AGE-STRUCTURED ASSESSMENT OF THE TOGIAK HERRING STOCK, 1978-1992, AND PRELIMINARY FORECAST OF ABUNDANCE FOR 1993

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INTRODUCTION

Stock assessment information of various kinds has been collected for the Togiak herring stock since 1977. These data include age compositions of the purse seine and gillnet catches, the age composition of the mature run, and aerial survey estimates of biomass. Harvest quotas for the fishery have been determined by applying a fixed exploitation rate (20%) to aerial survey estimates of biomass. However, in years when aerial survey conditions are poor, the aerial surveys likely underestimate biomass. Strong 1977-78 year classes caused a very large pulse of biomass in the Togiak stock during the mid 1980's according to cohort analysis reconstructions (Baker 1991, Wespestad 1991, Zheng *in press*). On the other hand, aerial survey biomass estimates during this time period included years of varying survey conditions and interpretations and do not reflect this trend in abundance.

The large numbers of fish collected in age-weight-length samples from the Togiak stock likely provide precise estimates of age composition. These age compositions reflect relative abundance trends in the stock such as the recruitment of the strong 1977-78 year classes. However, the information contained in the time series of age composition estimates has not been incorporated simultaneously with aerial survey data to estimate abundance. Age-structured analysis or "ASA" provides a tool that can incorporate age compositions and selected years of good aerial surveys to generate abundance estimates. The ASA approach we used essentially scales relative abundance trends from age compositions to the approximate magnitude of the biomass estimates from subsets of aerial surveys taken from years with "good" weather conditions and adequate sample sizes during aerial surveys.

Aerial survey abundance estimates largely rely on summing "peak" estimates from a 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. This ASA approach only partially corrects this tendency for aerial surveys to be conservative. Because years of poor weather or inadequate geographic and temporal coverage during aerial surveys are excluded from the analysis, much bias is removed by the ASA model. However, to the extent that some herring are unobserved even during years of good surveys, the resultant model estimates will tend to underestimate true herring abundance to some unavoidable degree. The primary goal of the ASA 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.

METHODS

Our approach uses an ASA model that incorporates auxiliary information, similar to that used by Deriso et al. (1985). Nonlinear least squares techniques are used to minimize a sum of squares constructed from heterogeneous types of auxiliary information. Many different sources of data can be incorporated into the parameter estimation process using this approach. ASA models that incorporate heterogenous data are reviewed by Hilborn and Walters (1992) and Megrey (1989). Whereas the primary goal was to use the model to generate a one-year forecast of abundance for 1993, the model is used to update estimates of historical abundances for 1978-1992, natural mortality, maturity, and gear selectivities for purse seine, and gillnet fisheries, as well.

In our conceptual model of the annual cycle of events affecting the Togiak herring stock (Figure 1), we increment age indices at the end of winter, coinciding with the approximate time of annulus formation. The population model begins accounting for herring cohorts at age 4, the first year that a measurable proportion usually return to spawn. Prior to spring, the conceptual model splits the herring population into two components: an immature portion that will not return to spawn, and the "pre-fishery mature" or "run" biomass that will return to inshore areas to spawn. Removals by purse seine and gillnet sac roe fisheries are then deducted to give the "escapement biomass" that actually spawns. In this preliminary model configuration, removals by the Dutch Harbor food and bait fishery and groundfish trawl bycatches are not explicitly accounted for, but are reflected in the survival rate estimate. These removals could be made explicit when catch by age is available from these fisheries. However, because selectivity in these fisheries is likely to be highly variable and these harvests occur on mixed stocks, catches from these fisheries may not provide useful "tuning" information for Togiak ASA model.

Survival Model

The survival model we used accounts for the above processes with a difference equation to describe the number of fish in the (N) in a cohort aged a in year y:

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

where S and is the annual survival rate estimated by the ASA model, $C_{a,y}^{seine}$ is the catch from the spring purse seine sac roe fishery, and $C_{a,y}^{gillnet}$ is the catch in the spring gillnet sac roe fishery. The number of fish in a cohort (N) includes both mature and immature herring measured at a time after annulus formation but before the spawning migration or spring roe fisheries (the "total population" of Figure 1). The model starts accounting for herring at age 4. Because herring age 9 and older were pooled in the age composition data for 1978-79, these fish are pooled into a single "9+" category for 1978-1979 estimates of abundance and age composition. Herring were aged to a "15+" category beginning in 1980, and recently have been aged to 18. In the model, the "9+" category of 1979 becomes the "10+" category of 1980, the "11+" category of 1982...until the "15+" category of 1985. From 1985 forward, herring aged 15 and older are pooled into the "15+" category.

The starting value for the annual proportionate survival rate was 70%, equivalent to a 0.35

instantaneous natural mortality rate (M). Starting values for the abundance of the 1969-88 year classes were estimated by graphically fitting mature run age compositions from the years 1978-92 and the 1981, 1988, and 1992 aerial survey biomass.

Observed Catch at Age

The harvest of herring by age for purse seine sac roe and gillnet sac roe fisheries was tabulated from published sources for the 1978 to 1992 period (Tables 1 and 2). For 1978 and 1979, the age composition of the harvest was obtained from Fried et al. (1983). Age composition were converted to number of fish in the harvest for 1978 and 1979 using the total catch weight for each gear (Skrade and Brookover 1991) and the weight at age (Table 3). For the 1980-89 period, catches at age were obtained from Baker (1991). For 1990 and 1991, catch in numbers at age was obtained from the catch weight at age distribution in the annual forecast report (Funk 1991, Funk and Harris 1992) and the weights at age of Table 3. Only preliminary purse seine catch at age data were available for 1992 at the time that this analysis was conducted.

The number of fish at age in the harvest was used as $C_{a,y}^{seine}$ and $C_{a,y}^{gillnet}$ in equation (1). Observed numbers of fish in the catch for each gear were also converted to age composition (percent by age) for each gear to compare with age compositions estimated from catch models.

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):

$$\hat{p}_{a,y} = \frac{s(a)N_{a,y}}{\sum_{a} [s(a) \cdot N_{a,y}]} , \tag{2}$$

This equation defines selectivity as the proportion of the total population susceptible to capture by the fishing gear; it includes both the effects of immature fish not being present on the fishing grounds (partial recruitment or maturity), and active selection or avoidance of certain fish sizes by the gear or fisher's behavior. Gear selectivity was estimated separately for the two gears. Functions chosen to describe the relationship between gear selectivity and age were limited to two parameters because it is desirable to minimize the number of parameters estimated by the model; two parameters are the fewest that can adequately describe the age-selectivity relationship. The choice of a particular functional form represents an assumption which limits the possible ranges of the selectivities. Purse seine gear was assumed to have asymptotic selectivity and was represented by a logistic function:

$$s(a) = \frac{1}{1 + e^{\beta(a-\alpha)}}, \tag{3}$$

where the two parameters to be estimated are α, the age of 50% selectivity and β, a steepness parameter. Purse seine selectivity was constrained to be at least 98% by age 10.

The gamma-type function of Deriso et al. (1985) was used for gillnet gear where selectivity might decrease at the older ages:

$$s(a) = \frac{a^{\gamma} e^{-(\delta \cdot a)}}{\max_{j} [\, j^{\gamma} e^{-(\delta \cdot j)} \,]}, \tag{4}$$

where γ and δ are the two parameters to be estimated, and the subscript j ranges over all age classes. The denominator of the expression merely scales the values of the function to one at the age of maximum selectivity. Initial values for selectivity parameters for purse seine and gillnet gears were chosen to give selectivities similar to those in Funk and Sandone (1990) for Prince William Sound.

Comparing Estimated and Observed Age Compositions of the Catch

One measure of goodness of fit from the model was obtained by comparing estimated and observed age compositions of the commercial catch. For each gear, the sum of squares measuring the goodness of fit of the age composition of the catch was computed as:

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

where $(\hat{p}_{a,y})$ was the estimated age composition of the catch from equation (2). The transformation, $\sin^{-1}$(square root), was applied to observed and estimated age composition proportions to stabilize the variance.

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 the abundances determined from equation (1) with aerial survey biomass estimates and mature run age compositions. Because maturity is expected to be an asymptotic function, a logistic expression was used:

$$\rho(a) = \frac{1}{1 + e^{\phi(a-\tau)}} \,, \tag{6}$$

where the two parameters to be estimated are τ, the age of 50% maturity, and ϕ, a steepness parameter. The maturity-age relationship was assumed not to change over the range of years in the model. The validity of this assumption was investigated by examining residuals of spawning age compositions for time trends over the duration of the model, which might indicate consistent shifts in the maturity-age relationship. Starting values for maturity parameters gave 50% maturity for age 4 with full maturity at age 7. Maturity function parameters were constrained in the model such that maturity at age 8 was essentially complete (98%). Biological sexual maturity is achieved at approximately age 6 (Wespestad 1991). Maturity as detected in 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. Maturity was constrained in this manner to prevent confounding with estimation of natural mortality.

Aerial Survey Biomass Estimates

During herring aerial surveys, observers estimate the surface area of herring schools on the spawning grounds. Surface areas are converted to biomass estimates using calibration samples in which entire herring schools were captured by purse seines after observers had estimated their surface area. Calibrations are stratified by three depth zones. The largest observed or "peak" biomass from each distinct spawning event is summed to obtain each year's biomass estimate. Distinct spawning events are identified by separation in space and time, differences in age composition, and differences in sexual maturity. Occasionally non-peak biomass estimates are included in the total estimate when age composition or sexual maturity data indicate herring that could not have been accounted for in the nearest "peak" estimate. Aerial surveys were rated during 1980-1992 (Table 4), taking into account survey frequency, the duration of the aerial surveys and weather during the main spawning events. Aerial surveys from five of the six highest rated years (1981, 1983, 1985, 1988, 1992) were considered for use in the ASA model. Although the 1982 aerial survey estimate was ranked relatively high according to aerial survey ratings, 1982 was excluded because the relatively low biomass estimated that year, relative to estimates from adjacent years with high ratings, contradicted the well documented phenomenon of the recruitment of the very strong 1977-78 year classes. Because relative ratings among these five remaining years were not obvious, the sensitivity of the ASA model to different subsets of these five years was evaluated. The 1992 aerial survey biomass was a preliminary estimate which will be updated when the final 1992 mature run age composition data become available.

A goodness of fit measure for the ASA model was developed from the differences between ASA estimates of mature run biomass and the aerial survey estimates of mature run biomass:

$$SSQ_{aerialbiomass} = \sum_{y} \{ \log_e (B_y^{survey}) - \log_e [\sum_{a} \rho(a) \, w_{a,y} \, N_{a,y}] \}^2 , \qquad (7)$$

where B_y^{survey} are the aerial survey biomass estimates in year y, $w_{a,y}$ is the weight at age a in year y (Table 1), and $\rho(a)$ is the proportion mature at age a to be estimated by the ASA model, and $N_{a,y}$ are the ASA estimates of abundance (equation 1). Because there were too few abundance estimates to evaluate the appropriateness of the log transformation in equation (7), the sensitivity of the model's results to this assumption was evaluated.

Age Compositions of the Pre-Fishery Mature "Run" Biomass

In addition to the time series of the catch by age, a relatively long time series of age compositions of the pre-fishery mature or "run" biomass are available. The age compositions of the "run" biomass was tabulated from published sources for the 1978 to 1991 period (Table 5). For 1978 and 1979, the age composition was calculated from numbers of fish published by Brannian and Rowell (1989). For the 1980-89 period, the numbers of fish at age were obtained from Baker (1991). For 1990 and 1991, the age composition was obtained from Funk (1991) and Funk and Harris (1992). A goodness of fit measure was developed from these age compositions as:

$$SSQ_{agecomp:run} = \sum_{y} \sum_{a} [p_{a,y}^{run} - \frac{\rho_a N_{a,y}}{\sum_{a} (\rho_a N_{a,y})}]^2 , \qquad (8)$$

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

Year-Ahead Forecast Methodology

The forecast of the abundance of mature herring for 1993 ($B_{1993}^{Forecast}$) is based on projecting the total abundance with the survival model (equation 1), modified by the ASA estimates of the proportion mature at age:

$$B_{1993}^{Forecast}) = \sum_{a} \rho(a)\, w_{a,1993}\, N_{a,1993}\ , \tag{9}$$

where $\rho(a)$ are the proportions mature at age a estimated by the ASA model, $w_{a,1993}$ are weights at age a from the Gompertz growth model fit to all years available data (Table 3) and $N_{a,1993}$ are the ASA estimates of abundance for 1993 from equation (1), except for the number of age 4 herring. At present, methods of predicting year class strengths are uncertain, and the median observed year class strength of the ASA estimates for the 1973-1988 year classes was used to generate the 1993 forecast of age 4 herring, $N_{4,1993}$. The median better represents recruitment in typical years than the mean year class strength, as the distribution of year class strengths is very skewed. Assumptions about future year class strength tend to be moderated by the fact that age 4 herring are only partially recruited (approximately 50%).

Parameter Estimation

Total Sum of Squares

A total sum of squares was computed by adding each of the components:

$$\begin{aligned} SSQ_{Total} = {} & \theta_{aerialsurvey}\,\lambda_{aerialsurvey}\ SSQ_{aerialsurvey}\ + \\ & \theta_{agecomp:seine}\,\lambda_{agecomp:seine}\ SSQ_{agecomp:seine}\ + \\ & \theta_{agecomp:gillnet}\,\lambda_{agecomp:gillnet}\ SSQ_{agecomp:gillnet}\ + \\ & \theta_{agecomp:run}\,\lambda_{agecomp:run}\ SSQ_{agecomp:run}\ , \end{aligned} \tag{10}$$

where the θ's and λ's are weights assigned to each sum of squares component. Because the variance of the aerial survey abundance estimator was unknown, an inverse variance weighting scheme could not be used. The θ's were used to scale each of the SSQ components to be of a similar order of magnitude, such that each SSQ component would have an approximately similar effect on the total SSQ when λ's were equal. The λ's were used to assign ad hoc weights to each SSQ component reflecting the degree of confidence in each component. The sensitivity of the model's results to varying λ's was evaluated. For most of the sensitivity analysis scenarios the three age composition data sources were weighted relative to each other according to the sample size for each data source. Mature run age compositions accounted for approximately 50% of the herring examined, while purse seine age compositions accounted for 34% and gillnet age composition accounted for 16% of the herring examined. Aerial survey biomass estimates were assigned weights ranging from 1% to 50% of the weight assigned to the combined age composition weights.

Minimization Methods

The model estimates a total of 27 parameters: 20 initial cohort sizes, four gear selectivity function parameters (α, β, γ, and δ) two maturity function parameters (ϕ and τ), and one survival rate parameter (S). When four aerial survey years were used, the four SSQ equations refer to 439 data observations. Therefore there would be 412 degrees of freedom and the data/parameter ratio is approximately 16. However, not all of the data observations are independent, so that the amount of information contained in the data is considerably less than would be the case with completely independent observations.

The Microsoft Excel[1] spreadsheet solver was used to estimate values for the parameters which minimized the combined weighted sums of squares. Parameter values manipulated by the solver were all scaled to a similar order of magnitude, as recommended by the software manufacturer. 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.

Sensitivity Analysis

The sensitivity of the model to three groups of assumptions was investigated. Because the choice of which aerial survey years to include in the analysis was somewhat subjective, various combinations of aerial survey years were chosen from the five highest rated years. The appropriateness of the assumption of a lognormal error structure for aerial survey biomass observations was also examined. The choice of ad hoc weights among the 4 auxiliary information components was also subjective and could influence model results. A total of 26 combinations of these three groups of assumptions were examined in the sensitivity analysis (Table 6).

RESULTS AND DISCUSSION

Regardless of assumptions about biomass error structure, weighting of SSQ components, or choice of aerial surveys, the ASA estimates of biomass are relatively low in the early 1980's, and increase to a maximum in 1983 with the recruitment of the strong 1977 and 1978 year classes (Figure 2). In all scenarios, biomass declines to a low in 1991 because of poor recruitment and rebounds again in 1992 and 1993 as the moderately strong 1987 and 1988 year classes enter the mature population. Three scenarios (runs 20, 21, and 22) estimated substantially higher abundance in 1982-87. These three were the only scenarios that did not include either the 1983 or the 1985 aerial survey abundance estimates. The median biomass trend closely tracks run 1, a combination of assumptions thought to be likely which included all five aerial survey years and moderate

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

weighting factors. Estimates of maturity and gear selectivity for run 1 are shown in Figure 3. The recruitment time series (Figure 4) indicates that the 1988 year class may be even stronger than the 1977 year class. However, the 1988 year class first appeared in age composition samples in 1992, and age composition information for 1992 is incomplete. Because only purse seine age composition information is available for 1992 and the selectivity to purse seine gear at age 4 is low, there is a large amount of uncertainty about the strength of this year class. The estimated size of the 1987 year class also varied among scenarios to a lesser extent. In general, ASA estimates of abundance are least certain for the most recent years. Survival estimates ranged from a low of 75% (M=0.29) to a high of 82% (M=0.20), depending on the combination of assumptions in the various scenarios.

The histogram of outcomes of the sensitivity analysis reflects the amount of uncertainty in the 1993 forecast of abundance (Figure 5). Most of the results were clustered around the median forecast of 135,102 tonnes. The two lowest forecasts resulted when the 1992 aerial survey estimate of abundance was excluded from the model. However, the 1992 survey conditions were generally regarded as excellent, such that the 1992 aerial surveys should probably be included. The highest forecast occurred when aerial surveys were given an unrealistically low weight of 1%, and the age compositions were given 99% of the weight (run 21). Excluding these observations, the remaining scenarios fall within +/- 10% of the median. Because the outcome of run 1 and other scenarios thought to be likely combinations of assumptions were also similar to the median, the median value of 135,102 tonnes was used for the preliminary 1993 forecast of abundance.

This abundance forecast will be updated when additional age composition data from the 1992 gillnet fishery and the 1992 mature run become available. Because purse seine age compositions from 1978-1991 corresponded reasonably well with mature run age compositions when ASA estimates of maturity and purse seine selectivity were taken into account, these new data are not expected to have a significant effect on the 1993 forecast.

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Table 1. Togiak commercial purse seine harvest by year (in millions of herring), 1978-1991.

Year	Age 4	5	6	7	8	9	10	11	12	13	14	15	Source
1978	29.306	9.482	2.755	0.250	0.286	0.107							Fried et al. (1983)
1979	3.402	12.572	7.397	1.808	0.027	0.085							McBride and Whitmore (1981)
1980	0.517	0.350	27.033	25.906	5.103	0.224	1.601						Baker (1991)
1981	19.439	3.162	0.615	9.200	4.893	1.889	0.068	0.167					Baker (1991)
1982	11.931	30.367	1.859	0.459	6.850	2.967	0.475	0.108	0.081				Baker (1991)
1983	1.141	18.771	40.685	1.310	1.273	4.985	1.602	0.000	0.000	0.000			Baker (1991)
1984	0.106	2.508	16.586	19.763	1.183	3.373	1.683	0.238	0.000	0.000	0.000		Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	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	Funk and Harris (1992)
1992	16.661	21.312	0.880	2.233	6.467	5.484	1.453	2.964	2.806	2.494	3.693	0.989	Preliminary 1992 data.

Shaded cells include all older ages. Oldest age was 9+ from 1978-79. Oldest age categories summed where needed for 1980+ data, from Baker (1991)

Table 2. Togiak commercial gillnet harvest by year (in millions of herring), 1978-1991.

	Age												
Year	4	5	6	7	8	9	10	11	12	13	14	15	Source
1978	0.597	1.458	0.808	0.035	0.009	0.018							Fried et al. (1983)
1979	1.735	10.957	4.558	1.181	0.124	0.054							McBride and Whitmore (1981)
1980	0.171	0.217	8.140	4.023	0.590	0.052	0.028						Baker (1991)
1981	5.934	1.060	0.209	1.744	0.557	0.102	0.007	0.019					Baker (1991)
1982	6.226	18.979	1.147	0.021	1.048	0.509	0.211	0.000	0.288				Baker (1991)
1983	0.027	6.641	8.398	0.380	0.260	1.464	0.302	0.070	0.000	0.017			Baker (1991)
1984	0.073	1.032	5.123	6.513	0.739	0.900	0.420	0.041	0.008	0.000	0.000		Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Baker (1991)
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	Funk (1991)
1991	0.029	0.000	0.042	0.977	1.793	0.461	1.017	0.6[illegible]	1.036	1.115	0.259	0.039	Funk and Harris (1992)

Shaded cells include all older ages. Oldest age was 9+ from 1978-79. Oldest age categories summed where needed for 1980+ data, from Baker (1991)

Table 3. Average weight (g) at age for the Togiak total run, 1977-1992. Shaded cells contained missing or bad data and were estimated f Gompertz growth model of Baker (1991).

	Age												
	4	5	6	7	8	9	10	11	12	13	14	15	Source
1977	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)
1978	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)
1979	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)
1980	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)
1981	184	215	265	300	330	340	350	397	392	391	543	483	Baker (1991) Appendix Table 14
1982	185	237	270	297	346	383	409	411	480	417	371	483	Baker (1991) Appendix Table 14
1983	178	232	280	301	323	366	394	330	456	359	469	483	Baker (1991) Appendix Table 14
1984	145	208	261	304	340	373	396	410	424	434	473	483	Baker (1991) Appendix Table 14
1985	150	196	249	309	354	393	417	444	450	402	473	483	Baker (1991) Appendix Table 14
1986	138	186	231	286	333	371	410	425	432	409	473	483	Baker (1991) Appendix Table 14
1987	134	184	244	295	343	392	435	452	498	463	473	483	Baker (1991) Appendix Table 14
1988	127	167	253	295	327	384	401	414	418	446	473	483	Baker (1991) Appendix Table 14
1989	115	188	235	297	340	379	393	417	450	403	473	477	Baker (1991) Appendix Table 14
1990	152	201	250	302	344	344	379	384	425	461	473	483	Baker (1991) Appendix Table 14
1991	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)
1992	158	208	257	302	342	376	404	428	446	461	473	483	Gompertz Growth Model from Baker (1991)

Table 4. Aerial survey biomass estimates and ratings for the Togiak herring stock, showing the six highest rated aerial su (1981, 1982, 1983, 1985, 1988, and 1992).

Survey Year	Days Surveyed (partial) C	Days Surveyed (Total) D	Ratio d/c+d E	Avg Survey Rating F	Peak Survey (5 pts) G	Survey Rating (Peak) H	Total # Surveys L	Total Surveys W/fish M	Sum E+F+G+H		Biomass (tonnes)
1980	15	5	0.25	3.1	2	4.5	21	20	9.9		62,311
1981	8	25	0.76	2.8	4	4.5	34	33	12.1	*	143,925
1982	3	13	0.81	3.4	5	4	18	16	13.2	*	88,815
1983	4	25	0.86	2.8	4	4.5	29	29	12.2	*	128,623
1984	3	15	0.83	3.5	3	3	33	18	10.3		104,218
1985	0	13	1.00	3.0	5	2.5	16	13	11.5	*	119,204
1986	6	15	0.71	2.4	4	3	28	21	10.1		85,910
1987	8	9	0.53	3.0	2	2	23	20	7.5		80,195
1988	5	9	0.64	3.9	4	4	21	13	12.6	*	122,213
1989	4	8	0.67	3.9	3	2.5	13	12	10.1		89,780
1990	16	4	0.20	2.7	2	3	28	20	7.9		79,928
1991	3	8	0.73	3.7	4	2.5	22	11	11.0		75,504
1992	9	3	0.25	4.1	3	4	28	12	11.3	*	132,483

Table 5. Age composition of the pre-fishery mature herring run at Togiak 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 (1991)
1981	0.619	0.071	0.012	0.167	0.094	0.034	0.001	0.003					Baker (1991)
1982	0.216	0.552	0.031	0.009	0.119	0.060	0.010	0.002	0.002				Baker (1991)
1983	0.070	0.388	0.441	0.016	0.017	0.050	0.016	0.003	0.001	0.000			Baker (1991)
1984	0.005	0.039	0.338	0.415	0.037	0.113	0.051	0.002	0.000	0.000	0.000		Baker (1991)
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 (1991)
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 (1991)
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 (1991)
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 (1991)
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 (1991)
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)

Shaded cells include all older ages. Oldest age was 9+ from 1978-79. Oldest age categories summed where needed for 1980+ data, from Baker (1991)

Table 6. Combinations of aerial surveys and weights (lambdas) used to examine the sensitivity of ASA model results. each combination, the scaling coefficients (thetas) were adjusted so that each sum of squares componen had approximately equal influence on the combined sum of squares before weighting.

	Aerial Surveys							Weights (Lambda's)					Equal Influence Scaling (Theta's)			
								Between		Within Age Compositions						
Run #	Log Transform	81	83	85	88	92	Total Surveys	Aerial Surveys	All Age Compositions	Total Run	Purse Seine	Gill Net	Aerial Surveys	Total Run	Purse Seine	Gill Net
1	Y	1	1	1	1	1	5	0.25	0.75	0.25	0.25	0.25	1	1.0	1.0	1.0
2	Y	1	1		1	1	4	0.5	0.5	0.5	0.34	0.16	5	0.8	0.9	0.9
3	Y	1	1	1		1	4	0.5	0.5	0.5	0.34	0.16	5	0.8	0.9	0.9
4	Y	1	1	1	1		4	0.5	0.5	0.5	0.34	0.16	5	0.8	0.9	0.9
5	Y	1		1	1	1	4	0.25	0.75	0.5	0.34	0.16	6	0.8	0.9	0.9
6	Y	1	1		1	1	4	0.25	0.75	0.5	0.34	0.16	4	0.8	0.9	0.9
7	Y	1	1	1		1	4	0.25	0.75	0.5	0.34	0.16	3	0.7	0.9	0.9
8	Y	1	1	1	1		4	0.25	0.75	0.5	0.34	0.16	4	0.9	0.9	0.9
9	N	1		1	1	1	4	0.25	0.75	0.5	0.34	0.16	4.0E-10	0.9	0.9	0.9
10	N	1	1		1	1	4	0.25	0.75	0.5	0.34	0.16	3.0E-10	0.9	0.9	0.9
11	Y	1	1	1	1	1	5	0.25	0.50	0.25	0.17	0.08	1	1.0	1.0	1.0
12	Y	1	1	1	1	1	5	0.50	0.50	0.28	0.17	0.08	2.5	1.0	1.0	1.0
13	N	1	1	1	1	1	5	0.25	0.75	0.25	0.25	0.25	1E-10	1.0	1.0	1.0
14	Y	1			1	1	3	0.50	0.50	0.50	0.34	0.16	5	0.8	0.9	0.8
15	Y		1		1	1	3	0.50	0.50	0.50	0.34	0.16	5	0.8	0.9	0.8
16	Y	1	1			1	3	0.50	0.50	0.50	0.34	0.16	7	0.5	0.5	0.5
17	Y	1		1	1		3	0.50	0.50	0.50	0.34	0.16	7	0.5	0.5	0.5
18	Y		1	1	1		3	0.50	0.50	0.50	0.34	0.16	7	0.5	0.5	0.5
19	Y		1		1	1	3	0.50	0.50	0.50	0.34	0.16	10	0.5	0.5	0.5
20	N	1			1	1	3	0.25	0.75	0.5	0.34	0.16	7.34E-09	0.9	0.9	1.0
21	N	1			1	1	3	0.01	0.99	0.5	0.34	0.16	7.34E-09	0.9	0.9	1.0
22	N	1			1	1	3	0.05	0.96	0.125	0.75	0.125	7.34E-09	0.9	0.9	1.0

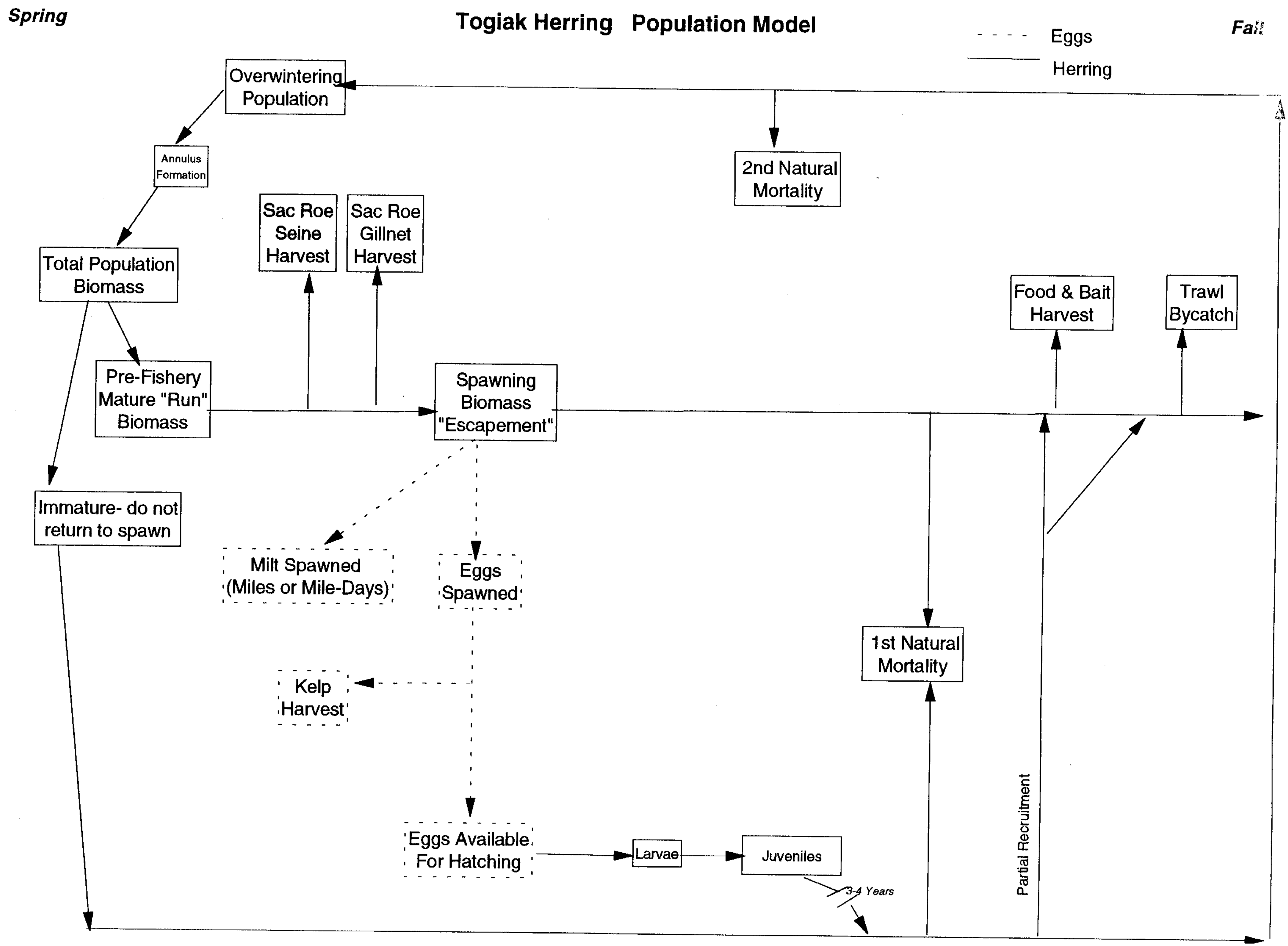

Figure 1. Conceptual model of the annual cycle of events affecting the Togiak herring stock.

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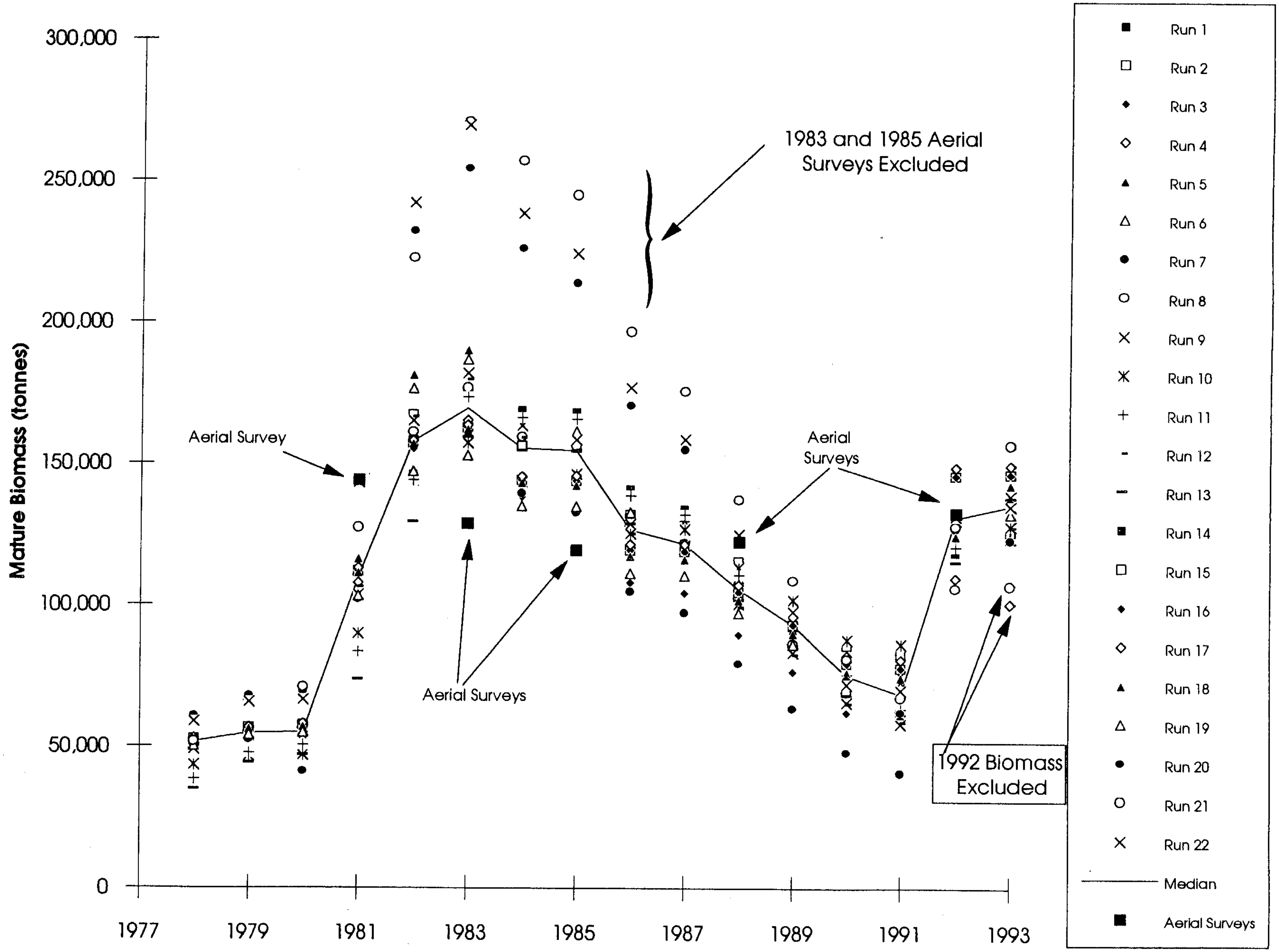

Figure 2. Mature biomass estimates resulting from the 22 sensitivity analysis scenarios for the Togiak ASA model, with the median of the 22 scenarios (solid line). Various combinations of 5 aerial survey biomass estimates (arrows) were used in the scenarios. The 1992 aerial survey biomass was not used in the 2 scenarios that generated unusually low 1993 forecast projections.

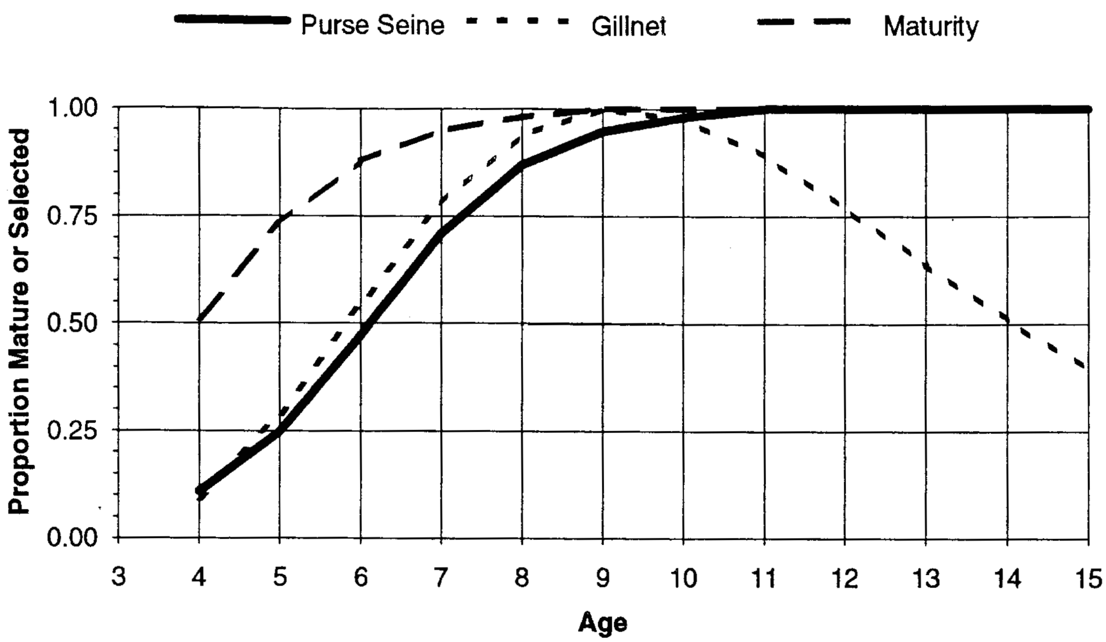

Figure 3. Maturity and selectivity proportions estimated by the Togiak ASA model under the assumptions of Run 1.

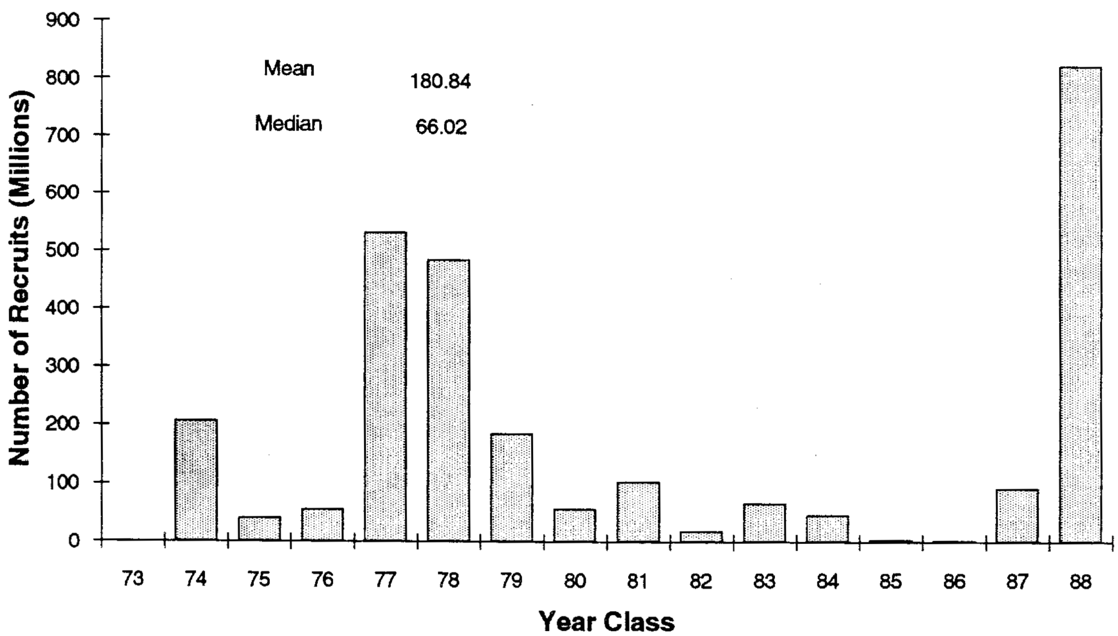

Figure 4. Recruit year class strength at age 4 estimated by the Togiak ASA model under the assumptions of Run 1.

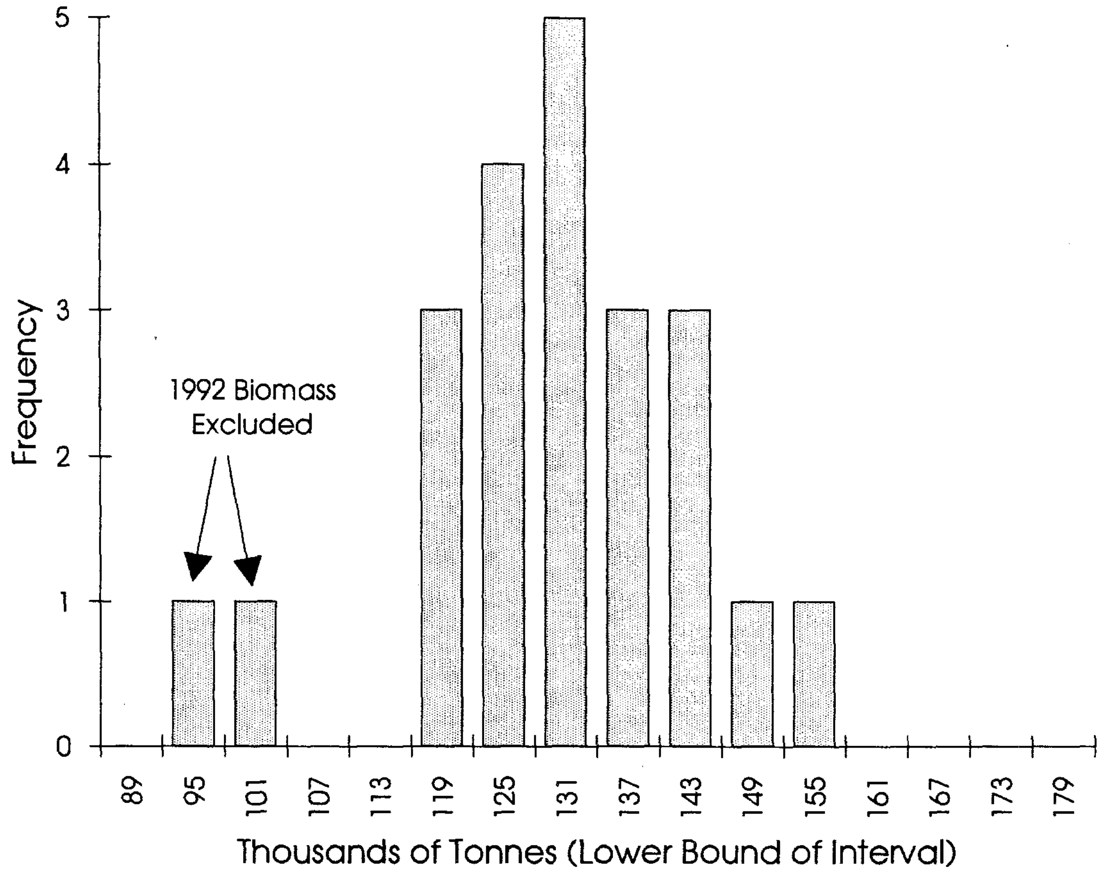

Figure 5. Histogram of 1993 forecast biomass from the 22 sensitivity analysis scenarios for the Togiak ASA model.