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# FORECAST OF THE PACIFIC HERRING BIOMASS IN TOGIAK DISTRICT, BRISTOL BAY, 1993


By

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# ABSTRACT

The 1992 Togiak District spawning migration consisted of 483 million Pacific herring *Clupea pallasi* weighing 156,955 tons. A total of 27,756 tons were harvested by the inshore sac roe fishery and Dutch Harbor food and bait fishery. The 1993 forecast represents the first 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 1993 spawning biomass of herring in the Togiak District is forecast to be 148,786 tons. An estimated 73% of the individuals and 62% of the biomass will be age-5 and -6 herring. The average size of an individual is expected to be 267 g.

The 1993 recommended total allowable harvest is 29,757 tons and 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, 1,978 tons for the Dutch Harbor food and bait fishery, and 26,279 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, test fish purse seine catches, and the mature run, as well as aerial survey estimates of biomass. Beginning in late April the nearshore area of 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 *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).

The large numbers of herring collected in age-weight-length samples from the Togiak population

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

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. Information contained in the historical time series of age composition estimates has never been incorporated simultaneously with aerial survey data to estimate or forecast abundance. Age-structured analysis (ASA) provides a tool that can incorporate age composition data and selected years of aerial surveys to generate abundance estimates. 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 it does remove much bias in abundance estimates by excluding aerial survey biomass estimates made during years having 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 with good surveys 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 1993. Specific objectives are (1) to document data sources and methodology used for the 1993 forecast, (2) to document and evaluate the performance of historic forecasts, and (3) to present the 1993 forecast, and through application of the Bristol Bay Herring Management Plan (ADF&G 1992a), propose a harvest guideline for the 1993 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 Hilborn and Walters (1992) and Megrey (1989). Whereas our primary goal was to generate a one-year-ahead forecast of herring abundance for 1993, the model also updated estimates of historical abundances for 1978-1992, 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 return 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 1993 Togiak herring biomass was forecast from the 1992 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 harvests, (2) age composition of the spawning biomass and 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 running the computer for each simulation model.

### *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 $y$:

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

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. until the "15+" category of 1985. From 1985 forward, herring aged 15 and older are pooled into the "15+" category.

The starting value used in the model for annual survival rate was 70%, which is equivalent to a 0.35 instantaneous natural mortality rate (M). Starting values for the abundance of the 1970 - 1988 year classes were estimated by graphically fitting 1978-1992 run biomass age composition estimates to 1981, 1988, and 1992 aerial survey biomass estimates.

### *Catch at Age*

Herring harvests by age for purse seine and gillnet sac roe 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 Fried et al. (1983) or McBride et al. (1981). 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 and 1991, this information was obtained using the catch weight at age distribution from the annual forecast report (Funk 1991, Funk and Harris 1992) 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 each gear were also converted to age composition estimates (percent by age) for each gear so that they could be compared with age composition estimates obtained from the ASA model.

### *Weight at Age*

Estimates of weight at age were obtained from Baker (1991b) for 1981-1990 (Table 4). For 1978-1980 and 1991-1993 weight at age was obtained from Baker (1991a) who estimated values using Schnute's (1981) general growth model:

$$W_a = W_\infty e^{-e^{-g(a-a_0)}} , \tag{2}$$

where $W_a$ is the estimated weight at age $a$, $W_\infty$ 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 1980-1989 Togiak commercial purse seine fishery samples were used to estimate model parameters. The resulting weight-age relationship was:

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

## *Estimation of the Age Composition of the Catch*

### Gear Selectivity

For each gear, an estimated age composition of the 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):

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

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 sizes classes of herring by the gear or fisher. Gear selectivity was estimated separately for each gear type used 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 $\alpha$ is the age at which selectivity is equal to 50%, and $\beta$ is a steepness parameter. The gamma-type function of Deriso et al. (1985) was used for gillnet gear since selectivity was assumed to decrease for older ages:

$$s(a) = \frac{(a-2)^{\gamma} e^{-\delta (a-2)}}{\max_j [\, j^{\gamma} e^{-\delta j} \,]} , \tag{6}$$

where $\gamma$ and $\delta$ are the two parameters to be estimated, and the subscript $j$ ranges over all age classes. The denominator of the expression scales the values of the function to one at the age of maximum selectivity. By subtracting two from $a$ in the numerator, the vulnerability of age-2 and younger herring was set to zero. This allowed for more flexibility and a better fit of the model for older ages. Initial values for parameters used in equations 5 and 6 were chosen to give selectivities similar to those reported by Funk and Sandone (1990) for Prince William Sound.

## 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. For each gear, the sum of squares measuring the goodness of fit of the age composition of the catch was computed as:

$$SSQ_{agecomp:catch} = \sum_{y} \sum_{a} \left(\frac{C_{a,y}}{\sum_{a} C_{a,y}} - \hat{p}_{a,y}\right)^2 , \tag{7}$$

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 $15^{+}$). In contrast, selectivity of age-4 herring was very low and variable for gillnet catches. Therefore the $SSQ_{agecomp:gillnet\ catch}$ was summed beginning at age 5, omitting age-4 deviations ($a$ = 5, 6, 7, ..., 15 in equation 7).

### *Maturity*

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

$$\rho(a) = \frac{1}{1 + e^{\phi(a-\tau)}} , \tag{8}$$

where $\tau$ is the age at which 50% of a cohort reach maturity, and $\phi$ 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 by examining run biomass age composition estimates to determine whether temporal trends in the sign or magnitude of their residuals were evident. Two time periods, each with a different pattern of residuals were identified, 1978-1987 and 1988-1992. A maturity function was fit to each time period (equation 8). Each time period corresponded to a different procedure for estimating the run biomass and its age composition. Initial values supplied for maturity parameters set a 50% maturity at age 4 increasing to 100% maturity at age 7. Biological sexual maturity is achieved at approximately age 6 (Wespestad 1991). Maturity based on ADF&G run age composition sampling is likely older than biological maturity because sampling tends to be curtailed at the end of the spawning run when younger fish are present.

We initially ran the ASA model using the same maturity function to compare abundances from both the aerial survey biomass and run biomass age composition estimates with model estimates. It became obvious after examining the response surfaces and the resulting dome-shaped pattern in the run biomass by age residuals, that the two data sources required very different maturity schedules. Therefore the maturity schedule was set equal to the biological maturity reported by Wespestad (1991) and was applied when comparing abundances determined from equation (1) with aerial survey biomass estimates.

### *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. Aerial survey data from 1980-1992 were given numerical ratings based on survey frequency, survey spatial and temporal coverage, and weather conditions (Table 5). Aerial surveys from the six highest rated years (1981-1983, 1985, 1988, 1992) were considered for use in the ASA model. The 1982 aerial survey estimate, although highly ranked was excluded after examining the abundance trends shown by these six years. The low biomass estimated for 1982, relative to estimates from adjacent years with high ratings, did not reflect the recruitment of the very strong 1977 and 1978 year classes. Because differences in relative ratings among the five remaining survey years were not obvious, the sensitivity of ASA model results to the use of different subsets of these five years was evaluated using a goodness of fit statistic based on the differences between ASA and aerial survey estimates of run biomass:

$$SSQ_{aerialbiomass} = \sum_{y} \{ \log_e ( B_y^{survey} ) - \log_e [ \sum_{a} \rho_b(a)\, w_{a,y}\, N_{a,y} ] \}^2 , \qquad (9)$$

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), $\rho_b(a)$ is the proportion biologically mature at age $a$ (Wespestad 1991) , 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 (9). 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.

### *Screening Aerial Survey Biomass Estimates with VPA*

We wanted to select a set of aerial survey run biomass estimates that would most accurately represent actual herring biomass. Our criteria for choosing estimates was based on information independent of surveys. 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 often difficult to recognize years for which these problem were particularly bad. We excluded aerial survey biomass estimates for years when the water was turbid, or weather or logistical constraints reduced the frequency of aerial survey flights, particularly during periods when biomass appeared to be increasing. However, because actual run timing was unknown, rates of immigration and emigration could not be determined, and effects of environmental conditions are complex, our screening method may not have excluded all years for which estimates were inaccurate. Therefore, an alternative approach using simple virtual population analysis (VPA) was examined to identify years during which aerial survey results were inconsistent with VPA estimates of run biomass based on conservative assumptions about survival, terminal fishing mortality, and maturity.

## Maturity

VPA (Gulland 1965, Megrey 1989) is used to reconstruct the total population biomass (mature and immature) of cohorts at an arbitrary first age, usually the age at which cohorts begin to enter the fishable population. Because we wanted to use VPA results as a bench mark against which to compare aerial survey estimates, assumptions were made concerning the proportion of the population that was mature and available for observation by aerial surveyors. Fried and Wespestad (1983), based on Russian studies of herring on the Bering Sea wintering grounds, derived a schedule of relatively rapid maturation (Figure 4). Brannian and Rowell (1989) and Baker (1991) derived different maturity schedules, using aerial survey data which the VPA is attempting to evaluate. Therefore, these schedules are not independent of the aerial survey estimates and were not used. Purse seine catch sample data contain relatively robust information about the age herring recruit to this gear (Figure 4, bottom). While we think recruitment into the purse seine fishery is similar to, but at older ages, than that observed for aerial surveys, average catch curves derived from catch data can be misleading because very strong year classes are present and may cause distortion. This may not be a severe problem with our current data because most members of recent strong year classes (1974, 1977 and 1978) have probably died and no longer contribute to catches. In 1992 however, substantial new recruitment was observed, which could once again distort the average catch curve. To avoid these problems, only data from 1978-1991 were used to build catch curves. The average catch curve for 1978-1991 reaches a maximum at age 7, but is nearly flat between ages 6 and 7, implying that herring are almost fully recruited to the purse seine fishery by age 6 (Figure 4). Recruitment to the population observed during aerial surveys should be at a younger age than that for purse seines, because aerial surveys and run age composition sampling continue after the fishery is over during the period when younger herring comprise a greater proportion of the spawning run. A conservative bound on maturity for the VPA analysis was assumed to be:

| Age | Percent mature |
|---|---|
| 4 | 50% |
| 5 | 75% |
| 6 | 90% |
| 7 | 99% |
| 8+ | 100% |

## Survival

Baker (1991) reviewed literature pertaining to herring mortality and concluded that instantaneous natural mortality rates ($M$) ranging from 0.25 to 0.35 were reasonable for Togiak herring. For Bering Sea groundfish species with similar life histories to herring, $M$ is estimated to range from 0.18 to 0.30 (NPFMC 1992). Those species with $M$ values below 0.2 are longer-lived than herring. Walleye pollock *Theragra chalcogramma*, one of the most thoroughly studied species in the Bering Sea are not as long lived as Togiak herring, and have an estimated $M$ value of 0.3 (Wespestad and Terry 1984). Therefore we chose to use 0.2 as a lower bound for $M$, equivalent to an upper bound for annual survival of 81.9%.

**Terminal F and Recent Cohort Size**

VPA reconstructions of cohorts that have completely aged through the fishery depend only on assumptions about survival. For cohorts which have not completely aged through the fishery, an additional assumption is required, usually termed the "terminal F" assumption. The assumption is typically stated as an exploitation rate, and provides an estimate of pre-fishery herring abundance for the most recent year of the VPA, as well as abundances of the oldest age herring for all years examined. For Togiak herring, a difference equation form of survival model, like that used for the ASA model, is most appropriate. Therefore, specifying a terminal exploitation rate is exactly the same as specifying a terminal biomass. For this analysis, Togiak aerial surveys were assumed to have measurement errors such that 95% confidence limits were ± 30% of the estimate. The 1992 Togiak aerial survey was felt to be reliable, when ranked on criteria of aerial survey conditions and coverage. The lower bound for the terminal (1992) biomass was specified to be 109,869 tons, 30% lower than the 1992 aerial survey estimate of 156,955 tons. For the oldest age considered in VPA (15) for 1978-1991, a terminal exploitation rate of 30% was set (higher exploitation rates are conservative and result in lower biomass estimates).

**Reconstructing a Lower Bound on Biomass with VPA**

The simplest form of VPA is to merely add up the catches for each year class. For example, a total of 211 million herring have been harvested from the 1977 year class, since it first recruited into the fishery in 1981 (Figure 5, top). However, all 211 million of these herring would not have been present on the spawning grounds and visible to aerial surveyors in 1981, because some of them were not yet mature. Applying the assumed older bound on maturity, results in a dome-shaped abundance trend of herring available to aerial surveys. Repeating this procedure for all year classes, and converting numbers of herring to biomass at each age, gives a very robust minimum VPA biomass estimate, based only on summing catches (Figure 5, bottom). Using the upper bound on survival rate (81.9%), increases the estimate of reconstructed biomass. Finally, adding the assumption of terminal biomass increases the biomass estimates, particularly for recent years.

### Comparison to Aerial Surveys

The VPA lower bound on biomass exceeds the likely upper bound of the aerial surveys in all but four years: 1980, 1981, 1988, and 1992 (Figure 6). While the precision of aerial survey biomass estimates was unknown, we felt it was great enough to achieve 95% confidence limits spanning ± 30% of the estimate, based on the precision achieved in other stock assessment methods like spawn deposition surveys. Consistent deviations in one direction that exceed the confidence interval are likely due to bias. The most recent year, 1992, could not be screened with this method.

The weakest assumption of this VPA is probably terminal biomass estimation. The effect of this assumption decreases for earlier years. Prior to 1983, the effect of this choice is very small. If assumptions we used concerning maturity, survival, and terminal biomass were indeed conservative and placed a lower bound on biomass, then the 1982-1987, and 1989-1991 aerial survey observations are inconsistent with these assumptions and the observed catch at age.

### *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 1978-1991 (Brannian and Rowell 1989, Baker 1991b, Funk 1991, and Funk and Harris 1992) (Table 6). The age composition of the 1992 run biomass was estimated using herring sampled from commercial fishery harvests as well as from areas where large concentrations of herring were sighted during aerial surveys. 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 three day periods whenever possible, in order to obtain sample sizes large enough (≥ 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:

$$SSQ_{agecomp:run} = \sum_y \sum_a [ p^{run}_{a,y} - \frac{\rho(a) N_{a,y}}{\sum_a (\rho(a) N_{a,y})} ]^2 , \qquad (10)$$

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

### *Forecast Methodology*

The forecast of herring run biomass for 1993 ($B^{Forecast}_{1993}$) was based on projecting total abundance with the survival model (equation 1) modified by the ASA estimates of the proportion of mature herring expected for each age:

$$B^{Forecast}_{1993} = \sum_a \rho_b(a)\, w_{a,1993}\, N_{a,1993} , \qquad (11)$$

where $\rho_b(a)$ is the proportion mature at age $a$ from Wespestad (1991), $w_{a,1993}$ is weight at age $a$ from Schnute's (1981) general growth model fit to all year's available data (Table 4) and $N_{a,1993}$ is the ASA estimate of age-$a$ herring for 1993 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 1993 forecast, $N_{4,1993}$. 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 $B^{Forecast}_{1993}$, ($p_{a,1993}$), was estimated using the maturity schedule for the recent years (1988-1992) of the run biomass age composition, $\rho_r$(a), ($\rho$(a) of equation 8), as:

$$\hat{p}_{a,1993} = \frac{N_{a,1993}\, \rho_r(a)}{\sum_a N_{a,1993}\, \rho_r(a)} , \qquad (12)$$

and the biomass at age became:

$$B^{Forecast}_{a,1993} = \hat{p}_{a,1993}\, w_{a,1993} \frac{B^{Forecast}_{1993}}{\sum_a \hat{p}_{a,1993}\, w_{a,1993}} \,. \tag{13}$$

Equations 12 and 13 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 presented by Wespestad (1991) since our samples do not span the 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 12) was used.

### *Parameter Estimation*

## Total Sum of Squares

A total sum of squares was computed by adding the sum of squares for each of the components (equations 7, 9, 10):

$$\begin{aligned} SSQ_{Total} = \; & \theta_{agecomp:seine}\, \lambda_{agecomp:seine}\, SSQ_{agecomp:seine} \; + \\ & \theta_{agecomp:gillnet}\, \lambda_{agecomp:gillnet}\, SSQ_{agecomp:gillnet} \; + \\ & \theta_{aerial\,survey}\, \lambda_{aerial\,survey}\, SSQ_{aerial\,survey} \; + \\ & \theta_{agecomp:run}\, \lambda_{agecomp:run}\, SSQ_{agecomp:run} \quad , \end{aligned} \tag{14}$$

where θ's and λ's are weights assigned to each sum of squares component. An inverse variance weighting scheme could not be used, because the variance of the aerial survey abundance estimator was unknown. The θ's were used to scale SSQ components to a similar order of magnitude, so that each SSQ component would contribute similarly to the total SSQ when λ's were equal. The λ's were used to assign ad hoc weights to each SSQ component reflecting our confidence in each component. The three age composition data sources were weighted relative to each other according to the sample sizes collected for each data source. Mature run age composition samples accounted for approximately 50%, purse seine samples accounted for 34%, and gillnet samples accounted for 16% of all herring examined. The sensitivity of the model's estimates of abundance to our choice of $\lambda$ was evaluated by varying $\lambda$. For the sensitivity analysis, aerial survey biomass estimates were assigned weights ranging from 20% to 80%.

### Minimization Methods

The ASA model estimated a total of 29 parameters: 20 initial cohort sizes, four gear selectivity function parameters ($\alpha$, $\beta$, $\gamma$, and $\delta$), four maturity function parameters ($\phi$ and $\tau$, early and late), and one survival rate parameter ($S$). When four aerial survey years were used, the four SSQ equations referred to 448 data observations with 415 degrees of freedom and a data to parameter ratio of approximately 15. 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 14). 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 were impossible and negative residuals cannot be $\sin^{-1}$ transformed.

### Sensitivity Analysis

The sensitivity of the ASA model to three assumptions was investigated by Funk et al. (1992). First, the choice of which aerial survey years to include in the analysis was somewhat subjective, so various combinations of aerial survey years were chosen from the five highest rated years to examine model sensitivity. Second, the assumption of a lognormal error structure for aerial survey biomass observations was examined. Third, the use of subjective weights for the four auxiliary information components was also examined. Funk et al. (1992) decided, based upon results of sensitivity analysis, to always include the 1988 and 1992 aerial surveys since these identified the abundance of two recent year classes (1987 and 1988) and were not disqualified through VPA screening. They also found that ASA model estimates did not change much in response to the choice of either error structure or weights. Therefore, we chose to use the 1988

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

and 1992 aerial surveys, a lognormal error structure for aerial survey biomass observations, and a similar weighting scheme for the final 1993 forecast calculations. We also conducted additional sensitivity analysis to determine which of the remaining three top five years (1981, 1983, and 1985) should be included in final model simulations.

## 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, year, year class, or estimated values. For example, to choose a function to describe purse seine selectivity we examined residuals for purse seine age composition displayed against year or age to see if the function resulted in residuals distributed as a horizontal band. Another pattern or trend in residuals might indicate that the functional structure of the data changed through time or by age which would necessitate the use of a time period or age-specific function. Ideally, model residuals should have a normal distribution with zero mean. Essentially, we applied the same principles of goodness of fit used in applied regression analysis and examination of residuals (Draper and Smith 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 (AA 27.060) and the Bristol Bay Herring Management Plan (AA 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 years or less) may be allowed if at least 20,000 tons of these younger herring are present in the district.

# RESULTS

## 1992 Spawning Migration

From aerial surveys and age composition sampling, we estimated that the 1992 Togiak District spawning run consisted of 483 million herring with a total weight of 156,955 tons (Table 7). A total of 27,756 tons of Togiak herring was harvested by all fisheries. An estimated 129,197 tons remained after the sac roe and food and bait fisheries were subtracted from the run biomass.

The biomass estimate was the sum of (1) the biomass observed on May 23 (122,887 tons), (2) the commercial harvest through May 23 (24,328 tons), and (3) the biomass observed on May 26 which had a distinct change in age composition (9,740 tons) (Table 8). Age- 9 or older herring represented 53% of the biomass and 35% of the individuals. Recruitment of age-3 through -5 herring represented 31.3% of the biomass and 51.1% of the individuals. The 1987 year class made the greatest contribution to the 1992 run biomass. These age-5 herring represented 20.6% of the biomass and 31% of the individuals. The number of 5-year-old herring totaled 149.9 million. This is the largest year class observed since 1983 when 189 million 5-year-old herring from the 1978 year class spawned (Figure 7). Since 1983, recruitment has averaged 11.3 million herring annually. The recruitment of the 1988 year class (age 4) into the spawning population during 1992 is also of note. It was the greatest number of age-4 herring observed since 1982.

The run biomass estimate for 1992 was nearly 2.6 times greater than the 60,214 tons forecasted from the 1991 escapement (Funk and Harris 1992). Part of this discrepancy was due to the forecasting method used. It did not forecast the proportion of age-4 herring, and therefore, the proportion of older aged herring, mainly age 8 and 9, observed was greater than forecast (Figure 8). When the effects of unanticipated recruitment of younger age classes (≤ age 5) were removed, the overall difference between the forecast and the run biomass estimated from aerial surveys was 62%. This difference resulted from a larger than expected return of age-8 and older herring (Figure 9). This could have occurred if the abundance estimate for 1991 was too low, the estimate for 1992 was too high, or estimates of natural mortality for older fish were too great.

## 1993 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, model 1-7), results varied mainly in run biomass estimates for 1981-1989 (Figure 10). Because all models used 1988 and 1992 aerial surveys, differences between maximum and minimum biomass estimates after 1989 dropped below 14,000 tons and represented only 4% of the average 1993 forecast (Table 10). Estimates from ASA models 1-7 agreed with the 1981, 1988 and 1992 survey estimates of run biomass. In contrast, these model estimates did not agree with 1983 and 1985 aerial surveys estimates. The smallest run biomass estimates were obtained from model 1, which included all five aerial surveys. The next smallest estimates were produced by models 2-4 using four surveys, or model 7, using three surveys one of which was the 1985 survey. Of the seven models giving equal weight to all data sources, model 5 had the smallest total sum of squares based on equation 14 (Table 9). While forecasts for 1992 were very similar for all models, model 5 produced the best fit through the 1981, 1988, and 1992 surveys. VPA estimates for these three years were below the upper limits of ± 30% bounds placed about aerial survey estimates. Estimates of run biomass varied little among the three models examined with different weightings of data sources (Table 9 and 10, models 5, 8 and 9). Run biomass estimates were highest when age composition was given 80% weight and lowest when given 20% weight (Figure 11). Since the 1993 forecast estimate was not sensitive to our choice of weights, we chose to use model 5 to forecast the 1993 run biomass. Although model 9 had a smaller total sum of squares than model 5, we did not feel comfortable giving 80% weight to aerial survey data.

The ASA model used for the 1993 forecast estimates annual survival to be 78.1% which is an instantaneous mortality rate of 0.248 (Table 11). Gear selectivity curves for the gillnet and purse seine fisheries estimate similar proportions of the population to be susceptible to capture through age 13 (Figure 12). The gillnet estimates were slightly higher for ages 5-11, and, due to the function specified had a descending right limb, rather than an asymptotic limit, as estimated for the purse seine fishery. In contrast, estimated and fixed maturity schedules were quite different (Figure 13). Biological sexual maturity is thought to be achieved at approximately age 6 (Wespestad 1991), however the ASA model estimated full maturity to be reached at approximately age 10 for the 1978-1987 period and at age 15 for the 1988-1992 period.

Residuals of the purse seine catch age composition from the ASA model formed a unimodal distribution about zero when pooled and a fairly horizontal band when displayed as a function of their estimated proportion (Figure 14). Though the pattern of the residuals was improved by the $\text{sine}^{-1}$ transformation their variability still seemed to decrease with age: there was a tendency for younger ages to have more negative residuals than age -9 through -12 herring (Figure 15). No strong trend was seen in residuals plotted by year (Figure 15) or year class (Figure 16). 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 and age-10 herring in 1987.

Pooled residuals of the gillnet catch age composition from the ASA model also formed a unimodal, symmetric distribution centered near zero (Figure 17). When displayed as a function of estimated proportions, residuals tended to positively increase. The distribution of residuals by age revealed a pattern of decreasing variability and a tendency for younger age herring to have more negative residuals than age -8 through -12 herring (Figure 18). Most noticeable was a switch in a trend of positive residuals for age-5 herring in 1978-1982 to negative residuals in

1983-1992 (Figure 18). Beginning in 1979, residuals by year class followed a trend of negative to positive values as each cohort aged (Figure 19). Even so, age composition estimates of gillnet fishery catches generally agreed closely with observed data from catch samples. Notable differences were found between estimated and observed age composition of the 1992 gillnet catch and percent occurrence of age-5 herring in 1980 and 1982 gillnet catches (Appendix B).

Pooled residuals of the run biomass age composition formed a unimodal distribution symmetric about zero and no strong pattern when displayed by the magnitude of the estimated proportion (Figure 20). Again the distribution of residuals by age showed a slight pattern of more negative values for younger aged herring than age 8-12 herring (Figure 21). A pattern of residuals by year (Figure 21) or year class (Figure 22) reflects a period of negative residuals for young herring (age 4-7) followed by a period of positive residuals. Again the age compositions of the run biomass estimated from the ASA model agree closely with that observed; with notable exceptions being the difference between estimated and observed for age-10 herring in 1987 (Appendix C).

Run biomass estimates obtained from the ASA model compared well with the three aerial surveys used as auxiliary data. In contrast, model estimates of biomass were much greater than aerial survey estimates for 1982-1987 which were not used in fitting the model (Figure 23).

## 1993 Forecast

The 1993 forecast of herring run biomass in Togiak District is 148,786 tons (Table 7). Age- 9 and older herring represent 32% of the forecasted biomass. The strong 1977 and 1978 year classes, returning as age-16 and -15 herring, are expected to contribute only 6% of the biomass and 4% of the individuals (Figures 24 and 25). The 1987 and 1988 year classes, returning as age-5 and age-6 herring, are expected to dominate the run, representing 62% of the biomass and 73% of the individuals. Average weight of herring in the 1993 run biomass is expected to be 267 g.

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. Forecasts of the youngest age classes (age 3 and 4), which are not fully recruited, are difficult to make. The Togiak herring forecast has been less than observed biomass every year since 1984 (Figure 26). Average forecast error (1984-1992) has been 30%.

For 1993, the total allowable harvest, based on the preseason forecast, is 29,757 tons (20% of forecasted biomass). In accordance with existing regulatory management plans, 1,500 tons is allocated to the Togiak District spawn-on-kelp fishery, 26,279 tons to the purse seine and gillnet sac roe fisheries and 1,978 tons to the 1993 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 estimate is obtained during the spring 1993 herring spawning migration.

## DISCUSSION

We hope use of an ASA model to forecast Togiak herring abundance will reduce or eliminate the recent under-forecasting trend. Improvement in forecast accuracy is expected from our selective use of aerial survey biomass estimates, as well as our use of all historical age composition data. In past years only age composition data from the year prior to the forecast were used, so a poor aerial survey for that year, used to weight samples combined across area and time, had large affects on our estimate as could weather limit our ability to collect samples.

The 1993 ASA model for Togiak herring provided a reasonable fit to our data. No serious problems were found through inspection of residuals, although some weak trends in residuals were noted which indicate a need to improve model fit. We are concerned that we were unable to use many of the aerial surveys (3 out of the last 5 years) in the model. If we do not obtain a good aerial survey biomass estimate during years of strong or weak recruitment, we will have difficulty determining the absolute magnitude of the recruitment. We also felt that the maturity schedule based on a combination of aerial survey data and run biomass age composition was not biologically possible. We attempted to correct this by setting the maturity schedule for survey biomass estimates to levels reported in the literature and estimating another schedule from run age composition data. Since the maturity schedules were quite different we applied the age composition of the estimated run biomass to the forecast biomass at age (equation 13). This problem may be caused by shortcomings in aerial survey biomass assessment techniques. Not only may aerial estimates underestimate total biomass due to our inability to determine herring movement patterns and residence time, but younger age classes may be underestimated to a greater extent than older age classes due to their late entry pattern, often after we have ended our monitoring projects. As a cohort ages we observe its magnitude annually, and therefore more information on it enters the model. For many cohorts, if its abundance observed today is true, then it must have been larger than observed historically. One way the model deals with such inconsistencies is to set maturity values below their actual level (Figure 13). Further work is needed to determine whether aerial surveys represent absolute estimates or just indices of abundance. If they are indices we need to determine whether we can estimate a constant of proportionality with the true abundance.

We are also concerned that estimates of parameters for the 1993 ASA model may not be independent. If so, our estimates may not represent the process (mortality, maturity, selectivity, etc) outside the constraints of the model. We had indications of this in earlier modelling attempts. As we tried to fix maturity schedules to more biologically believable levels, the model provided estimates of mortality that were too great. Again, this result could occur if our estimates of biomass were too low. Even so, our estimates of mortality from the ASA model equalled the estimate for age-9 herring used for the 1992 forecast (Funk and Harris 1992) and based on data through 1989.

The analysis of aerial survey data to obtain a biomass estimate has changed during the past 12 years. The method has changed with our understanding of herring migration to and from the fishing grounds. The estimate has also been influenced by the perspective of different staff members responsible for the analysis. Re-examination of the aerial survey database to apply new calibration factors and standardize analytical methodology may improve our model. It should also be completed prior to evaluation of whether to treat surveys as relative or absolute abundance.

Lastly, our evaluation of the fit of the model to the data was limited to graphical displays of residuals and comparisons of observed and model estimates. Calculation of variance estimates would improve our ability to assess model performance. This would require a bootstrapping technique which under current methods of spreadsheet computations would be too cumbersome. Some efforts are underway to develop computer programs that can be used to carry out these calculations more efficiently.

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Table 1. Run biomass and commercial harvests for Togiak herring, 1968-1992.

| 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 |
| Mean[g] | 126,666 | 10,357 | 252,917 | 2,414 |

[a] Data not available prior to 1978.
[b] Source: Appendices A,B Brannian and Rowell 1989; 1978-1987; Rowell in press, 1988; ADF&G 1992b, 1992; ADF&G 1992c, 1989-1991.
[c] Source: Sandone and Brannian 1988, 1980-1987; ADF&G 1988, 1968-1979; Rowell in press, 1988; ADF&G 1992b, 1992; ADF&G 1992c, 1989-1991.
[d] Source: ADF&G 1992c.
[e] Source: ADF&G 1992d; Catches documented since 1929. Fishery did not occur between 1946. and 1980.
[f] No fishery conducted.
[g] Mean calculated for total run biomass, sac roe and spawn on kelp harvest are years 1978-1992; Dutch Harbor food and bait fishery, years 1981-1992.

Table 2. Togiak District commercial purse seine harvest by year (in millions of herring), 1978-1992.

| | 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 | Funk (1991) |
| 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 | Funk and Harris (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 | |

Table 3. Togiak District commercial gillnet harvest by year (in millions of herring), 1978-1992.

| | 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 | Funk (1991) |
| 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 | Funk and Harris (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 | |

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 | 483 | 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 | 344 | 344 | 379 | 384 | 425 | 461 | 473 | 483 | Baker (1991b) Appendix Table 14 |
| 1991 | 158 | 208 | 257 | 302 | 342 | 376 | 404 | 428 | 446 | 461 | 473 | 483 | Schnute's Growth Model from Baker (1991a) |
| 1992 | 158 | 208 | 257 | 302 | 342 | 376 | 404 | 428 | 446 | 461 | 473 | 483 | Schnute's Growth Model from Baker (1991a) |
| 1993 | 158 | 208 | 257 | 302 | 342 | 376 | 404 | 428 | 446 | 461 | 473 | 483 | Schnute's Growth Model from Baker (1991a) |

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

| Survey Year | C Surveys (partial) | D Surveys (Complete) | E Ratio d/c+d | F Avg Survey Rating | G Peak Survey (5 pts) | H Survey Rating (Peak) | I Total # Surveys | J Total Surveys W/fish | Sum 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 |

Table 6. Age composition of the herring run biomass in Togiak District for 1978-1992.

| | 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 | 0.096 | 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 | Funk (1991) |
| 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 | Funk and Harris (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 | |

Table 7. Year class composition of the 1992 Togiak herring harvest, escapement, and run biomass, and the biomass forecasted for 1993.

| | | 1992 Harvest (tons) | | | | 1992 Postspawning Escapement (tons) | 1992 Run Biomass[a] | | | | 1993 Togiak Forecasted Run Biomass[b] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sac Roe | | | | | | | | | | | | | | |
| Year Class | Age Class | Purse Seine | Gill Net | Food and Bait | Total Harvest (tons) | | Biomass (tons) | No. of Fish (X 1,000) | % by Wt. | % by No. | Year Class | Age Class | Biomass (tons) | No. of Fish (x 1,000) | % by Wt. | % by No. |
| 1989 | 3 | 17 | 0 | 0 | 17 | 221 | 238 | 1,463 | 0.2% | 0.3% | 1990 | 3 | 0 | 0 | 0.0% | 0.0% |
| 1988 | 4 | 2,009 | 1 | 0 | 2,010 | 14,411 | 16,421 | 95,635 | 10.5% | 19.8% | 1989 | 4 | 4,925 | 28,300 | 3.3% | 5.6% |
| 1987 | 5 | 4,157 | 124 | 5 | 4,286 | 28,058 | 32,344 | 149,902 | 20.6% | 31.0% | 1988 | 5 | 48,782 | 212,800 | 32.8% | 42.0% |
| 1986 | 6 | 222 | 29 | 2 | 253 | 655 | 908 | 3,790 | 0.6% | 0.8% | 1987 | 6 | 43,979 | 155,500 | 29.6% | 30.7% |
| 1985 | 7 | 206 | 178 | 6 | 390 | 1,207 | 1,597 | 4,558 | 1.0% | 0.9% | 1986 | 7 | 1,456 | 4,400 | 1.0% | 0.9% |
| 1984 | 8 | 2,146 | 1,307 | 408 | 3,861 | 18,904 | 22,765 | 59,693 | 14.5% | 12.4% | 1985 | 8 | 1,278 | 3,400 | 0.9% | 0.7% |
| 1983 | 9 | 2,447 | 1,352 | 459 | 4,258 | 16,922 | 21,180 | 49,134 | 13.5% | 10.2% | 1984 | 9 | 11,671 | 28,200 | 7.8% | 5.6% |
| 1982 | 10 | 622 | 165 | 93 | 880 | 4,879 | 5,759 | 12,732 | 3.7% | 2.6% | 1983 | 10 | 9,212 | 20,700 | 6.2% | 4.1% |
| 1981 | 11 | 1,915 | 548 | 305 | 2,768 | 10,117 | 12,885 | 25,909 | 8.2% | 5.4% | 1982 | 11 | 1,316 | 2,800 | 0.9% | 0.6% |
| 1980 | 12 | 1,431 | 296 | 191 | 1,918 | 5,412 | 7,330 | 14,657 | 4.7% | 3.0% | 1981 | 12 | 5,411 | 11,000 | 3.6% | 2.2% |
| 1979 | 13 | 1,597 | 332 | 216 | 2,145 | 11,204 | 13,349 | 25,410 | 8.5% | 5.3% | 1980 | 13 | 965 | 1,900 | 0.6% | 0.4% |
| 1978 | 14 | 2,697 | 469 | 205 | 3,371 | 10,819 | 14,190 | 25,462 | 9.0% | 5.3% | 1979 | 14 | 4,652 | 8,900 | 3.1% | 1.8% |
| 1977 | 15 | 1,049 | 196 | 56 | 1,301 | 4,372 | 5,673 | 10,328 | 3.6% | 2.1% | 1978 | 15+ | 15,140 | 28,500 | 10.2% | 5.6% |
| 1974 | 16 | 114 | 20 | 3 | 137 | 1,054 | 1,191 | 2,283 | 0.8% | 0.5% | | | | | | |
| 1973 | 17 | 30 | 0 | 0 | 30 | 727 | 757 | 1,456 | 0.5% | 0.3% | | | | | | |
| 1972 | 18 | 120 | 12 | 0 | 131 | 235 | 368 | 672 | 0.2% | 0.1% | | | | | | |
| Total | | 20,779 | 5,030 | 1,949 | 27,756 | 129,197 | 156,955 | 483,084 | | | | | 148,786 | 506,400 | | |

[a] Revised run biomass estimate and age composition derived from inseason biological sampling weighted by selected observed biomass estimates.
[b] Forecasted age composition and run biomass estimated from age structure population model.

Table 8. Daily observed biomass estimates of herring during the 1992 season by index area, Togiak District, Bristol Bay, Alaska.[a]

| Date | Survey Conditions | Survey Time | Milt Sightings No. | Milt Sightings Length (Mi) | NUS | KUK | MET | NUK | UGL | TOG | TNG | MTG | HAG | OSK | PYR | CN | WAL | Daily Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Estimated Biomass by Index Area in Tons[b] | | | | | | | | | | | | | |
| 4/20 | Fair | pm | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | - | - | - | - | - | - | - | 0 |
| 4/29 | Exc | pm | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0[c] | - | - | - | - | - | 0 |
| 5/01 | Good | pm | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | 0[c] | 0[c] | 0 | - | - | - | - | 0 |
| 5/02 | Exc | am | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | 0[c] | 0[c] | 0 | - | - | - | - | 0 |
| 5/05 | Good | pm | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0[c] | 12 | - | - | - | - | 12 |
| 5/06 | Fair-Poor | pm | 0 | 0.00 | - | - | - | - | - | - | 0 | 0 | 0 | - | - | - | - | 0 |
| 5/07 | Fair | pm | 0 | 0.00 | - | - | 0 | 0 | 0 | 0 | 0[c] | 0 | 0 | - | - | - | - | 0 |
| 5/09 | Fair | pm | 0 | 0.00 | - | - | - | - | 0 | 0 | 0[c] | 0 | 0 | - | - | - | - | 0 |
| 5/10 | Good | pm | 0 | 0.00 | - | - | - | - | 0 | 0 | 0[c] | - | 0 | - | - | - | - | 0 |
| 5/13 | Fair-Poor | am | 0 | 0.00 | - | - | 0 | 0 | 0 | 0 | 0 | - | 0 | - | - | - | - | 0 |
| 5/15 | Fair-Unsat | am | 0 | 0.00 | - | - | - | - | 0 | 0 | 0 | - | 0 | - | - | - | - | 0 |
| 5/16 | Good-Poor | am | 0 | 0.00 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 62 | 0 | - | - | - | 62 |
| 5/17 | Good-Poor | am | 0 | 0.00 | - | 0 | 0 | 136 | 0 | 0[c] | 0 | 0 | 0 | - | - | - | - | 136 |
| 5/17 | Good-Fair | pm | 0 | 0.00 | - | - | 72 | 323 | 826 | - | - | - | - | - | - | - | 109 | 1,330 |
| 5/18 | Good | pm | 0 | 0.00 | - | 114 | 0 | 81 | 632 | 0[c] | 0 | 0 | 13,379 | 0 | 1,882 | - | 86,281 | 102,369 |
| 5/19 | Good | am | 2 | 1.50 | 29,701 | 7,336 | 62 | 2,553 | 1,187 | 46,810 | 13,713 | 10,932 | 15,006 | 52 | - | - | 1,904 | 129,256 |
| 5/19 | Exc | pm | 5 | 7.00 | - | - | - | - | 13,137 | 47,270 | 21,209 | 20,408 | 7,950 | - | - | - | - | 109,974 |
| 5/20 | Good | am | 5 | 4.80 | - | 8,923 | 4,104 | 0 | 5,157 | 17,246 | 967 | 15,980 | - | 0 | 9,347 | - | - | 61,724 |
| 5/20[d] | Good | pm | 29 | 19.40 | | | | | | | | | | | | | | |
| 5/21[d] | Good | pm | 55 | 34.25 | | | | | | | | | | | | | | |
| 5/22 | | am | 24 | 8.50 | - | 4,082 | 537 | 4,960 | 1,611 | - | - | - | - | - | - | - | - | 11,190 |
| 5/23 | Good | pm | 28 | 14.90 | 9,440 | 38,260 | 9,085 | 9,104[e] | 13,204 | 21,102[e] | 5,569[e] | 3,676 | 452 | 2,022 | 10,633 | 0 | 340 | 122,887 |
| 5/24 | Fair | pm | 9 | 8.75 | - | 283 | 1,296 | 522 | - | - | - | - | - | - | - | - | - | 2,101 |
| 5/25 | Good | pm | 6 | 2.50 | - | 2,186 | 3,937 | 3,767[e] | - | - | - | - | - | - | - | - | - | 9,890 |
| 5/26 | Good | am | 3 | 1.30 | - | 2,016 | 3,668 | 1,556 | 1,961 | 539 | - | - | - | - | - | - | - | 9,740 |
| 5/26 | Good | am | 2 | 1.20 | - | - | 2,811 | - | - | - | - | - | - | - | - | - | - | 2,811 |
| 5/27 | Fair | am | 1 | 0.30 | - | 57 | 223 | 1,322 | 169[e] | - | - | - | - | - | - | - | - | 1,771 |
| Total | | | 160 | 96.90 | | | | | | | | | | | | | | |

[a] The revised run biomass for Togiak District Pacific herring was estimated at 156,955 tons for the 1992 season.
The revised run biomass estimate is the summation of:
1) 122,887 tons observed during the aerial survey conducted 23 May,
2) the commercial catch of 24,328 tons harvested up to the 23 May survey date, and
3) 9,740 tons observed during the aerial survey conducted 26 May.

[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.

[c] Smelt schools observed.

[d] Spawn and fishing effort survey.

[e] Includes estimates of observed dead loss.

Table 9. Combinations of aerial surveys and weights used to examine the sensitivity of ASA model results. Scaling coefficients (thetas) were adjusted so that each sum of squares components had approximately equal influence on the combined sum of squares before weighting.

| | | | | | | | Weights | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Between Data Sources | | Within Age Composition Data | | | Total |
| Model | Aerial Surveys | | | | | Total | Aerial | All Age | Total | Purse | Gill | Sum of |
| No. | 81 | 83 | 85 | 88 | 92 | Surveys | Surveys | Compositions | Run | Seine | Net | Squares |
| 1 | 1 | 1 | 1 | 1 | 1 | 5 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.567 |
| 2 | 1 | 1 | | 1 | 1 | 4 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.550 |
| 3 | 1 | | 1 | 1 | 1 | 4 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.478 |
| 4 | | 1 | 1 | 1 | 1 | 4 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.596 |
| 5 | 1 | | | 1 | 1 | 3 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.372 |
| 6 | | 1 | | 1 | 1 | 3 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.618 |
| 7 | | | 1 | 1 | 1 | 3 | 0.5 | 0.5 | 0.5 | 0.34 | 0.16 | 0.467 |
| 8 | 1 | | | 1 | 1 | 3 | 0.2 | 0.8 | 0.5 | 0.34 | 0.16 | 0.589 |
| 9 | 1 | | | 1 | 1 | 3 | 0.8 | 0.2 | 0.5 | 0.34 | 0.16 | 0.149 |

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

| Model | Estimated Pre-Fishery Mature Biomass (Tons) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
| 1 | 59,018 | 61,989 | 59,503 | 116,069 | 188,964 | 199,004 | 168,564 | 161,262 | 128,009 | 124,288 | 111,231 | 96,427 | 79,303 | 101,673 | 153,000 | 155,261 |
| 2 | 66,935 | 69,223 | 66,190 | 137,385 | 224,934 | 236,004 | 196,936 | 185,243 | 144,245 | 136,675 | 119,291 | 99,876 | 78,874 | 101,199 | 152,649 | 152,064 |
| 3 | 67,009 | 69,309 | 66,279 | 137,696 | 225,053 | 236,425 | 197,347 | 184,119 | 142,933 | 135,154 | 117,730 | 98,414 | 77,661 | 99,959 | 152,242 | 151,772 |
| 4 | 66,715 | 68,969 | 65,882 | 135,758 | 224,331 | 235,392 | 196,418 | 183,314 | 142,286 | 134,690 | 117,548 | 98,369 | 77,706 | 100,189 | 152,379 | 152,019 |
| 5 | 67,985 | 70,882 | 68,538 | 154,416 | 261,793 | 281,156 | 239,161 | 225,870 | 179,238 | 167,734 | 141,417 | 116,774 | 91,214 | 106,009 | 152,874 | 148,786 |
| 6 | 69,724 | 72,535 | 70,021 | 158,542 | 267,012 | 284,585 | 240,151 | 224,584 | 176,334 | 162,718 | 134,946 | 109,657 | 84,437 | 98,199 | 156,843 | 153,474 |
| 7 | 66,808 | 69,077 | 65,999 | 136,292 | 224,531 | 236,099 | 197,108 | 183,977 | 142,879 | 135,285 | 118,098 | 98,841 | 78,096 | 100,542 | 152,402 | 151,996 |
| 8 | 68,488 | 71,470 | 69,275 | 159,048 | 271,985 | 293,566 | 250,789 | 237,467 | 189,311 | 177,133 | 148,788 | 122,680 | 95,520 | 106,164 | 145,646 | 140,043 |
| 9 | 68,269 | 71,223 | 68,968 | 155,920 | 262,754 | 281,252 | 238,811 | 224,562 | 177,585 | 164,935 | 137,505 | 112,524 | 86,948 | 100,291 | 155,649 | 152,235 |
| Model 1-7 | | | | | | | | | | | | | | | | |
| Min | 59,018 | 61,989 | 59,503 | 116,069 | 188,964 | 199,004 | 168,564 | 161,262 | 128,009 | 124,288 | 111,231 | 96,427 | 77,661 | 98,199 | 152,242 | 148,786 |
| Max | 69,724 | 72,535 | 70,021 | 158,542 | 267,012 | 284,585 | 240,151 | 225,870 | 179,238 | 167,734 | 141,417 | 116,774 | 91,214 | 106,009 | 156,843 | 155,261 |
| Average | 66,313 | 68,855 | 66,059 | 139,451 | 230,946 | 244,095 | 205,098 | 192,624 | 150,846 | 142,363 | 122,894 | 102,623 | 81,042 | 101,110 | 153,198 | 152,196 |
| Difference | 10,706 | 10,546 | 10,518 | 42,473 | 78,048 | 85,581 | 71,588 | 64,608 | 51,229 | 43,446 | 30,186 | 20,347 | 13,553 | 7,810 | 4,601 | 6,475 |

Table 11. Parameter values estimated by the 1993 Togiak herring ASA model.

| Parameter | Estimate | Estimate Early | Estimate Late |
|---|---|---|---|
| Survival | 78.06% | | |
| Instanteanous Mortality | 0.248 | | |
| Gear Selectivity | | | |
| Purse Seine | | | |
| $\alpha$ | 7.122 | | |
| $\beta$ | -0.811 | | |
| Gillnet | | | |
| $\gamma$ | 3.364 | | |
| $\delta$ | 0.346 | | |
| Maturity Schedules | | | |
| $\tau$ | | 7.345 | 5.781 |
| $\Phi$ | | -.0702 | -1.088 |

| | Million of Herring | | | | | |
|---|---|---|---|---|---|---|
| Year | Age-4 | Age-5 | Age-6 | Age-7 | Age-8 | Age-9 |
| 1978 | 230.06 | 106.35 | 23.06 | 1.38 | 3.27 | 1.45 |
| 1979 | 49.83 | | | | | |
| 1980 | 66.63 | | | | | |
| 1981 | 620.42 | | | | | |
| 1982 | 604.44 | | | | | |
| 1983 | 243.32 | | | | | |
| 1984 | 76.28 | | | | | |
| 1985 | 141.86 | | | | | |
| 1986 | 26.87 | | | | | |
| 1987 | 102.37 | | | | | |
| 1988 | 82.56 | | | | | |
| 1989 | 7.47 | | | | | |
| 1990 | 6.76 | | | | | |
| 1991 | 223.98 | | | | | |
| 1992 | 427.10 | | | | | |

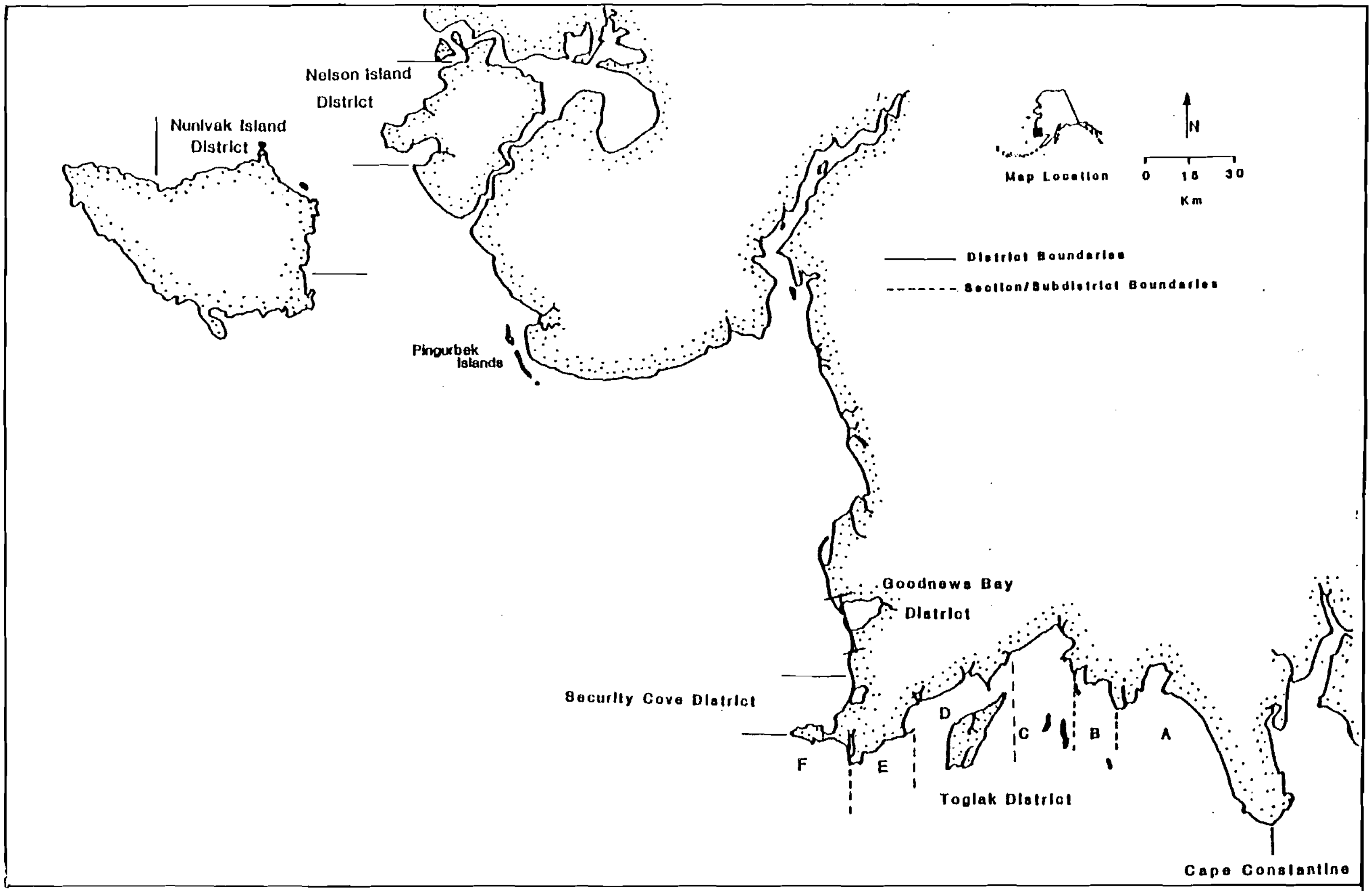



Figure 1. Togiak, Security Cove, Goodnews Bay, Nelson Island, and Nunavak Island herring commercial fishing districts, Bering Sea, Alaska.

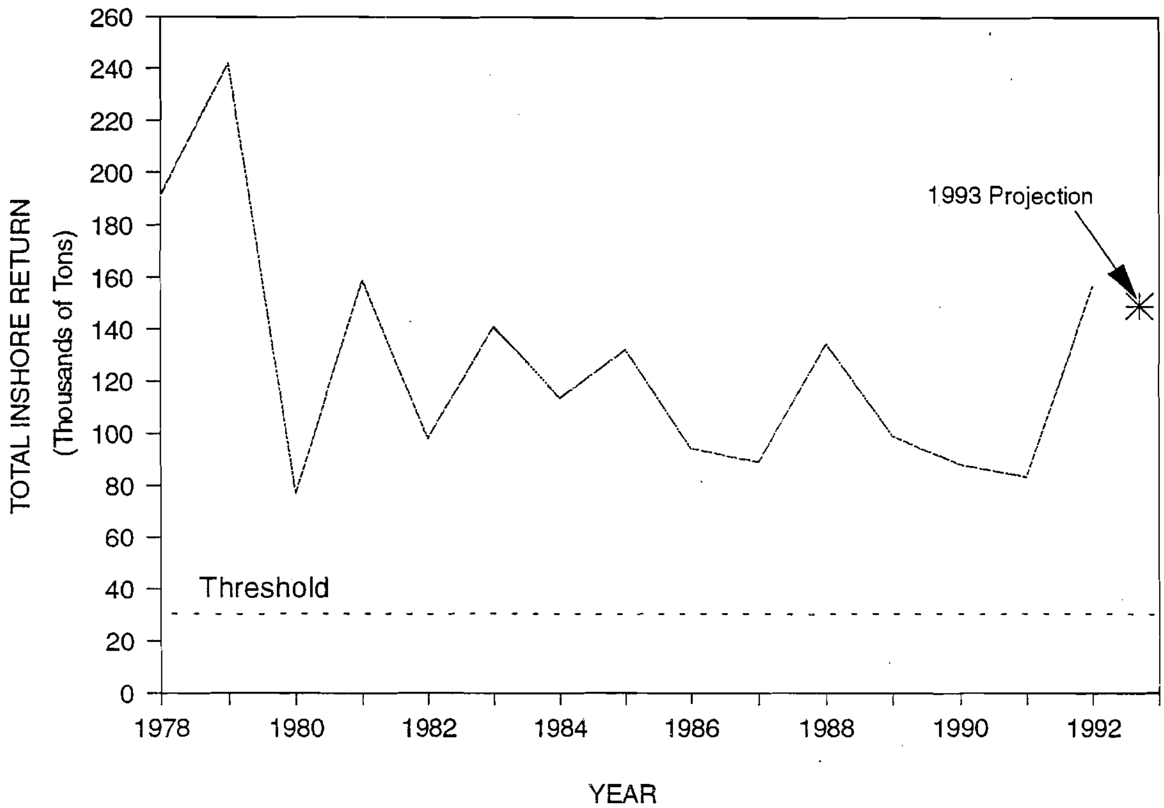



Figure 2. Historical sequence of the Togiak District herring run biomass as estimated from aerial surveys. The 1993 run biomass (asterisk) was forecasted using an age structured analysis of catch and abundance data. Documentation of the 35,000 ton threshold biomass is required before a commercial harvest is allowed.

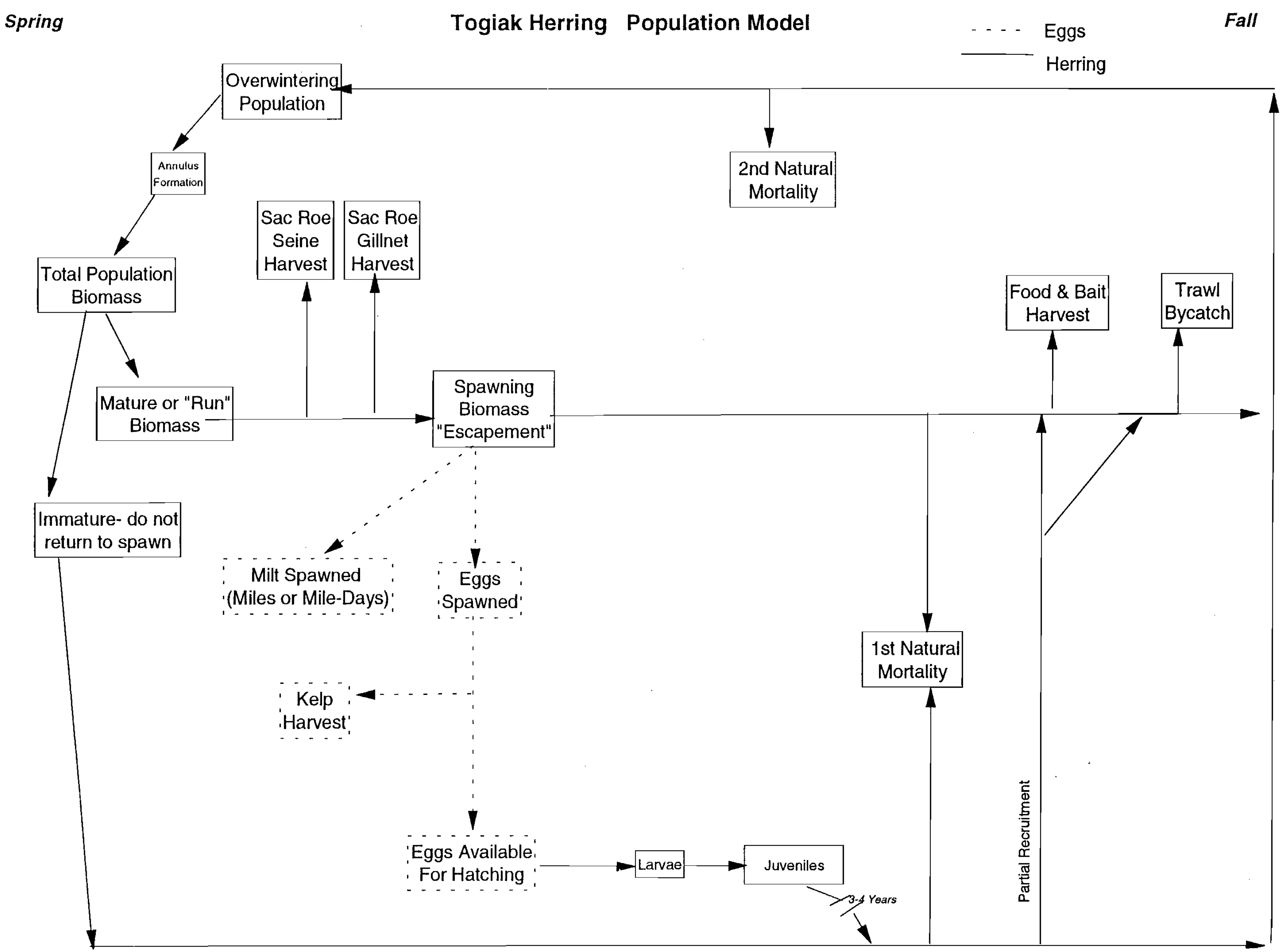
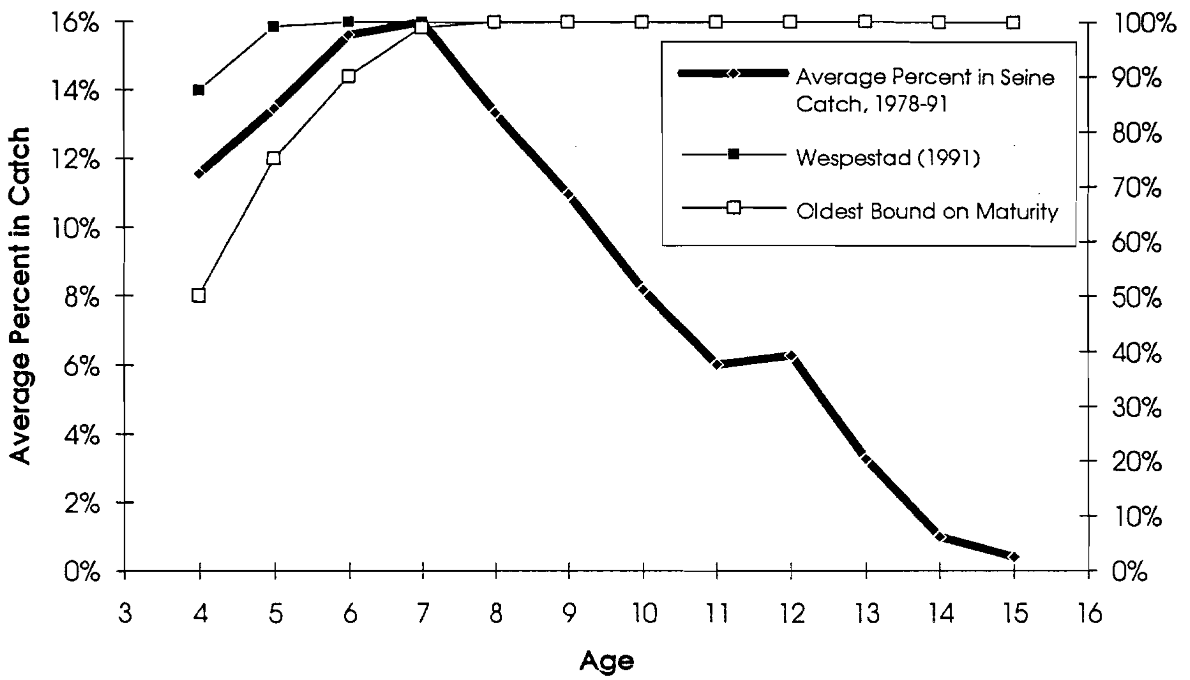



Figure 3. Conceptual model of the annual cycle of events affecting the Togiak herring population.

*TOGMODEL.XLC 11/29/93*



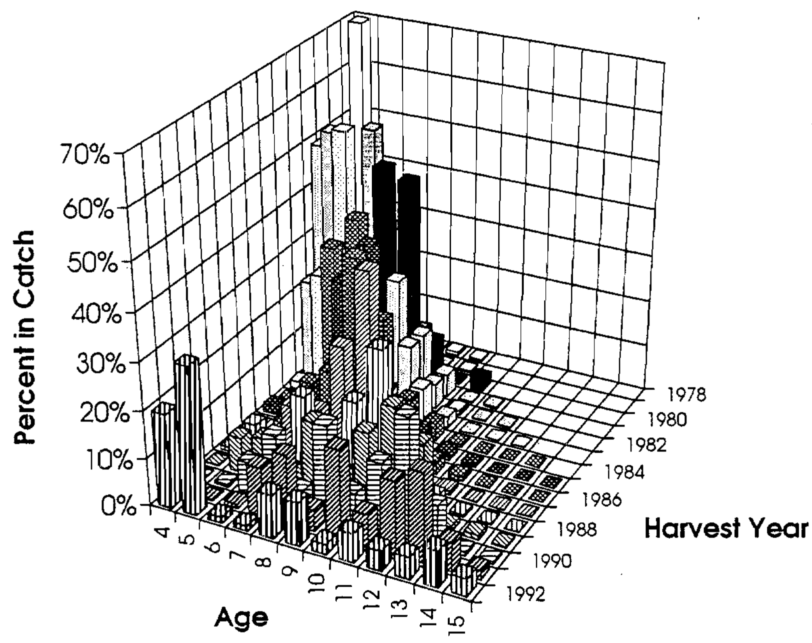




Figure 4. Average 1978-1991 age composition of the Togiak purse seine catch and maturity schedules for Togiak herring (top), and age composition of the purse seine catch for each year, 1978-1992 (bottom).

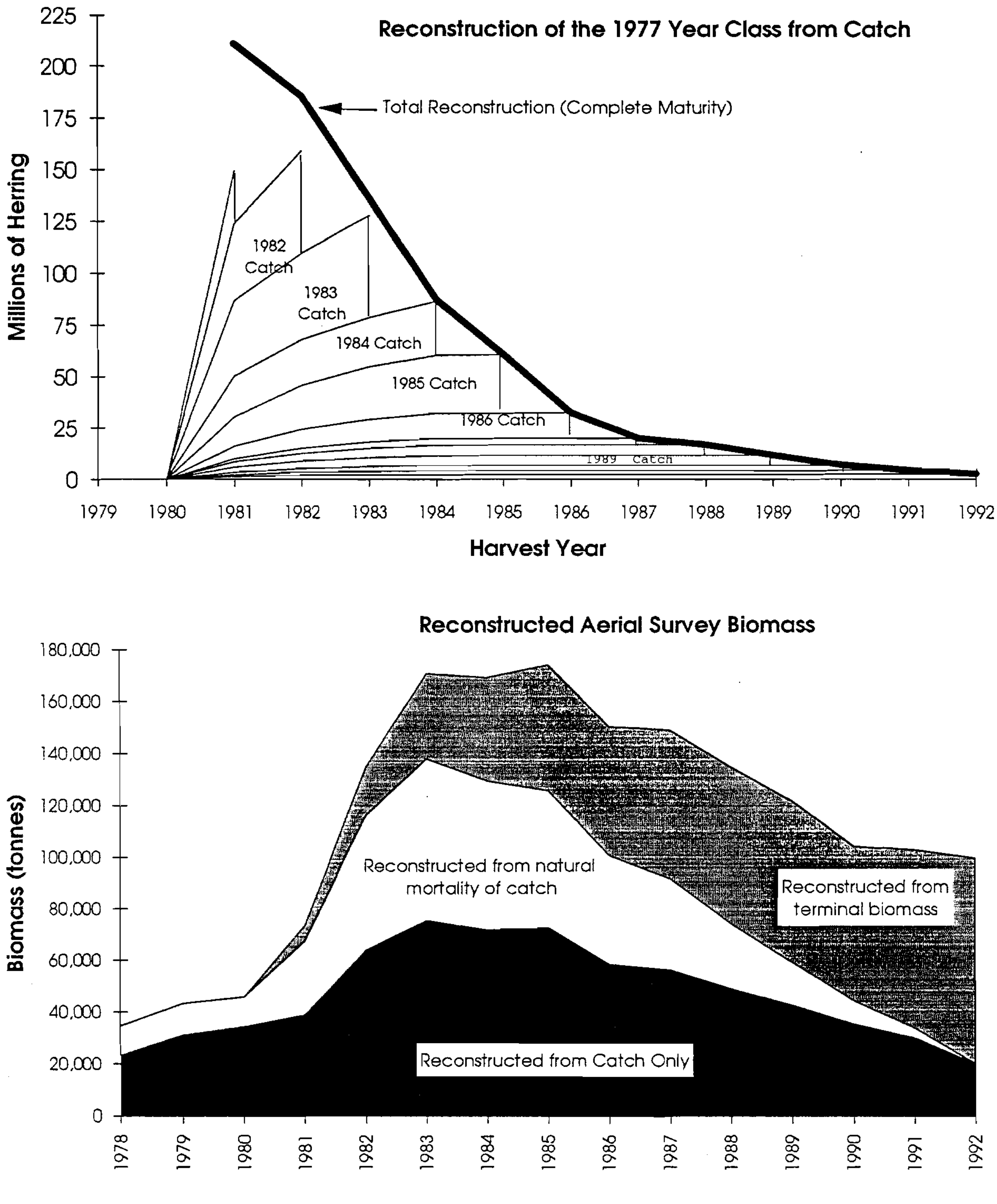



Figure 5. Reconstruction of the 1977 year class from 1981-1992 catches, showing total reconstructed cohort size (heavy solid line) and available cohort size reconstructed from catches in each year (top), and biomass available to aerial surveys from all year classes, reconstructed from catch, natural mortality , and terminal biomass assumptions (bottom)

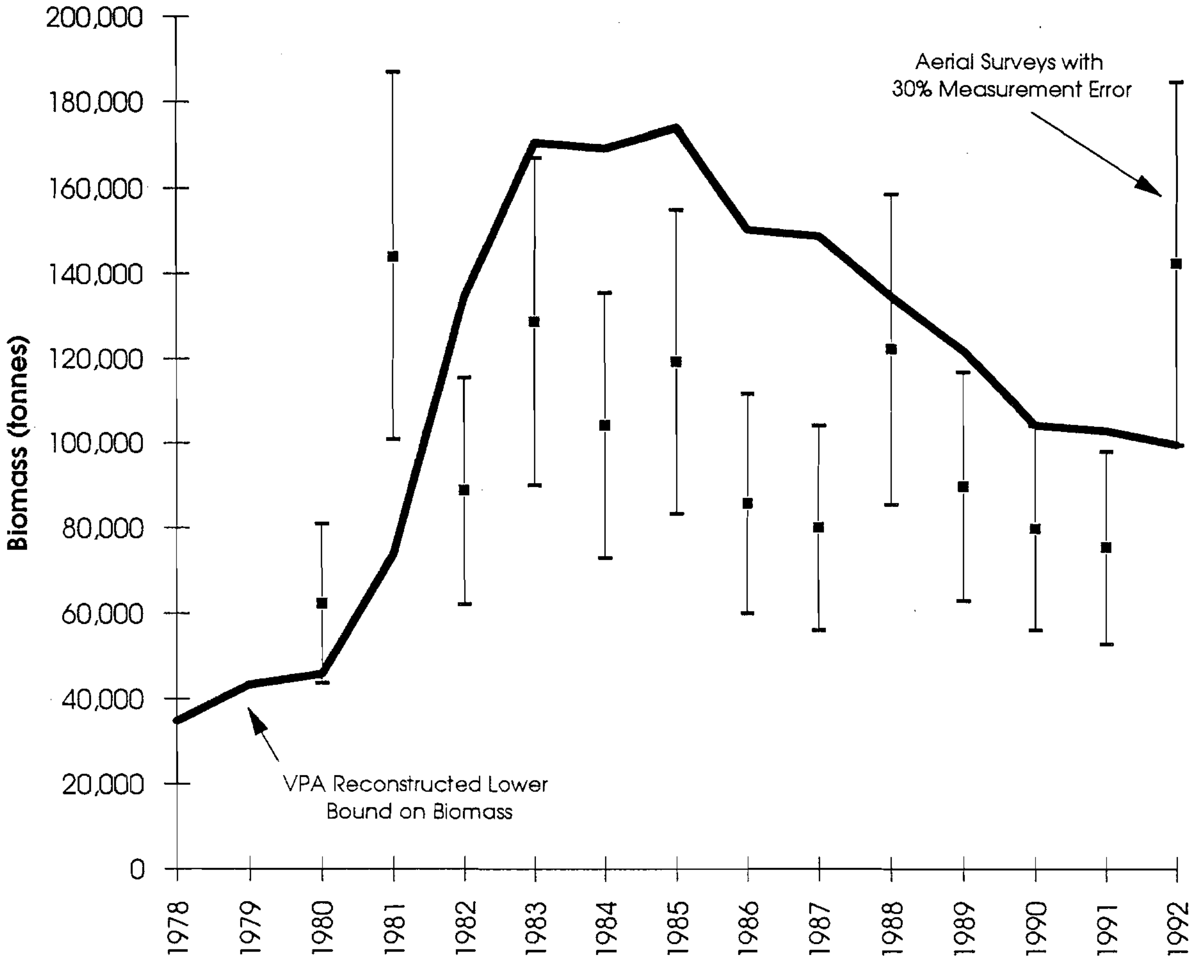



Figure 6. VPA reconstruction of the lower bound of aerial survey biomass estimates, 1978-1992. Aerial survey biomass estimates and ranges corresponding to 95% confidence limits that are within +/- 30% of the estimate are also shown.

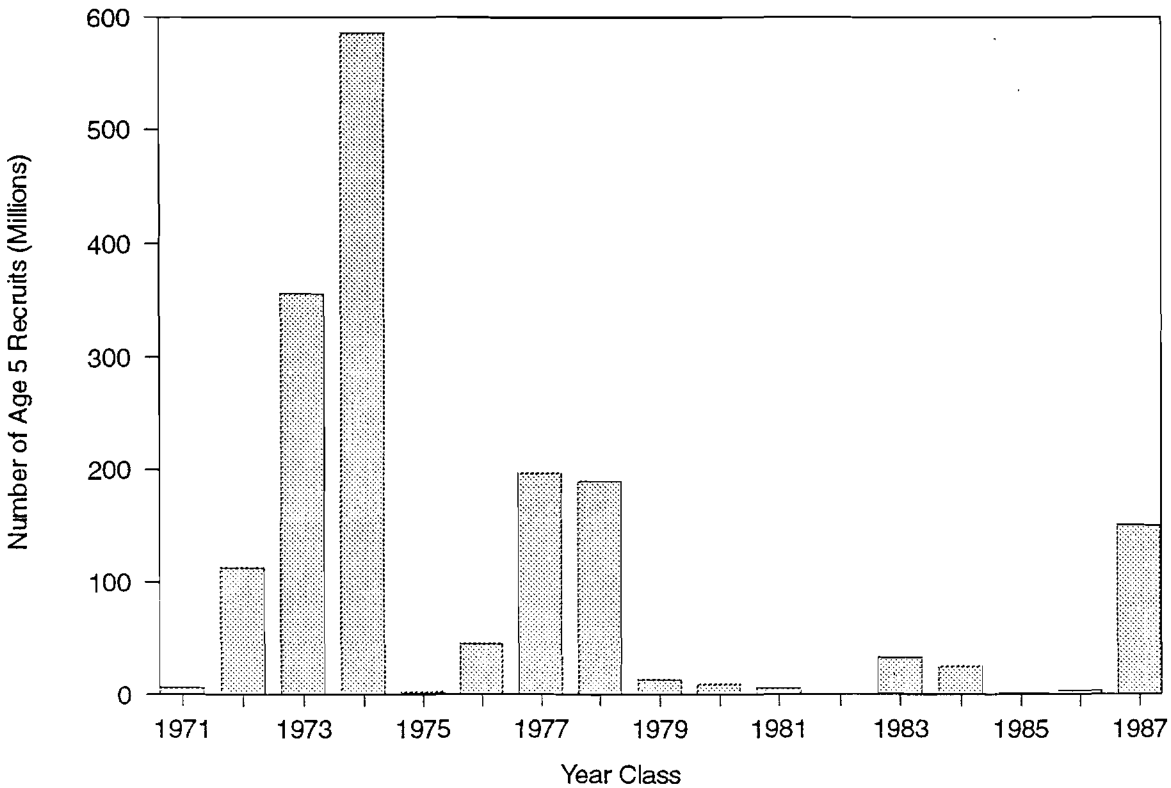



Figure 7. Year class strength of Togiak District herring cohorts in numbers of five year old recruits.

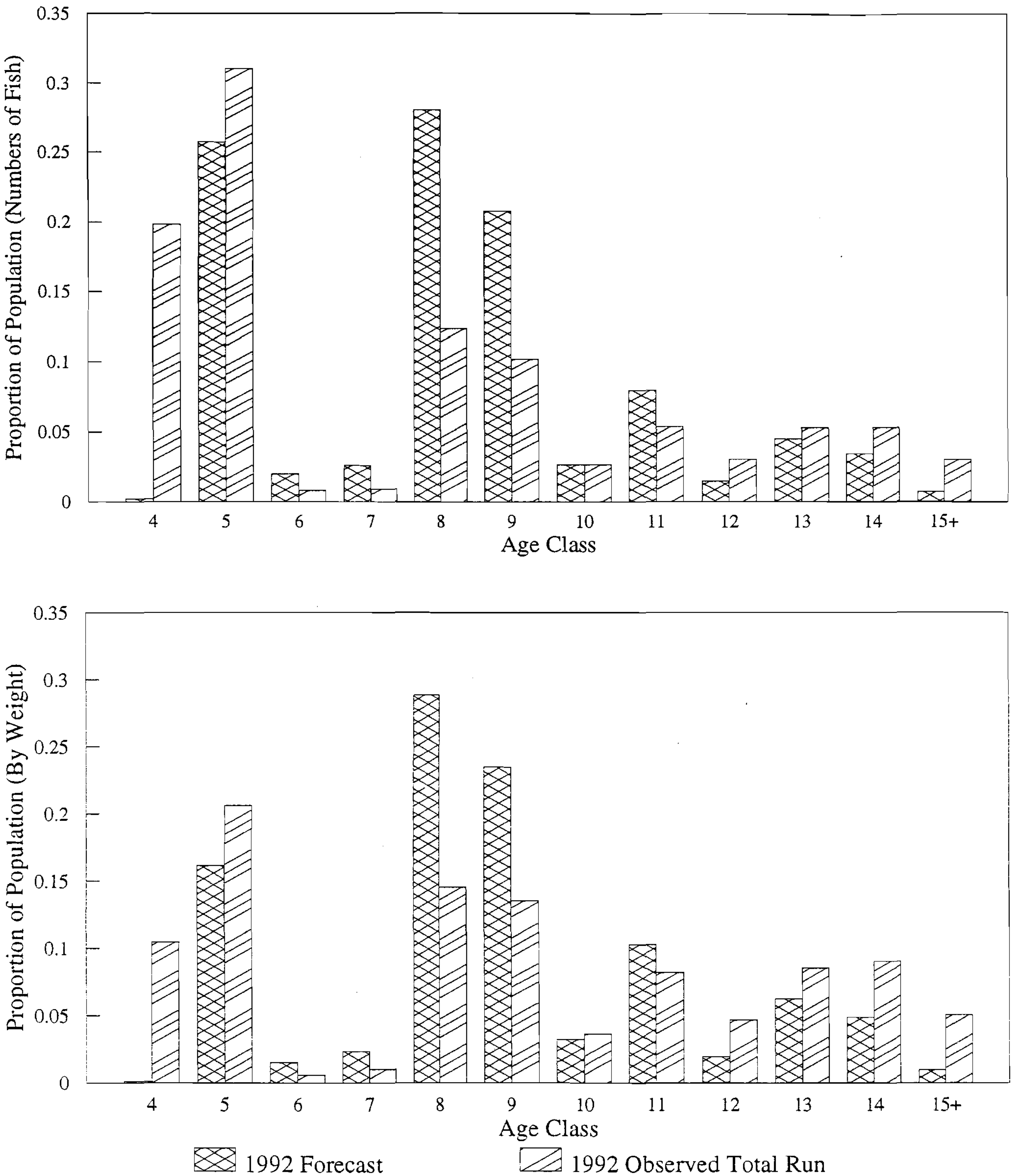



Figure 8. Age composition of the number of individuals (top) and biomass (bottom) of the Togiak District herring population in 1992 compared to that forecasted from 1991.

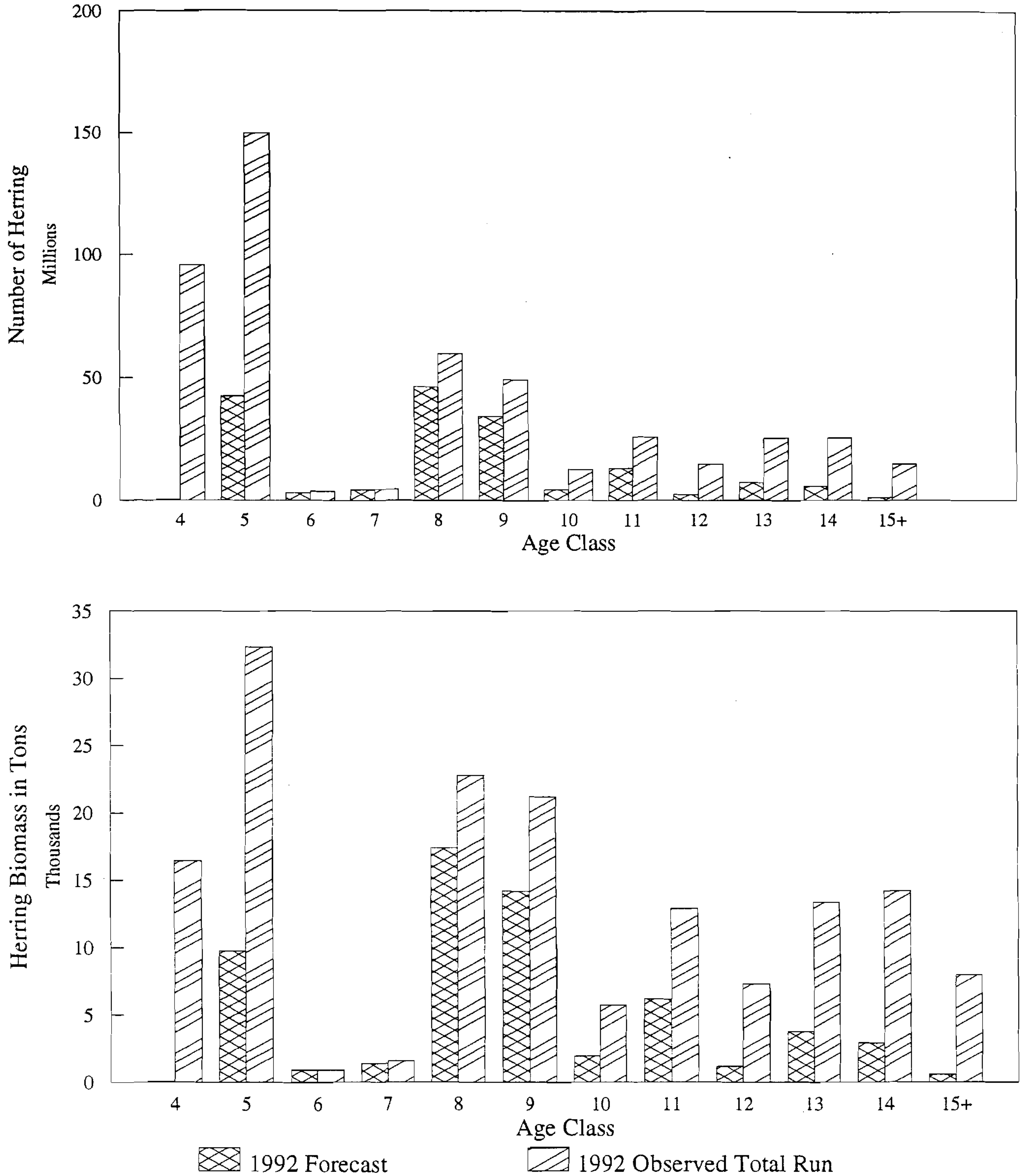



Figure 9. Age class strength in numbers (top) and biomass (bottom) of the Togiak District herring population in 1992 compared to that forecasted from 1991.

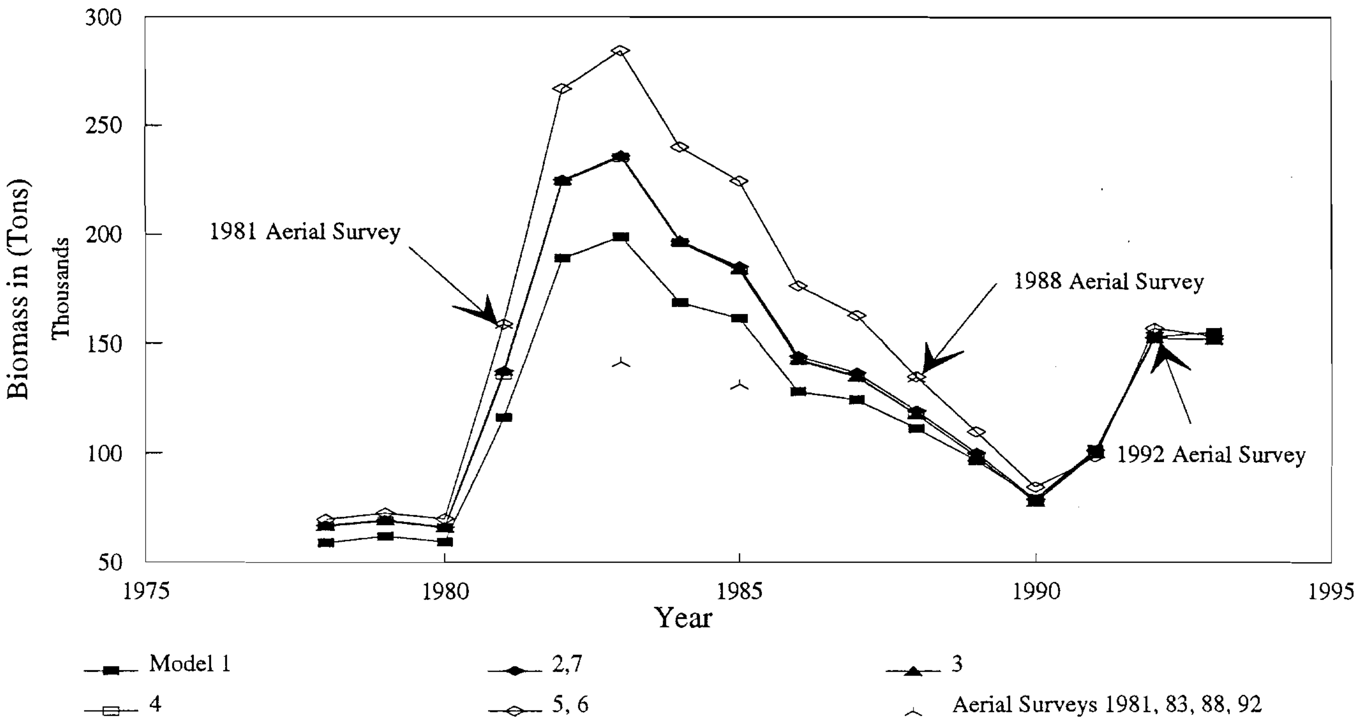



Figure 10. Estimates of run biomass from ASA models using different subsets of aerial survey run biomass estimates.

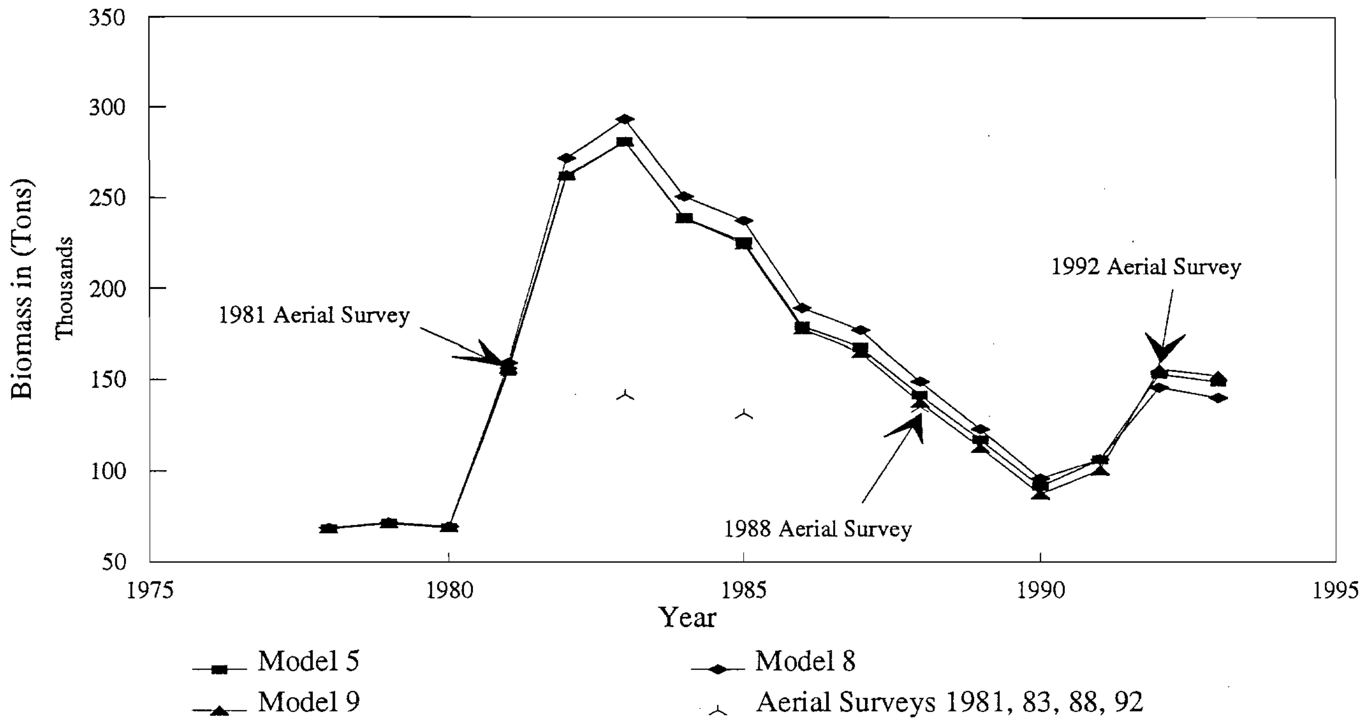



Figure 11. Estimates of run biomass from ASA models using different weights for aerial survey run biomass and age composition data.

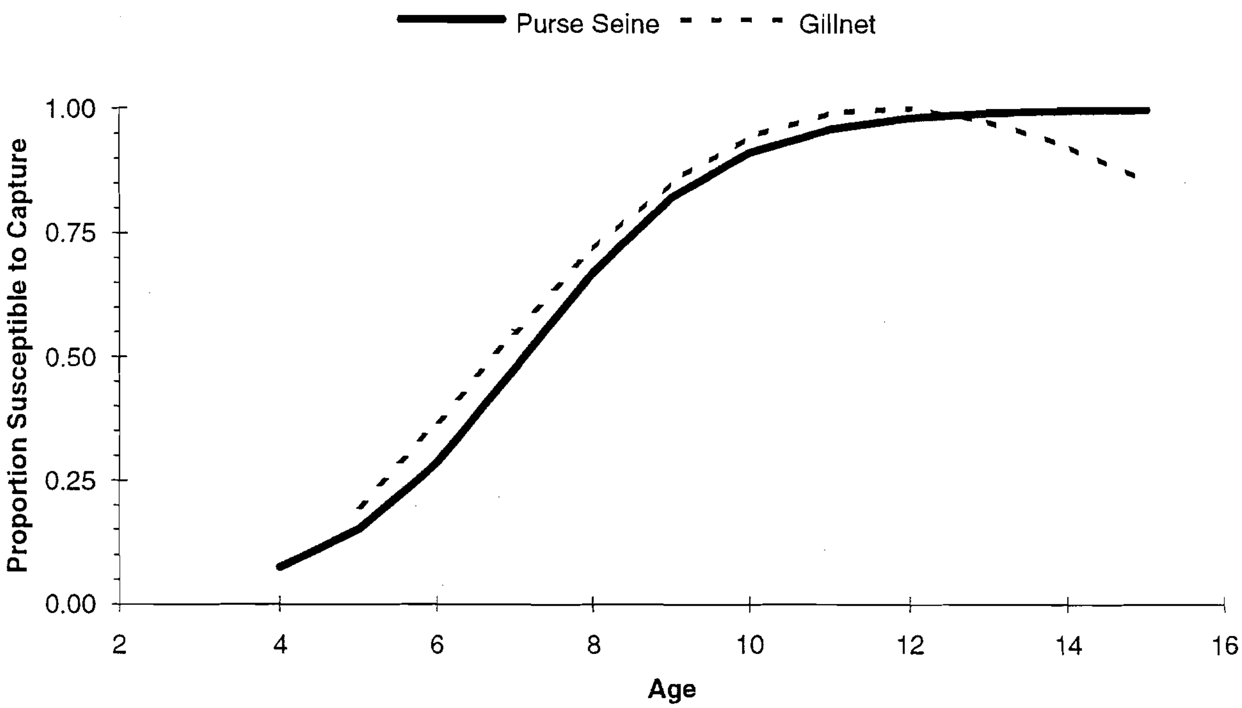



Figure 12. Gear selectivity curve estimated by the 1993 Togiak herring ASA model.

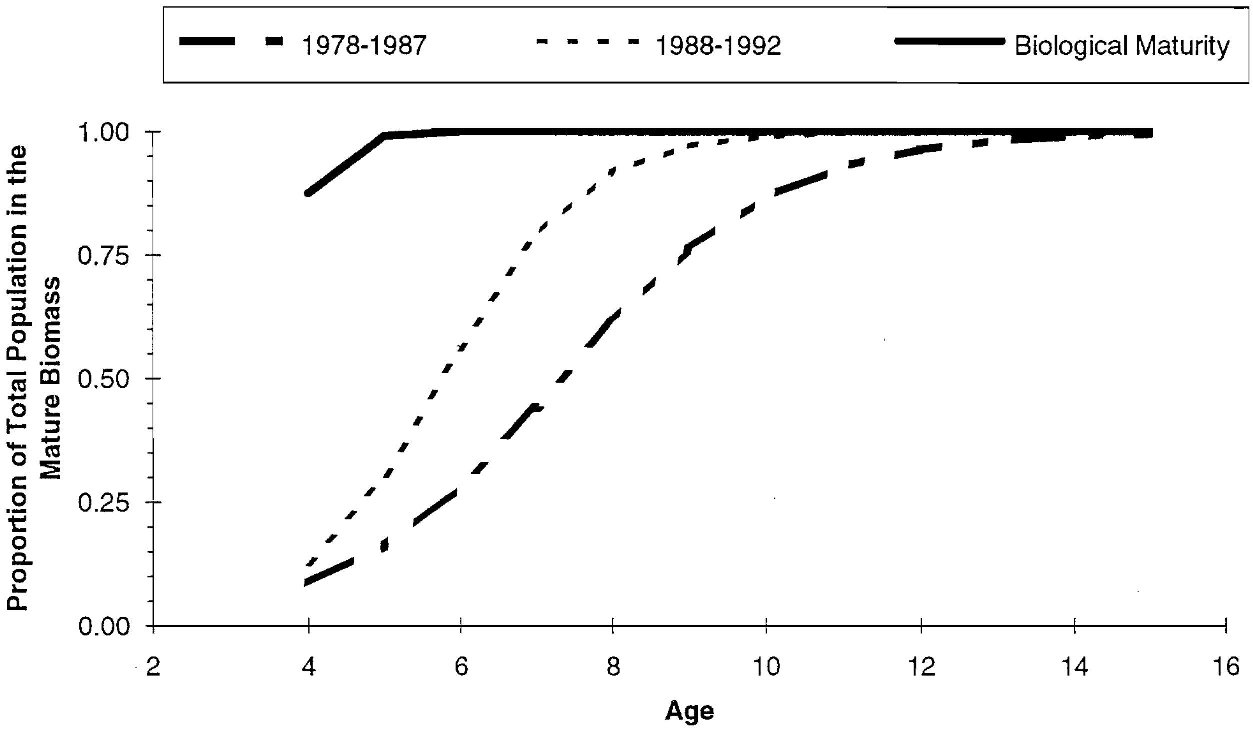
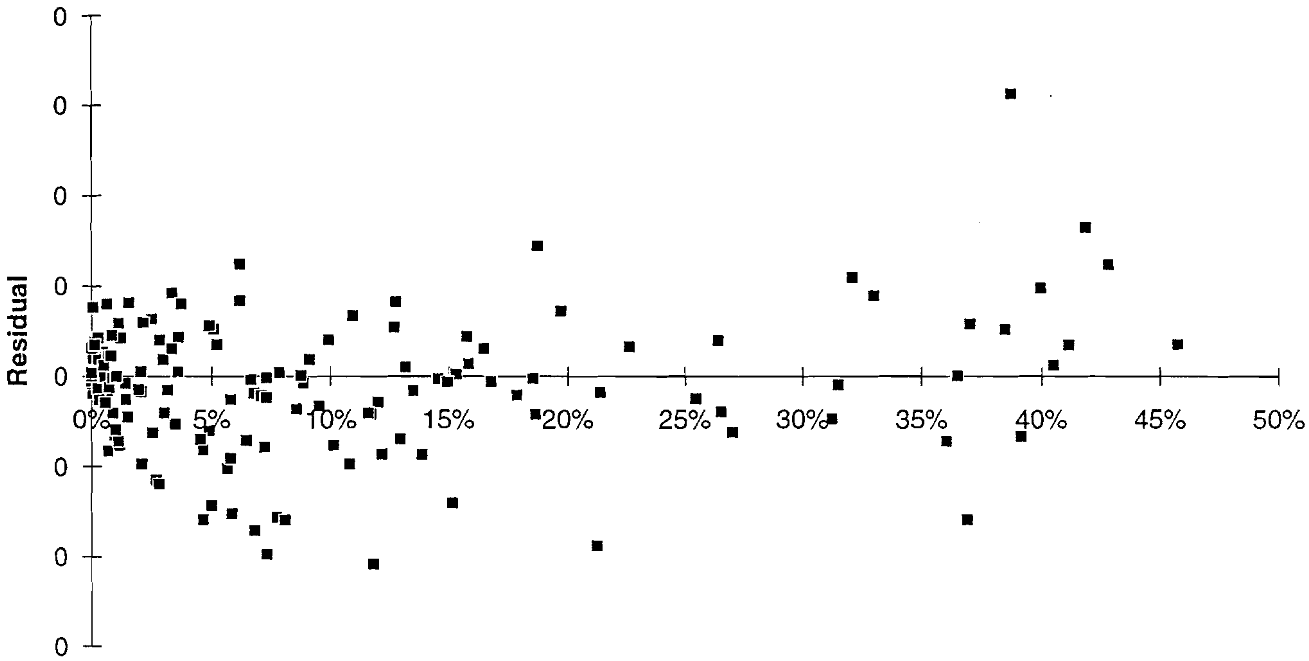



Figure 13. Maturity schedules supplied (biological maturity, solid line) or estimated by the 1993 Togiak herring ASA model (1978-1987 and 1988-1992, dashed lines).

## Residual vs Estimated Proportion - Transformed




## Residual Distribution for: Seine Agecomp

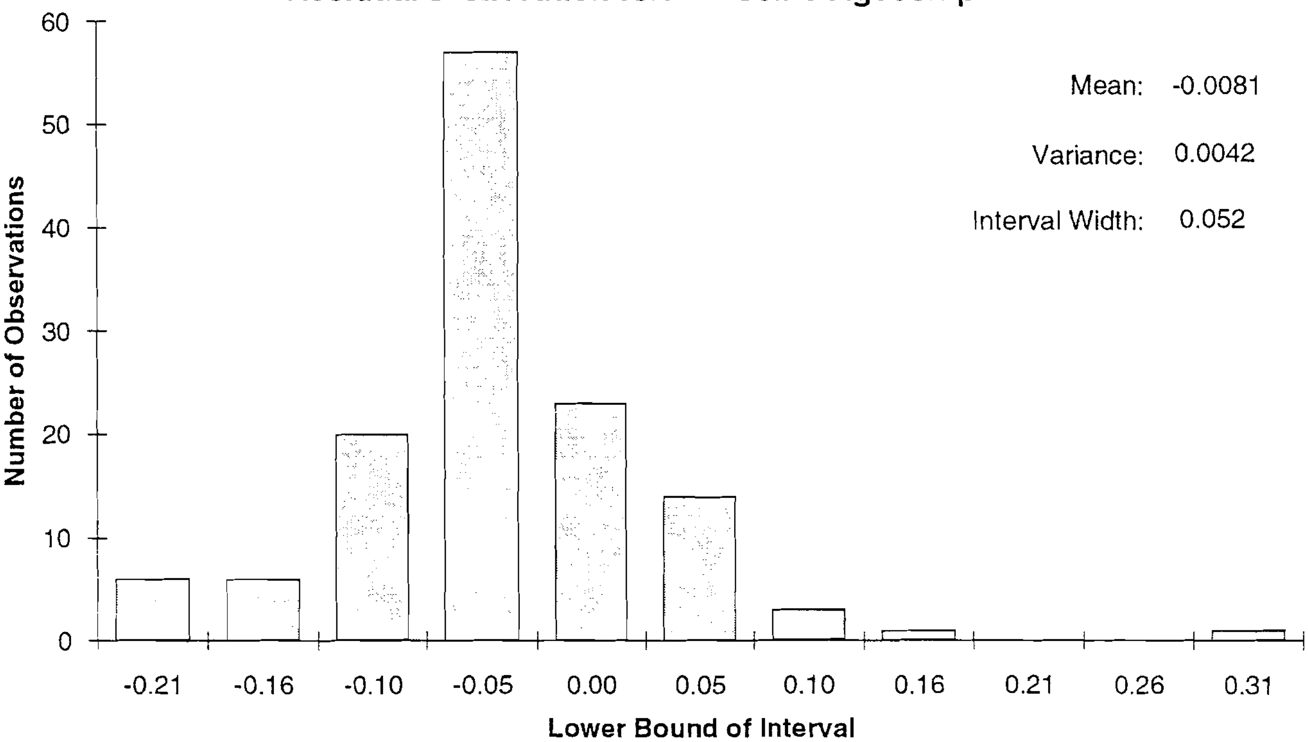
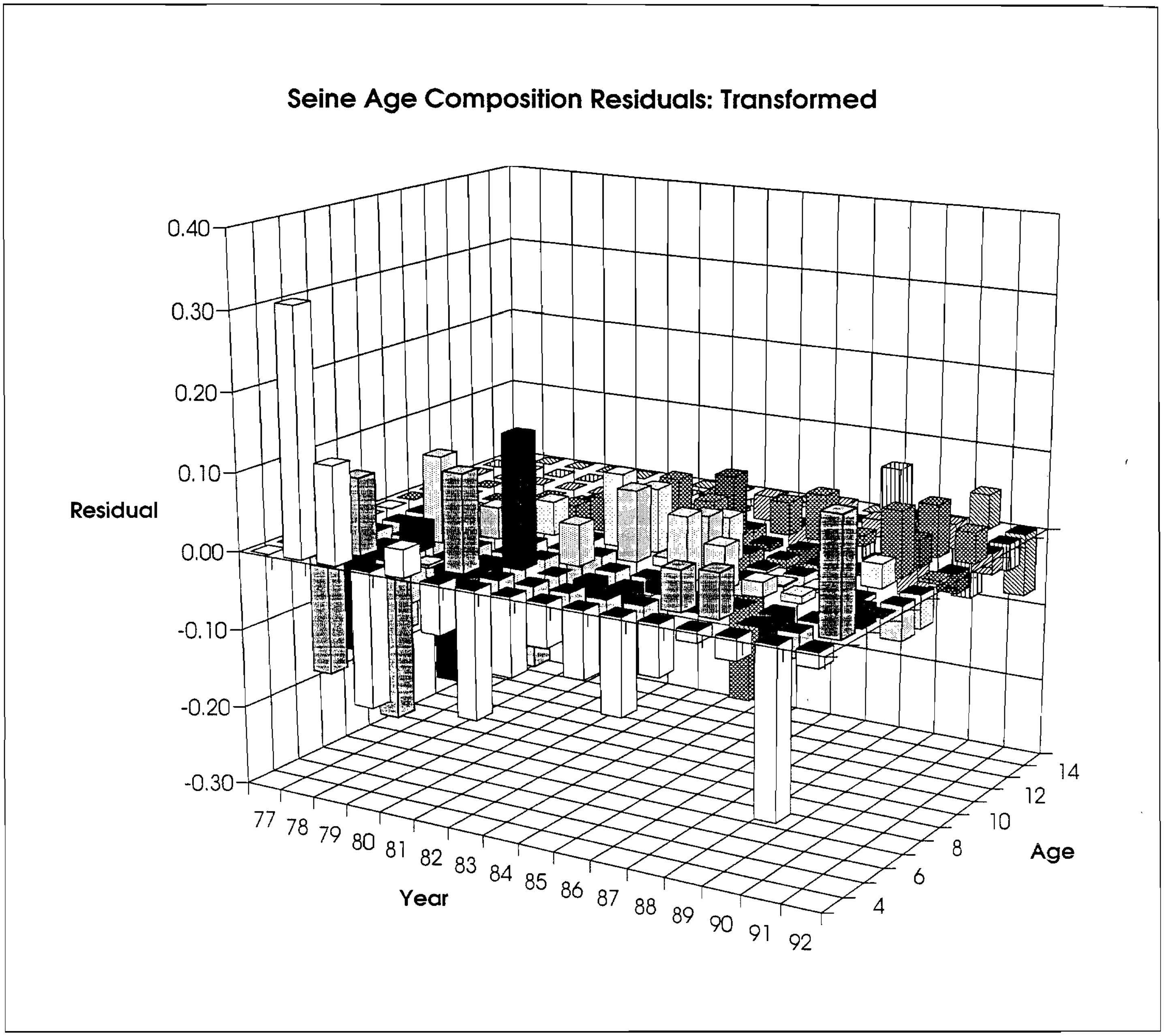
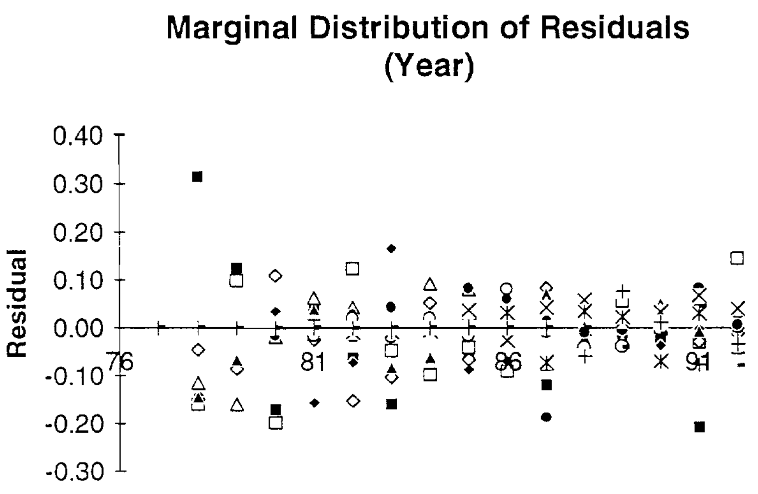



Figure 14. Distribution of purse seine age composition residuals for the Togiak herring ASA model.



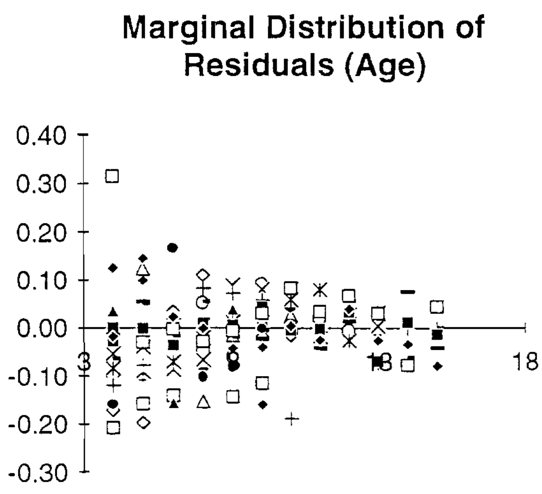




Figure 15. Purse seine age composition residuals for the Togiak herring ASA model plotted by age and year.

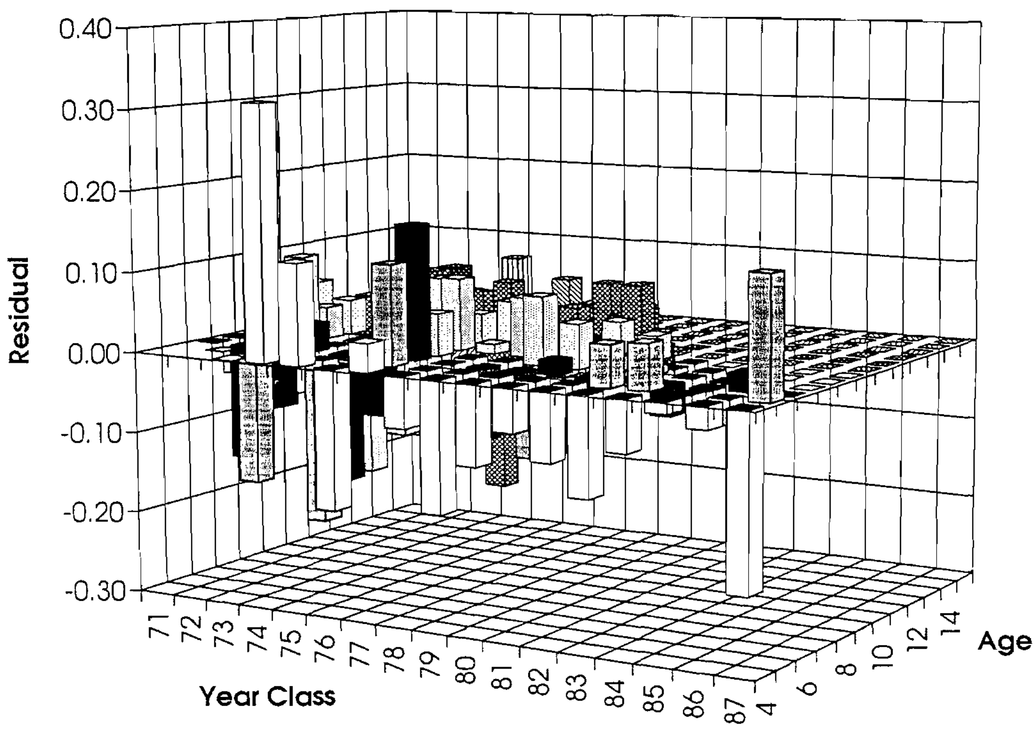
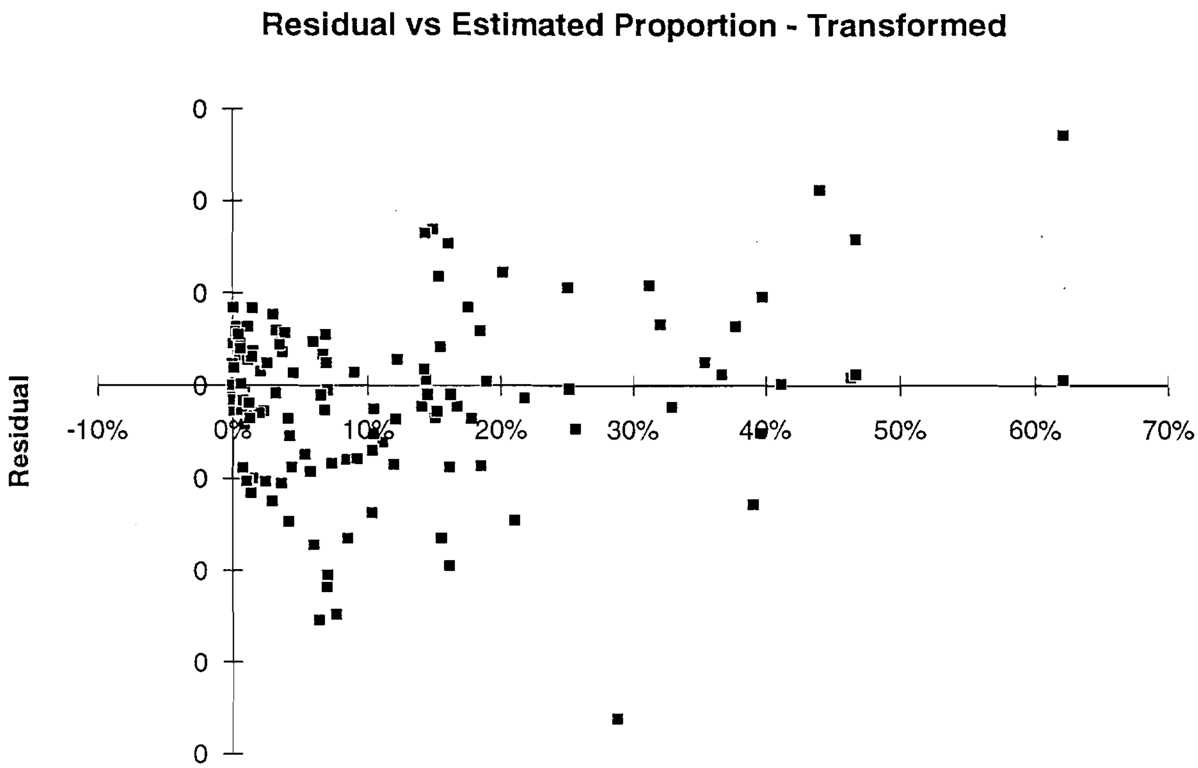



Figure 16. Purse seine age composition residuals for the Togiak herring ASA model plotted by year class.



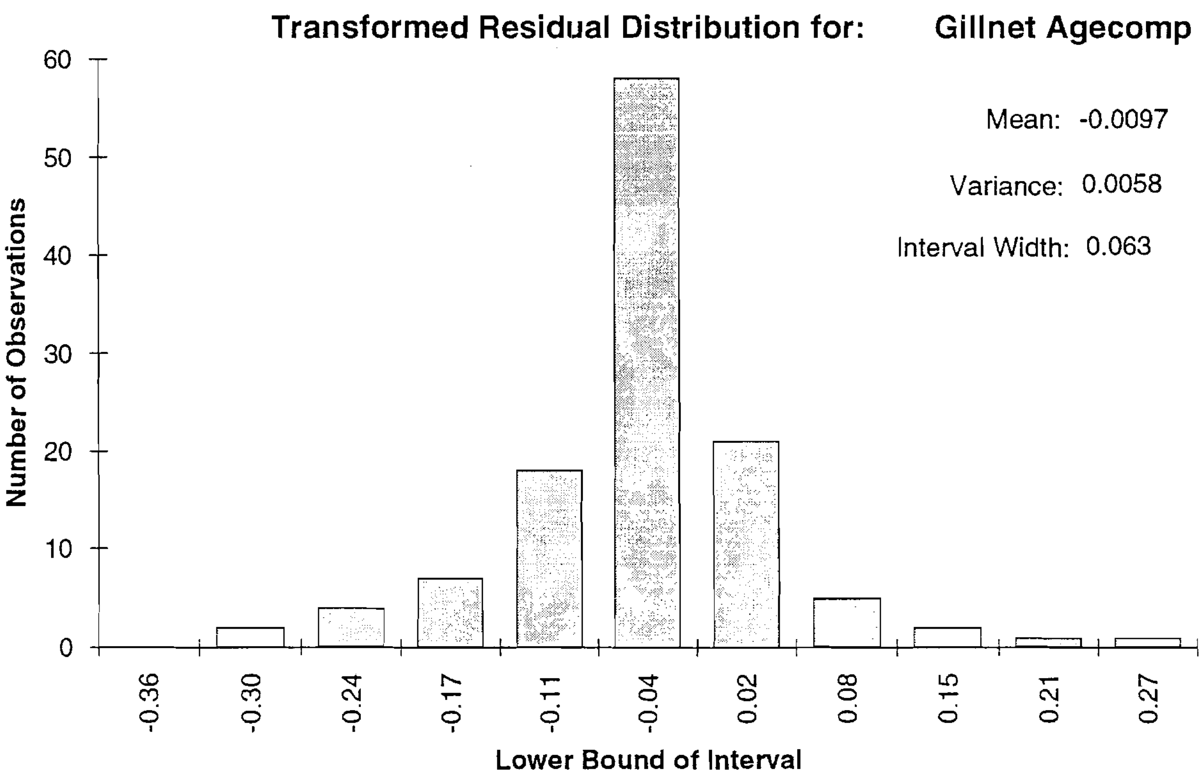
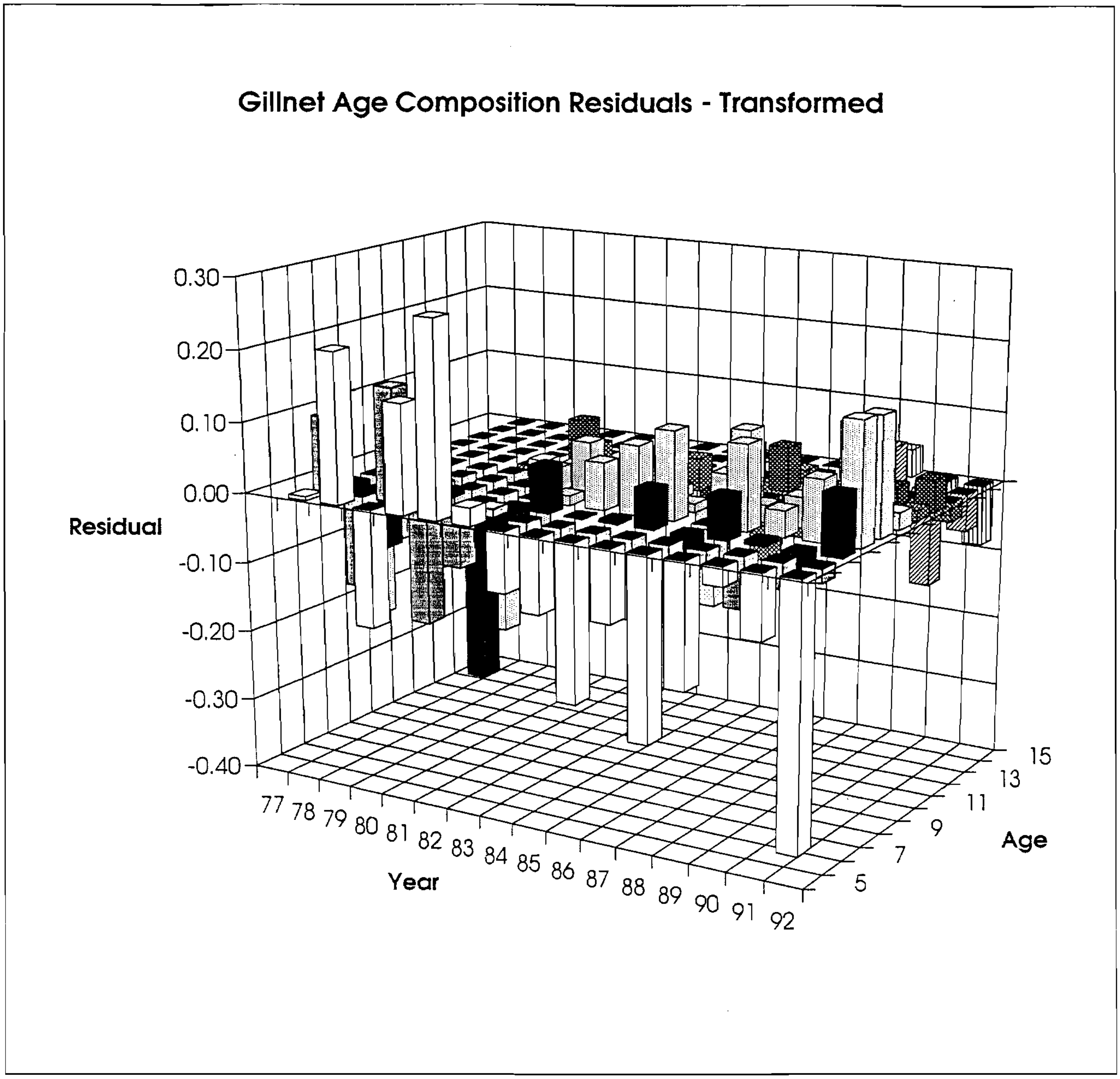
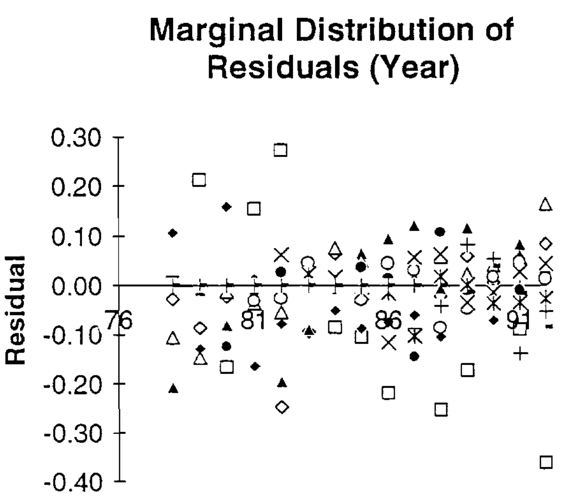




Figure 17. Distribution of gillnet age composition residuals for the Togiak herring ASA model.



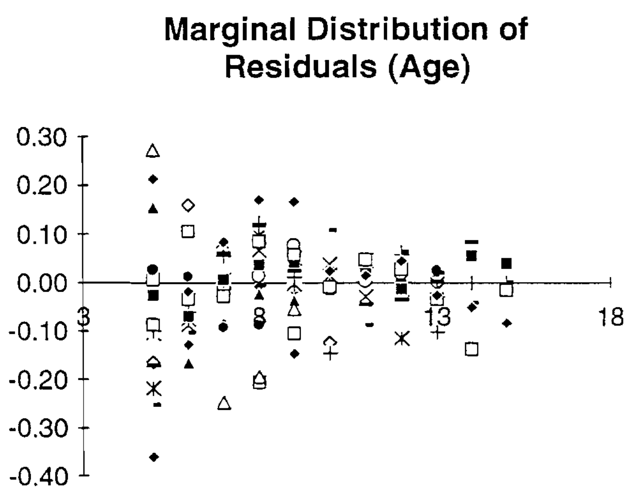




Figure 18 . Gillnet age composition residuals for the Togiak herring ASA model plotted by age and year.

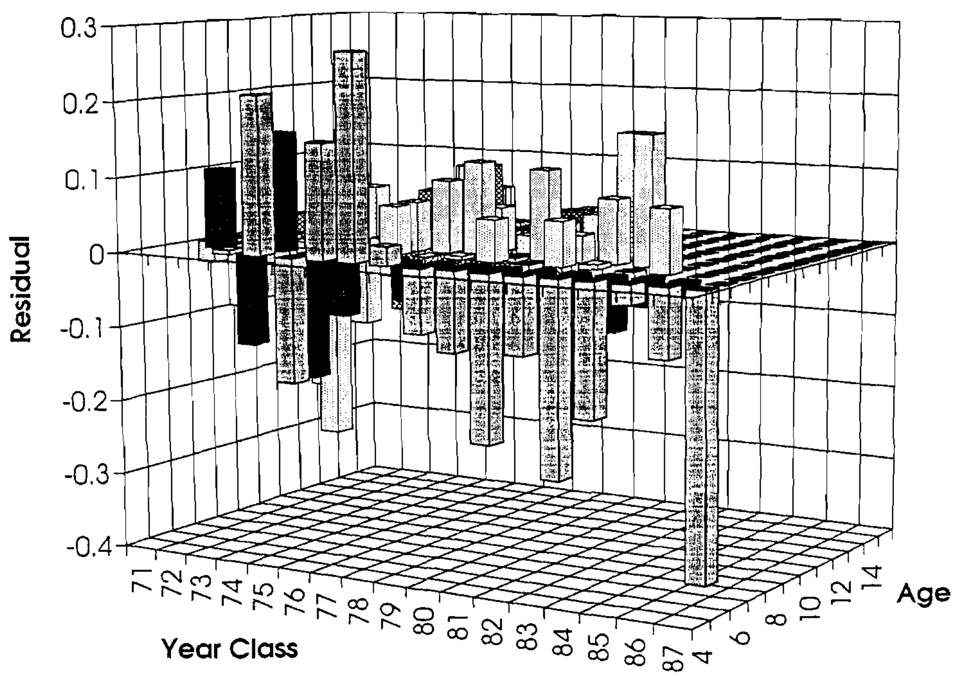
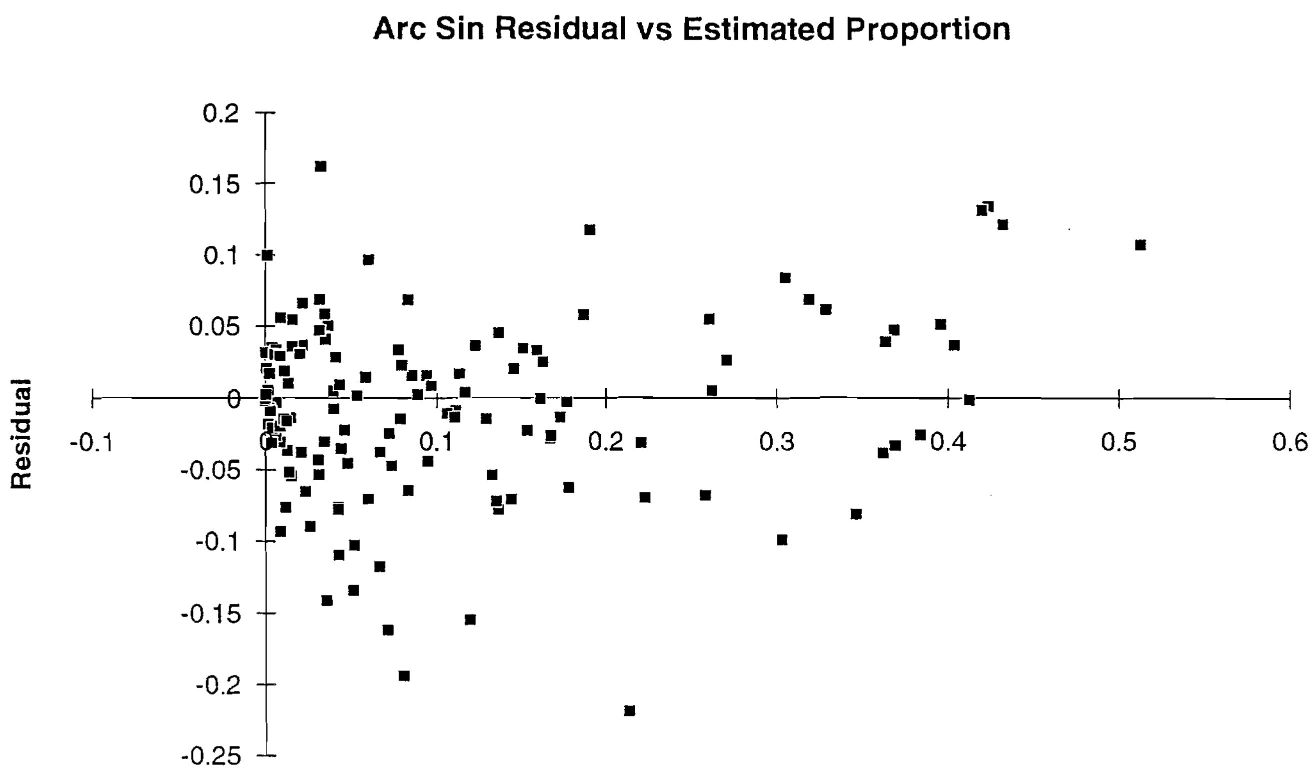



Figure 19. Gillnet age composition residuals for the Togiak herring ASA model plotted by year class.



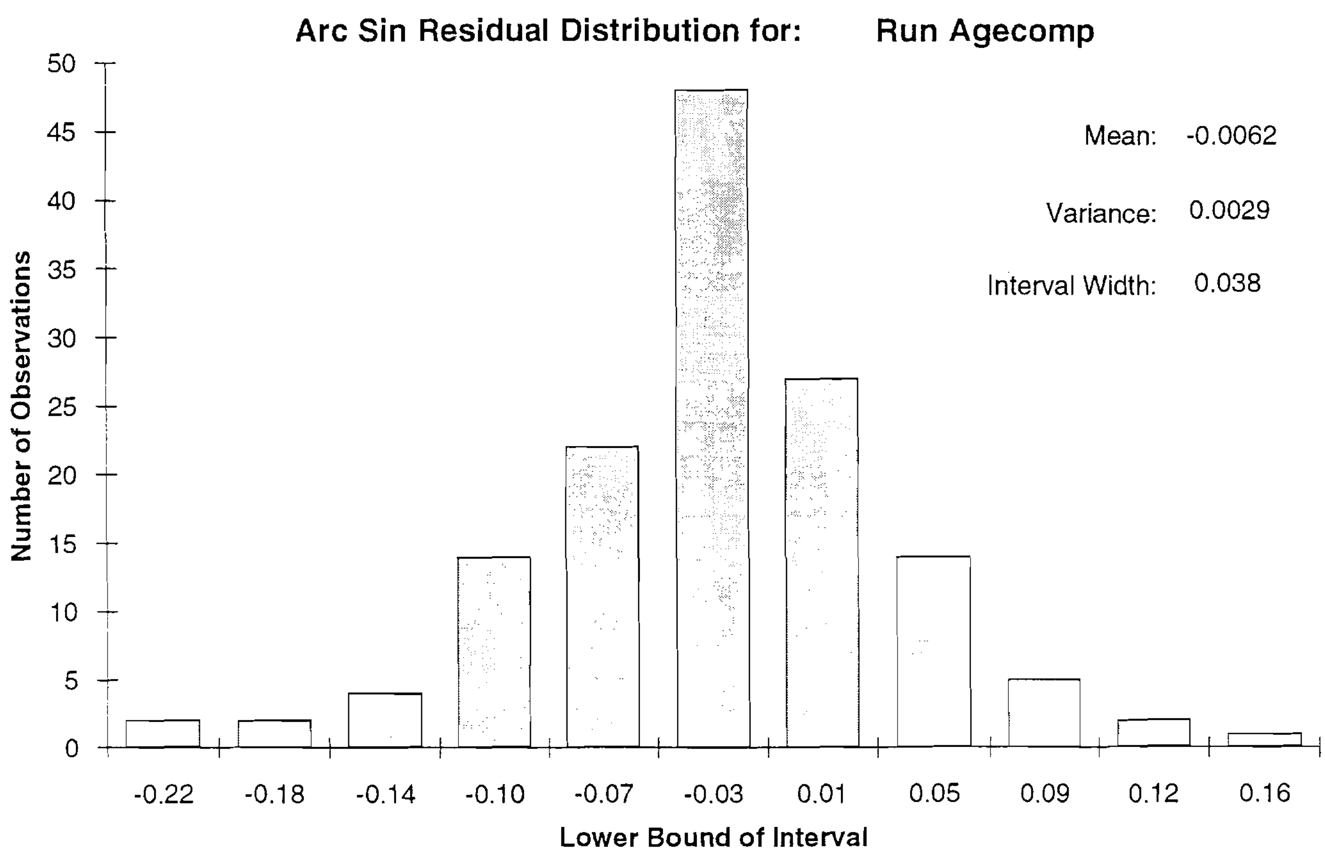
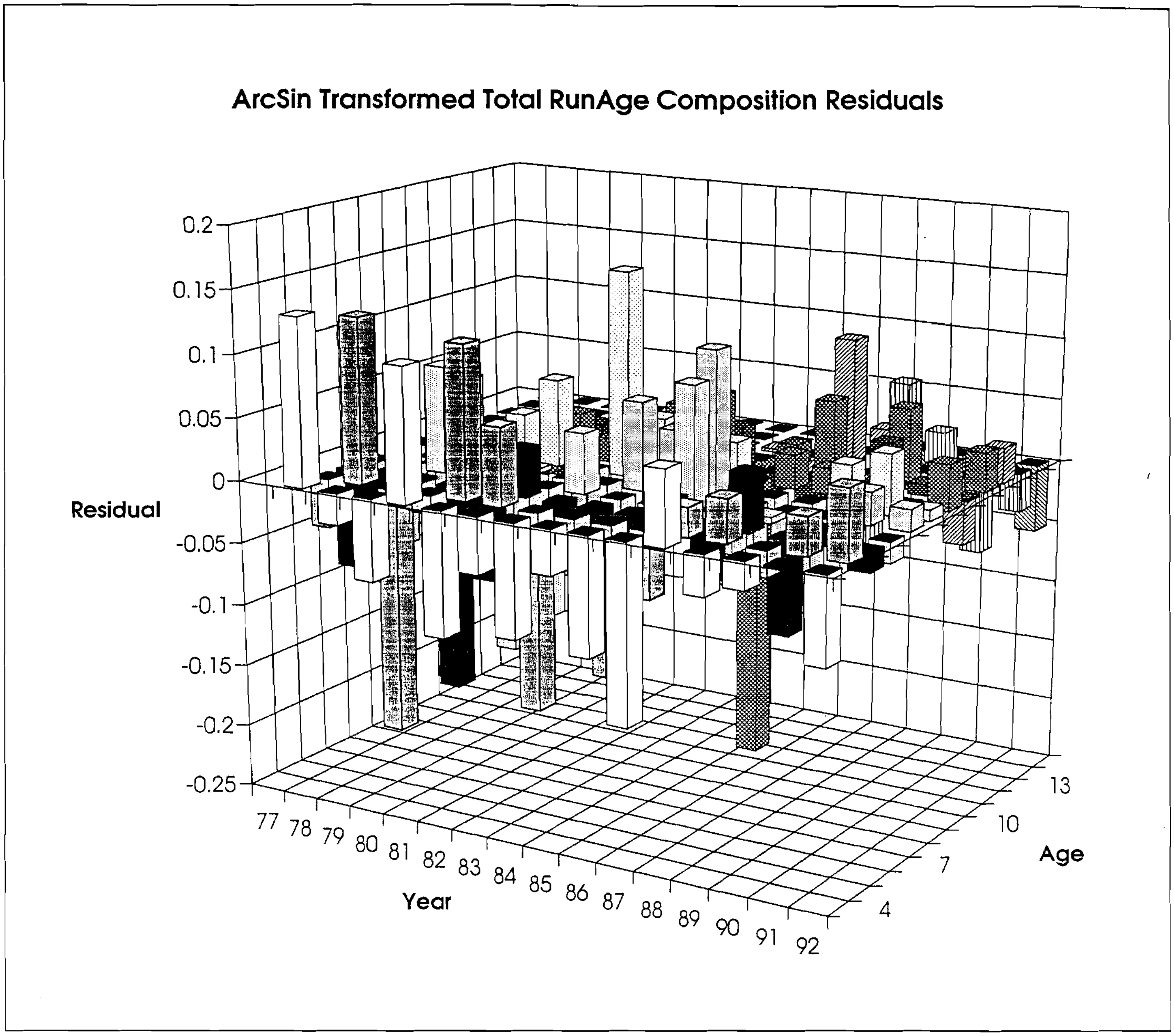
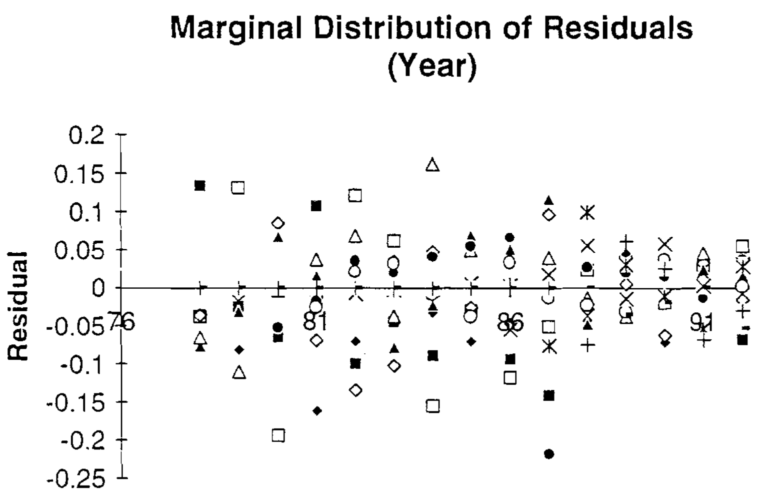




Figure 20. Distribution of run biomass age composition residuals for the Togiak herring ASA model.



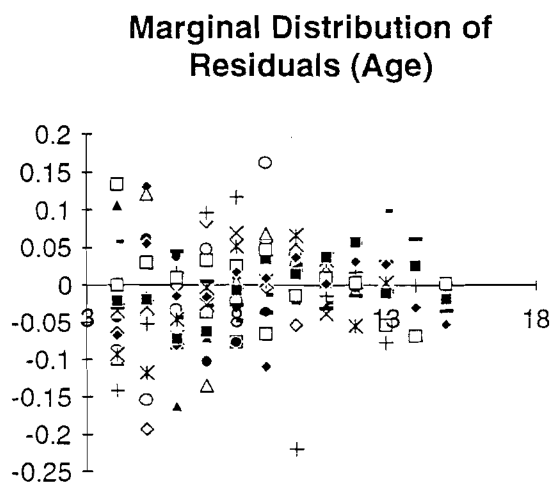




Figure 21. Run biomass age composition residuals for the Togiak herring ASA model plotted by age and year.

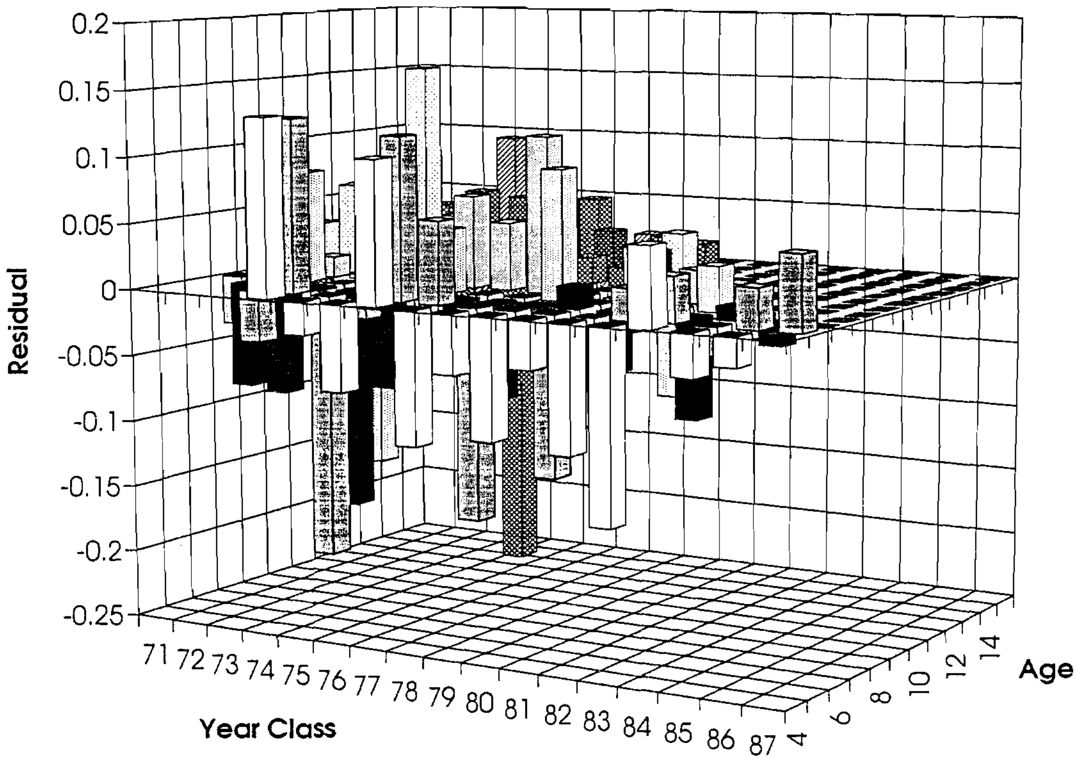



Figure 22. Run biomass age composition residuals for the Togiak herring ASA model plotted by year class.

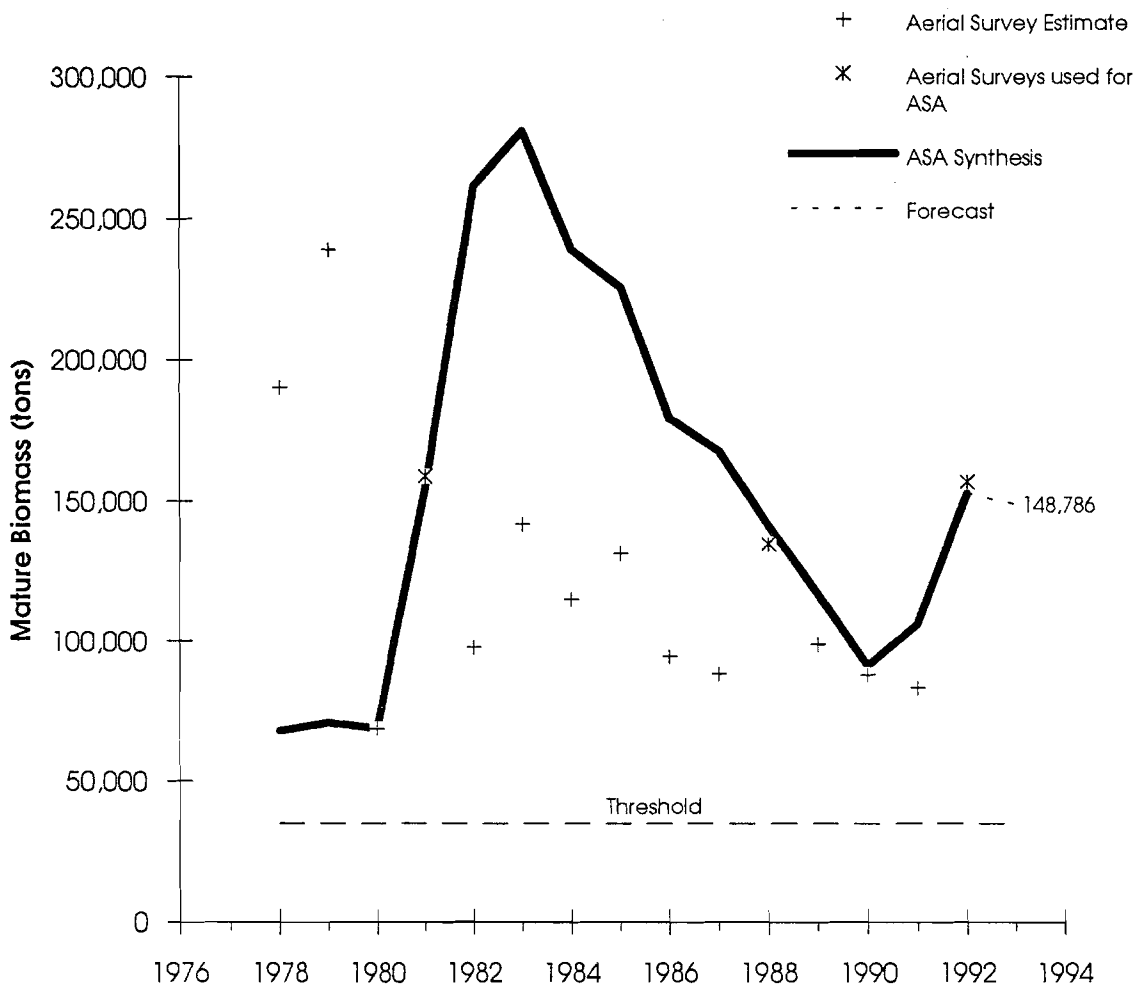



Figure 23. Estimates of abundance for Togiak District herring from aerial surveys and from the age-structured assessment (ASA) model, showing the threshold level below which fishing is not allowed.

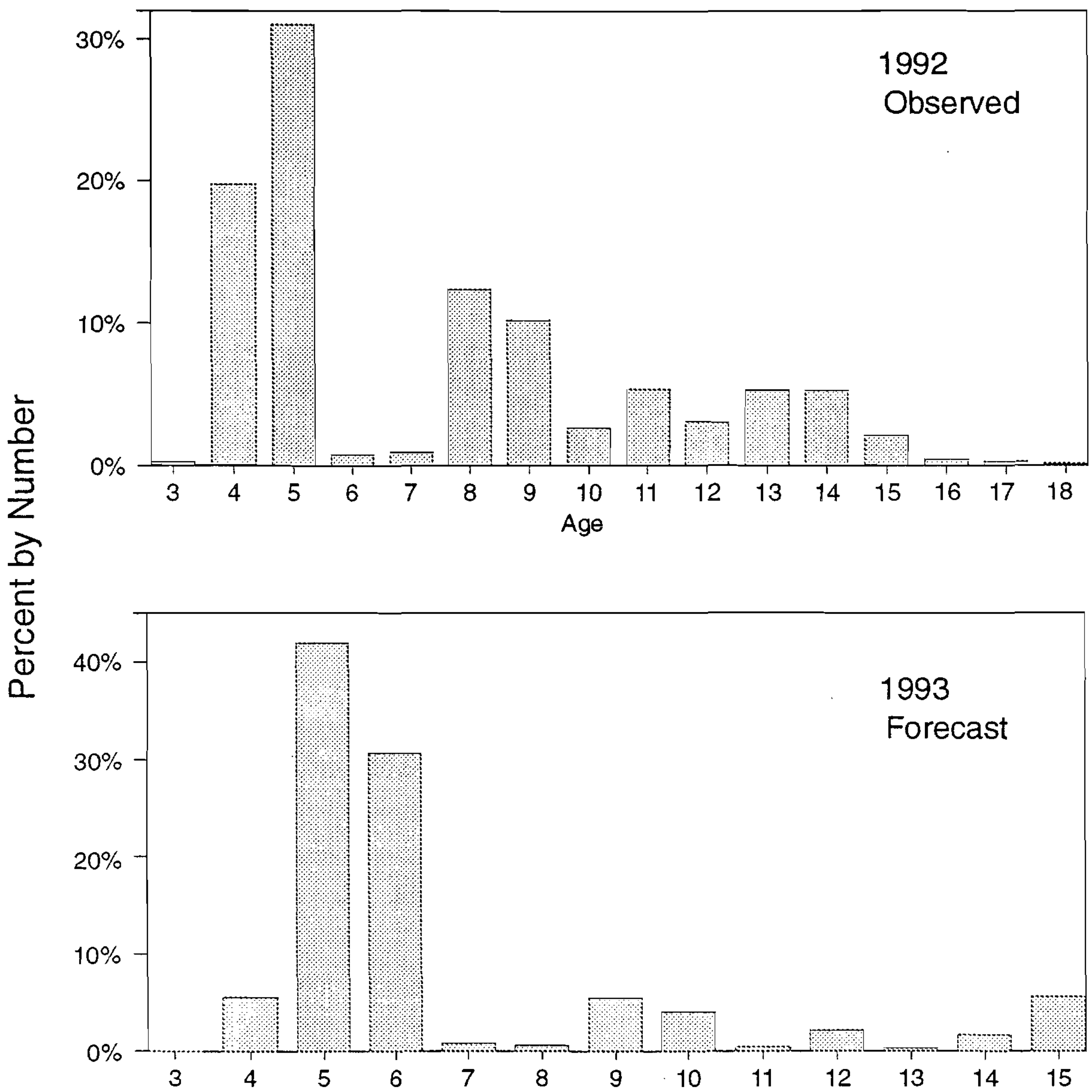



Figure 24. Age distribution of the Togiak District herring population, by number, observed (top) in 1992 and forecasted (bottom) for 1993.

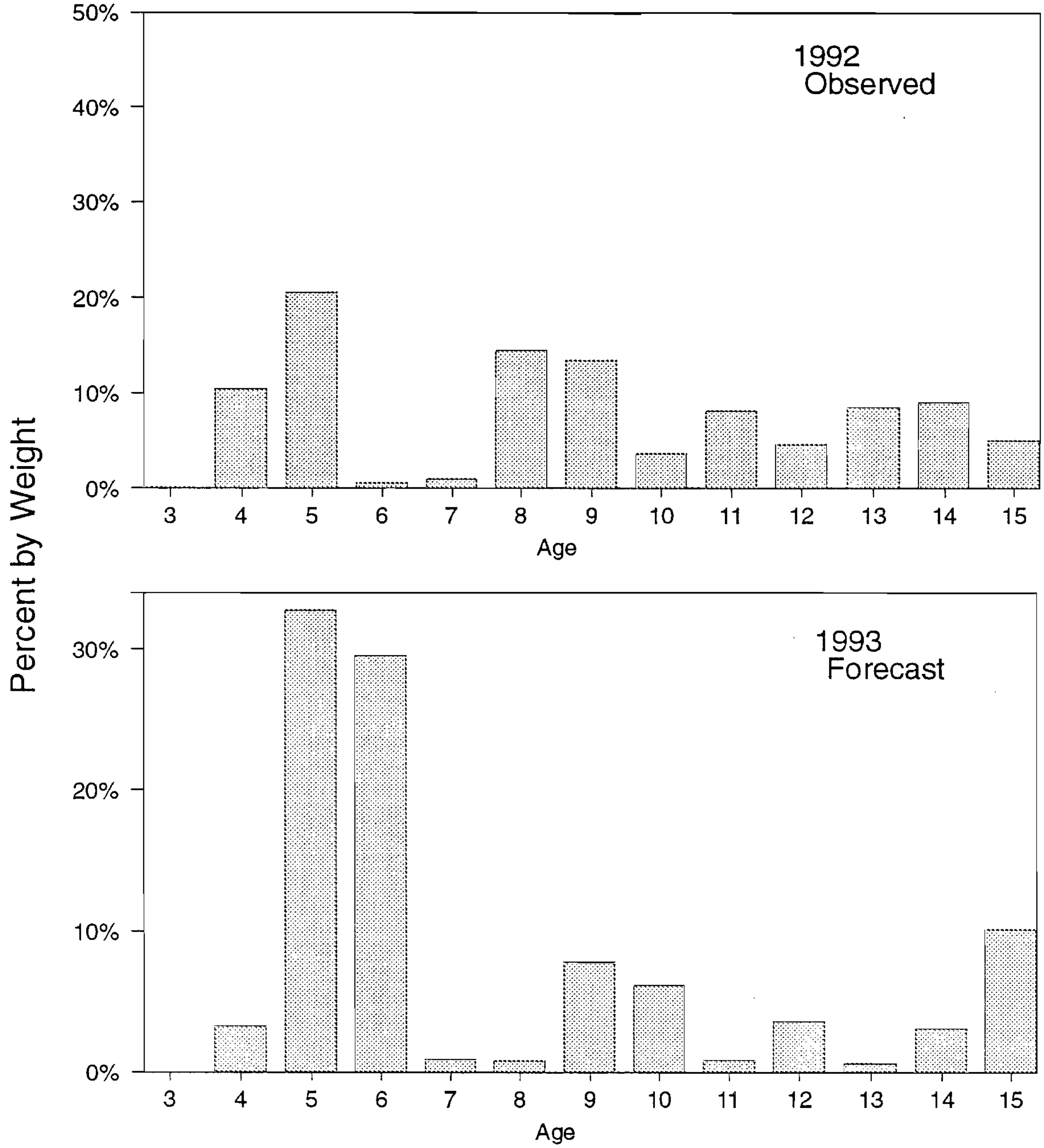



Figure 25. Age distribution of the Togiak District herring biomass, by weight, observed in 1992 (top) and forecasted for 1993 (bottom).

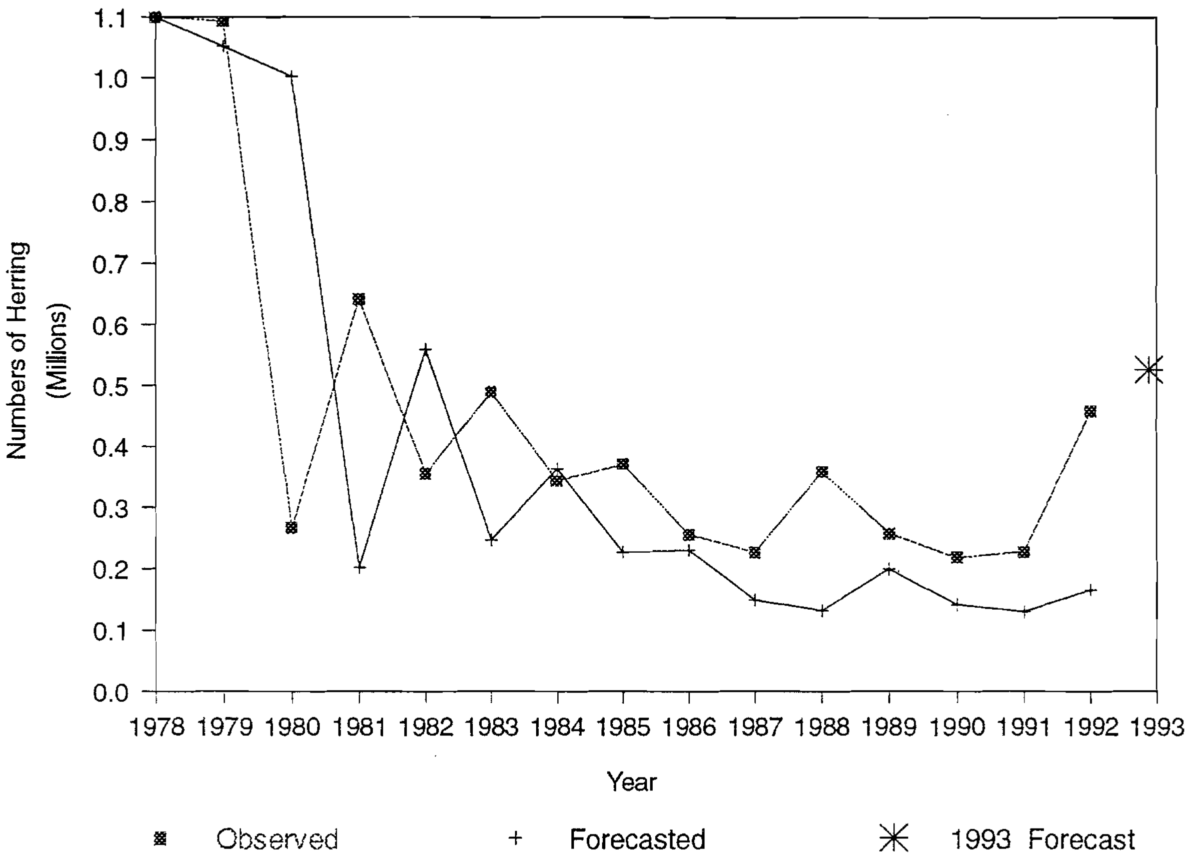
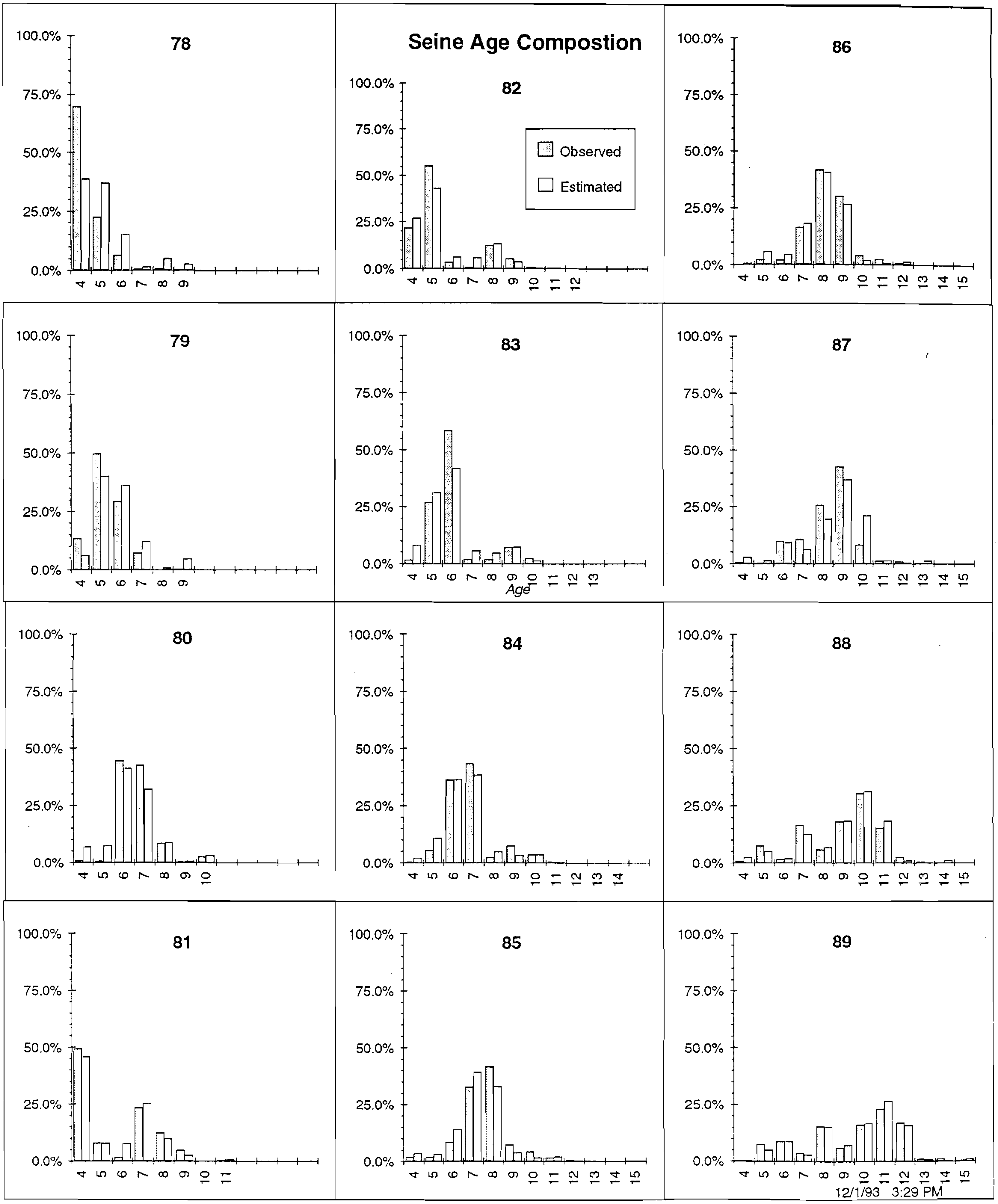
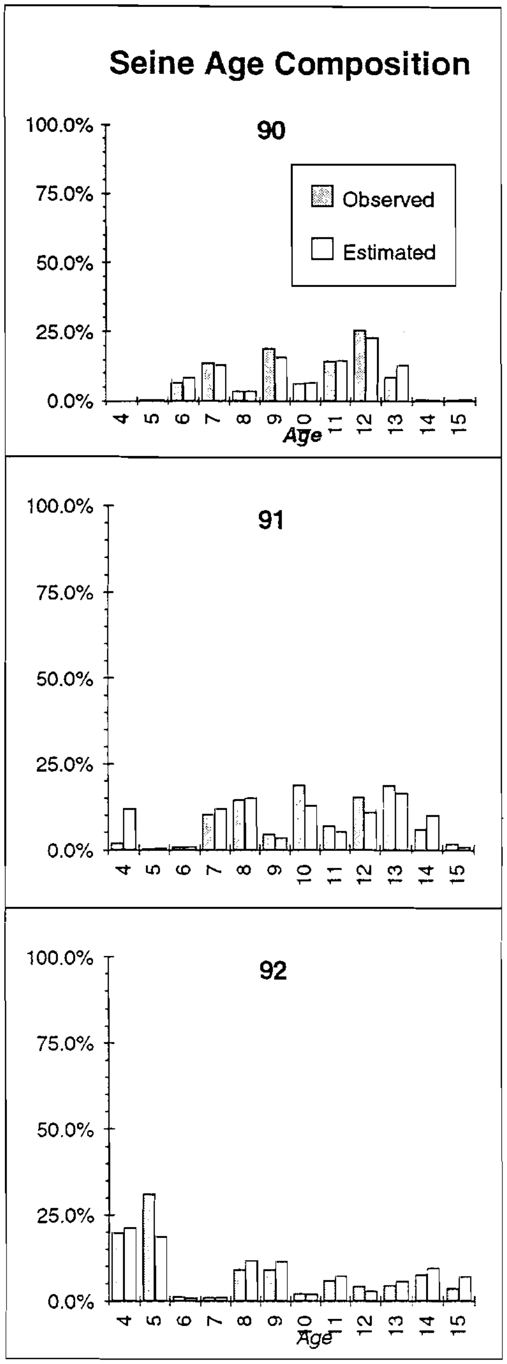



Figure 26. Performance of the Togiak District herring forecast based on a schedule of increasing mortality with age (1978-1992) and the 1993 forecast based on an ASA model.

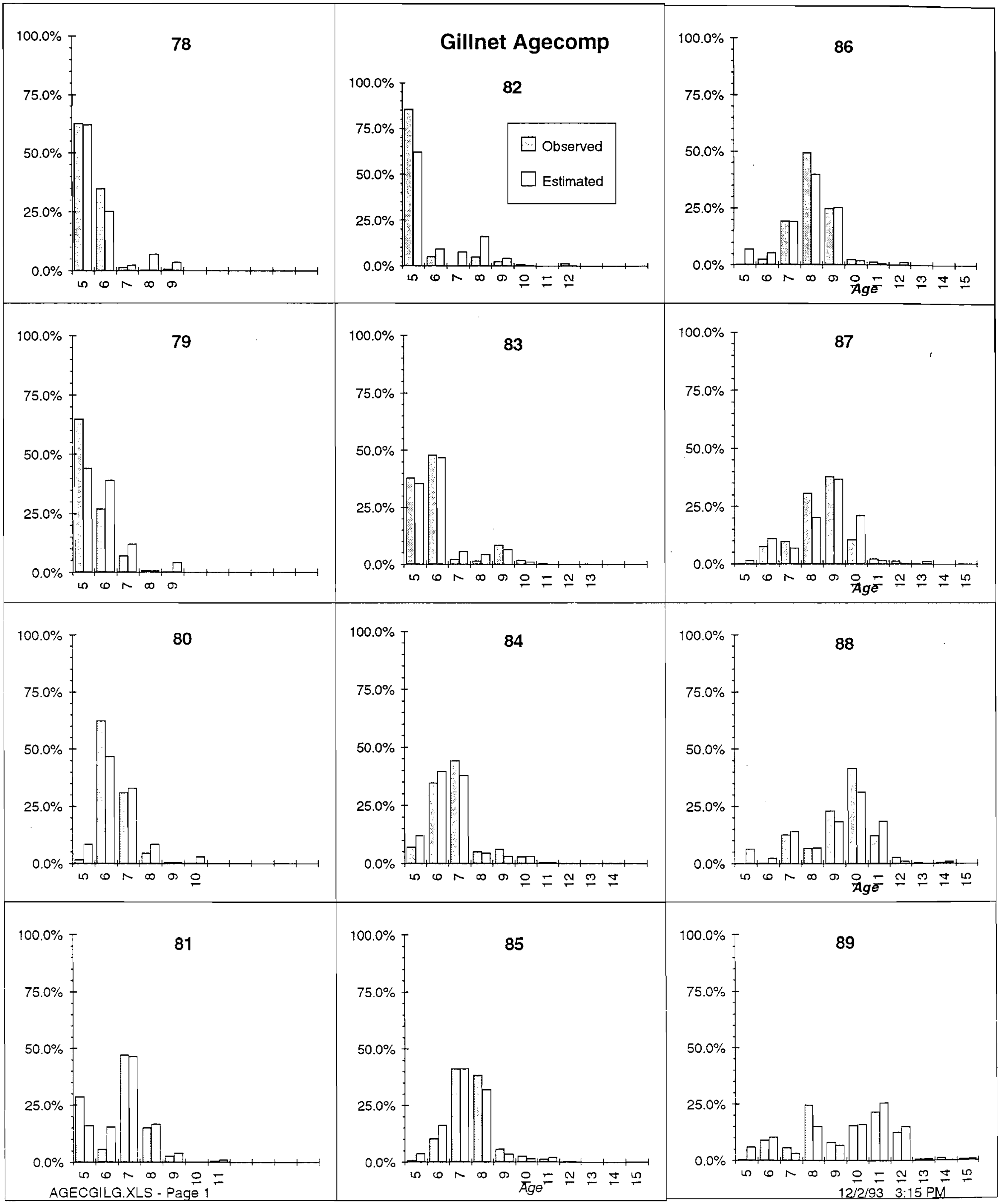
Appendix A. Observed age composition of the purse seine catch versus that estimated to be available by the ASA model for Togiak herring.



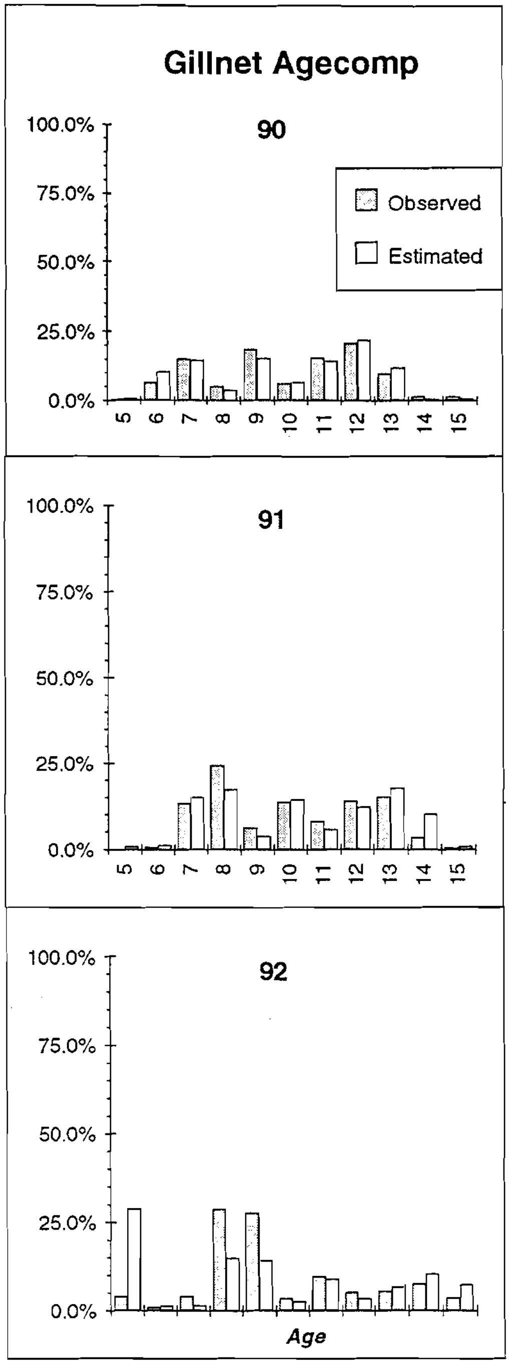
Appendix A. Continued (page 2 of 2).



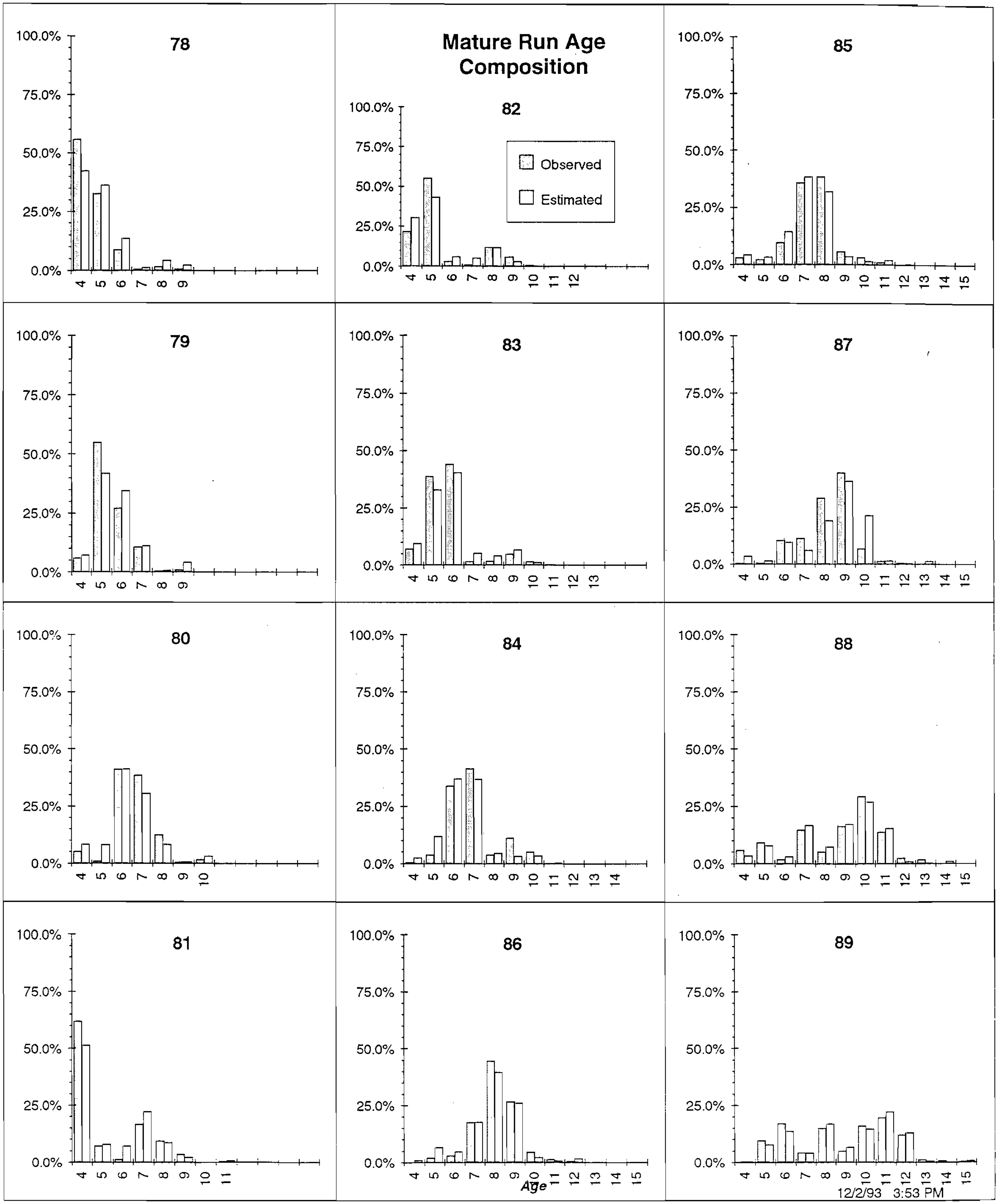
Appendix B. Observed age composition of the gillnet catch versus that estimated to be available by the ASA model for Togiak herring .



Appendix B. Continued (page 2 of 2).



Appendix C. Observed age composition of the run biomass versus that estimated by the ASA model for Togiak herring.



Appendix C. Continued (page 2 of 2).