have a normal distribution with zero mean. Essentially, we applied the same principles of goodness of fit used in applied regression analysis and examination of residuals (Draper and Smith 1980).

Harvest Projection

Commercial harvest levels for herring which spawn in Togiak District have been set by the Alaska Board of Fisheries in the Bering Sea Herring Management Plan (AAC 27.060) and the Bristol Bay Herring Management Plan (AAC 27.865) (ADF&G 1992a). These regulatory plans specify a maximum exploitation rate of 20% and a threshold biomass of 35,000 tons on the grounds before a harvest can occur. Before opening the sac roe fishery, approximately 1,500 tons of herring are set aside for the Togiak District herring spawn-on-kelp harvest and 7% of the remaining available harvest is set aside for the Dutch Harbor food and bait fishery. The remaining harvestable surplus is allocated to the sac roe fishery by gear type: 25% for the gillnet fleet and 75% for the purse seine fleet. In years when circumstances prevent adequate biomass assessment during the season, the fishery harvest will be based on the preseason forecast.

Should a manageable separation of the year classes occur, a harvest of up to 20% of the younger age classes (age 4 or less) may be allowed if at least 20,000 tons of these younger herring are present in the district.

RESULTS

1993 Spawning Migration

From aerial surveys and age composition sampling, we estimated that the 1993 Togiak District spawning run consisted of 496 million herring with a total weight of 193,847 tons (Table 7). A total of 17,929 tons of Togiak herring was harvested by all spring sac roe fisheries. An estimated 172,996 tons remained after the harvest of both the sac roe and food and bait fisheries were subtracted from the run biomass.

The biomass estimate was the sum of (1) the peak biomass estimate observed April 26 (164,137 tons), and (2) the biomass observed May 4 (29,717 tons; Table 8). Age-9 or older herring represented 67% of the biomass and 54% of the individuals (Table 7). Recruitment of age-3 through -6 herring represented 30% of the biomass and 43% of the population. The 1987 year class made the greatest contribution to the 1993 run biomass. These age-6 herring represented 23% of the biomass and 32% of the individuals. Abundance of this cohort was 149.9 million herring in 1992 as age-5 fish and 156,907 million herring in 1993 as age-6 fish. This is the largest year class observed since 1983 when 189 million 5-year-old herring from the 1978 year class spawned (Figure 4). Since 1983, the number of age-5 herring has averaged 29.0 million herring annually.

The 1993 run biomass estimate from aerial surveys was nearly 1.3 times greater than the 148,786 tons forecasted from the 1993 escapement (Brannian et al. 1993), and the difference between the forecast and the observed biomass was 23%. The increased accuracy is a result of utilizing the age structured analysis and selective biomass estimates rather than attempting to forecast off the previous year's potentially poor biomass estimate. The true error in the forecast for 1993 can not be established until the 1993 biomass estimated from the ASA model stabilizes with inclusion of biomass estimates and age composition data in subsequent years.

The forecast of age-6 herring was very accurate whereas the return of age-4 and age-5 herring was overforecast with the greatest error occurring in the forecast of age-5 herring (Figures 5 and 6). The prediction of age-4 herring unlike that for other ages, was calculated as the median of the abundance of four year old herring rather than year class strength the previous year; therefore the forecast of this year class will be overforecast 50% of the time. The return of all remaining age classes was underestimated particularly for herring age 9 and older (Figures 5 and 6). Underforecasting the return biomass may have occurred if the presence of age-5 herring on the grounds was underestimated, or if the maturity schedule assumed a greater number of recruit herring into the biomass at age 5 than would occur in actuality, or if the estimates of natural mortality for older fish were too large.

1994 ASA Model

When ASA models were fit to subsets of good aerial surveys, and equal weight was given to aerial surveys and age compositions (Table 9, models 1-3), results varied the most in run biomass estimates after 1990 (Figure 7), mainly because all models used 1981 and 1988 aerial surveys. Among models 1-3, the greatest differences in 1994 forecasts was 54,000 tons which represented 40% of the average for all of the 1994 forecast scenarios (Table 10, models 1-3). Estimates from ASA models 1-3 agreed fairly well with the 1981, 1988, 1992, and 1993 survey estimates of run biomass. The smallest run biomass estimates were obtained from model 3, which did not include the 1993 aerial survey and was in poorest agreement with the selected observed aerial survey estimates. The largest estimates were produced by model 2 using 1981, 1988, and 1993 surveys. It appears that the 1992 and 1993 aerial surveys direct the model towards different levels of recent abundance (1991-1994). Because we have no overwhelming reason to exclude either estimate, and the inclusion of both aerial surveys results in estimates that fall between the two other ASA biomass estimates (models 2 and 3), we chose to include both the 1992 and 1993 aerial surveys in addition to 1981 and 1988. ASA model 1 estimated the biomass for 1983, when the 1977 and 1978 year classes recruited into the biomass at 277,735 tons (Figure 7, Table 10).

Biological maturity of the Togiak herring biomass is believed to reach 100% at approximately age 6 (Wespestad 1991). Three scenarios (models 1,4,5) were used to determine the best maturity schedule for the 1994 model. Estimates of run biomass varied little between models 4 and 5 which differed from the other trials in that the run age composition and run biomass were used to estimate the same maturity schedule (Table 9 and 10). These maturity schedules drove the historical biomass estimates very high with peak estimates of 450,000 to 478,000 tons (Figure 7, Table 10). Model 5 differed in that it constrained our choice of maturity schedules to those with ≥95% mature by age 12. Model 1 where run biomass and age composition estimated separate schedules resulted in more reasonable historical biomass estimates and estimated full maturity at approximately age 13 for the 1978-1987 time period and about age 15 for the 1988-1993 time period. We therefore chose model 1 to forecast the 1994 run biomass.

The ASA model used for the 1994 forecast estimates annual survival to be 78.06% which is an instantaneous mortality rate of 0.25 (Table 11). The gear selectivity curve for the purse seine fishery was similar to that estimated last year for the 1993 forecast model. In 1994, the maturity schedules estimated were quite different for each data source. Biological sexual maturity is thought to be achieved at approximately age 6 (Wespestad 1991), and the ASA model estimated full maturity to be reached at approximately age 7 when using run biomass estimated by aerial surveys, age 12 for the 1978-1987 period and at age 10 for the 1988-1992 period (Figure 8). Of the five models, the sum of squares was smallest for model 2 which incorporated the 1981, 1988 and 1992 biomass data with separate maturity schedules (Table 9). The sum of squares was 0.09 for Model 1 which was selected for the 1994 forecast.

Variability of the residuals of the purse seine age composition from the ASA model appeared to decrease slightly by age (Figure 9). There was also a tendency for age composition estimates of younger herring to display a greater frequency of negative residuals. Overall, no strong trend was evident in the residual pattern for purse seine age composition by year. Residuals of run age class composition showed decreased variability to age 10 with increasing variability for ages greater than 10 (Figure 10). As with the purse seine data, negative residuals appear greater for younger year classes.

The age composition of the purse seine catch estimated from the ASA model agreed well with the observed age composition of catch samples (Appendix A). Noticeable differences between estimated and observed values occurred for the percent of age-4 herring in 1978 and 1991, age-5 herring in 1982, age 6 in 1983, and and 1991 and age-10 herring in 1987. Age compositions of the run biomass estimated from the ASA model also agreed reasonably well with those observed; with notable exceptions being the difference between estimated and observed for age-4 herring in 1978 and 1981, age-5 herring in 1979 and 1982, and age-10 herring in 1987 (Appendix B).

Run biomass estimates obtained from the ASA model also compared reasonably well with the four aerial surveys used as auxiliary data (Figure 11). In contrast, model estimates of biomass were much greater than aerial survey estimates for 1982-1987 which were not used in fitting the model.

1994 Forecast

The forecasted Togiak District herring biomass for 1994 is 142,498 tons (Table 7). Herring age 9 or older are expected to account for 29% of the 1994 biomass. Herring age 15 and older, which include the strong 1977 and 1978 year classes that will return as age-17 and -18 herring are expected to contribute 11% of the run in biomass and 6% of the total population in number of herring. The 1987 and 1988 year classes returning as age-6 and -7 herring, are expected to represent 66% of the biomass and 72% of the total in number of herring. The 1984 and 1983 year classes returning as age-10 and -11 herring are expected to be the dominant older age classes, representing 12% of the biomass and 9% of the total number of herring. Average weight of an individual herring in the commercial purse seine fishery is expected to be 298 grams and 286 grams in the run biomass.

In past years, older herring have arrived on the fishing grounds before younger and newly recruited age classes. The fishery and, therefore, biomass assessments, have been directed towards older herring. Temporal separation of older and younger age classes, while useful for management, has made it difficult to collect information on younger and later arriving herring. It is difficult to forecast abundance of the youngest age classes (age 3 and 4), which are not fully recruited into the biomass. The Togiak herring forecast has been less than the observed biomass every year since 1984 (Figure 12). Average forecast error (1983-1992) using the previous forecast methodology has been 32%.

For 1994, the total allowable harvest based on the forecast is 28,499 tons (20% of forecasted biomass). In accordance with existing regulatory management plans, 1,500 tons will be allocated to the Togiak District spawn-on-kelp fishery, 25,109 tons to the purse seine and gillnet sac roe fisheries and 1,890 tons to the 1994 Dutch Harbor food and bait fishery. The Togiak sac roe and Dutch Harbor food and bait guideline harvest levels will be revised, if a reliable biomass can be obtained during the spring of 1994.

DISCUSSION

Past forecasts were published even when derived from previous year biomass estimates that were knowingly low due to extremely poor weather or survey conditions. The reason we applied age structured analysis was to attempt reduction of the forecast error everpresent in Togiak herring forecasts. Age structure analyses was first used for the forecast of the Togiak biomass in 1993. Previous forecast methodology produced error rates ranging from 6-275% and averaged 32% from 1983 through 1992. The potential for decreased error rates looks promising with the reduced forecast error of 23% evident in the 1993 forecast. The 1993 model over-forecasted herring ages 4-6 and underforecast herring ages 9-15. The forecast of age-4 herring is based on the historical median of the abundance of all years' biomass of age-4 herring and not on the abundance of age-3 herring the previous year, thus will be overforecast 50% of the time. The overforecast of age-5 herring, a new recruit year class, is probably a function of overestimating the percentage of the population that has matured or been recruited to the biomass by age 6. It is hoped this problem is corrected by allowing the 1994 forecast model to estimate the maturity schedules. The over forecast of younger herring can result in the underforecast of older age classes.

The 1994 ASA model for Togiak herring provided a reasonable fit to the data. Residuals were within reason and showed little abnormal trend. It was apparent, however, that the observed age composition for the 1994 forecast seemed to underepresent presence of older herring. The same problem occurred with the 1993 forecast (Brannian et al. 1993). We again corrected this problem by applying the age composition of the estimated run biomass to the forecast biomass at age (Equation 12). However as with the 1993 model, the forecasted contribution of the age-10 and -11 herring in 1994 (age 9 and 10 in 1993) seems less than one would expect when examining the observed age composition data for 1993 (Figure 5 and 13).

The 1994 forecast model is subject to the limitations addressed in Brannian et al. (1993). Re-examination and standardization of the historical age and abundance data and development of variance estimates would definitely improve our ability to model the population and provide a reliable forecast.

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TABLES

Table 1. Run biomass and commercial harvests for Togiak herring, 1968–1993.

Year	Run Biomass (Tons)[a,b]	Togiak Sac Roe Harvest (Tons)[c]	Spawn on Kelp Harvest (lbs)[d]	Dutch Harbor Food and Bait Harvest (Tons)[e]
1968		80		
1969		47	10,125	
1970		28	38,855	
1971		[f]	51,795	
1972		80	64,165	
1973		51	11,596	
1974		123	125,646	
1975		56	111,087	
1976			295,780	
1977		2,795	275,774	
1978	191,537	7,734	329,858	
1979	242,297	11,558	414,727	
1980	76,960	22,288	189,662	
1981	158,860	11,353	378,207	704
1982	98,022	19,837	234,924	3,565
1983	141,053	24,352	274,866	3,567
1984	113,471	17,654	406,587	3,578
1985	132,420	23,466	[f]	3,480
1986	94,390	14,796	374,142	2,394
1987	89,086	14,117	307,307	2.503
1988	134,639	12,853	489,320	2,004
1989	98,965	12,258	559,780	3,081
1990	88,105	12,253	413,844	820
1991	83,229	14,970	348,357	1,325
1992	156,955	25,808	363,600	1,949
1993	193,847	17,929	383,000	2,700
Mean [g]	130,865	10,659	258,120	2,436

[a] Data not available prior to 1978.

[b] Source: Appendices A,B Brannian and Rowell 1989; 1978–1987; Rowell *In Press,* 1988; ADF&G 1993, 1989–1993;

[c] Source: Sandone and Brannian 1988, 1980–1987; ADF&G 1988, 1968–1979; ADF&G 1992b, 1992; ADF&G 1992c, 1989–1991; Rowe *In Press,* 1988

[d] Source: ADF&G 1993.

[e] Source: ADF&G 1992d; Catches documented since 1929. Fishery did not occur between 1946, and 1980; Campbell 1993 for 1993 harvest.

[f] No fishery conducted.

[g] Mean calculated for total run biomass, sac roe and spawn on kelp harvest are years 1978–1993; Dutch Harbor food and bait fishery, years 1981–1993.

Table 2. Togiak District commercial purse seine harvest by year (in millions of herring), 1978–1993.

	AGE												
YEAR	4	5	6	7	8	9	10	11	12	13	14	15	Total	Source
1978	29.306	9.482	2.755	0.250	0.286	0.107							42.188	Fried et al. (1983)
1979	3.402	12.572	7.397	1.808	0.027	0.085							25.290	McBride et al. (1981)
1980	0.517	0.350	27.033	25.906	5.103	0.224	1.601						60.734	Baker (1991b)
1981	19.439	3.162	0.615	9.200	4.893	1.889	0.068	0.167					39.433	Baker (1991b)
1982	11.931	30.367	1.859	0.459	6.850	2.967	0.475	0.108	0.081				55.097	Baker (1991b)
1983	1.141	18.771	40.685	1.310	1.273	4.985	1.602	0.000	0.000	0.000			69.767	Baker (1991b)
1984	0.106	2.508	16.586	19.763	1.183	3.373	1.683	0.238	0.000	0.000	0.000		45.440	Baker (1991b)
1985	1.032	1.016	4.840	18.805	23.835	4.201	2.409	0.922	0.314	0.002	0.000	0.000	57.376	Baker (1991b)
1986	0.000	0.769	0.695	5.478	14.025	10.070	1.413	0.848	0.295	0.075	0.000	0.000	33.668	Baker (1991b)
1987	0.073	0.032	3.147	3.325	7.956	13.229	2.553	0.385	0.267	0.035	0.000	0.000	31.002	Baker (1991b)
1988	0.247	1.975	0.411	4.319	1.522	4.772	7.980	4.031	0.699	0.123	0.041	0.000	26.120	Baker (1991b)
1989	0.034	1.716	1.993	0.820	3.507	1.354	3.689	5.241	3.822	0.249	0.222	0.065	22.712	Baker (1991b)
1990	0.017	0.113	1.417	2.971	0.808	4.093	1.371	3.083	5.448	1.862	0.149	0.109	21.443	Rowell and Brannian (1993b)
1991	0.539	0.052	0.223	2.719	3.865	1.205	5.001	1.829	4.117	5.011	1.594	0.496	26.651	Rowell (1992)
1992	11.798	18.455	0.734	0.612	5.417	5.407	1.298	3.589	2.529	2.739	4.513	2.176	59.267	Brannian et al. (1993)
1993	0.469	6.217	14.278	0.976	0.615	4.795	4.513	1.277	2.297	0.972	1.099	2.942	40.45	Rowell and Brannian *In Press*

Table 3. Togiak District commercial gillnet harvest by year (in millions of herring), 1978–1993.

	AGE												
YEAR	4	5	6	7	8	9	10	11	12	13	14	15	Total 5+	Source
1978	0.597	1.458	0.808	0.035	0.009	0.018							2.327	Fried et al. (1983)
1979	1.735	10.957	4.558	1.181	0.124	0.054							16.873	McBride et al. (1981)
1980	0.171	0.217	8.140	4.023	0.590	0.052	0.028						13.050	Baker (1991b)
1981	5.934	1.060	0.209	1.744	0.557	0.102	0.007	0.019					3.698	Baker (1991b)
1982	6.226	18.979	1.147	0.021	1.048	0.509	0.211	0.000	0.288				22.203	Baker (1991b)
1983	0.027	6.641	8.398	0.380	0.260	1.464	0.302	0.070	0.000	0.017			17.532	Baker (1991b)
1984	0.073	1.032	5.123	6.513	0.739	0.900	0.420	0.041	0.008	0.000	0.000		14.776	Baker (1991b)
1985	0.006	0.086	1.239	4.996	4.641	0.681	0.303	0.147	0.006	0.000	0.000	0.000	12.099	Baker (1991b)
1986	0.000	0.021	0.232	1.812	4.623	2.330	0.233	0.140	0.000	0.000	0.000	0.000	9.391	Baker (1991b)
1987	0.000	0.003	0.506	0.655	2.051	2.525	0.702	0.149	0.077	0.000	0.000	0.000	6.668	Baker (1991b)
1988	0.000	0.000	0.024	1.102	0.588	2.032	3.648	1.077	0.245	0.024	0.024	0.000	8.764	Baker (1991b)
1989	0.000	0.037	0.618	0.387	1.693	0.557	1.066	1.496	0.872	0.045	0.076	0.034	6.881	Baker (1991b)
1990	0.000	0.022	0.460	1.056	0.361	1.321	0.424	1.101	1.473	0.698	0.105	0.094	7.115	Rowell and Brannian (1993b)
1991	0.029	0.000	0.042	0.977	1.793	0.461	1.017	0.611	1.036	1.115	0.259	0.039	7.351	Rowell (1992)
1992	0.005	0.477	0.096	0.475	3.314	3.187	0.385	1.127	0.603	0.636	0.868	0.410	11.578	Brannian et al. (1993)
1993	0.000	0.141	0.767	0.181	0.253	1.448	1.257	0.472	0.61	0.374	0.263	0.605	6.371	Rowell and Brannian *In Press*

Table 4. Average weight (g) at age for the Togiak herring run biomass, 1978–1993.

	AGE												
YEAR	4	5	6	7	8	9	10	11	12	13	14	15	Source
1978	158	208	257	302	342	376	404	428	446	461	473	483	Schnute's Growth Model from Baker (1991a)
1979	158	208	257	302	342	376	404	428	446	461	473	483	Schnute's Growth Model from Baker (1991a)
1980	158	208	257	302	342	376	404	428	446	461	473	483	Schnute's Growth Model from Baker (1991a)
1981	184	215	265	300	330	340	350	397	392	391	543	483	Baker (1991b) Appendix Table 14
1982	185	237	270	297	346	383	409	411	480	417	371	483	Baker (1991b) Appendix Table 14
1983	178	232	280	301	323	366	394	330	456	359	469	483	Baker (1991b) Appendix Table 14
1984	145	208	261	304	340	373	396	410	424	434	473	483	Baker (1991b) Appendix Table 14
1985	150	196	249	309	354	393	417	444	450	402	473	483	Baker (1991b) Appendix Table 14
1986	138	186	231	286	333	371	410	425	432	409	473	483	Baker (1991b) Appendix Table 14
1987	134	184	244	295	343	392	435	452	498	463	473	483	Baker (1991b) Appendix Table 14
1988	127	167	253	295	327	384	401	414	418	446	473	449	Baker (1991b) Appendix Table 14
1989	115	188	235	297	340	379	393	417	450	403	473	477	Baker (1991b) Appendix Table 14
1990	152	201	250	302	345	344	379	384	425	516	473	489	Baker (1991b) Appendix Table 14
1991	158	203	229	318	359	408	437	479	500	469	541	548	Unpublished data
1992	163	206	246	268	324	358	392	423	443	473	479	490	Unpublished data
1993	142	186	225	286	334	374	397	425	450	461	500	491	Unpublished data

Table 5. Aerial survey run biomass estimates and ratings for the Togiak herring population. The highest rated aerial surveys, (1981, 1983, 1985, 1988, 1992, 1993) are marked with an asterisk.[a]

	C	D	E	F	G	H	I	J		
Survey Year	Surveys (partial)	Surveys (Complete)	Ratio D/(C+D)	Avg Survey Rating	Peak Survey (5 pts)	Survey Rating (Peak)	Total # Surveys	Total Surveys with fish	Rating Total (E+F+G+H)	Biomass (tons)
1980	15	5	0.25	3.1	2	4.5	21	20	9.9	68,686
1981	8	25	0.76	2.8	4	4.5	34	33	12.1 *	158,650
1982	3	13	0.81	3.4	5	4.0	18	16	13.2 *	97,902
1983	4	25	0.86	2.8	4	4.5	29	29	12.2 *	141,782
1984	3	15	0.83	3.5	3	3.0	33	18	10.3	114,881
1985	0	13	1.00	3.0	5	2.5	16	13	11.5 *	131,400
1986	6	15	0.71	2.4	4	3.0	28	21	10.1	94,699
1987	8	9	0.53	3.0	2	2.0	23	20	7.5	88,400
1988	5	9	0.64	3.9	4	4.0	21	13	12.6 *	134,717
1989	4	8	0.67	3.9	3	2.5	13	12	10.1	98,965
1990	16	4	0.20	2.7	2	3.0	28	20	7.9	88,105
1991	3	8	0.73	3.7	4	2.5	22	11	11.0	83,229
1992	9	3	0.25	4.1	3	4.0	28	12	11.3 *	156,955
1993	4	9	0.69	2.9	3	3.8	13	13	10.4 *	193,847

[a] The 1982 aerial survey rated highly but was not used in the 1994 forecast model.

Table 6. Age composition of the herring run biomass in the Togiak District for 1978–1993.

	AGE												
YEAR	4	5	6	7	8	9	10	11	12	13	14	15	Source
1978	0.556	0.326	0.087	0.006	0.017	0.008							Brannian and Rowell (1989)
1979	0.060	0.550	0.271	0.105	0.004	0.010							Brannian and Rowell (1989)
1980	0.051	0.009	0.411	0.385	0.125	0.005	0.015						Baker (1991b)
1981	0.619	0.071	0.012	0.167	0.094	0.034	0.001	0.003					Baker (1991b)
1982	0.216	0.552	0.031	0.009	0.119	0.060	0.010	0.002	0.002				Baker (1991b)
1983	0.070	0.388	0.441	0.016	0.017	0.050	0.016	0.003	0.001	0.000			Baker (1991b)
1984	0.005	0.039	0.338	0.415	0.037	0.113	0.051	0.002	0.000	0.000	0.000		Baker (1991b)
1985	0.031	0.024	0.098	0.359	0.385	0.058	0.032	0.012	0.002	0.000	0.000	0.000	Baker (1991b)
1986	0.000	0.020	0.030	0.174	0.446	0.266	0.045	0.013	0.005	0.000	0.000	0.000	Baker (1991b)
1987	0.002	0.004	0.104	0.114	0.290	0.402	0.067	0.011	0.005	0.001	0.000	0.000	Baker (1991b)
1988	0.059	0.092	0.017	0.147	0.051	0.163	0.294	0.137	0.023	0.017	0.000	0.000	Baker (1991b)
1989	0.001	0.006	0.169	0.041	0.148	0.049	0.160	0.195	0.120	0.011	0.007	0.003	Baker (1991b)
1990	0.002	0.005	0.089	0.132	0.037	0.176	0.065	0.148	0.234	0.099	0.008	0.003	Rowell and Brannian (1993)
1991	0.161	0.015	0.016	0.184	0.182	0.050	0.102	0.047	0.090	0.098	0.048	0.007	Rowell (1992)
1992	0.201	0.310	0.008	0.009	0.124	0.102	0.026	0.054	0.030	0.053	0.053	0.030	Brannian et al. (1993)
1993	0.010	0.102	0.316	0.018	0.012	0.132	0.14	0.022	0.067	0.031	0.034	0.104	Rowell and Brannian *In Press*

Table 7. Year class composition of the 1993 Togiak District herring harvest, escapement, run biomass and the biomass forecast for 1994.

		1993 Harvest (tons)					1993 Total Run				1994 Togiak Forecast Herring Biomass					
		Sac Roe														
Year Class	Age	Purse Seine	Gill Net	Food/Bait Harvest	Total	1993 Escapement (tons)	Biomass (tons)	Number of Fish (thousands)	% by Weight	% by Number	Year Class	Age	Biomass (tons)	Number of Fish (thousands)	% by Weight	% by Number
1990	3	0	0	0	0	0	0	0	0.0%	0.0%	1991	3	0	0	0.0%	0.0%
1989	4	85	0	7	92	826	918	4,903	0.5%	1.0%	1990	4	3,594	22,960	2.5%	5.1%
1988	5	1,424	35	20	1,664	10,388	12,052	50,789	6.2%	10.2%	1989	5	2,973	14,500	2.1%	3.2%
1987	6	3,941	1,125	1,262	6,328	38,678	45,006	156,907	23.2%	31.6%	1988	6	35,580	143,330	25.0%	31.7%
1986	7	297	56	125	478	2,796	2,796	9,124	1.4%	1.8%	1987	7	57,726	182,850	40.5%	40.5%
1985	8	226	99	161	486	2,276	2,278	6,130	1.2%	1.2%	1986	8	1,919	5,210	1.3%	1.2%
1984	9	1,924	585	411	2,920	27,070	27,070	65,299	14.0%	13.2%	1985	9	1,205	2,920	0.8%	0.6%
1983	10	1,970	538	208	2,716	31,439	31,439	69,387	16.2%	14.0%	1984	10	10,036	22,910	7.0%	5.1%
1982	11	617	216	97	930	8,221	8,221	16,479	4.2%	3.3%	1983	11	7,242	15,470	5.1%	3.4%
1981	12	1,141	288	59	1,488	17,097	17,097	33,212	8.8%	6.7%	1982	12	864	1,740	0.6%	0.4%
1980	13	511	185	73	769	8,166	8,166	15,243	4.2%	3.1%	1981	13	5,231	10,030	3.7%	2.2%
1979	14	591	133	54	778	9,289	9,289	16,790	4.8%	3.4%	1980	14	923	1,670	0.6%	0.4%
1978	15	1,173	240	38	1,451	19,064	20,515	35,836	10.6%	7.2%	1979	15 +	15,205	28,110	10.7%	6.2%
1977	16	347	67	0	414	6,079	6,493	11,291	3.3%	2.3%						
1976	17	100	0	0	100	2,170	2,270	3,994	1.2%	0.8%						
1975	18	15	0	0	15	0	237	530	0.1%	0.1%						
Total		14,362	3,567	2,700	20,629	172,996	193,847	495,914	100.0%	100.0%			142,498	451,700	100.0%	100.0%

Table 8. Daily observed biomass estimates (tons) of herring during the 1993 season by index area, Togiak District, Bristol Bay.[a]

Date	Time Surveyed	Survey[c] Condition	Miles of Spawn (Mi)	Estimated Biomass by Index Area.[b] NUS	KUK	MET	NUK	UGL	TOG	TNG	MTG	HAG	OSK	PYR	CN	WAL	Daily Total (Tons)
4/24	1340	3.7	0.0		5,704	73	101	1,170	48,376	8,983	7,077	566	2,398			67	74,514
4/25	1315	3.4	0.3		10,664	0	514	2,793	73,765	5,893	26,228	251	6,316			0	126,424
4/26	1410	2.2	5.1	0	24,983	976	827	6,363	83,779	9,268	30,077	837	4,127	2,898			164,135
4/27	1930	4.4	21.3			0	6,357	904									7,261
4/28	1800	3.4	13.0			133	452	2,925	2,366	21	1,530	159	160	372			8,118
4/29	1300	2.9	6.0			930	501	1,293	1,897	429	623	287	436	1,504	319		8,218
4/30	1400	3.1	4.0		312	712	761	631	7,557	122	349		15	737			11,196
5/01	1510	3.0	2.2			298	1,194	1,186	39,438		81		54				42,250
5/03	1730	2.9	1.5		422	209	144	194	23,613	2,004	85	30	38	42	95		26,875
5/04	1745	3.0	0.0		52	1,689	571	205	25,561	1,629	0	11					29,717
5/05	1900	2.9	0.0		2,174	3,740	5,225	27									11,165
5/06	1800	3.5	0.0	74	2,219	2,137	2,567	550	15,395	3,339	39	0	243				26,562
5/07	1730	3.0	0.0	0	1,199	3,128	614	64									5,005
		Total	53.3														

[a] The final 1993 Togiak District Pacific herring biomass was estimated at 193,847 short tons which is a summation of:

1) Preliminary peak estimate of 164,130 tons observed 26 April (later revised to 164,135 tons), and
2) the biomass observed 4 May of 29,717 tons.

[b] Index Areas: NUS- Nushagak Peninsula; KUK-Kulukak; MET-Metervik; NUK-Nunavachak; UGL-Ungalikthluk/Togiak; TOG-Togiak; TNG-Tongue Point;
MTG-Matogak; HAG;Hagemeister; OSK-Osviak; PYT-Pyrite Point; CN-Cape Newenham; WAL-Walrus Islands Area.

[c] Survey condition rating: 1= Excellent, 2=Good, 3=Fair, 4=Poor, 5=Unacceptable.

Table 9. Combinations of aerial surveys, maturity schedules, and weighting scenarios used to examine the sensitivity of ASA model results.

								Weights				
								Between Data Sources		Within Age Composition Data		
Model No.	Aerial Surveys 81	88	92	93	Total Surveys	Maturity Schedules Shared[a]	Constrained	Aerial Surveys	All Age Compositions	Total Run	Purse Seine[a]	Total Sum of Squares
1	x	x	x	x	4	No	No	0.5	0.5	0.6	0.4	0.092
2	x	x		x	3	No	No	0.5	0.5	0.5	0.3	0.079
3	x	x	x		3	No	No	0.5	0.5	0.5	0.3	0.094
4	x	x	x	x	4	Yes	No	0.5	0.5	0.6	0.4	0.356
5	x	x	x	x	4	Yes	Yes[b]	0.5	0.5	0.6	0.4	0.359

[a] Shared data sources but different maturity schedules used for run age composition and aerial survey data for models 1, 2 and 3; whereas the same maturity schedule values were used for models 4 and 5.
[b] Scheduled maturity constrained to be equal to or greater than 95% mature by age 12.

Table 10. Estimated run biomass by age from ASA models using different combinations of aerial surveys and maturity schedules for the Togiak herring population.

Model	Estimated Pre-Fishery Biomass																
No.	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	63,623	66,045	65,174	153,315	256,943	277,735	243,192	238,801	195,290	188,087	162,580	139,428	101,799	148,064	181,789	156,430	142,497
2	65,458	67,456	66,246	156,990	262,709	282,417	245,802	240,958	196,467	189,552	164,433	141,238	103,234	157,835	201,482	175,518	159,967
3	51,990	52,551	52,314	148,119	248,946	264,073	227,367	222,057	180,909	173,227	147,957	124,829	89,831	126,896	148,114	118,074	106,391
4	31,605	51,929	70,488	121,974	231,847	350,791	423,330	478,263	437,176	422,698	195,274	180,829	143,190	164,563	170,891	144,222	137,520
5	33,053	53,894	72,943	124,755	230,265	341,530	406,330	450,288	400,565	375,351	228,344	198,726	149,626	160,820	161,778	141,968	144,334
Minimum	31,605	51,929	52,314	121,974	230,265	264,073	227,367	222,057	180,909	173,227	147,957	124,829	89,831	126,896	148,114	118,074	106,391
Maximum	65,458	67,456	72,943	156,990	262,709	350,791	423,330	478,263	437,176	422,698	228,344	198,726	149,626	164,563	201,482	175,518	159,967
Average	49,146	58,375	65,433	141,031	246,142	303,309	309,204	326,073	282,081	269,783	179,718	157,010	117,536	151,636	172,811	147,242	138,142
Difference	33,853	15,527	20,629	35,016	32,444	86,718	195,963	256,206	256,267	249,471	80,387	73,897	59,795	37,667	53,368	57,444	53,576

Table 11. Parameter values estimated by the 1994 Togiak herring ASA model with parameter estimates from the final forecast model.

Parameter	Estimate	Early	Late	Survey
	Estimate			
Survival	78.06%			
Instanteanous Mortality	0.248			
Gear Selectivity				
Purse Seine				
α	7.301			
β	-0.804			
Maturity Schedules				
τ		7.560	6.589	1.145
Φ		0.697-	0.857	-0.526

Year	Million of Herring Age-4	Age-5	Age-6	Age-7	Age-8	Age-9
1978	237.08	106.35	23.10	1.38	3.27	1.45
1979	50.59					
1980	65.38					
1981	667.30					
1982	647.06					
1983	263.02					
1984	91.34					
1985	177.14					
1986	36.31					
1987	133.33					
1988	115.08					
1989	11.29					
1990	13.55					
1991	397.03					
1992	351.57					
1993	48.94					

FIGURES

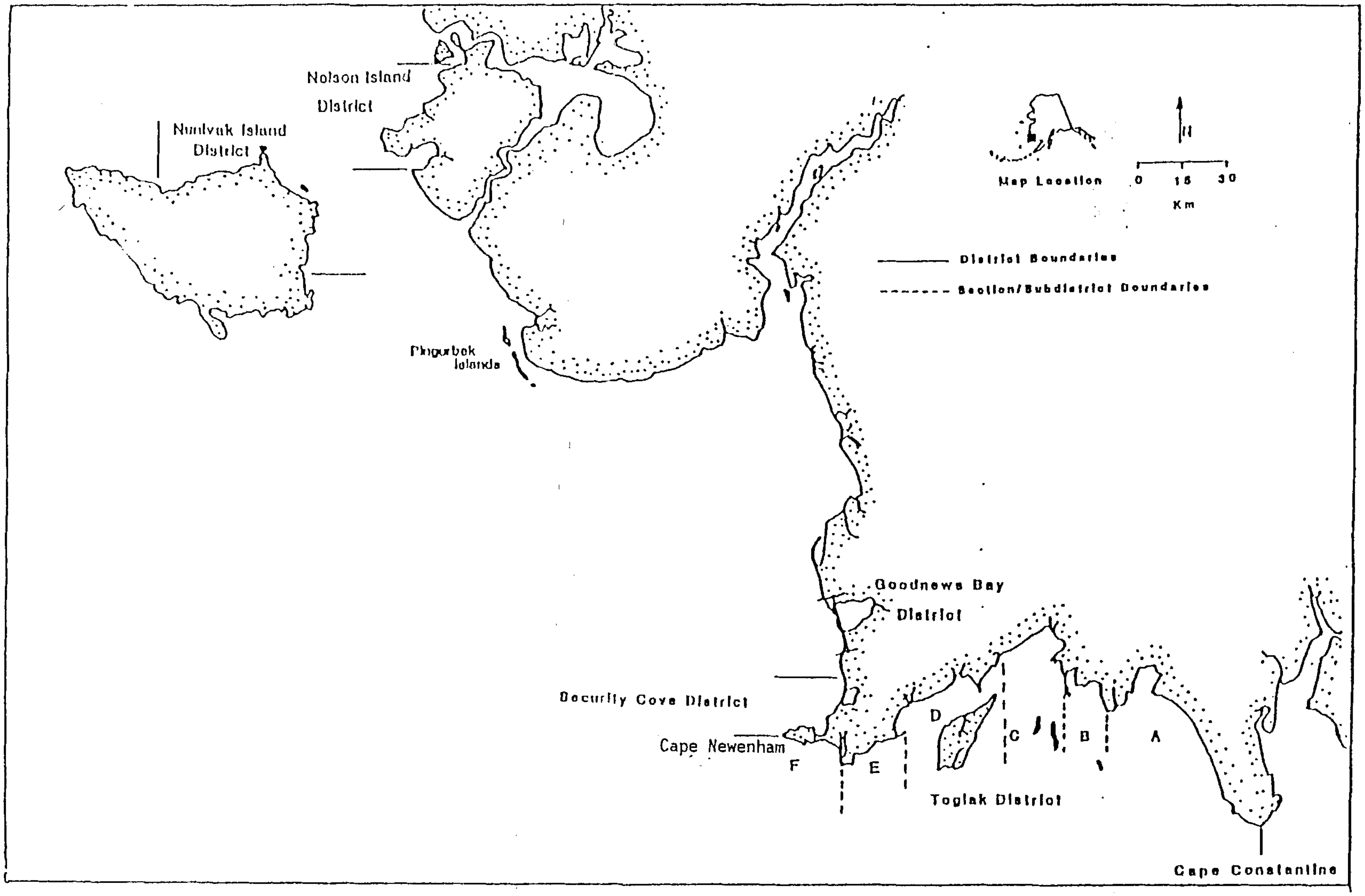


Figure 1. Togiak, Security Cove, Goodnews Bay, Nelson Island, and Nunivak Island herring commercial fishing districts, Bering Sea, Alaska.

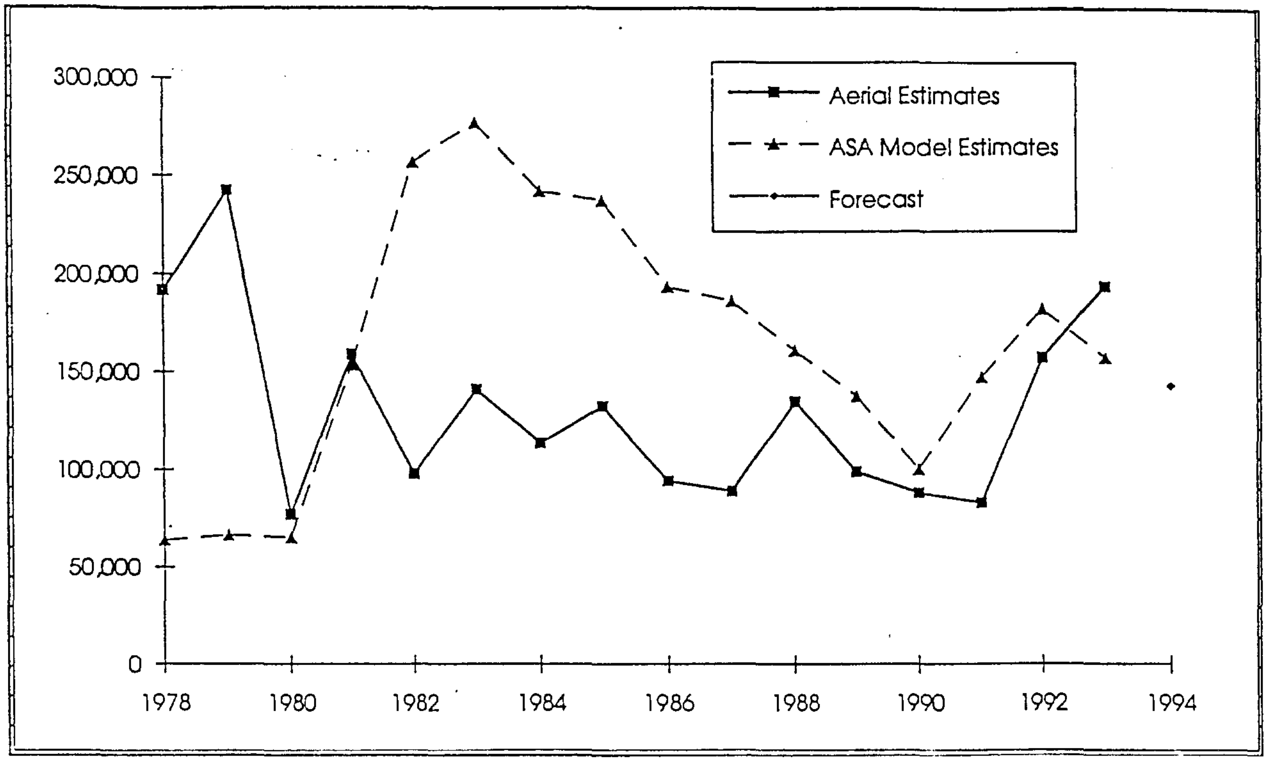


Figure 2. Historical sequence of the Togiak District herring run biomass as estimated from aerial surveys. The 1994 run biomass (diamond) was forecasted using an age structured analysis of catch and abundance data. Documentation of the 35,000 ton threshold biomass is required before a commercial harvest is allowed.

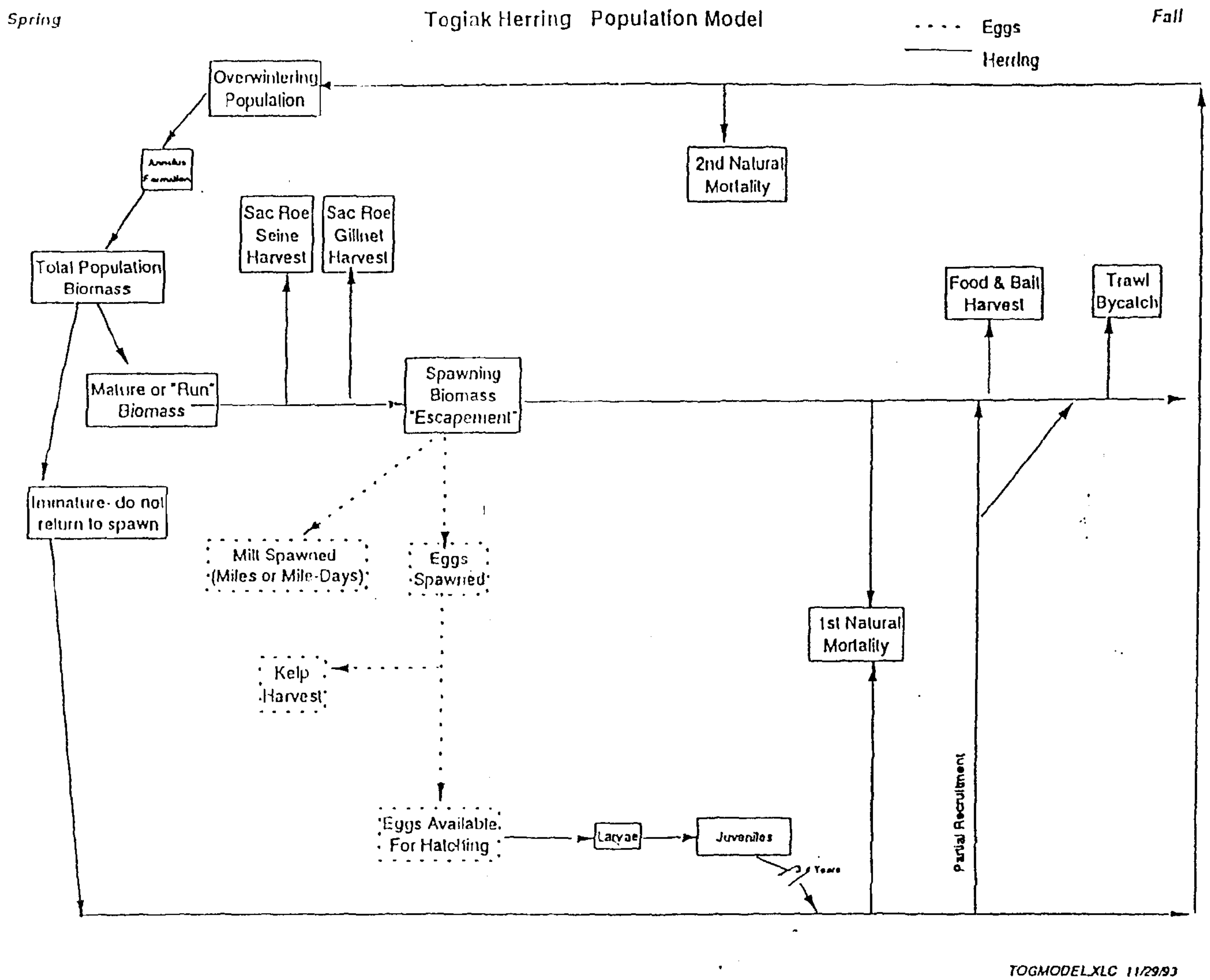


Figure 3. Conceptual model of the annual cycle of events affecting the Togiak herring population.

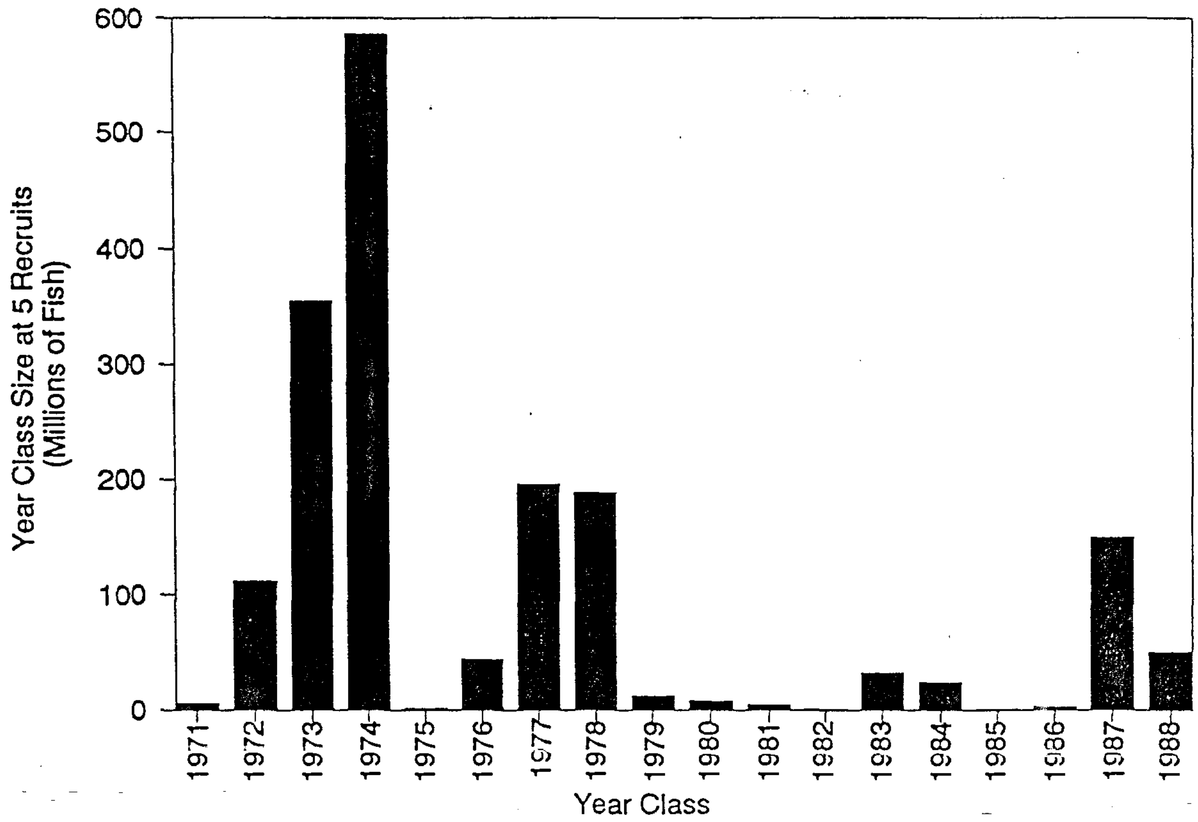


Figure 4. Year class strength of Togiak District herring in numbers of five year old recruits.

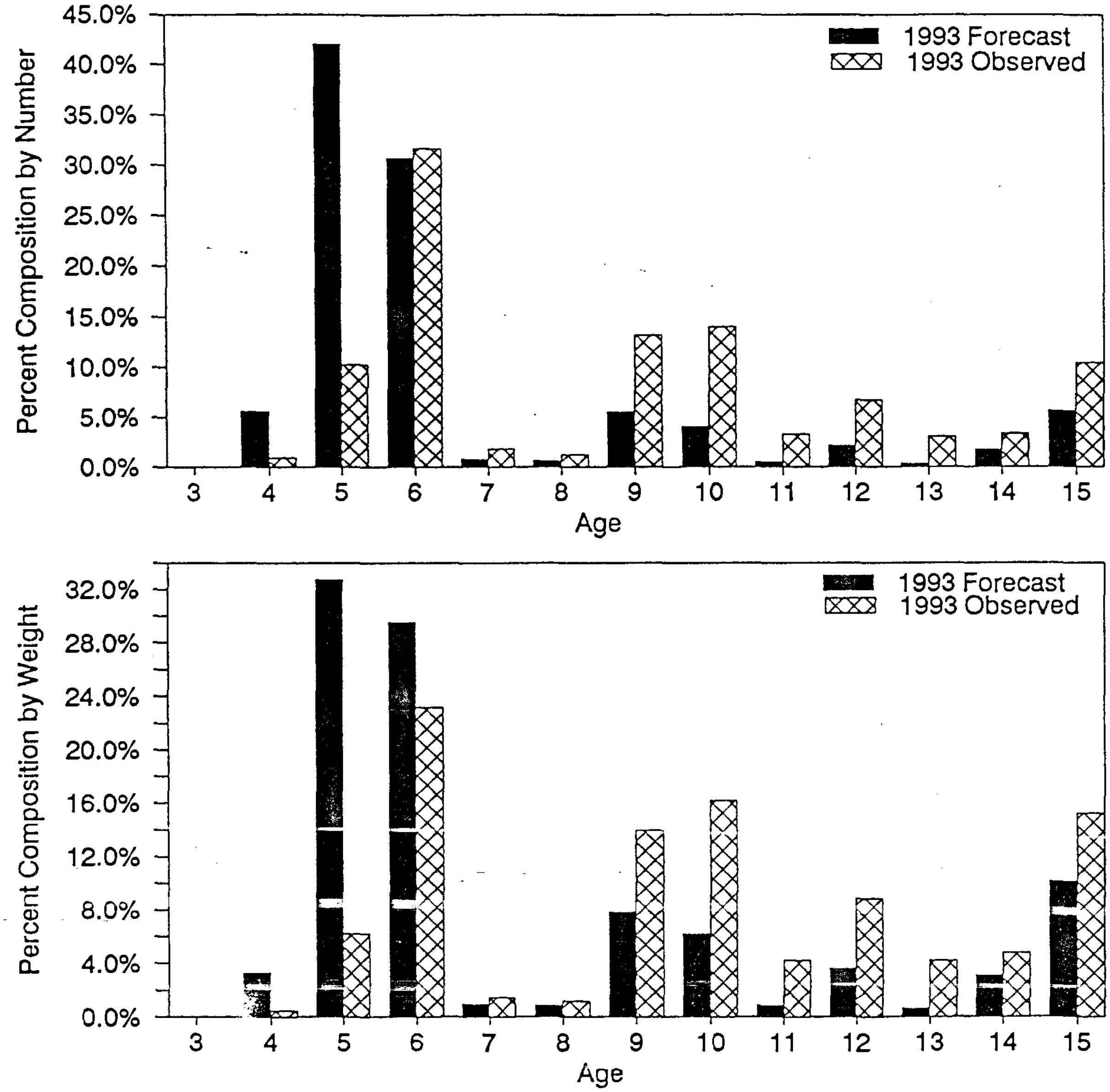


Figure 5. Comparison of the 1993 observed Togiak District age composition in number of individuals(top) and biomass (bottom) to the forecast for the same year.

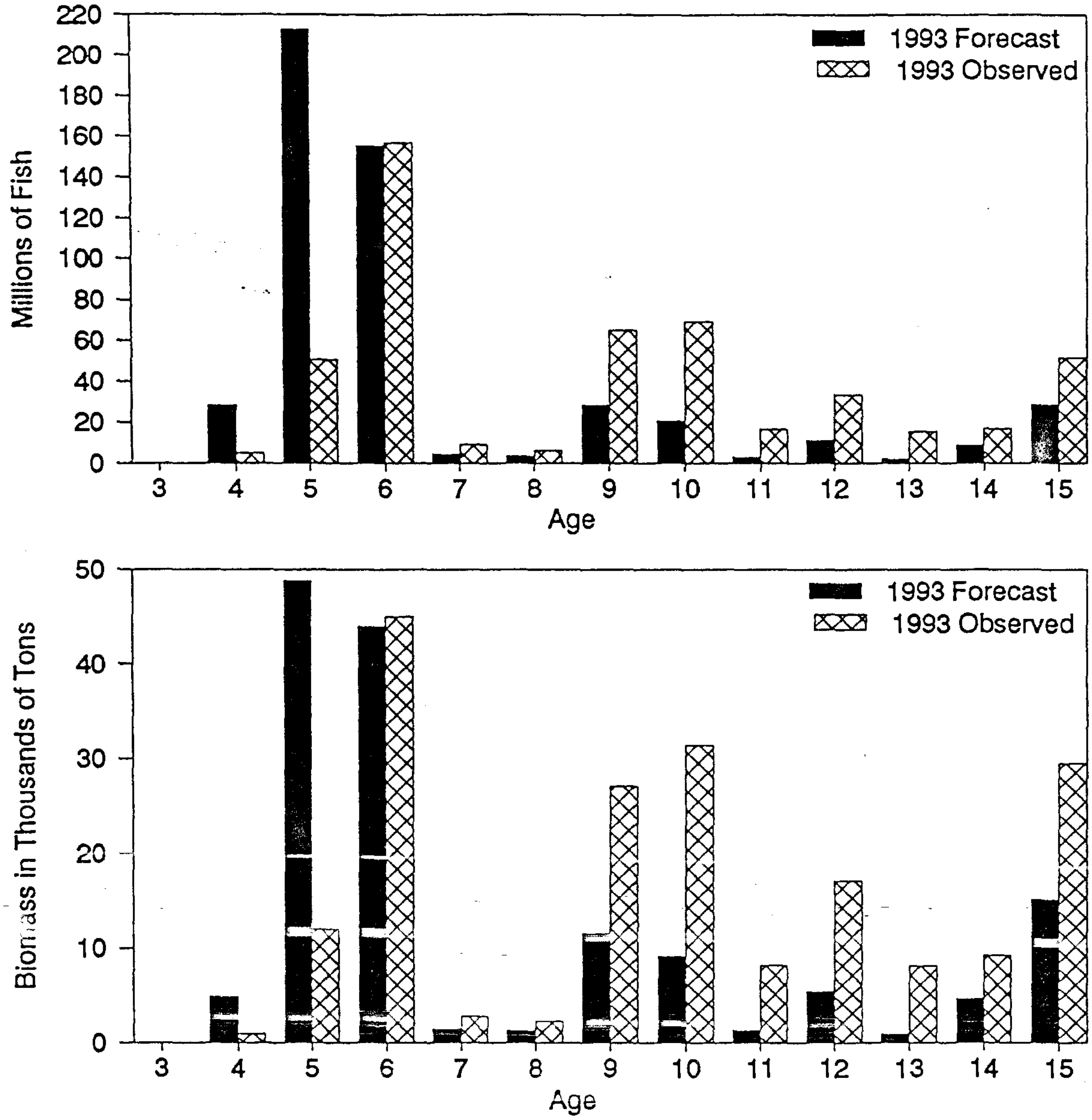


Figure 6. Comparison of the 1993 observed Togiak District run in number of individuals (top) and biomass (bottom) to the 1994 forecasted age composition.

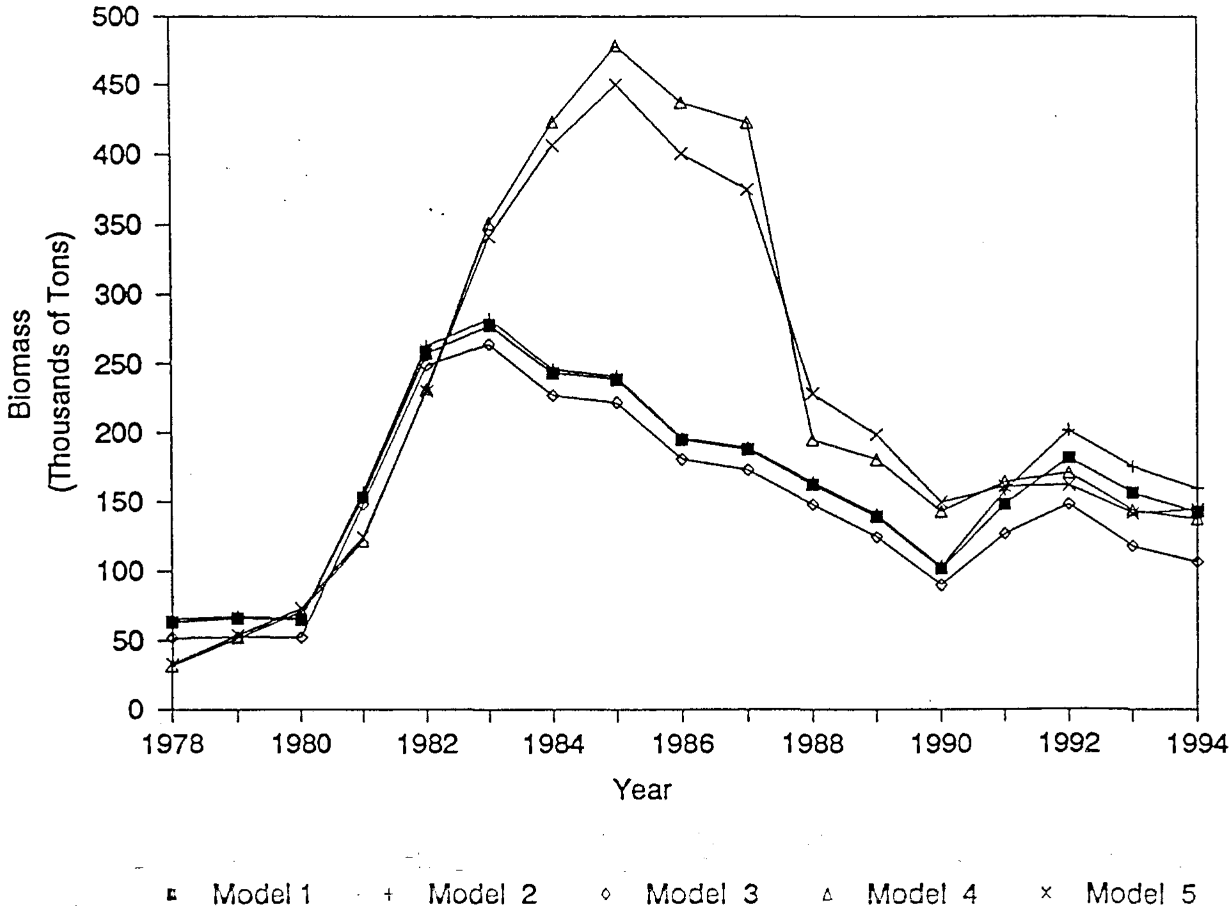


Figure 7. Estimates of run biomass from ASA models using different subsets of aerial survey run biomass estimates and maturity schedules .

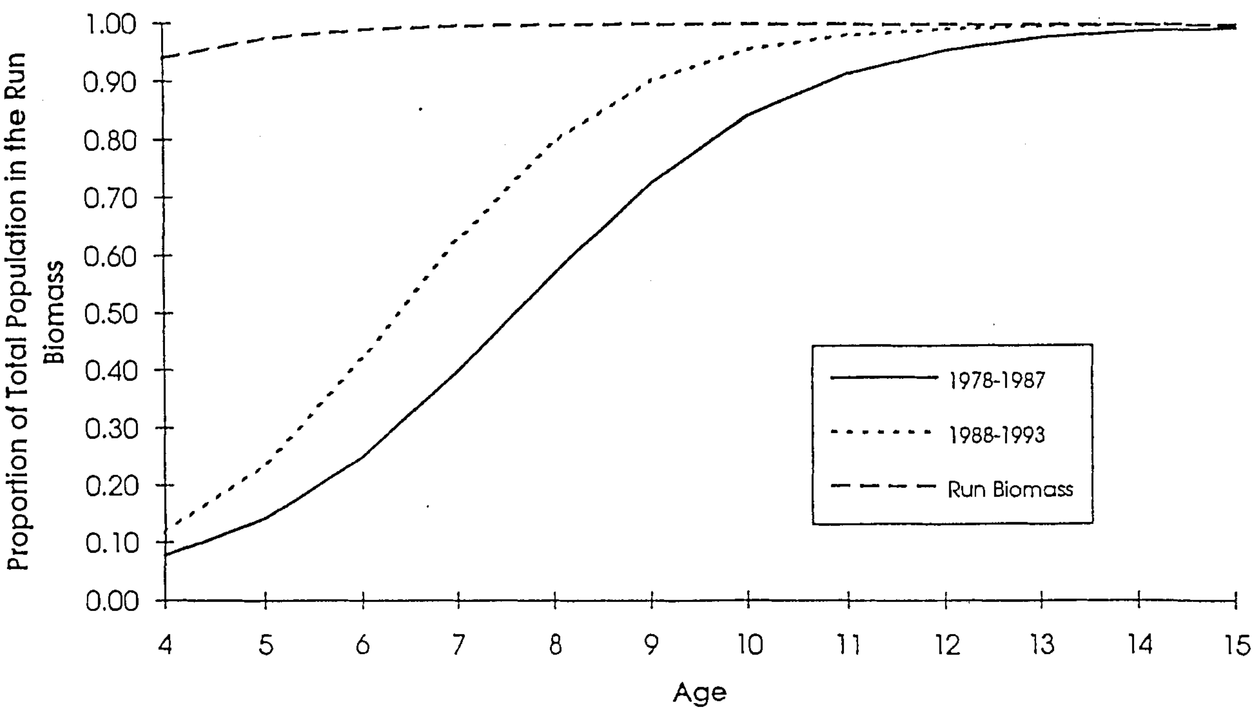


Figure 8. Maturity schedules estimated by the 1994 Togiak herring ASA model. Maturity schedules from 1978-1987 and 1988-1993 were estimated by the run age composition and the run biomass from aerial survey data.

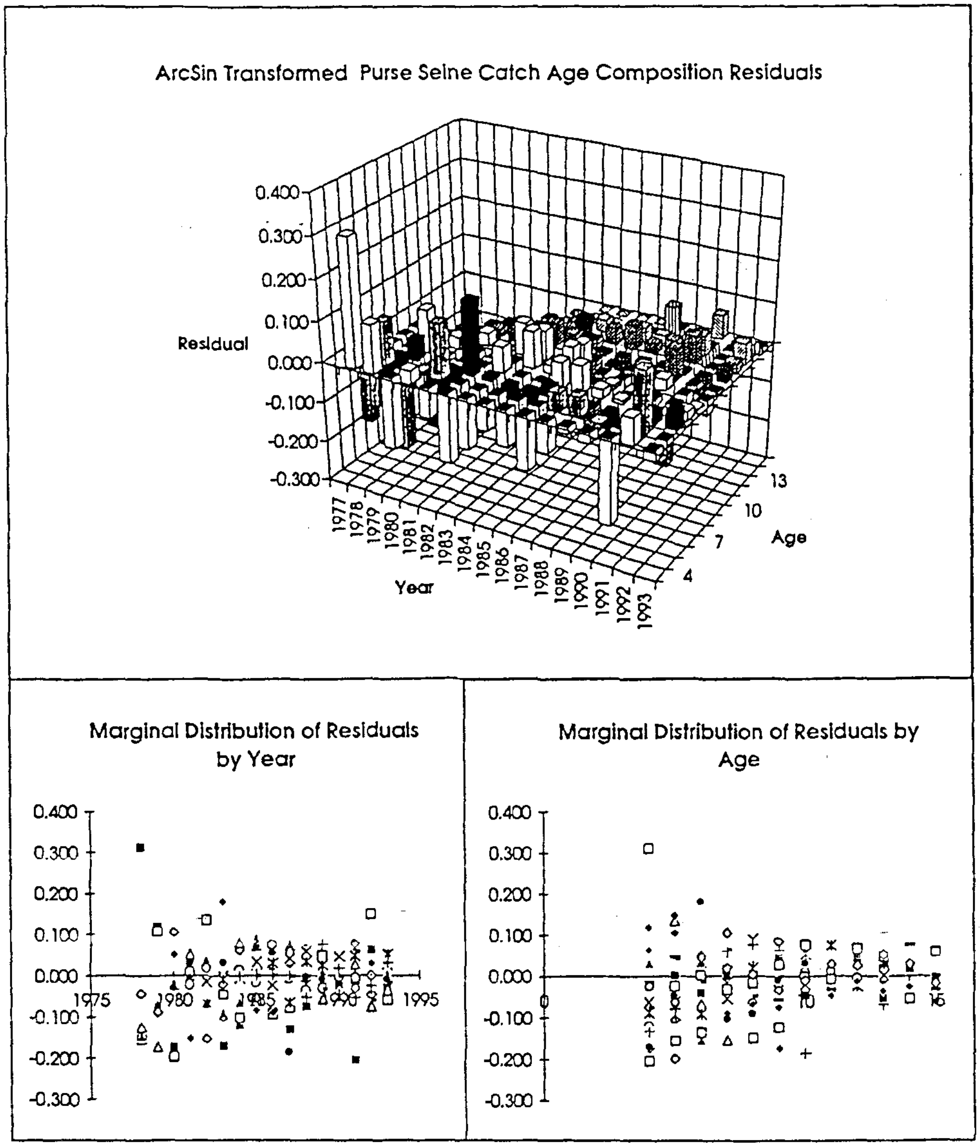


Figure 9. Purse seine age composition residuals for the Togiak herring ASA model plotted by age and year.

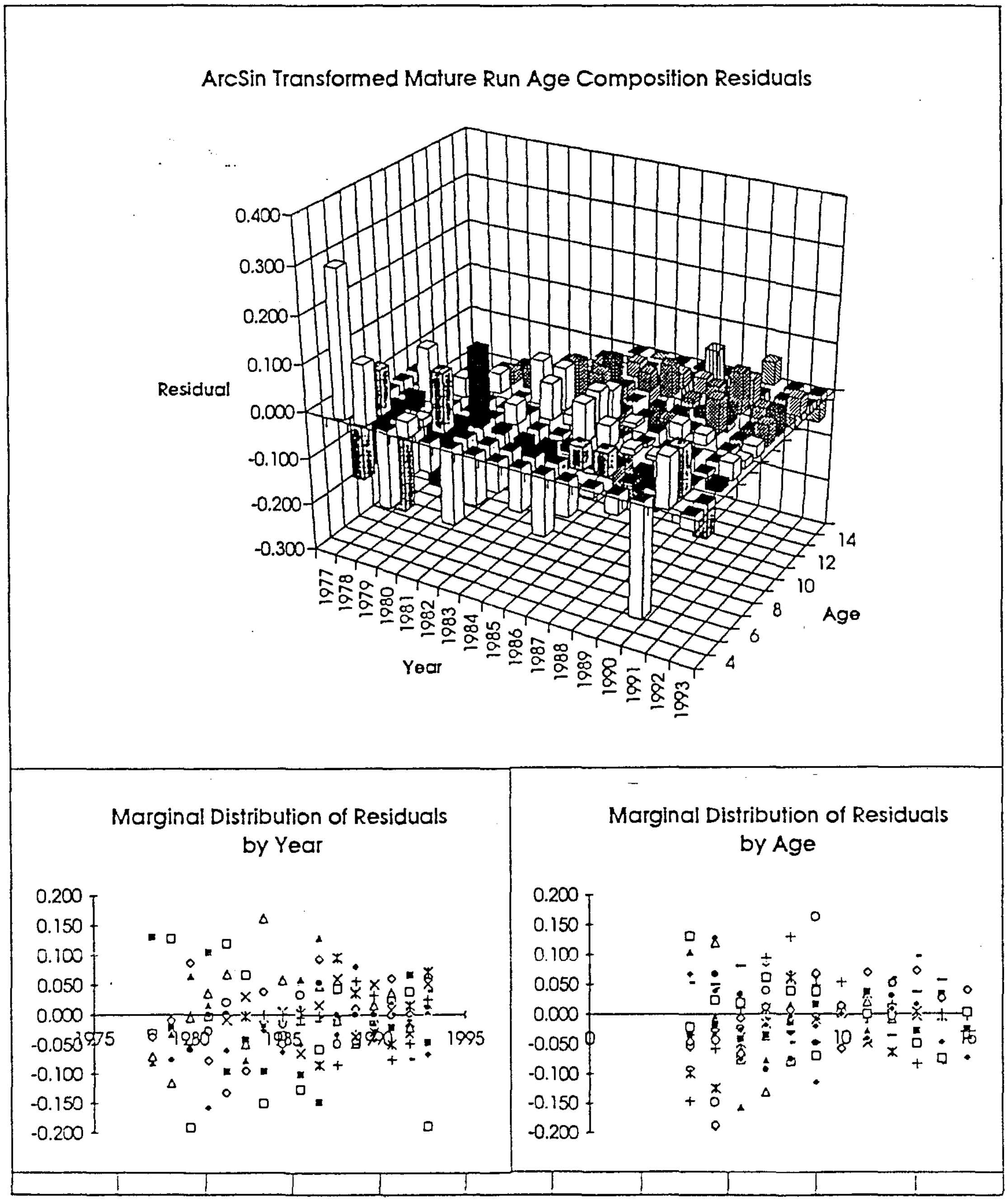


Figure 10. Run biomass age composition residuals for the Togiak herring ASA model plotted by age and year.

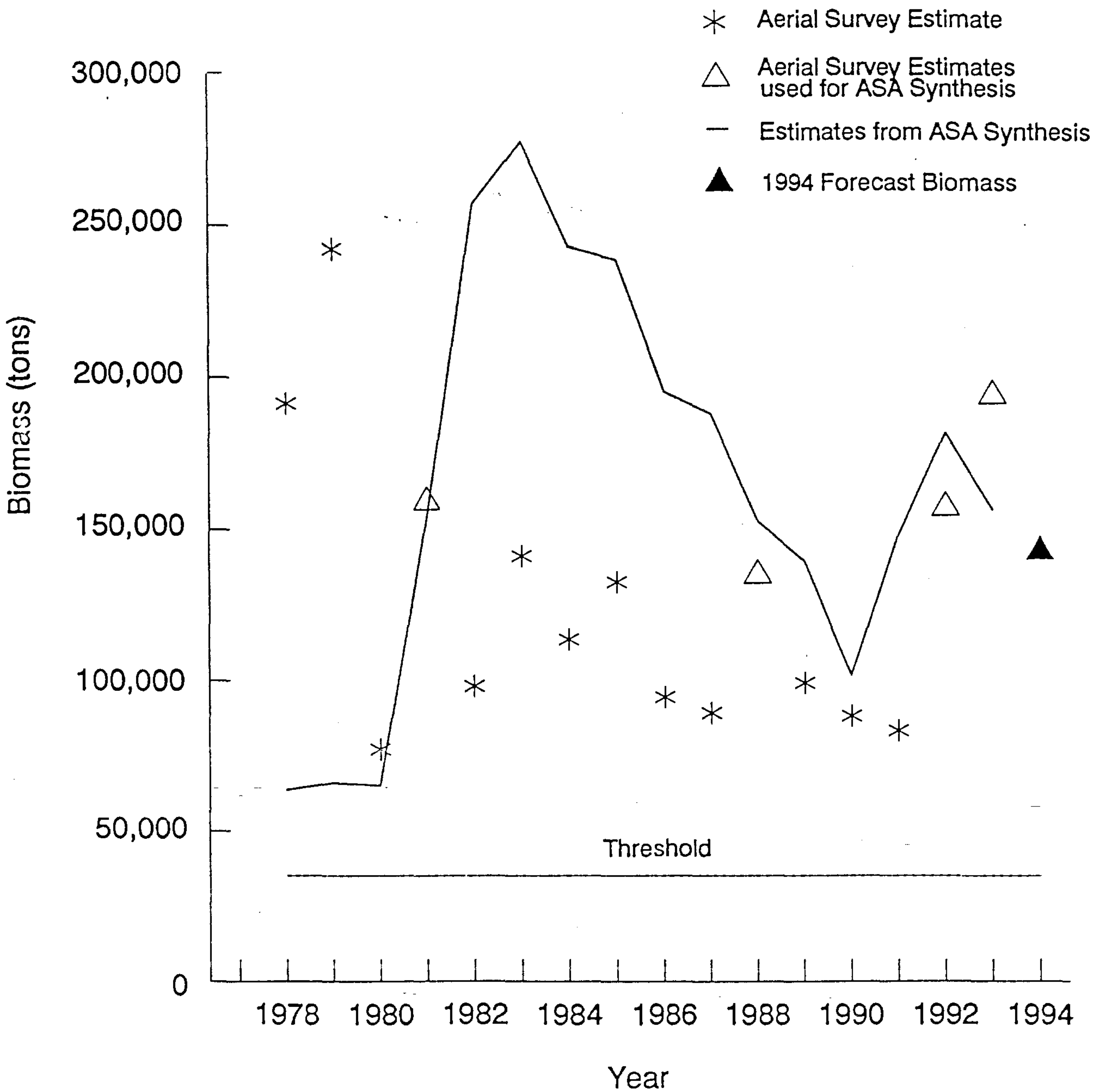


Figure 11. Estimates of abundance for Togiak District herring from aerial surveys and from the age-structured assessment (ASA) model, showing the threshold level below which fishing is not allowed.

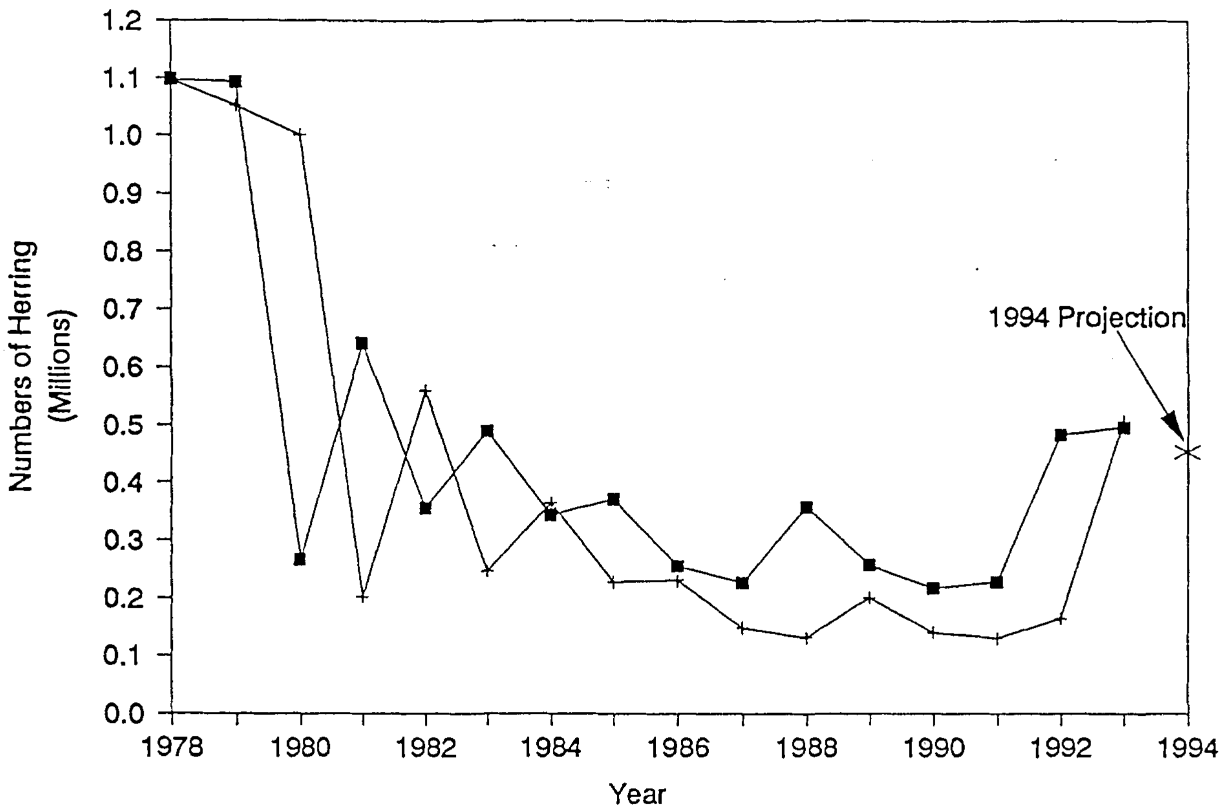


Figure 12. Performance of the Togiak District herring forecast based on a schedule of increasing mortality with age for 1978-1992, ASA for 1993 and the 1994 forecast based on an ASA model.

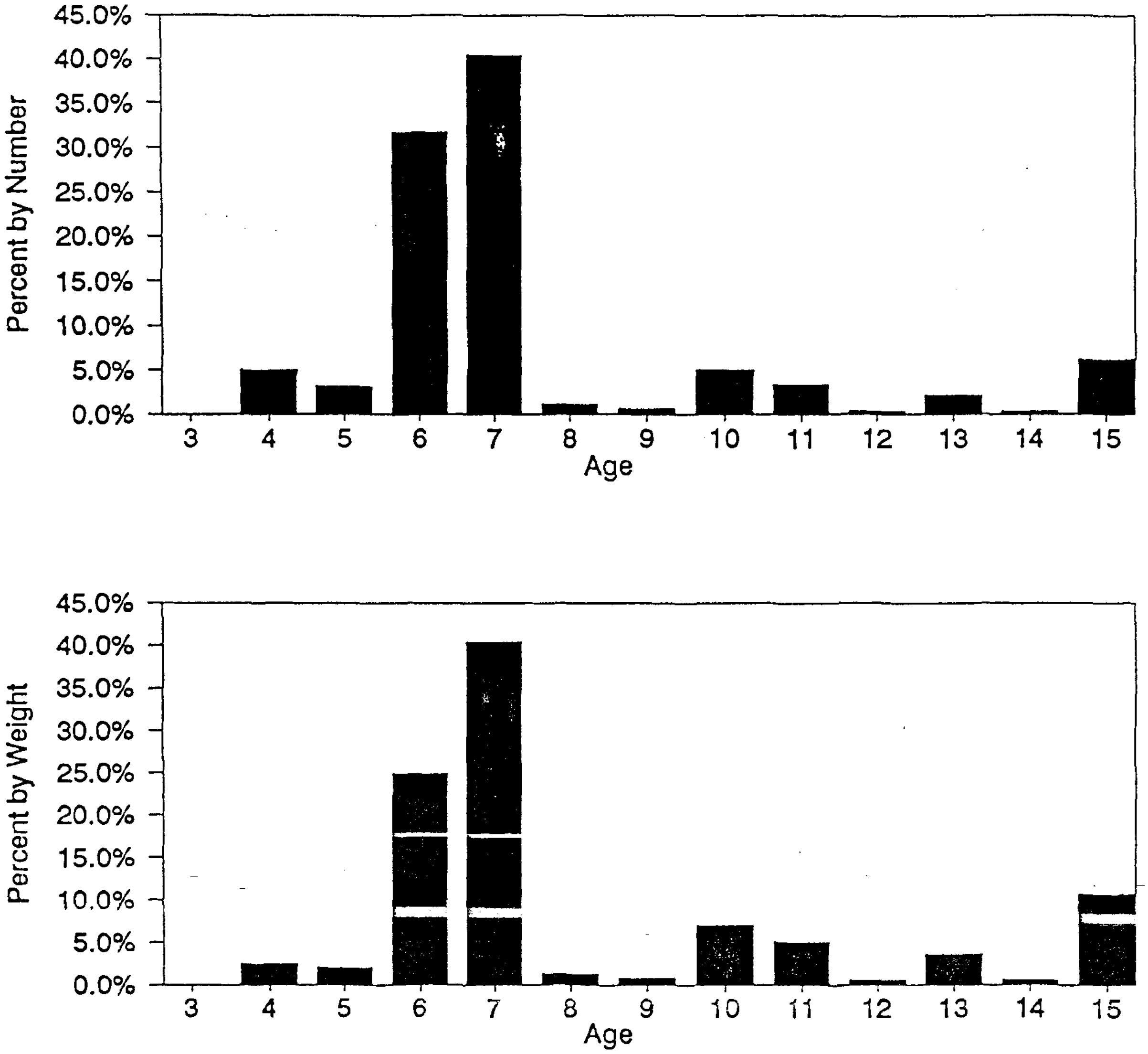
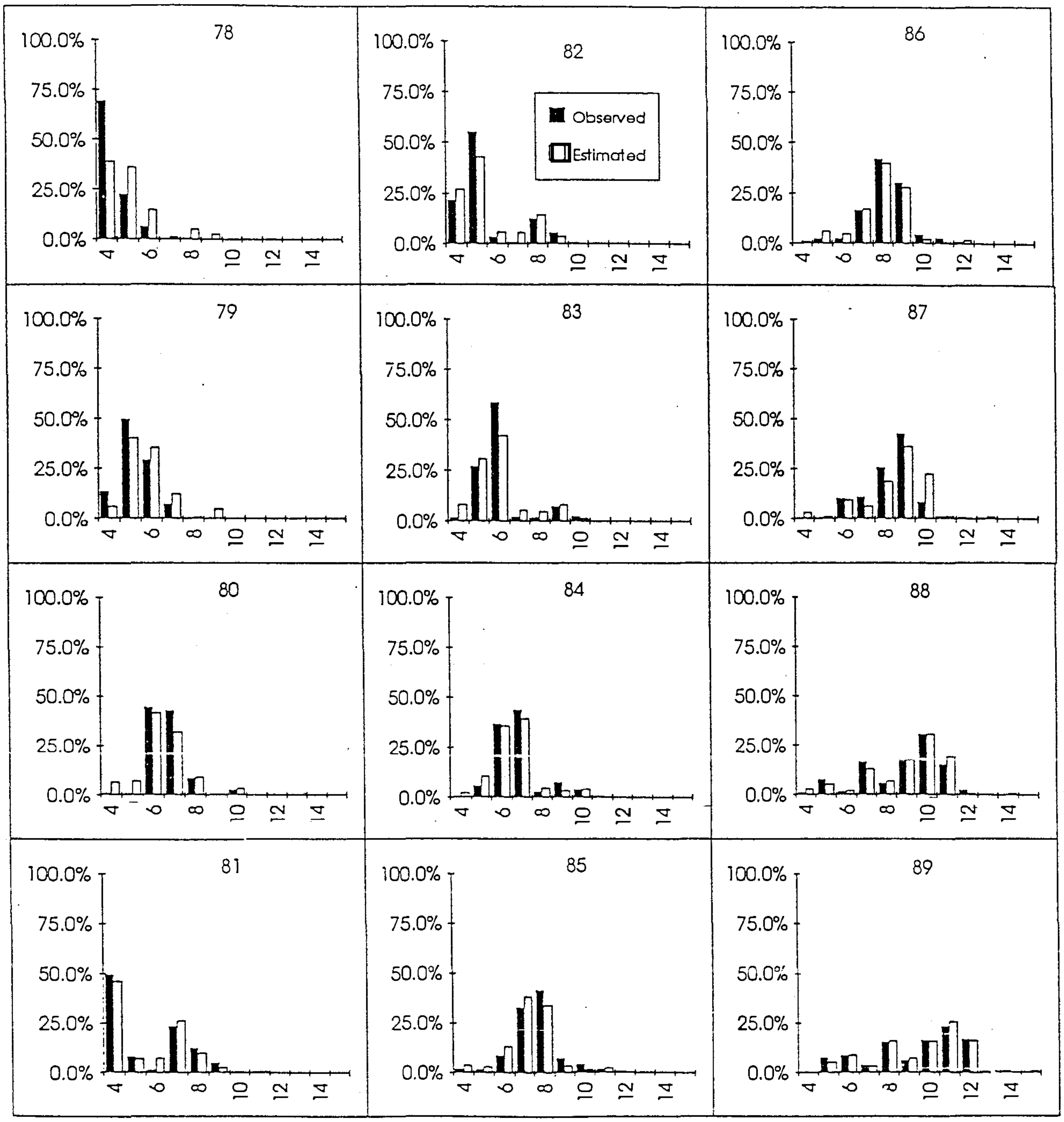


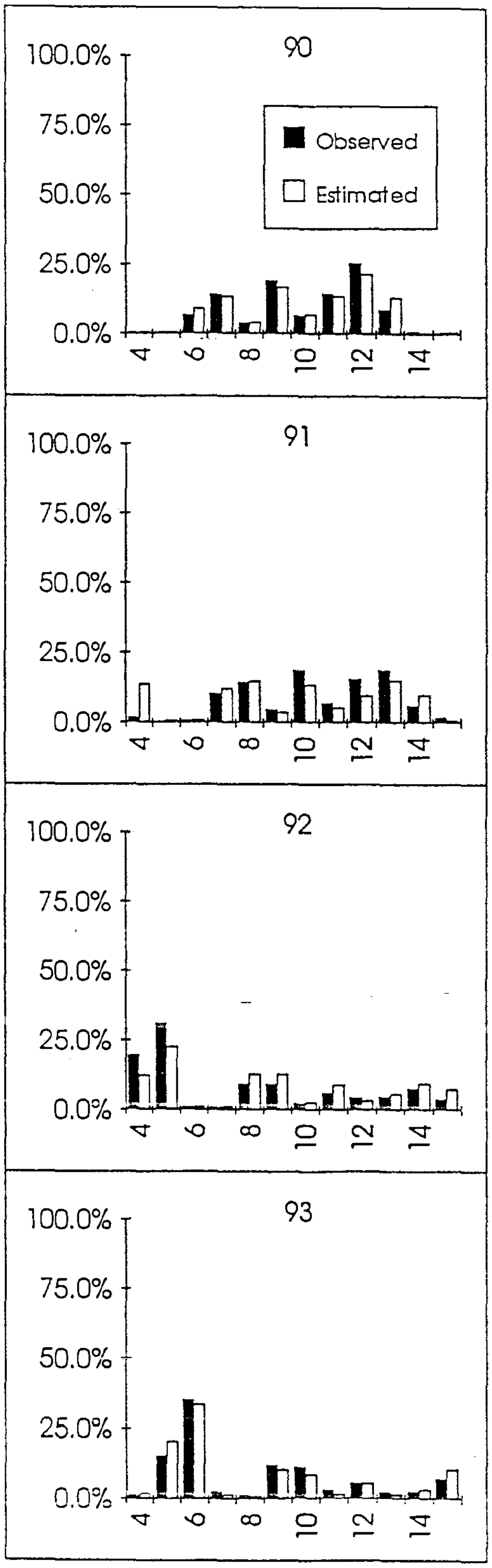
Figure 13. Forecasted age composition of the Togiak District herring population, by number (top) and weight (bottom) for 1994.

APPENDIX

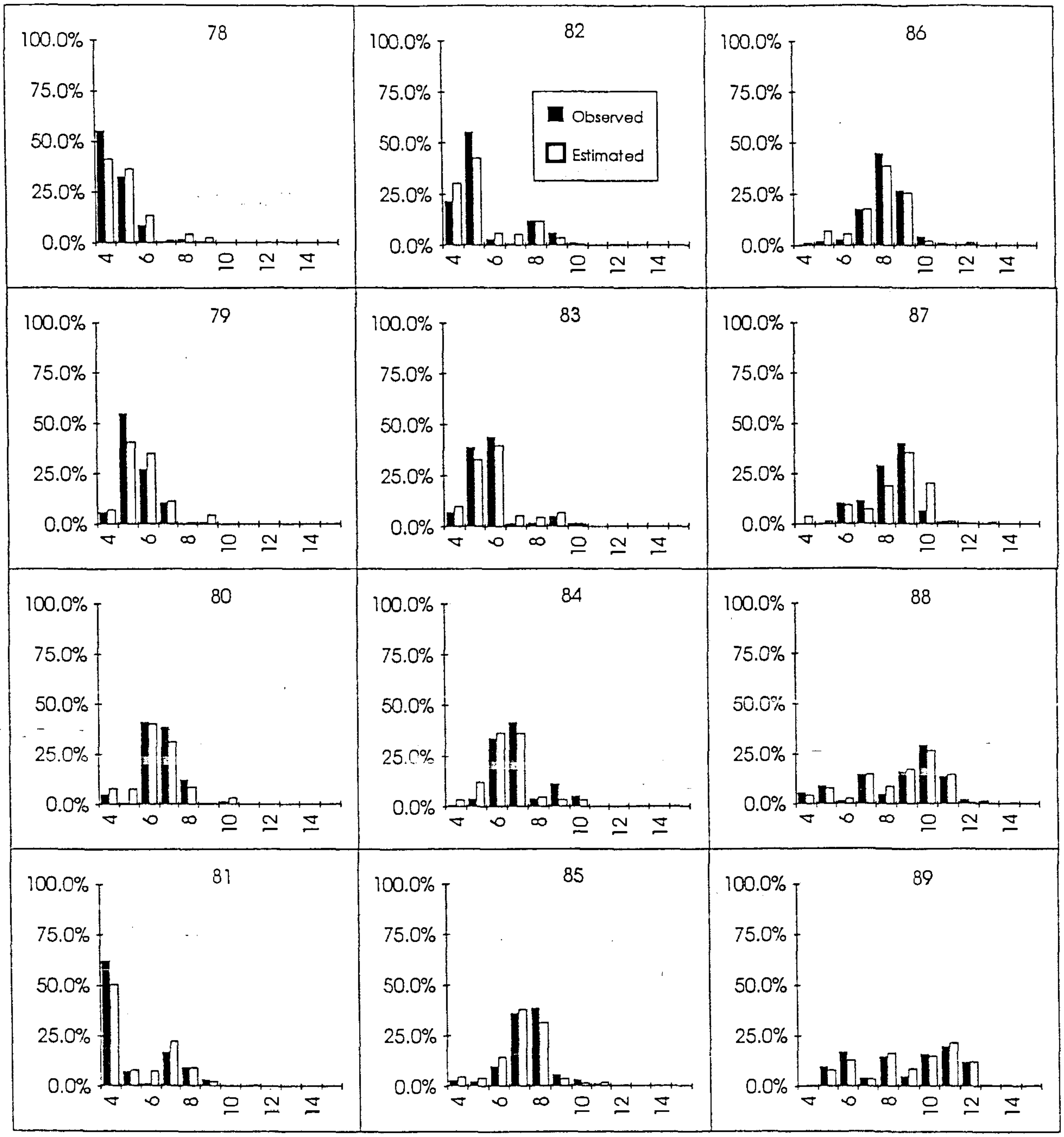
Appendix A. Observed age composition of the purse seine catch versus that estimated to be available by the ASA model for Togiak herring.



Appendix A. (Continued).



Appendix B. Observed age composition of the run biomass versus that estimated to be available by the ASA model for Togiak herring.



Appendix B. (Continued)