FORECAST OF THE PACIFIC HERRING BIOMASS IN PRINCE WILLIAM SOUND, ALASKA, 1993

By

Fritz Funk

REGIONAL INFORMATION REPORT NO. 5J94-04

Alaska Department of Fish and Game
Commercial Fisheries Management and Development Division
P.O. Box 25526
Juneau, Alaska 99802-5526

February 1994

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AUTHOR

Fritz Funk is statewide herring biometrician for the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, P.O. Box 25526, Juneau, AK 99802-5526.

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ABSTRACT

An age-structured assessment (ASA) model is used to forecast the abundance of herring expected to return to spawn in Prince William Sound in 1993. The ASA model develops 1973-92 biomass estimates by smoothing differences in abundance trends suggested by spawn deposition surveys, aerial milt surveys, and the time series of purse seine, gillnet, and spawning age composition samples. The abundance trends in the 1984, and 1988-92 spawn deposition surveys are very different from abundance trends in the other indices. In addition to estimating abundance, the ASA model also estimates natural survival, maturity, and vulnerability to fishing gear. The 1993 spawning biomass is estimated to be 121,684 tonnes. At the 20% exploitation rate under the current harvest policy, the allowable harvest for the 1993 management year is 26,827 tons of herring. Following the allocations specified in the management plan, the fall 1993 food and bait herring fishery is allocated 4,373 tons of herring, the 1993 wild spawn-on-kelp fishery is allocated 2,146 tons of herring (equivalent to 268 tons of spawn-on-kelp product), the 1993 pound spawn-on-kelp fishery is allocated 3,809 tons of herring (equivalent to 305 tons of spawn-on-kelp product), the 1993 purse seine sac roe fishery is allocated 15,586 tons, and the 1993 gillnet sac roe fishery is allocated 912 tons.

INTRODUCTION

The abundant herring of Prince William Sound have supported some of the largest herring fisheries in Alaska, during both the recent herring roe period and during the earlier food and reduction fisheries. Fluctuations in the abundance of herring in Prince William Sound prompted studies of their population dynamics as early as the 1920s (Rounsefell and Dahlgren 1935). Harvest quotas were established in 1939 to attempt to stabilize catches. The first abundance forecasts were prepared in the 1940s (Dahlgren and Kolloen 1943, 1944; Kolloen and Elling 1948) as the basis for setting harvest quotas and to allow the fishing industry time to adjust processing logistics in accord with projected harvests. This document reviews the status of Prince William Sound herring through the fall of 1992 and forecasts the abundance of herring which will return to spawn in the spring of 1993.

Commercial exploitation of herring in Prince William Sound was first recorded in 1913, when 20,000 pounds were salt-cured and 1,600 pounds were sold for halibut bait (Rounsefell and Dahlgren 1935). The growth of the salt-cured herring fishery was stimulated by the shortage of European herring during World War I. Reduction plants were first installed in Prince William Sound in 1920 to make use of waste from the curing plants. As the new markets for herring oil and fish meal expanded, the fishery soon began to target harvests of smaller herring explicitly for reduction. The largest herring harvest in Prince William Sound of 50,941 tonnes occurred in 1938 (Figure 1). Reduction harvests declined throughout Alaska as cheaper sources of fish meal and oil became available elsewhere in the world, principally from Peruvian anchovetta fisheries. The last reduction plant in Prince William Sound closed in 1958. Prince William Sound herring have long supported relatively small fisheries for bait, initially for halibut longline fisheries and more recently for crab and groundfish longline fisheries.

Herring began to be harvested during the spawning season for export to the Japanese herring roe markets in 1969 and now comprise most of the harvest. Other spring herring fisheries harvest herring spawn on wild and impounded kelp. The herring bait fishery occurs in the fall, when herring are in good condition for use as bait in longline and crab fisheries.

The 1992 the total harvest of herring in Prince William Sound was 26,267 tons (J. Wilcock, Alaska Department of Fish and Game, Cordova, personal communication), the highest harvest since the inception of the roe fishery. Of this total, 22,367 tons was harvested during spring roe fisheries and 3,900 tons during the fall 1992 food and bait fishery. Of the spring fisheries, the purse seine sac roe fishery harvested 16,784 tons, and the gillnet sac roe fishery 940 tons.

The management boundaries of the Prince William Sound District extend from Cape Fairfield on the west to Point Whitshed on the east. All herring that spawn or harvested in these waters are managed as a single unit. The large harvests taken by the reduction fishery were primarily taken near the southwestern entrances to Prince William Sound (Figure 2). Recent harvests from the sac roe fisheries have occurred primarily in the northeast and north (Cedar, Granite, and Fairmount Bays) areas of Prince William Sound and along the northern shore of Montague Island.

A harvest policy framework has been established by the Alaska Board of Fisheries' Prince William Sound herring management plan (5 AAC 27.365). which allows for an exploitation rate ranging from 0% to 20% of the projected spawning biomass (Figure 3). Commercial fishing is not allowed if the spawning biomass is expected to be less than 8,400 tons. When the projected spawning biomass is between 8,400 and 42,500 tons, an exploitation rate between 0 and 20% is allowed. If the projected spawning biomass exceeds 42,500 tons, the exploitation rate is set at 20%. The allowable harvest of herring is allocated as follows: 16.3% to the fall food and bait fishery, 8% to the natural spawn-on-kelp fishery, 14.2% to the pound spawn-on-kelp fishery, 58.1% to the purse seine sac roe fishery, and 3.4% to the gillnet sac roe fishery.

Each year, the Alaska Department of Fish and Game collects an assortment of information about the Prince William Sound herring stock. Based on this information, the following year's spawning biomass is estimated. The purpose of this report is to document the methods used to derive the projected spawning biomass estimate on which the 1993 harvest quotas are based. The age-structured assessment (ASA) model of Funk and Sandone (1990) was revised and used to estimate the biomass of herring expected to return to spawn in 1993. The ASA model synthesizes most of the herring information collected for recent years into a single abundance forecast. The ASA approach differs from that used in previous years when the forecast was a choice among several differing sources of abundance information (aerial surveys, spawn deposition surveys etc.). The ASA model is also able to make use of the abundance information contained in the time series of age compositions of the catch and spawning population, which ADF&G has collected since the inception of the sac roe fishery.

METHODS

A graphical conceptual model illustrates the annual cycle of events affecting the Prince William Sound herring stock (Figure 4). Age indices are incremented at the end of winter, coinciding with the approximate time of annulus formation. The population model begins tracking herring cohorts at age 3, 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. Pound, purse seine sac roe, and gillnet sac roe fishery removals are then deducted to give the "naturally spawning biomass". Of the herring captured by the pound fishery, 50% are assumed to survive to become part of the "escapement biomass", which also includes all of the naturally spawning biomass. One-half of the annual natural mortality is assumed to occur between the time of spring spawning and the time of the fall food and bait fishery. The model allows for some recruitment of fish from the immature portion of the population to the fall food and bait fishery. The second half of the annual natural mortality is removed between the fall food and bait fishery and the following spring.

Data Sources

Information from seven sources is incorporated into the ASA model (Table 1). Information from the first five sources is used by the ASA model to evaluate goodness of fit. The latter two sources (food/bait and pound spawn on kelp catch-at-age) are used only for accounting purposes and not for inferences about abundance.

All of the information used by the ASA model is collected during the spring spawning period, except for the catch from the food and bait fishery. Beginning in late March ADF&G staff survey the coastline of Prince William Sound about twice weekly from small aircraft until a significant biomass of herring is observed. Once herring are sighted, daily aerial surveys are conducted when weather permits to measure the accumulation of herring biomass, to document herring distribution, and to map the observed miles of spawn. When the herring have completed spawning, ADF&G divers conduct spawn deposition surveys. Additional sampling is conducted to estimate the age, weight, length, and sex composition of the harvest and spawning population.

Number of Eggs Deposited

Spawn deposition surveys were conducted in 1983, 1984, and 1988-92. However, the 1983 spawn deposition survey was not used in the ASA model because it was considered a preliminary pilot study and did not cover all areas of Prince William Sound. In spawn deposition surveys, spawning beds are initially delineated from aerial survey records of milt sightings, and are sometimes refined by additional surveys from small vessels. Two-stage quadrat sampling along transects placed perpendicular to shore is used to expand estimates of the number of eggs in each quadrat to total eggs deposited. SCUBA divers' estimates of the number of eggs in each quadrat are corrected for diver error from a small number of training samples. Ten percent of the eggs are assumed to disappear from the spawning grounds due to wave action and predation, prior to the diving surveys. Because the 1988 spawn on wild kelp fishery occurred before the spawn deposition survey, the number of eggs harvested by the spawn on wild kelp fishery is added to the 1988 spawn deposition survey estimate. Prince William Sound spawn deposition survey methodology is described in more detail in Biggs and Funk (1988). The numbers of eggs deposited used in fitting the ASA model is given in Table 2.

Miles of Milt Index

The amount of milt deposited by male herring each year is often assumed to be approximately proportional to the mature biomass. ADF&G aerial herring surveys have routinely recorded the miles of shoreline adjacent to milt discolorations visible in the water since 1972 (Table 2). Data for 1978-91 were obtained from Donaldson et al. (1992), and data from 1972-77 and 1992 were obtained from unpublished ADF&G records (Evelyn Biggs, Alaska Department of Fish and Game, Cordova, personal communication).

These data do not reflect the number of days a particular shoreline mile was observed with milt (the "mile-days" index). The primary reason for incorporating milt information was to stabilize ASA abundance estimates for the 1970's. ASA abundance estimates for these early years are not well-stabilized by the more recent spawn deposition surveys. While the "mile-days" index may better represent abundance, the index unfortunately very strongly reflects the smaller number of days surveyed during the early years. The "miles of milt" index was felt to be more robust to changes in the number of days surveyed. Since 1987 the miles of milt index has apparently been erratic for unknown reasons. Only the 1972-87 observations were used for tuning the ASA model. Spawn deposition surveys have been conducted every year since 1988 and were used as the primary abundance index for tuning the ASA model from 1988-92.

Commercial Catch-at-Age, Age Composition and Weight at Age

ADF&G removes samples from commercial herring catches for determination of age, length, and weight. The numbers of fish in the harvest for each age ("catch at age"), is obtained by this information combined with total commercial catch weights for each gear. Commercial harvest weights for each gear are summarized by Donaldson et al. (1992) for 1969-1991. The 1992 harvest weights were obtained from unpublished preliminary catch summaries.

Average herring weight at age, computed from all samples combined, used for fitting the age-structured assessment model is given in Table 3. The harvest of herring by age for purse seine sac roe, gillnet sac roe, pound, and food and bait fisheries was tabulated for the 1973 to 1992 period (Tables 4 and 5). For the 1973-1987 period, the number of fish in the harvest was obtained from Sandone (1988). For 1988-1991, the harvest by age was obtained from the annual forecast document (Funk and Savikko 1989, 1990), Funk (1991), and Funk and Harris (1992). An estimate of the age composition of the harvest from spring 1992 fisheries was obtained from preliminary information from the 1992 fishery (John Wilcock, Alaska Department of Fish and Game, Cordova, personal communication). For the spawn on pound kelp fishery, the number of herring killed by the pound fishery was assumed to be 50% of the estimated amount captured. Observed numbers of fish in the catch for each gear were also converted to age composition (percent by age) for purse seine and gillnet catches, for comparison to age compositions estimated by the ASA model.

Age Composition of the Spawning Population

In addition to the time series of the catch by age, a relatively long time series of age compositions of the spawning population is available. Since 1984, specific efforts have been made to collect age samples from spawning herring. Such samples collected from the five area strata (southeast, northeast, north shore, Naked Island, and Montague Island) were weighted by the relative aerial survey biomass estimates from each area strata to obtain an overall age composition (Table 6). Sampling effort was lower for years prior to 1984, and spawning age compositions were reconstructed primarily from purse seine catch samples from each area, again weighted by the aerial survey estimate of biomass in each area. Sample sizes were judged to be too small in 1973, 1974-78, and 1980-81 to reliably construct estimates of spawning age composition.

Age Structured Assessment Model

The age structured assessment model estimates initial herring cohort sizes and other parameters which best fit the data from the five sources (eggs deposited, miles of milt, age composition of purse seine harvests, gillnet harvests, and spawning population), described in detail above. Given a set of estimates of initial cohort sizes, the model constructs the abundance of each cohort at every age (and equivalently of all cohorts in any one year) according to a survival model, which accounts for all sources of mortality from year to year. The model views observed sampling data as being drawn from this theoretical population, with some kind of bias specific to that data. For age composition samples, the bias (gear selectivity) is assumed to vary by age (but not year), and the model computes the parameters of a gear selectivity function which give the closest agreement between the theoretical population, viewed through the filter of gear selectivity, and the observed age composition samples.

The statistical approach to determining the best parameters for the information from the various data sources is similar to that used by Deriso et al. (1985). Nonlinear least squares techniques are used to minimize a sum of squares constructed from heterogeneous "auxiliary" information. While the primary goal was to use the model to forecast year-ahead abundance, the model also estimates the historical abundance time series, natural mortality, maturity, and gear selectivities for purse seine, gillnet, pound, and food and bait fisheries, and a coefficient which relates miles of milt observed in aerial surveys to spawning biomass.

The following assumptions are incorporated into the structure of the model:

1. Gillnet selectivity for all years can be described by a gamma function whose shape is determined by 2 parameters, to be estimated.

2. Purse seine selectivity from 1973-84 can be described by a gamma function whose shape is determined by 2 parameters, to be estimated.
3. Purse seine selectivity from 1985-92 can be described by a logistic function whose shape is determined by 2 parameters, to be estimated.
4. Availability of herring to the gear used to sample the spawning population for all years can be described by a logistic function whose shape is determined by 2 parameters, to be estimated.
5. By age 5, at least 95% of a herring cohort is available to the gear used to sample the spawning population in 1974, 1979, and 1982-92.
6. The proportion of herring dying as a result of causes not reflected in the commercial fishing catches is constant from age 3 to the oldest age
7. The number of miles of spawn was directly proportional to the abundance of mature males from 1972-87.
8. The proportion of males and females mature at age is described by the availability to the gear used to sample the spawning population.
9. The sex ratio observed in the gear used to sample the spawning population reflects the sex ratio of the spawning population.
10. Fecundity by age can be adequately specified by the function in Funk and Sandone (1990) and did not change substantially in 1984, 1988-92.
11. Measurement errors in each of the 5 data sources are independent.
12. The model is correctly specified with respect to the amount and type of available data such that parameter estimates are not correlated and differences between model estimates and observed values are caused by measurement error, not errors in correctly specifying mathematical forms of underlying processes.
13. Simultaneously minimizing the squared measurement errors from all five data sources provides the best estimate of the true parameter values, where purse seine, gillnet and spawning age compositions are arc sine transformed, milt index and egg deposition errors are log transformed, and error terms are scaled and weighted as described below.

Some of the assumptions (e.g. 1-4) control the type of curvature in relationships among quantities in the model. Assumption 5 further constrains the maturity age relationship to be greater than a specific value (0.95) at a specific age. Assumptions 6 and 7 are probably oversimplifications of the natural processes, but are required for the crucial assumption 12 to hold. The last assumption is the crux of the rationale for the ASA model. Because the model fits data measured in different units which may be of varying utility in identifying true parameter values, there is not a rigorous statistical theory underlying the parameter estimation procedure, such as exists for linear least squares. The intuitive rationale for this last assumption follows from the notion that the "best" parameter estimates should "fit" all of the observed data reasonably well. The goodness of fit approach taken here borrows from conventional least squares procedures as much as possible. For example, observed data are transformed where necessary to achieve symmetric and approximately normal error distributions, although the robustness of the parameter estimates to departures from normality is not known.

Survival Model

The survival model accounts for the processes depicted in the conceptual model (Figure 4) with a difference equation to describe the number of fish in the ($\hat{N}$) in a cohort aged a in year y:

$$\hat{N}_{a+1,y+1} = \hat{S}_2\left[\hat{S}_1\left(\hat{N}_{a,y} - C_{a,y}^{spring}\right) - C_{a,y}^{fall}\right], \quad (1)$$

where $\hat{S}_1$ and $\hat{S}_2$ are the first and second half-year survival rates (assumed identical) to be estimated by the ASA model, $C_{a,y}^{spring}$ is the catch from the spring purse seine and gillnet sac roe fisheries and 50% of the amount captured in the pound fishery, and $C_{a,y}^{fall}$ is the catch in the fall food and bait fishery. The number of fish in a cohort ($\hat{N}$) includes both mature and immature herring measured at a time after annulus formation but before the spawning run or spring roe fisheries (the "total population" of Figure 4). The model begins tracking herring at age 3 and pools herring aged 9 and older into a single "9+" category.

Unlike some other formulations of catch-age models, the observed catch-at-age is deducted from the survivors in equation 1, rather than an estimated catch-at-age. The model does not explicitly compute an estimated catch-at-age; the estimated age composition of the catch is computed solely for comparison to observed age composition of the catch as one of measure goodness of fit. In so doing, this model is able to avoid estimating an exploitation rate parameter for each year. Estimation of exploitation rates seems to be of little value, but the nagging problem of correlations between exploitation rates and abundance estimates (Hilborn and Walters 1992) has plagued many attempts at age-structured analysis which use a formulation that includes estimating exploitation rates.

The model estimates initial cohort sizes for age 3 herring in every year from 1973-92 and for age 4, 5, and 6 herring in 1973. Given an initial cohort size estimate (e.g.$\hat{N}_{3,y}$) and a survival rate estimate $\hat{S}$, the abundance of the cohort in all other years is specified by equation 1 (Table 7). The objective of the model is to determine the initial cohort sizes which, after computing cohort abundances for all years, best fit the observed data. Because cohort abundance is not observed directly, other parameters such as gear selectivities must also be estimated to attempt to account for the biases imposed by not being able to directly observe cohort abundance. Given the available data, we have chosen to indirectly observe cohort abundance by examining the number of eggs deposited, the amount of milt deposited, the age composition of the purse seine and gillnet commercial catches, and the age composition of the spawning population.

Comparison to Measures of Abundance from Observations of Spawning Herring

The number of eggs which were spawned "naturally" (not in herring impoundments) each year y was estimated using:

$$\hat{Eggs}_y^{ASA} = \sum_a R_y^{♀} \left[\rho(a) \cdot \hat{N}_{a,y} - C_{a,y}^{Spring} \right] \cdot f(a) \cdot 10^{-6} , \tag{2}$$

where $R_y^{♀}$ is the female sex ratio (proportion of females) estimated from spawning population samples (Table 6), $\rho(a)$ is the proportion mature at age a to be estimated by the ASA model, and $f(a)$ is the fecundity of a female herring at age (Table 6) taken from the function given in Funk and Sandone (1990). The fit of the ASA model's estimate of the numbers of eggs deposited to those observed during spawn deposition surveys was measured by:

$$SSQ_{eggs} = \sum_y \frac{1}{Var(Eggs_y^{Survey})} \cdot \left[\log_e \left(Eggs_y^{Survey} \right) - \log_e \left(Eggs_y^{ASA} \right) \right]^2 . \tag{3}$$

Because the variance of the egg deposition survey estimates varied considerably from year to year, the residual from each year was weighted by the inverse of this variance. The logarithmic transformation was used because the lognormal is an appropriate error distribution for most abundance measures.

The miles of milt expected to be deposited by the number of herring specified by the survival model ($\hat{N}$), was estimated by:

$$\hat{Miles}_y^{ASA} = \sum_a \frac{1}{\alpha} \left[R_y^{♂} \cdot w_a \cdot \rho(a) \cdot \hat{N}_{a,y} \right], \tag{4}$$

where α is the tonnes of mature male herring required to produce one mile of milt (to be estimated), $R_y^{♂}$ is the male sex ratio ($1 - R_y^{♀}$), and w_a is the weight at age (Table 3). Note that this assumes that miles of milt is directly proportional to mature male biomass. A goodness of fit measure for miles of milt was developed by assuming:

$$SSQ_{Milt} = \sum_y \left[\log_e \left(Miles_y^{survey} \right) - \log_e \left(Miles_y^{ASA} \right) \right]^2 , \tag{5}$$

where $Miles_y^{survey}$ is the aerial estimate of milt in year y. The log transformation was used because residuals from preliminary runs of the model were approximately lognormally distributed.

Comparisons to Observed Age Compositions

Estimated Age Compositions. Age compositions ($\hat{p}_{a,y}$) were computed from the ASA model's estimates of abundance ($\hat{N}_{a,y}$) for comparison to observed age compositions using:

$$\hat{p}_{a,y} = \frac{s(a) \cdot \hat{N}_{a,y}}{\sum_{a} \left[s(a) \cdot \hat{N}_{a,y} \right]}, \tag{6}$$

where *s(a)* is a function describing how the proportion of the total population available to the gear changes with age. Parameters determining the shape of *s(a)* are estimated by the ASA model. Three sets of age composition data were computed, using four selectivity functions which allowed comparison to observed purse seine age compositions, gillnet age compositions, and spawning population age compositions.

Gear Selectivity. Gear selectivity is defined here 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 fishermen's behaviour. Gear selectivity is allowed to be different for each gear. Two-parameter functions were used to describe the relationship between gear selectivity and age. Two-parameter functions were used because it is desirable to minimize the number of parameters estimated by the model and 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. A logistic function was used for gears which were thought to have asymptotic selectivities; a gamma-type function was used for gears where selectivity might decrease at the older ages.

Residuals from initial runs of the model showed that seine selectivity changed after the 1984 season. Prior to 1984, selectivity tended to decline for old ages, while after 1984, selectivity did not decline for old ages. To allow for a "dome-shaped" relationship between selectivity s and age a for years 1973-84, the gamma-type function of Deriso et al. (1985) was used:

$$s(a) = \frac{a^{\theta_1} e^{-(\theta_2 \cdot a)}}{\max_{j} \left[j^{\theta_1} e^{-(\theta_2 \cdot j)} \right]}, \tag{7}$$

where θ_1 and θ_2 are the two parameters to be estimated, and the subscript j ranges over all ages. The denominator of the expression merely scales the values of the function to one at the age of maximum selectivity.

For 1985 and subsequent years, a two parameter logistic function was used for purse seine gear:

$$s(a) = \frac{1}{1 + e^{-\theta_2(a - \theta_1)}}, \tag{8}$$

where θ_1 and θ_2 are the two parameters to be estimated. For this logistic function, θ_1 is the age of 50% selectivity, and θ_2 is a steepness parameter whose value is 4 times the maximum slope, which occurs at age θ_1.

Gillnets are known to have reduced selectivity for small and large size herring. The gamma-type function (equation 7) was used to represent gillnet selectivity because it allows for an asymmetrical domed shape.

A logistic function (equation 8) was also used to describe the selectivity of the gears used to estimate the age composition of the spawning population. This relationship was also used as the maturity function $\rho(a)$ for comparing ASA model abundances to eggs spawned (equation 2) and milt deposited (equation 4). The maturity-age relationship was assumed to be independent of time in the model. The validity of this assumption was investigated by examining residuals for milt surveys, spawn deposition surveys, and spawning age compositions for time trends over the duration of the model, which might indicate consistent shifts in the maturity-age relationship.

Initial values for selectivity function parameters for purse seine and gillnet gears and for the maturity function were chosen to give selectivities similar to those in Funk and Sandone (1990).

Comparing Observed and Estimated Age Compositions. Parameter estimation from age compositions is based on the assumption that observed age composition data are measured with error:

$$\hat{p}^{ASA}_{a,y} = p^{OBSERVED}_{a,y} + \varepsilon_{a,y} , \tag{9}$$

where the ε are assumed normally distributed. Because age composition data are proportions, it was found that residuals were more closely normal after an arcsin transformation. The sensitivity of the parameter estimation procedure to departures from normality was not investigated. Residuals were examined to assure reasonable compliance with normality.

Based on equation 9, the measure of goodness of fit for age compositions of the commercial catch data was

$$SSQ_{agecomp:catch} = \sum_y \omega_y \sum_a \left[\sin^{-1}\left(\frac{C_{a,y}}{\sum_a C_{a,y}} \right) - \sin^{-1}(\hat{p}_{a,y}) \right]^2 , \qquad (10)$$

where ω_y was a weighting factor which gave more weight to years with larger age composition sample sizes (Table 4). The ω_y was computed for each gear by dividing the number of fish in age composition samples for year y by the number of fish in age composition samples for all years. A sum of squares was computed separately for gillnet and purse seine gears, using equation 10, where $\hat{p}_{a,y}$ was the estimated age composition from equation 6, and $C_{a,y}$ was the observed catch for the appropriate gear.

The goodness of fit measure for the age composition of the spawning population was:

$$SSQ_{agecomp:spawning} = \sum_y \sum_a \left[\sin^{-1}\left(p_{a,y}^{spawn} \right) - \sin^{-1}(\hat{p}_{a,y}) \right]^2 , \qquad (11)$$

where $p_{a,y}^{spawn}$ are the age compositions observed in samples of the spawning population (Table 6).

The starting value for the survival rate was 64%, equivalent to the 0.45 midpoint of the instantaneous natural mortality rate range used by Funk and Sandone (1990). Starting values for abundances at age 3 for the 1973-92 year classes and for the abundance of age 4, 5, and 6 herring in 1973 were determined by examining the fit of egg deposition, miles of milt and age composition data by eye. The number of herring aged 7, 8, and "9+" in 1973 could not be reliably estimated by the model because there was too little auxiliary information about these year classes before they aged out of the population. As a result, initial cohort sizes for these year classes were set so their proportions at age exactly matched those of the age 7, 8, and "9+" purse seine age compositions in 1973. None of the available data indicate that these cohorts were abundant and therefore this procedure has very little effect on other parts of the model.

Year-Ahead Biomass Projection

The forecast of the biomass of mature herring for 1993 ($B_{1993}^{forecast}$) results from projecting the total abundance with the survival model (equation 1), reduced by the ASA estimate of the proportion mature at age ($\rho(a)$), and multiplied by the 1985-1992 average weight at age (w_a) from Table 3:

$$B_{1993}^{Forecast} = \sum_a \rho(a)\ w_a\ \hat{N}_{a,1993}\ , \tag{12}$$

The size of the 1990 year class ($\hat{N}_{3,1993}$) is specified as the median of the year class sizes at age 3 for the 1970 to 1989 year classes estimated by the ASA model. The effect of this assumption on the forecast biomass is moderated by the fact that only a small proportion of herring are mature at age 3 in Prince William Sound.

Parameter Estimation

The ASA model determines best estimates for its parameters by simultaneously minimizing the squared deviations of model predictions from observed data from each of the five sources. A total sum of squares was computed as a weighted sum of the component for each data source:

$$SSQ_{Total} = \sum_{i=1}^{5} \left(\phi_i\ SSQ_i\right) \tag{13}$$

where the ϕ's are used to scale the SSQ's to a common range. Because the variance of the aerial milt survey was unknown, an inverse variance weighting scheme could not be used. The ϕ'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 approximately the same effect on the total SSQ when λ's were equal. No additional weighting scheme was used so that each data source had approximately equal influence on the final parameter estimates.

The model estimates a total of 33 parameters: 23 initial cohort sizes, 8 gear selectivity function parameters (θ's), one survival rate parameter (S), and one proportionality coefficient (α) for the milt index. The four SSQ equations refer to 350 data observations. Therefore there would be 317 degrees of freedom and the data/parameter ratio is approximately 11. 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 in equation 12. Parameter values manipulated

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

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.

RESULTS AND DISCUSSION

For all reasonable guesses at parameter starting values, the estimation procedure converged to approximately the same minimum on the SSQ_{total} response surface. The small differences in parameter values among different runs can likely be attributed to shallow response surfaces coupled with the stopping criterion used by the numerical method. The final sums of squares are given in Table 8.

The estimated survival rate of 68% (equivalent to an instantaneous rate of 0.39) was slightly higher than the midpoint of the range used by Funk and Sandone (1990). The milt survey coefficient was estimated to be 350.4 tonnes of spawning male herring per mile of milt observed. Estimates of initial cohort sizes and gear selectivity function parameters at the solution are given in Table 9. The 1993 forecast biomass is 121,684 tonnes (134,133 short tons).

The ASA biomass estimates are relatively low (20,000-40,000 t.) during the 1970's and increase to higher levels (50,000-110,000 t.) in the 1980's. (Figure 5). The ASA biomass estimate followed the general trends of the aerial milt survey, but did not follow the trends of the spawn deposition survey biomass estimates. In general, the age composition data was not consistent with the spawn deposition survey biomass estimates and the model fit the year class trends in the age composition data, while scaling the biomass to a "smooth" of recent spawn deposition survey biomass estimates. While the strong 1984 year class began dominating the age compositions in 1987 (Table 6), the spawn deposition biomass did not increase until 1990. The cause for this discrepancy is unknown, but it may indicate that spawn survey measurement error is much greater than anticipated. The design goal for spawn deposition surveys was a precision such that 95% confidence intervals for the true biomass would be +/- 25% of the estimated value. Spawn deposition survey biomass absolute deviations from the ASA biomass estimate averaged 48%. Deviations in individual years ranged from -52% in 1989 to +92% in 1991.

Year class strength in Prince William Sound is characterized by occasional years of very strong recruitment (Figure 6). The size of herring year classes at age three has ranged from the 2.147 billion herring of the 1988 year class to 24.6 million of the 1986 year class. Beginning with the 1976 year class, strong year classes have occurred every four years. The relationship between spawning biomass and resulting recruits is not well defined (Figure 6, bottom), so that the strong year classes have resulted from a wide range of spawning stock sizes.

The Appendix shows residuals and other details of the fit of the ASA model to the SSQs for age composition of the purse seine and gillnet catches and the age composition of the spawning population. All residuals were reasonably symmetrically distributed about a zero mean. No consistent year or age trends were evident in the catch-age composition residuals.

Because the 1993 spawning biomass is projected to exceed 42,500 tons, the 1993 allowable harvest is determined using the maximum exploitation rate of 20%. The allowable harvest for the 1993 management year is 26,827 tons of herring. Following the allocations specified in the management plan, the fall 1993 food and bait herring fishery is allocated 4,373 tons of herring, the 1993 wild spawn-on-kelp fishery is allocated 2,146 tons of herring (equivalent to 268 tons of spawn-on-kelp product), the 1993 pound spawn-on-kelp fishery is allocated 3,809 tons of herring (equivalent to 305 tons of spawn-on-kelp product), the 1993 purse seine sac roe fishery is allocated 15,586 tons, and the 1993 gillnet sac roe fishery is allocated 912 tons (Table 10).

LITERATURE CITED

Biggs, E.F., and F. C. Funk. 1988. Pacific herring spawn deposition surveys for Prince William Sound, 1988, with historic overview. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2C88-07, Anchorage.

Dahlgren, E.H., and L.N. Kolloen. 1943. Outlook for the Alaska herring fishery in 1943. U.S. Fish and Wildlife Service, Fishery Leaflet 16.

Dahlgren, E.H., and L.N. Kolloen. 1944. Outlook for the Alaska herring fishery in 1944. U.S. Fish and Wildlife Service, Special Scientific Report 25.

Deriso, R.B., T.J. Quinn II, and P.R. Neal. 1985. Catch-age analysis with auxiliary information. Canadian Journal of Fisheries and Aquatic Sciences 42:815-824.

Donaldson, W., S. Morstad, E. Simpson, and E. Biggs. 1992. Prince William Sound management area 1991 annual finfish management report. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A92-09, Anchorage.

Funk, F. 1991. Preliminary forecasts of catch and stock abundance for 1991 Alaska herring fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J91-03, Juneau.

Funk, F. and M. Harris. 1992. Preliminary forecasts of catch and stock abundance for 1992 Alaska herring fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J92-04, Juneau.

Funk, F.C., and G.J. Sandone. 1990. Catch-age analysis of Prince William Sound, Alaska, herring, 1973-1988. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin 90-01, Juneau.

Funk, F., and H. Savikko. 1989. Preliminary forecasts and projections for 1989 Alaska herring fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J89-02, Juneau.

Funk, F., and H. Savikko. 1990. Preliminary forecasts of catch and stock abundance for 1990 Alaska herring fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J90-02, Juneau.

Hilborn, R., and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.

Kolloen, L.N., and C.H. Elling. 1948. Outlook for the Alaska herring fishery in 1948. U.S. Fish and Wildlife Service, Special Scientific Report 52.

Megrey, B.A. 1989. Review and comparison of age-structured stock assessment models from theoretical and applied points of view. American Fisheries Society Symposium 6: 8-48.

Reid, G.M. 1971. Age composition, weight, length, and sex of herring, Clupea pallasii, used for reduction in Alaska, 1929-66. NOAA Technical Report NMFS SSRF 634, Seattle.

Rounsefell, G.A., and E.H. Dahlgren. 1935. Fluctuations in the supply of herring, Clupea pallasii, in Prince William Sound, Alaska. Bulletin of the U.S. Bureau of Fisheries 47:263-291.

Sandone, G.J. 1988. Estimated age-class contribution of Pacific herring to the commercial sac roe harvests of Prince William Sound, 1973-87. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A88-18, Anchorage.

Table 1. Sources of information incorporated into the age structured assessment model used to forecast the abundance of Prince William Sound herring in 1993.

Information	Source(s)	Years Used
1. Number of Eggs Deposited	Spawn deposition surveys	1984, 1988-92
2. Miles of milt index	Aerial milt surveys	1972-87
3. Purse seine catch-at-age and age composition	Fish tickets, Commercial catch samples	1973-88, 1990-92
4. Gillnet catch at age and and age composition	Fish tickets, Commercial catch samples	1974, 1977-78, 1980-88, 1990-92
5. Spawning age composition	Commercial seine catch samples ADF&G test fishing	1974, 1979, 1982-92
6. Food/bait catch-at-age	Fish tickets, Commercial catch samples	1978-91
7. Number killed by age by pound spawn on kelp fishery	Fish tickets, Commercial catch samples	1980-88, 1990-92

Table 2. Herring eggs deposited, as assessed by spawn deposition surveys, and miles of spawn, from aerial milt surveys, used for fitting the age-structured assessment model for Prince William Sound herring.

Year	Eggs Deposited (Trillions)	Miles of Spawn
1972		60.00
1973		42.50
1974		38.50
1975		34.20
1976		31.90
1977		39.25
1978		28.65
1979		54.50
1980		50.50
1981		85.30
1982		48.95
1983		67.35
1984	4.60	60.10
1985		101.20
1986		72.35
1987		65.25
1988	3.73	166.35
1989	3.13	98.40
1990	7.64	94.10
1991	8.99	58.00
1992	7.72	74.70

Table 3. Weight (grams) at age for Prince William Sound herring, 1972-1992.

Year	AGE 3	4	5	6	7	8	9+
1972	69.0	93.5	115.5	134.2	149.6	162.0	171.7
1973	69.0	97.6	124.2	142.0	149.0	162.0	185.1
1974	69.0	101.0	129.0	148.0	149.6	162.0	171.7
1975	69.8	96.8	114.1	154.0	149.6	162.0	171.7
1976	61.9	83.5	107.5	123.9	138.2	162.0	171.7
1977	66.0	85.0	110.0	130.0	142.0	160.0	171.7
1978	54.0	80.0	91.0	98.0	119.0	162.0	173.9
1979	74.3	76.2	103.5	134.2	149.6	162.0	171.7
1980	78.8	98.2	106.1	134.2	149.6	162.0	171.7
1981	69.0	100.0	111.5	134.2	149.6	162.0	171.7
1982	60.0	80.0	115.0	136.0	136.0	162.0	171.7
1983	84.5	100.8	125.8	144.0	153.8	159.4	171.7
1984	73.2	90.1	107.3	127.6	152.3	166.8	173.0
1985	82.2	107.0	124.3	138.8	159.5	177.1	185.3
1986	86.2	101.6	126.2	138.2	156.3	170.8	189.5
1987	76.0	100.0	121.0	140.0	155.0	163.0	188.5
1988	58.7	89.8	107.6	135.1	151.6	165.0	190.4
1989	71.3	88.4	112.6	131.8	156.2	170.2	187.6
1990	45.5	91.0	113.9	130.7	142.4	165.3	183.2
1991	65.9	79.3	119.0	129.4	141.5	154.5	176.5
1992	67.5	87.9	89.2	116.2	134.5	143.9	161.4
1993[a]	69.2	93.1	114.2	132.5	149.6	163.7	183.6

[a] An average of 1985-92 weights was used to forecast the 1993 weights at age.

Table 4. Observed catch (millions of fish), number of fish sampled, and weights assigned to annual age compositions (ω_y) for purse seine ("Seine") and gillnet sac roe fisheries.

Gear	Year	AGE 3	4	5	6	7	8	9+	Sample Size	Weights (ω_y)
Seine	1973	45.155	7.400	10.361	6.496	2.039	0.151	0.076	567	0.015
Seine	1974	1.314	43.346	5.655	3.001	0.581	0.036	0.000	890	0.023
Seine	1975	4.242	26.900	21.744	1.408	0.060	0.000	0.000	1,198	0.031
Seine	1976	2.407	5.751	6.001	8.544	2.171	0.444	0.074	300	0.008
Seine	1977	1.345	1.543	4.114	3.323	5.617	0.791	0.237	429	0.011
Seine	1978	0.801	3.060	3.511	2.726	1.530	0.682	0.201	412	0.011
Seine	1979	41.971	4.707	1.457	0.440	0.264	0.196	0.000	862	0.022
Seine	1980	6.942	42.742	6.153	0.527	0.501	0.000	0.000	511	0.013
Seine	1981	2.501	22.205	82.129	7.757	0.998	0.000	0.000	237	0.006
Seine	1982	10.206	9.323	11.089	23.062	4.809	0.294	0.000	605	0.016
Seine	1983	2.481	1.629	1.815	2.932	8.426	0.697	0.123	814	0.021
Seine	1984	10.841	22.813	5.750	3.299	4.148	3.017	0.566	1,337	0.035
Seine	1985	2.059	11.874	17.487	6.382	2.912	2.022	6.084	1,861	0.048
Seine	1986	2.700	4.168	19.276	21.454	5.115	1.989	5.873	5,645	0.146
Seine	1987	5.028	2.637	3.227	10.032	8.397	1.117	1.974	3,656	0.094
Seine	1988	0.796	45.991	3.921	2.128	6.337	3.931	1.561	6,685	0.173
Seine	1989								0	
Seine	1990	0.000	0.164	5.005	38.708	4.477	2.670	3.937	3,669	0.095
Seine	1991	10.547	1.832	0.909	6.980	51.339	4.163	6.645	6,779	0.175
Seine	1992	0.767	77.792	2.097	1.967	6.771	40.614	2.575	2,248	0.058
Gillnet	1974	0.000	0.019	0.006	0.004	0.001	0.000	0.000	119	0.017
Gillnet	1975								0	
Gillnet	1976								0	
Gillnet	1977	0.001	0.001	0.003	0.003	0.003	0.000	0.000	325	0.046
Gillnet	1978	0.032	0.160	0.162	0.083	0.076	0.039	0.012	223	0.031
Gillnet	1979								0	
Gillnet	1980	0.000	0.162	0.216	0.622	0.474	0.135	0.027	121	0.017
Gillnet	1981	0.000	0.011	0.742	0.502	0.274	0.103	0.023	145	0.020
Gillnet	1982	0.000	0.135	0.376	1.619	0.337	0.106	0.000	267	0.038
Gillnet	1983	0.003	0.009	0.027	0.092	0.412	0.049	0.009	197	0.028
Gillnet	1984	0.000	0.023	0.114	0.308	0.644	0.731	0.146	493	0.069
Gillnet	1985	0.000	0.088	0.656	0.456	0.228	0.251	0.688	509	0.072
Gillnet	1986	0.004	0.023	0.474	1.080	0.376	0.174	0.418	1,971	0.277
Gillnet	1987	0.000	0.000	0.092	0.799	1.086	0.374	0.651	586	0.082
Gillnet	1988	0.000	0.037	0.071	0.162	0.676	0.608	0.355	565	0.079
Gillnet	1989								0	
Gillnet	1990	0.000	0.020	0.194	1.583	0.282	0.523	0.555	409	0.058
Gillnet	1991	0.000	0.000	0.041	0.255	3.373	0.224	0.357	417	0.059
Gillnet	1992	0.000	0.072	0.022	0.079	0.575	4.324	0.438	767	0.108

Table 5. Observed catch or utilization (millions of fish), and number of fish sampled for pound and food and bait ("Bait") fisheries. Pound fishery mortality was assumed to be 50% of the utilization.

Gear	Year	AGE 3	4	5	6	7	8	9+	Sample Size
Pound	1980	0.021	0.222	0.024	0.000	0.000	0.000	0.000	77
Pound	1981	0.008	0.135	0.617	0.103	0.055	0.016	0.000	118
Pound	1982	0.314	0.412	0.368	0.888	0.188	0.000	0.000	244
Pound	1983	0.441	0.308	0.106	0.239	0.597	0.060	0.014	384
Pound	1984	0.575	1.047	0.347	0.119	0.109	0.136	0.011	432
Pound	1985	0.241	0.899	1.126	0.319	0.070	0.129	0.261	1,090
Pound	1986	0.302	0.667	1.643	1.460	0.274	0.028	0.330	670
Pound	1987	6.057	0.647	0.327	0.705	0.385	0.072	0.122	2,324
Pound	1988	0.207	12.535	0.725	0.208	0.570	0.414	0.130	577
Pound	1989								0
Pound	1990	0.156	0.026	0.675	6.836	0.445	0.327	0.645	1,475
Pound	1991	1.009	0.256	0.228	1.479	11.909	0.988	1.402	430
Pound	1992	0.022	9.775	0.396	0.374	0.947	6.869	1.035	882
Bait	1978	4.180	2.264	1.553	0.909	0.281	0.079	0.020	739
Bait	1979	4.122	0.592	0.357	0.168	0.022	0.011	0.000	704
Bait	1980	4.541	6.327	1.877	1.075	0.530	0.091	0.000	170
Bait	1981	2.198	3.578	3.731	1.789	0.409	0.562	0.064	407
Bait	1982	0.000	1.263	1.579	3.332	1.687	0.208	0.208	79
Bait	1983	1.174	1.228	0.265	0.120	0.040	0.026	0.000	216
Bait	1984	1.177	4.372	2.744	1.259	0.348	0.133	0.133	611
Bait	1985	2.806	3.798	2.388	1.331	0.679	0.196	0.157	2,475
Bait	1986	2.816	3.275	3.183	1.650	0.812	0.485	0.196	1,258
Bait	1987	6.461	2.175	1.667	0.448	0.132	0.013	0.000	1,125
Bait	1988	2.821	4.994	1.828	1.033	0.464	0.199	0.119	536
Bait	1989	0.931	1.394	1.920	0.353	0.237	0.053	0.011	418
Bait	1990	1.215	0.994	2.859	4.945	0.393	0.123	0.037	1,504
Bait	1991	30.554	0.991	0.526	1.238	2.477	0.093	0.062	1,607

Table 6. Observed spawning population age composition and sex ratio estimates used for the ASA model, taken from age-weight-length samples by area, weighted by the aerial survey estimate of biomass by area, and estimates of fecundity at age from Funk and Sandone (1990).

	AGE							
Year	3	4	5	6	7	8	9+	Percent Female
1972								50.0%
1973								50.0%
1974	1.3%	68.4%	17.8%	10.3%	2.1%	0.2%	0.0%	50.0%
1975								50.0%
1976								50.0%
1977								50.0%
1978								50.0%
1979	80.4%	12.0%	4.5%	1.8%	1.0%	0.3%	0.0%	50.0%
1980								50.0%
1981								50.0%
1982	16.7%	17.2%	18.7%	39.4%	7.7%	0.3%	0.0%	50.0%
1983	16.2%	12.4%	11.0%	16.9%	39.7%	3.3%	0.6%	50.0%
1984	26.9%	44.9%	12.7%	4.8%	5.4%	4.6%	0.6%	51.5%
1985	5.1%	24.6%	35.4%	13.2%	5.4%	4.3%	11.9%	50.0%
1986	11.0%	11.0%	32.1%	29.5%	6.8%	2.1%	7.5%	50.0%
1987	35.2%	8.4%	7.9%	23.7%	17.5%	3.2%	4.1%	50.0%
1988	1.8%	79.5%	5.5%	2.7%	5.2%	3.7%	1.6%	52.7%
1989	0.6%	7.6%	80.2%	4.4%	1.9%	2.8%	2.3%	44.1%
1990	0.7%	0.7%	9.0%	72.0%	7.4%	3.8%	6.4%	48.4%
1991	28.8%	2.3%	1.0%	7.2%	51.8%	3.9%	5.1%	44.6%
1992	0.7%	64.7%	3.3%	0.8%	3.6%	24.2%	2.7%	43.1%
Fecundity:	11,486	13,970	18,996	22,955	25,329	26,608	27,264	

Table 7. Diagram of the scheme used by the ASA survival model (equation 1) to project the abundances of cohorts at all ages, given estimates of the initial abundances (N) of the cohorts. Initial 1973 abundances were projected backwards to 1972 only for comparison to the milt index in 1972. Bold-faced letters designate parameters estimated by the model. Abundance at ages 7, 8, and 9+ in 1973 were specified using the model's parameter estimates for ages 3-6 in 1973 and the 1973 purse seine age composition.

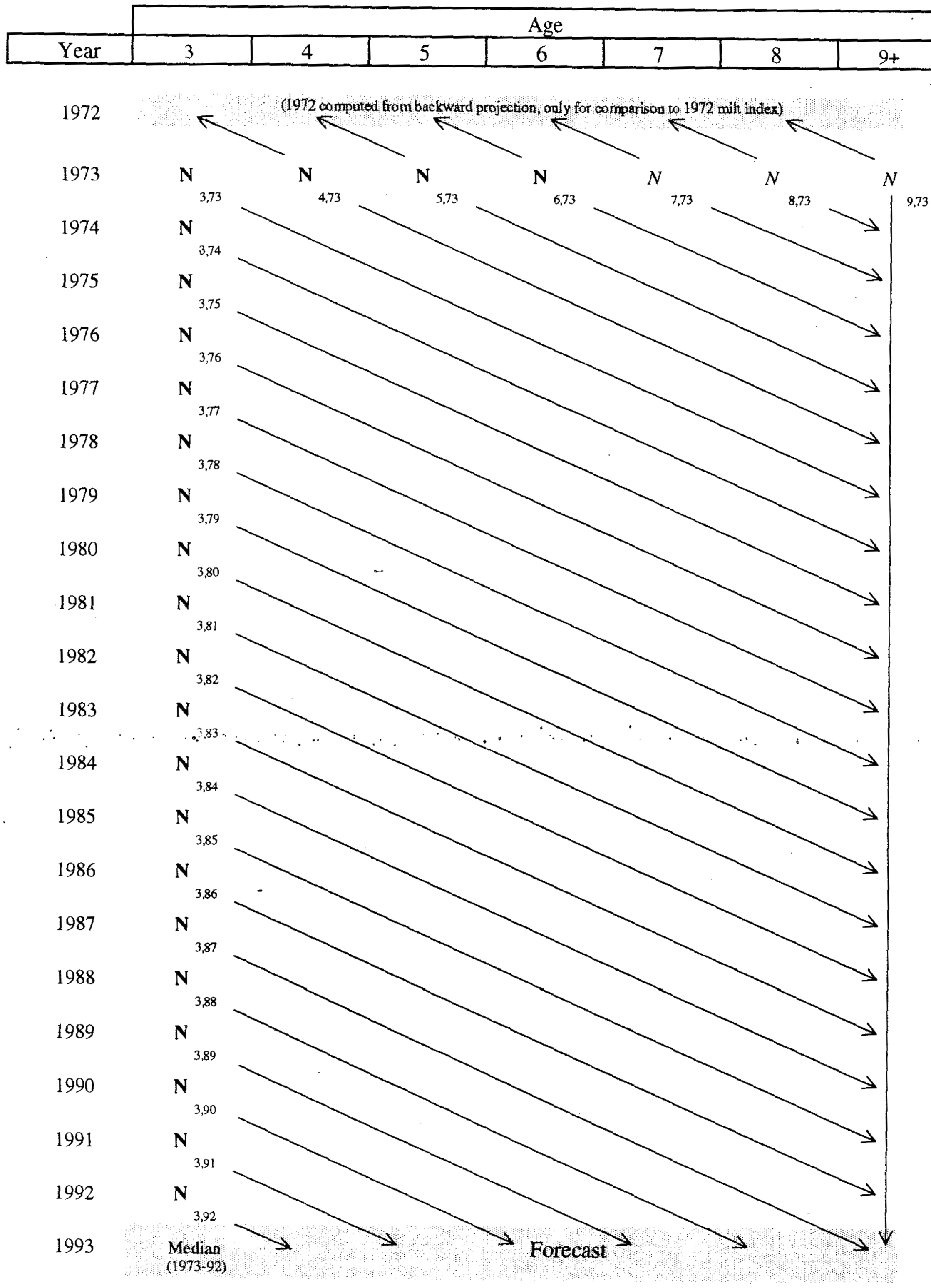


Table 8. Summary of the final sums of squares used for the ASA model.

Component	Data Source	N	Unscaled Sum of Squares	Scaling Coefficient	Scaled Sum of Squares
SSQ_{eggs}	Spawn Survey	5	1.0261	1.0	1.0261
SSQ_{milt}	Aerial Milt Survey	16	0.6982	1.4	0.9775
$SSQ_{agecomp:seine}$	Catch Sampling	133	0.0477	19.0	0.9066
$SSQ_{agecomp:gillnet}$	Catch Sampling	105	0.1010	10.0	1.0102
$SSQ_{agecomp:spawn}$	Misc. Sampling	91	1.3743	0.7	0.9620
TOTAL:		350			4.8825

Table 9. Initial cohort sizes and selectivity function parameters estimated by the ASA model for Prince William Sound herring.

Initial Cohort Sizes

	AGE						
YEAR	3	4	5	6	7	8	9
1973	353.91	51.17	73.96	99.98	17.01	1.26	0.63
1974	130.28						
1975	116.67						
1976	110.33						
1977	81.85						
1978	146.42						
1979	889.64						
1980	245.65						
1981	136.31						
1982	187.98						
1983	480.55						
1984	362.42						
1985	103.35						
1986	127.34						
1987	1,516.30						
1988	179.98						
1989	24.66						
1990	57.87						
1991	2,146.63						
1992	83.80						

Selectivity Function	Function Type	Parameter Estimates θ_1	Parameter Estimates θ_2
Purse Seine (1973-84)	Gamma	3.037	-9.310
Purse Seine (1985-92)	Logistic	4.241	2.738
Gill Net	Gamma	12.766	2.381
Spawning Age Composition (Maturity)	Logistic	3.673	2.218

Table 10. Harvest quota allocations in short tons by fishery, based on the 1993 Prince William Sound herring forecast of 134,133 short tons (121,684 tonnes).

Fishery	Allocation	Quota (short tons)
Purse Seine	58.1%	15,586
Gillnet	3.4%	912
Spawn on Pound Kelp	14.2%	3,809
Spawn on Wild Kelp	8.0%	2,146
Food and Bait	16.3%	4,373
Total	100.0%	26,827 = 20% of 134,133 short tons

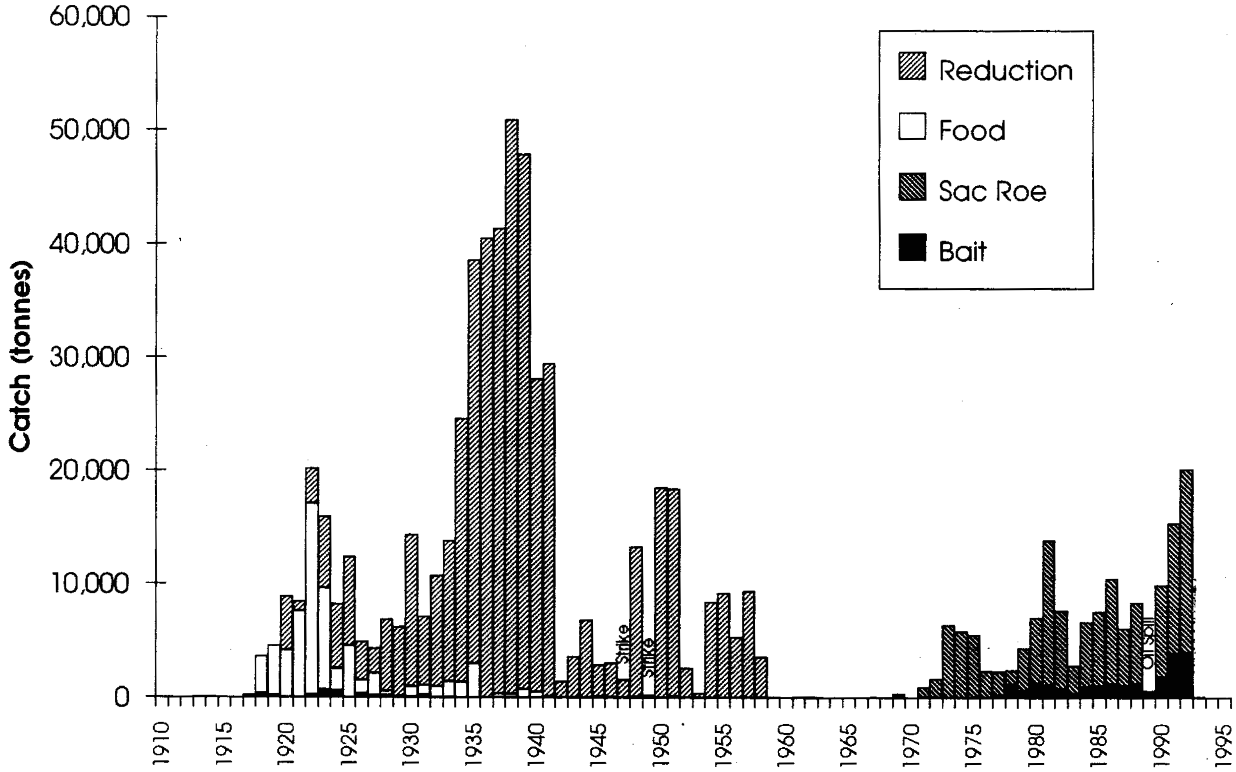


Figure 1. Prince William Sound herring catch (tonnes) by fishery, 1910-92.

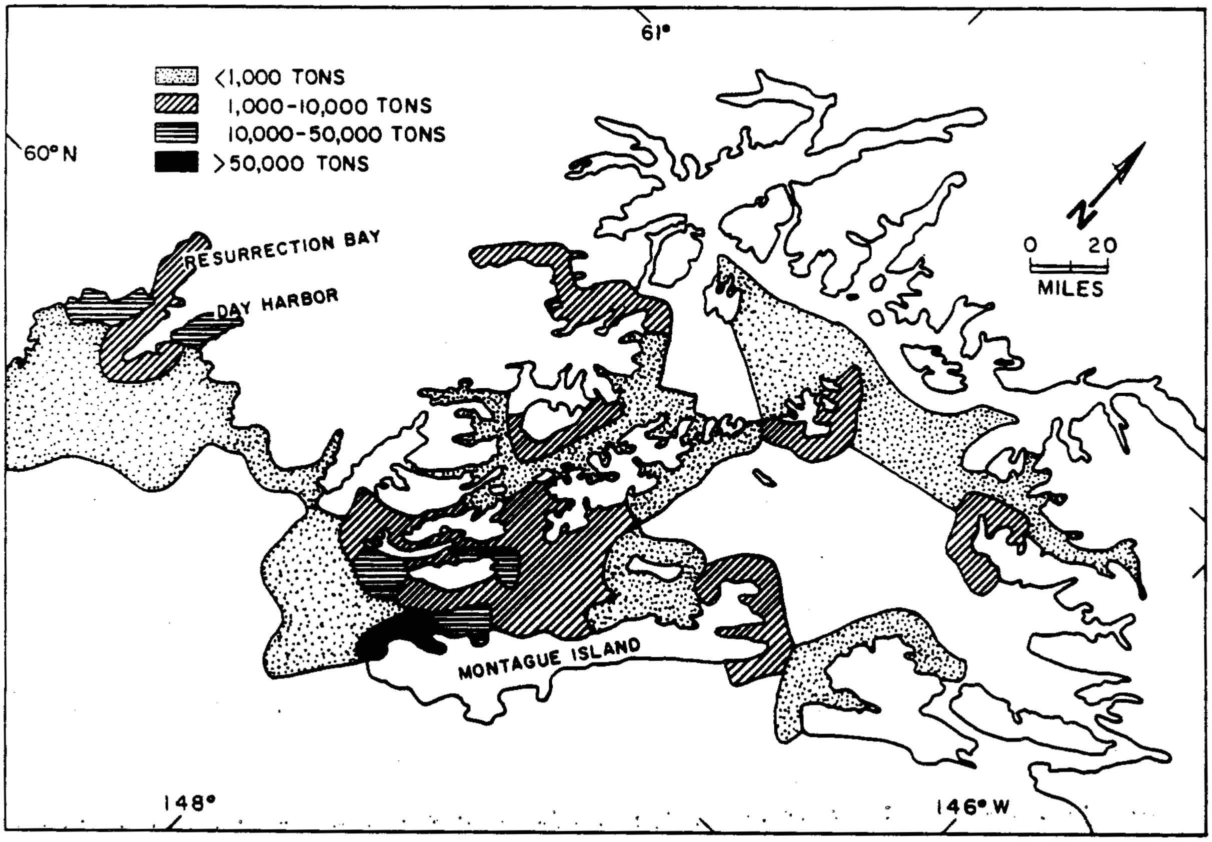


Figure 2. Distribution of herring catches in Prince William Sound during the 1937-58 reduction fishery (reproduced from Reid 1971).

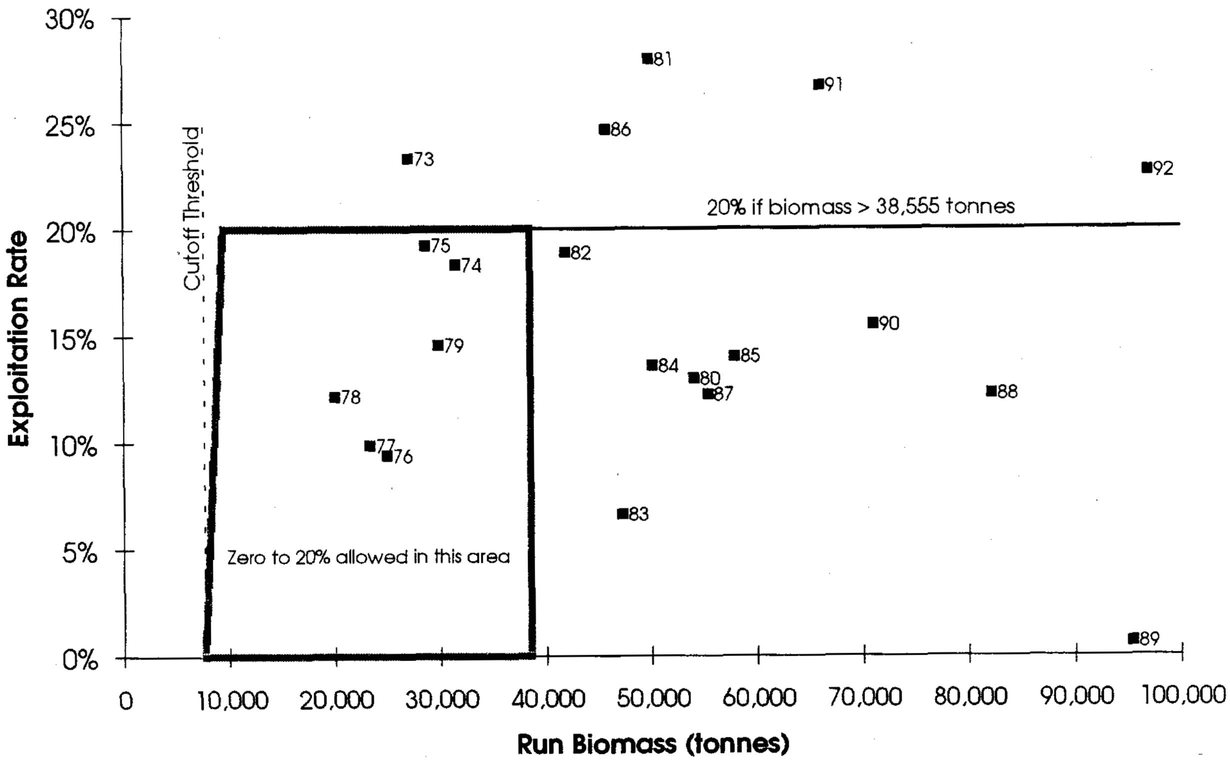


Figure 3. Current harvest policy for Prince William Sound herring, and estimated exploitation rates for 1973-92, calculated using biomass estimates from the ASA model.

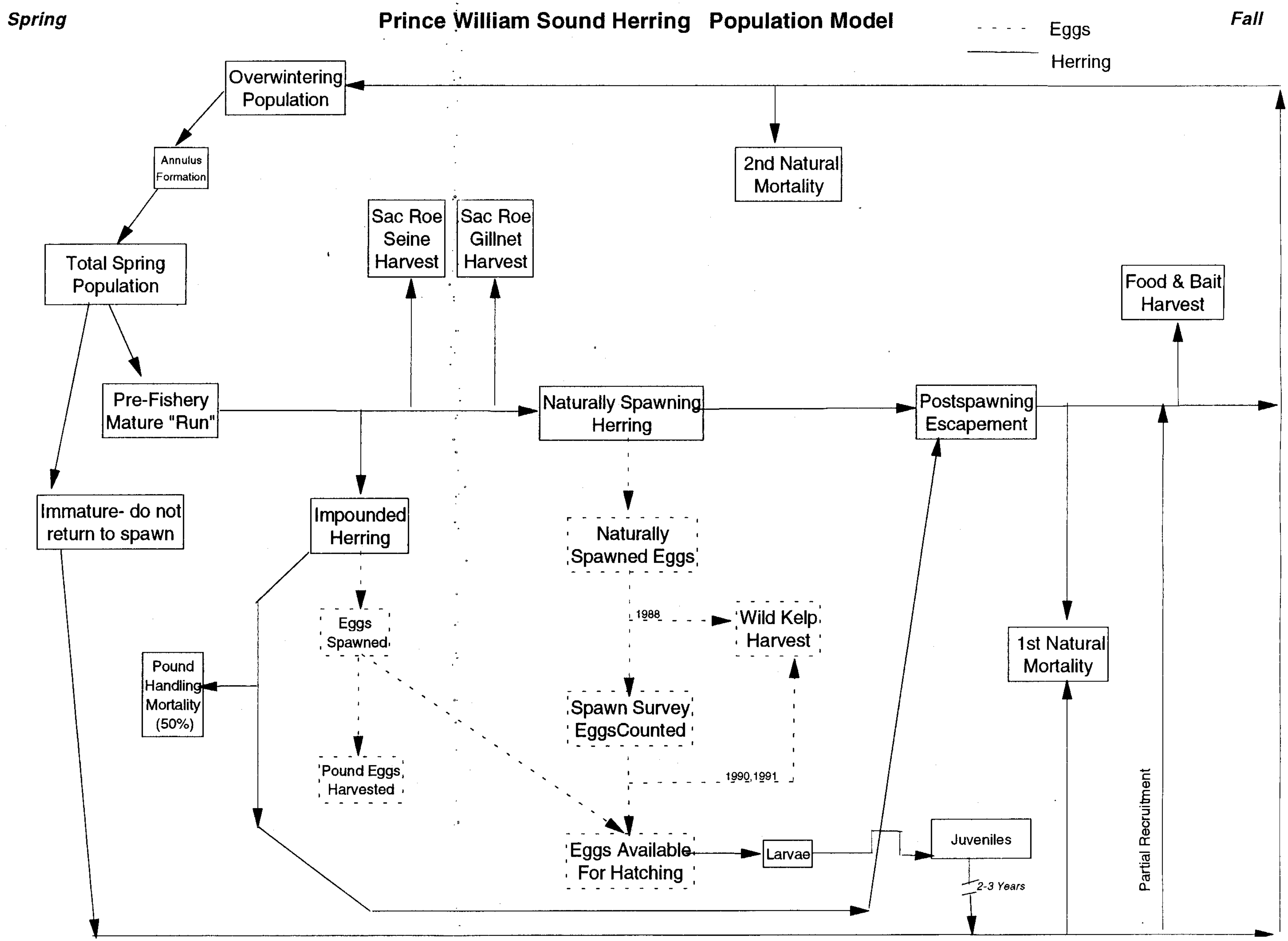


Figure 4. Conceptual model of the annual cycle of events affecting Prince William Sound Herring.

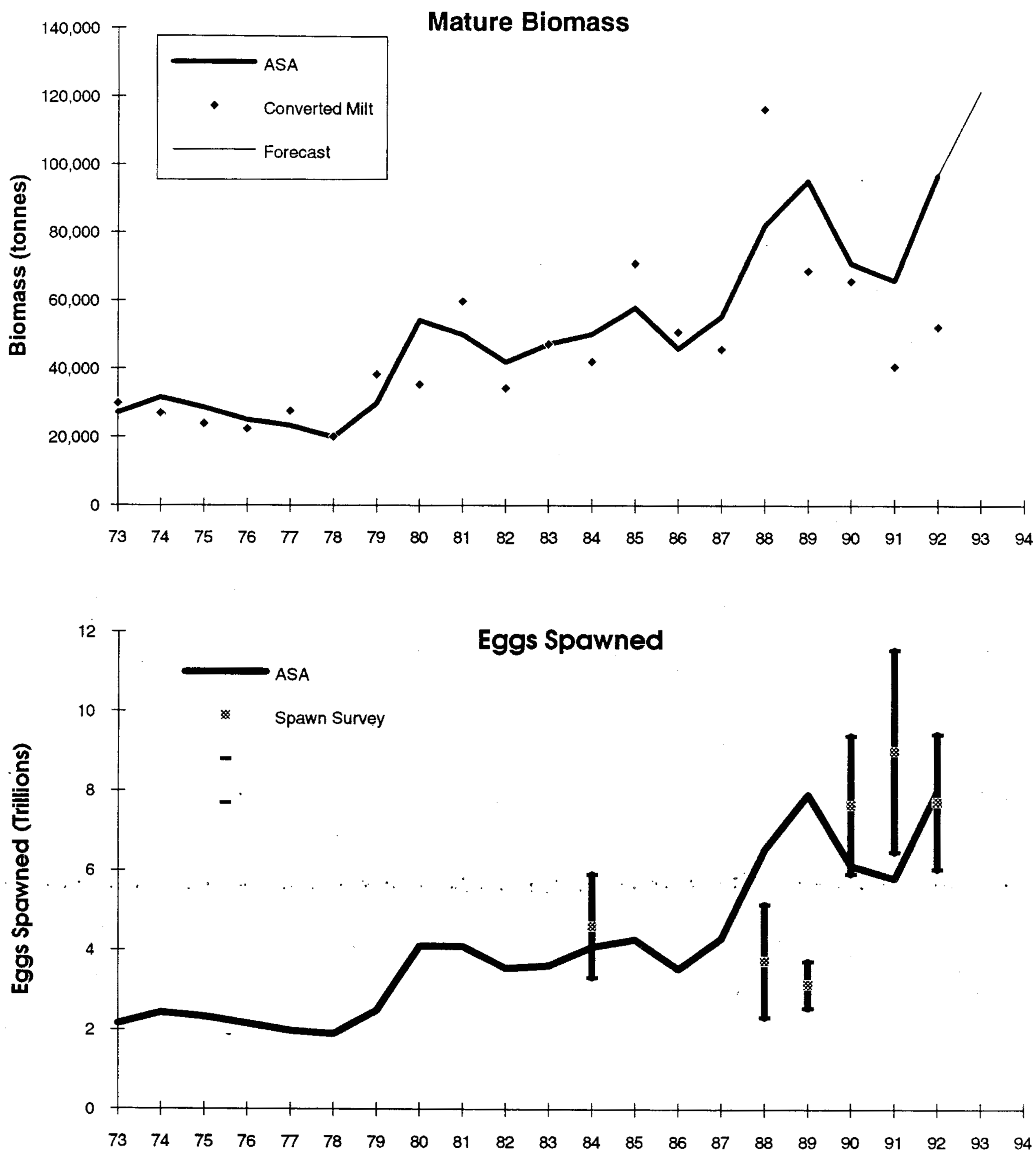


Figure 5. Fit of the ASA model biomass to converted miles of milt (top), using the ASA estimate of 350.4 tonnes of spawning herring per mile of milt, and the fit of the ASA model estimates of eggs spawned to the spawn deposition survey estimates (bottom), showing the 95% confidence intervals around the spawn survey estimates.

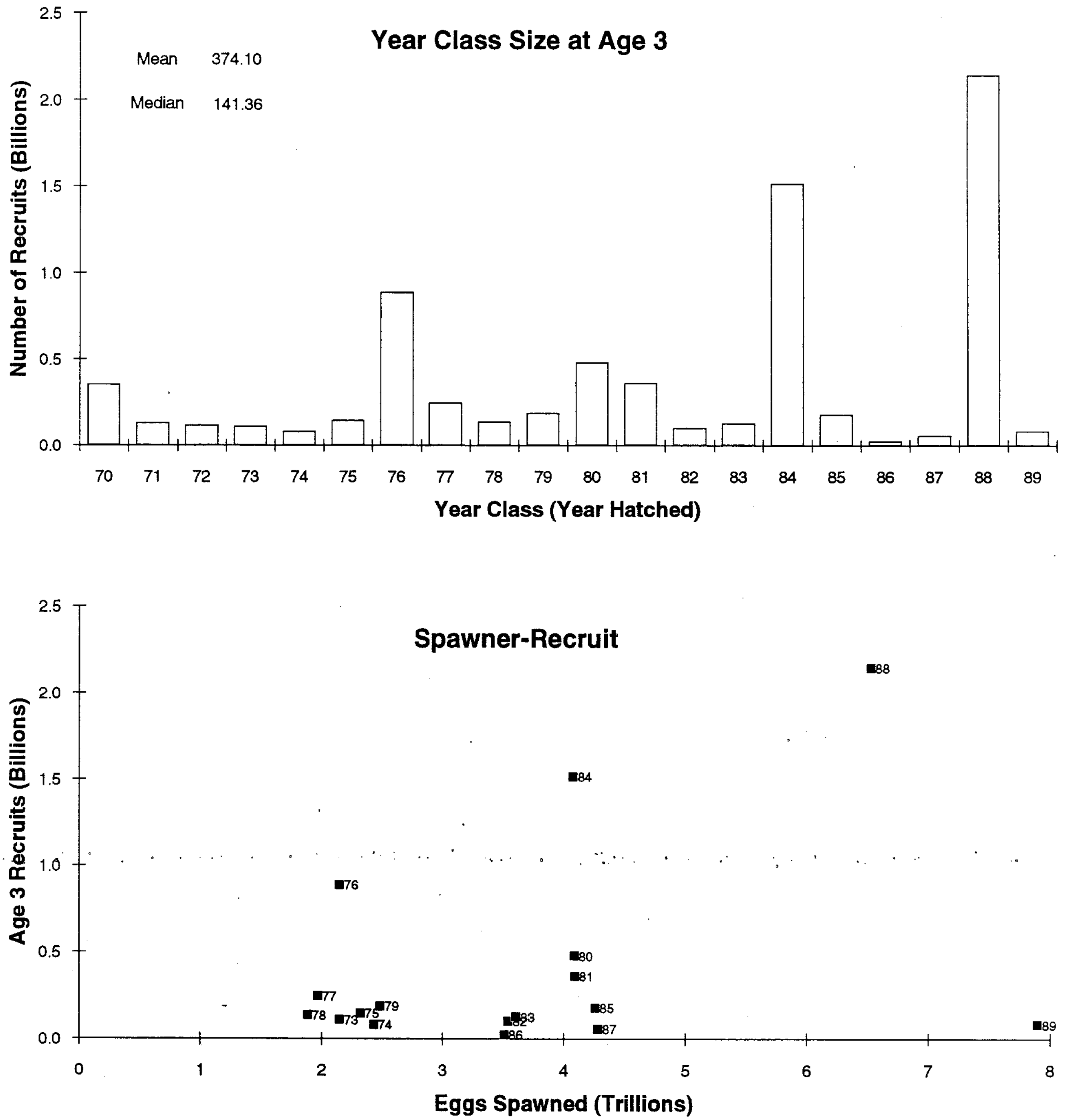
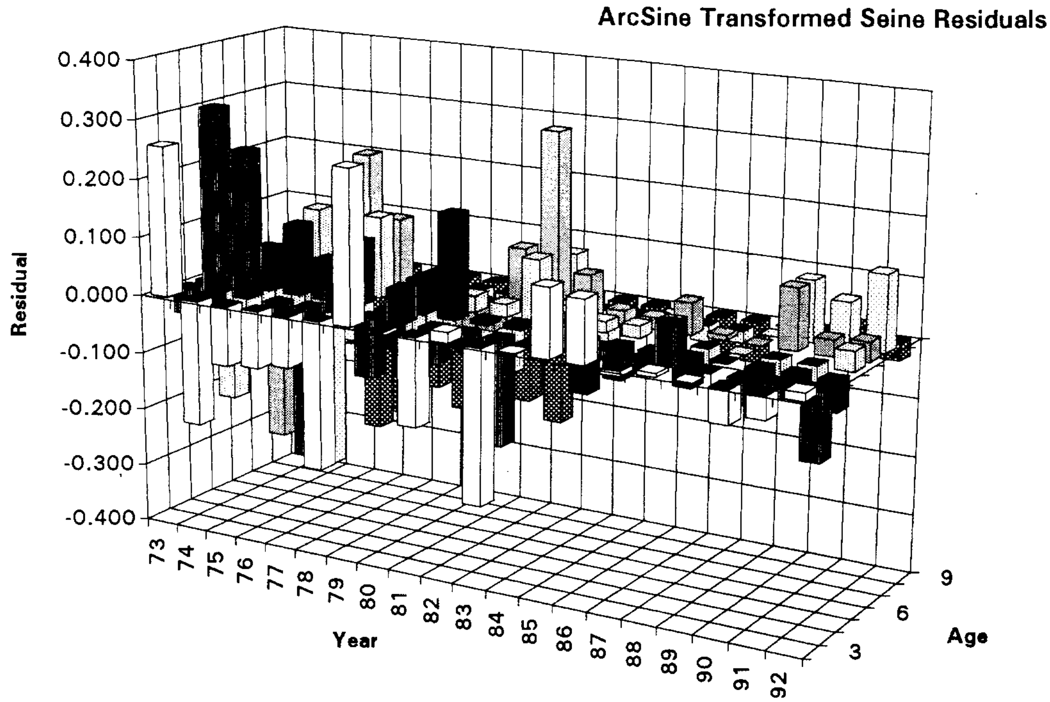
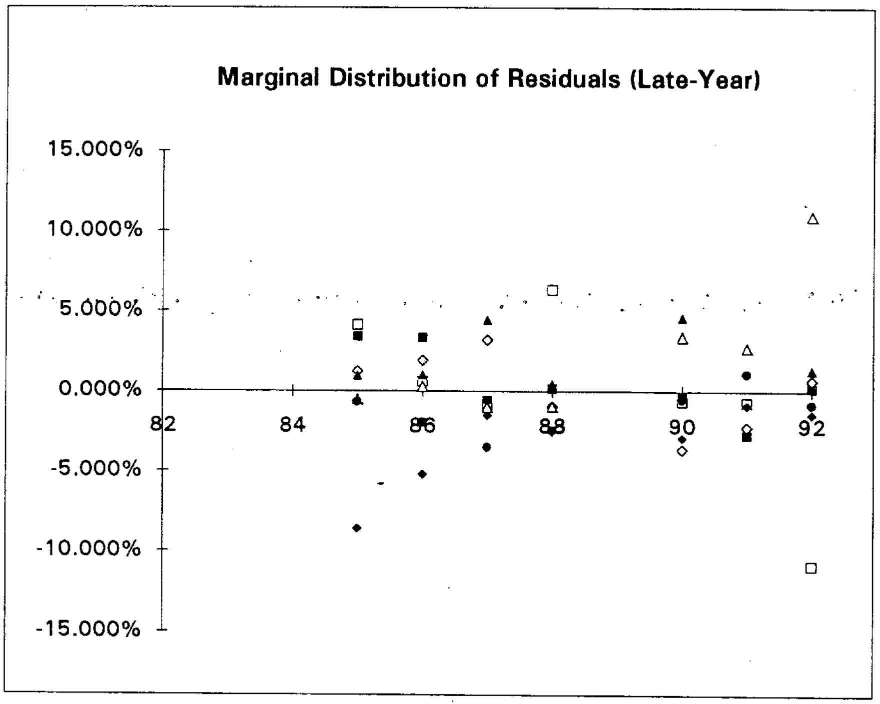
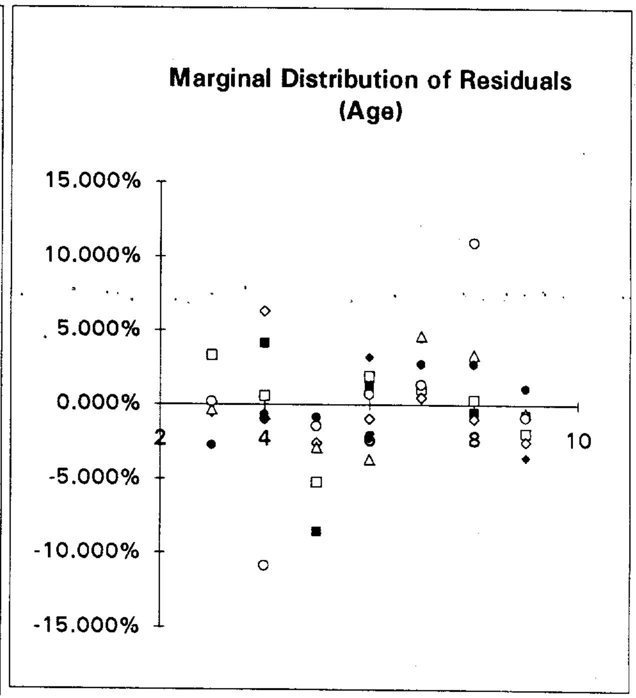


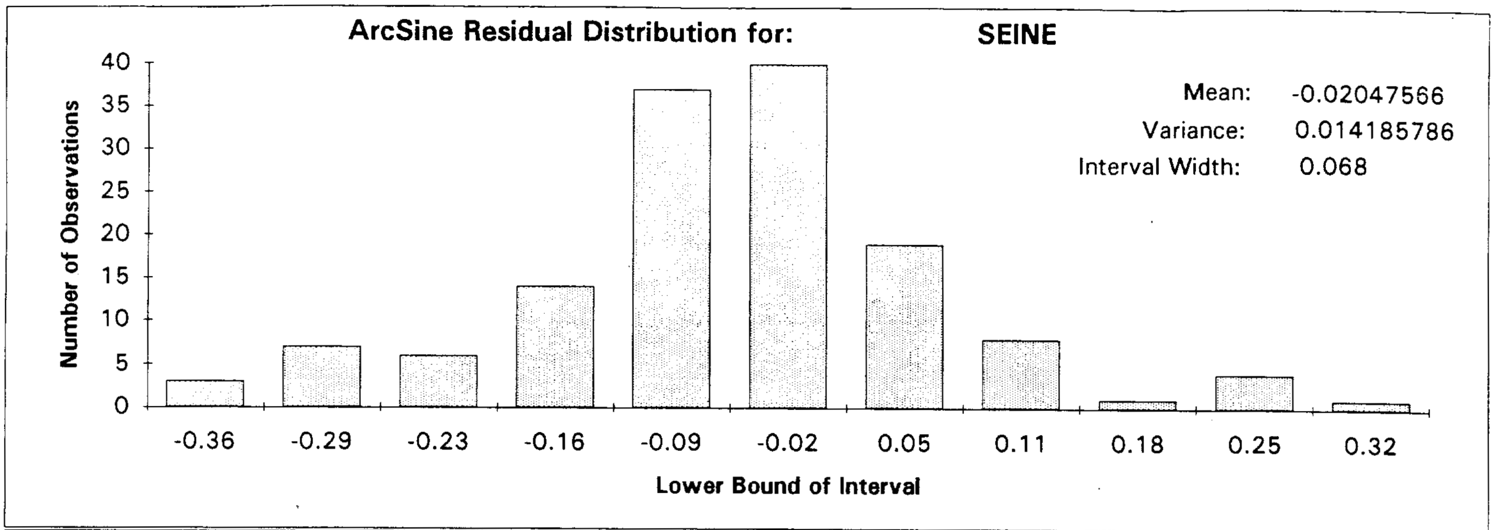
Figure 6. Year class size (top), for the 1970-89 herring year classes in Prince William Sound, and eggs spawned and resulting age 3 recruits (bottom), for each year class.

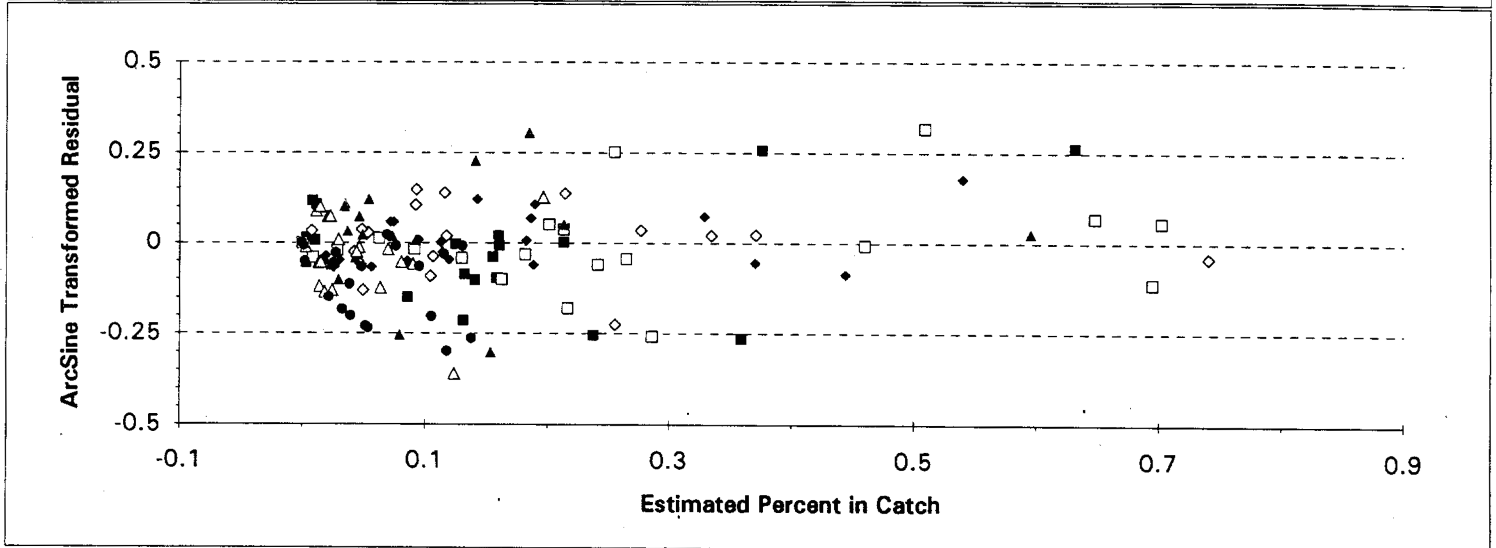
APPENDIX: Residuals of fit to catch and spawning age compositions.

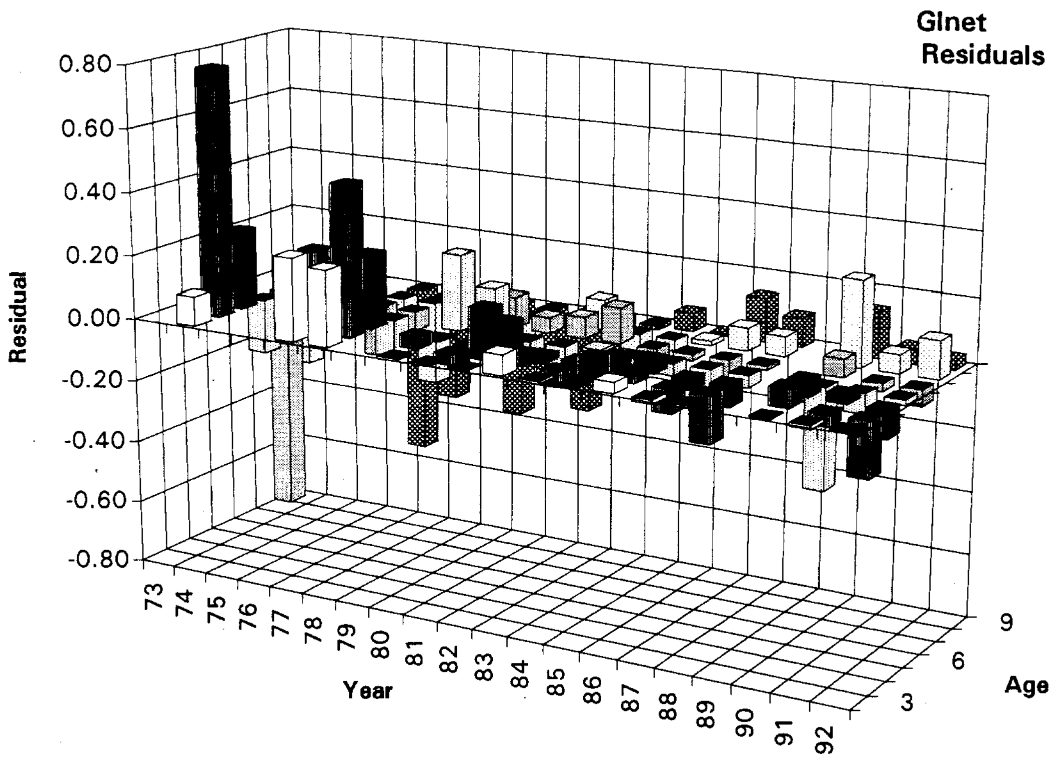

ArcSine Transformed Seine Residuals
Residual
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
-0.400
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92
Year
3 6 9
Age

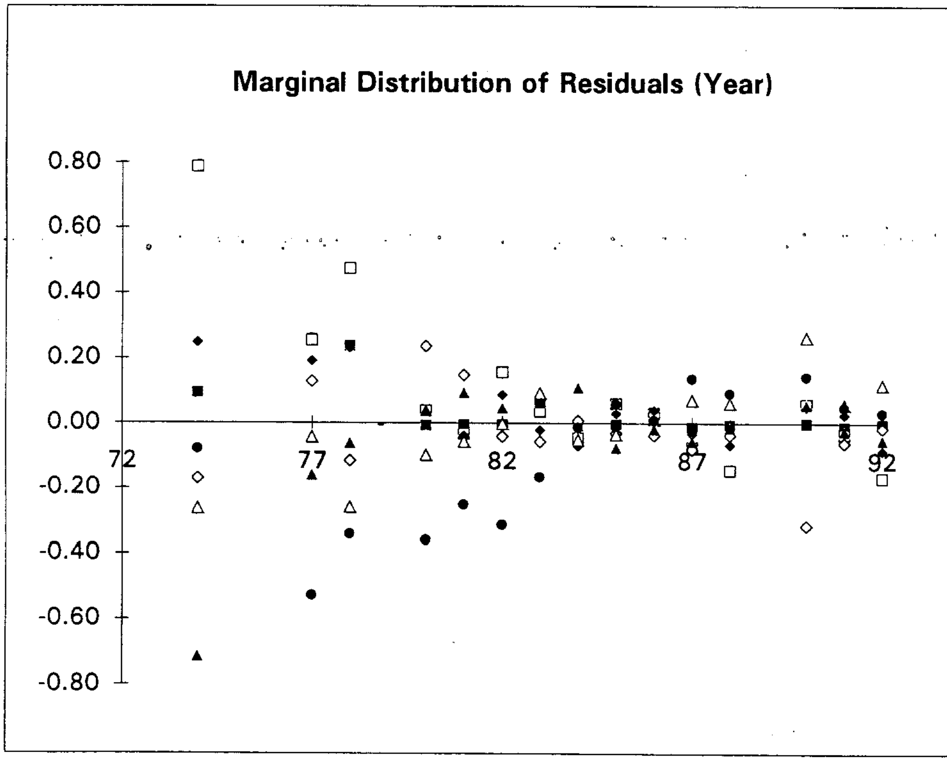

Marginal Distribution of Residuals (Late-Year)
15.000%
10.000%
5.000%
0.000%
-5.000%
-10.000%
-15.000%
82 84 86 88 90 92

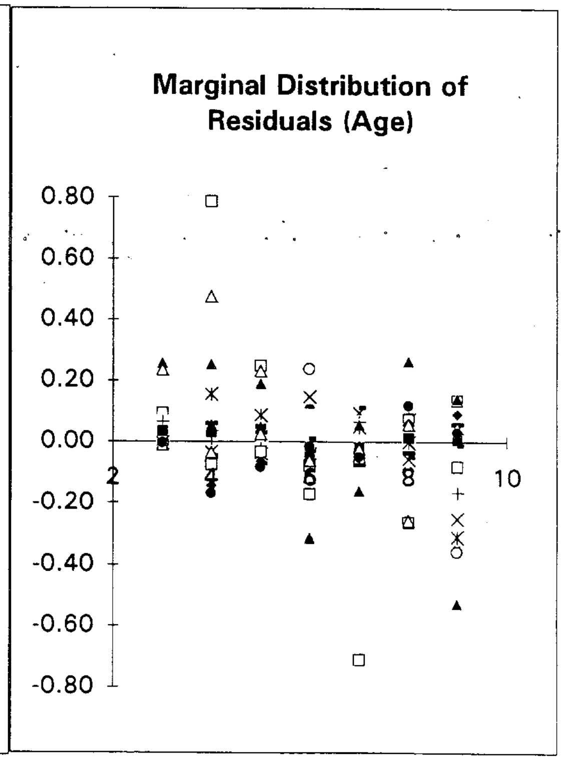

Marginal Distribution of Residuals (Age)
15.000%
10.000%
5.000%
0.000%
-5.000%
-10.000%
-15.000%
2 4 8 10

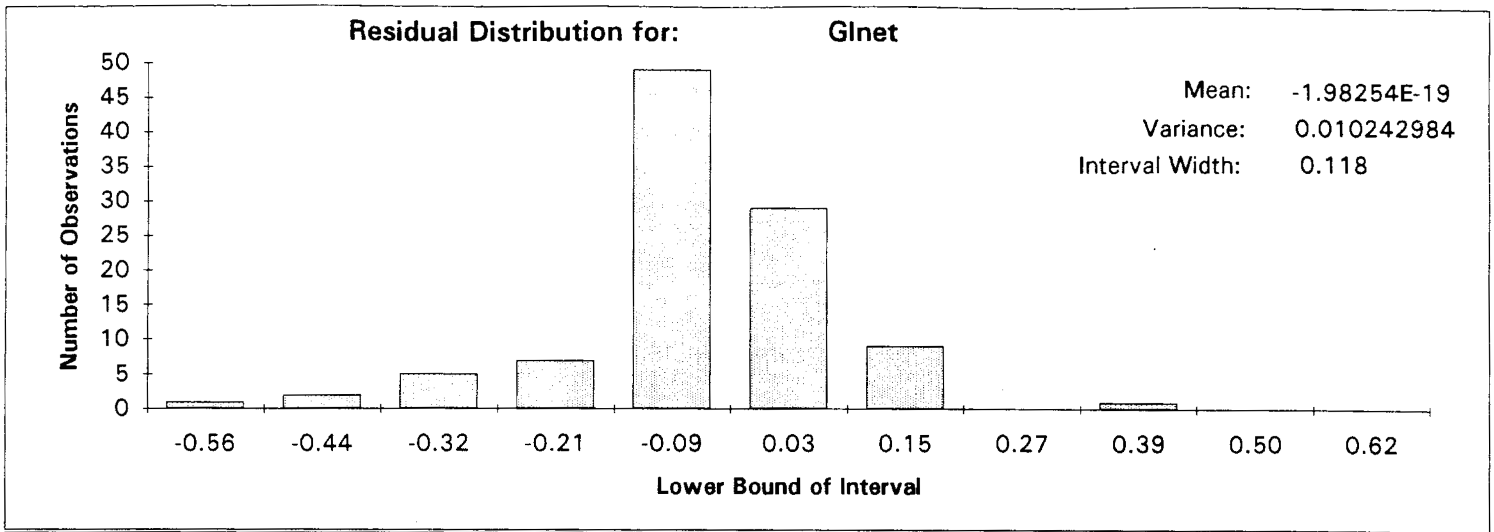

ArcSine Residual Distribution for:
SEINE
Mean: -0.02047566
Variance: 0.014185786
Interval Width: 0.068
Number of Observations
40
35
30
25
20
15
10
5
0
-0.36
-0.29
-0.23
-0.16
-0.09
-0.02
0.05
0.11
0.18
0.25
0.32
Lower Bound of Interval


ArcSine Transformed Residual
0.5
0.25
0
-0.25
-0.5
-0.1
0.1
0.3
0.5
0.7
0.9
Estimated Percent in Catch

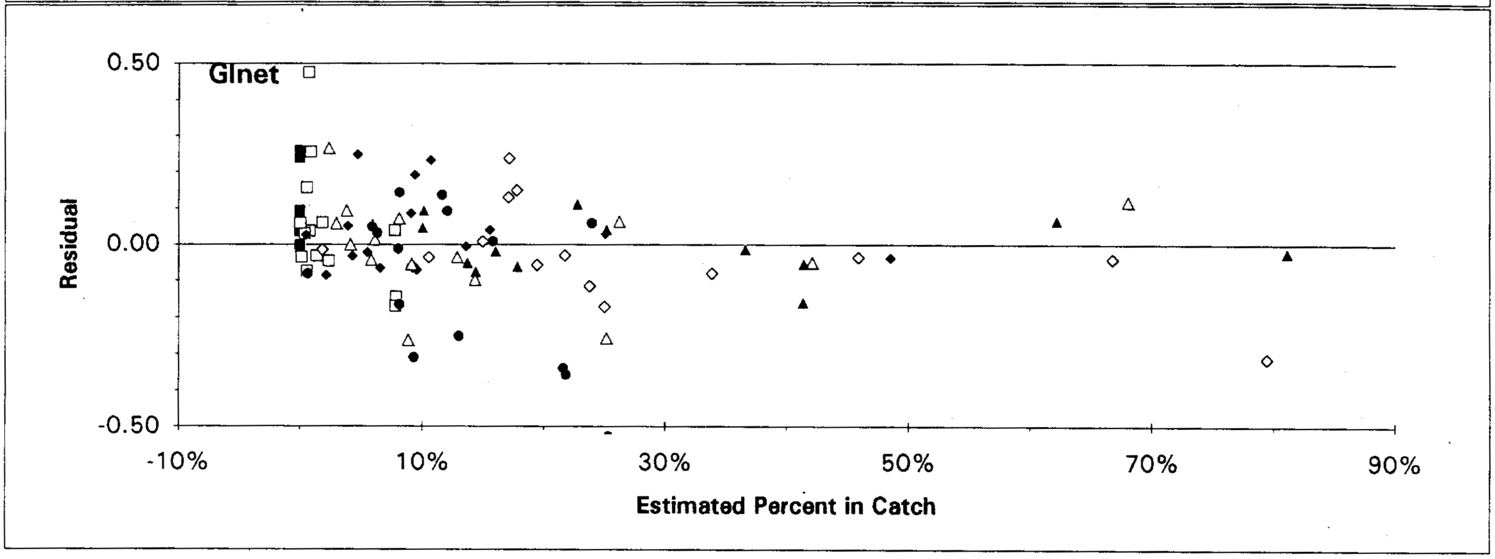

Glnet
Residuals
Residual
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92
Year
9
6
3
Age


Marginal Distribution of Residuals (Year)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
72
77
82
87
92

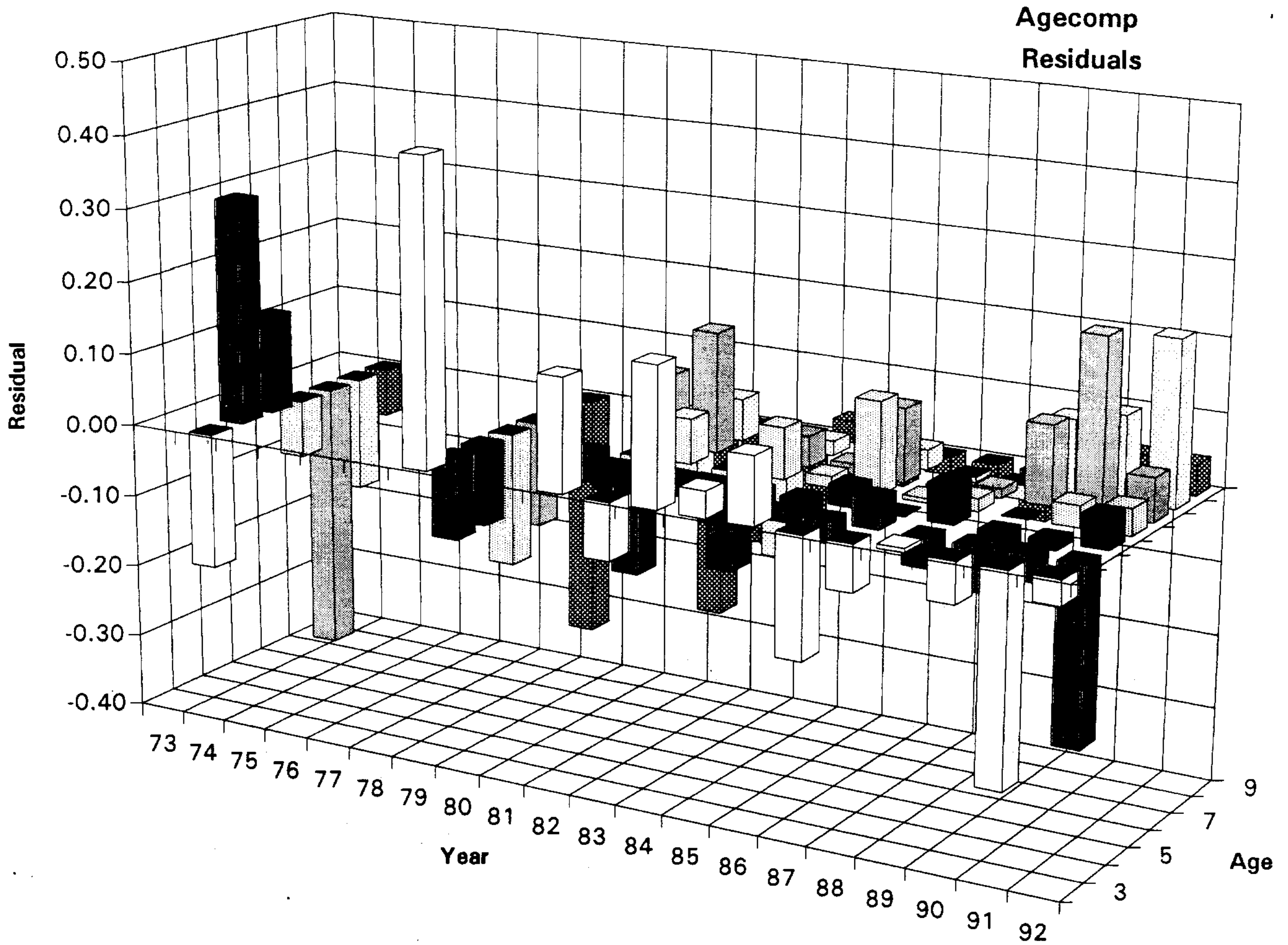

Marginal Distribution of Residuals (Age)
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
2
4
6
8
10



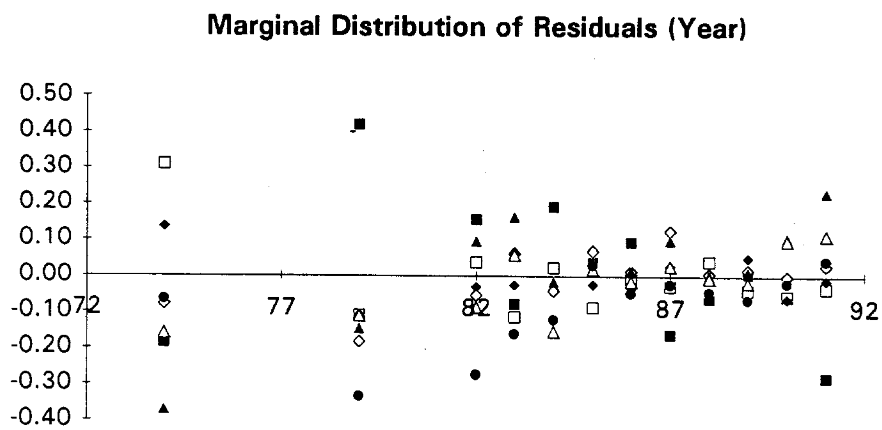
Residual Distribution for: Glnet
Mean: -1.98254E-19
Variance: 0.010242984
Interval Width: 0.118
Number of Observations
50
45
40
35
30
25
20
15
10
5
0
-0.56
-0.44
-0.32
-0.21
-0.09
0.03
0.15
0.27
0.39
0.50
0.62
Lower Bound of Interval



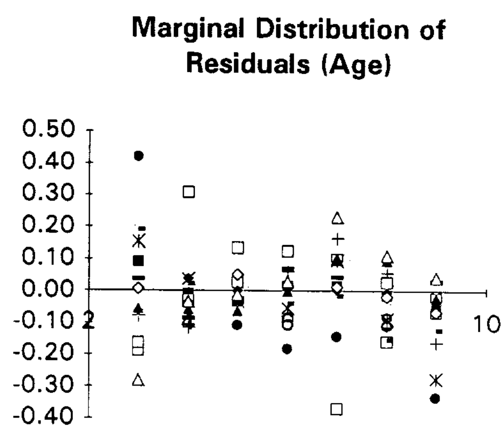
Glnet
Residual
0.50
0.00
-0.50
-10%
10%
30%
50%
70%
90%
Estimated Percent in Catch



Agecomp
Residuals
Residual
Year
Age

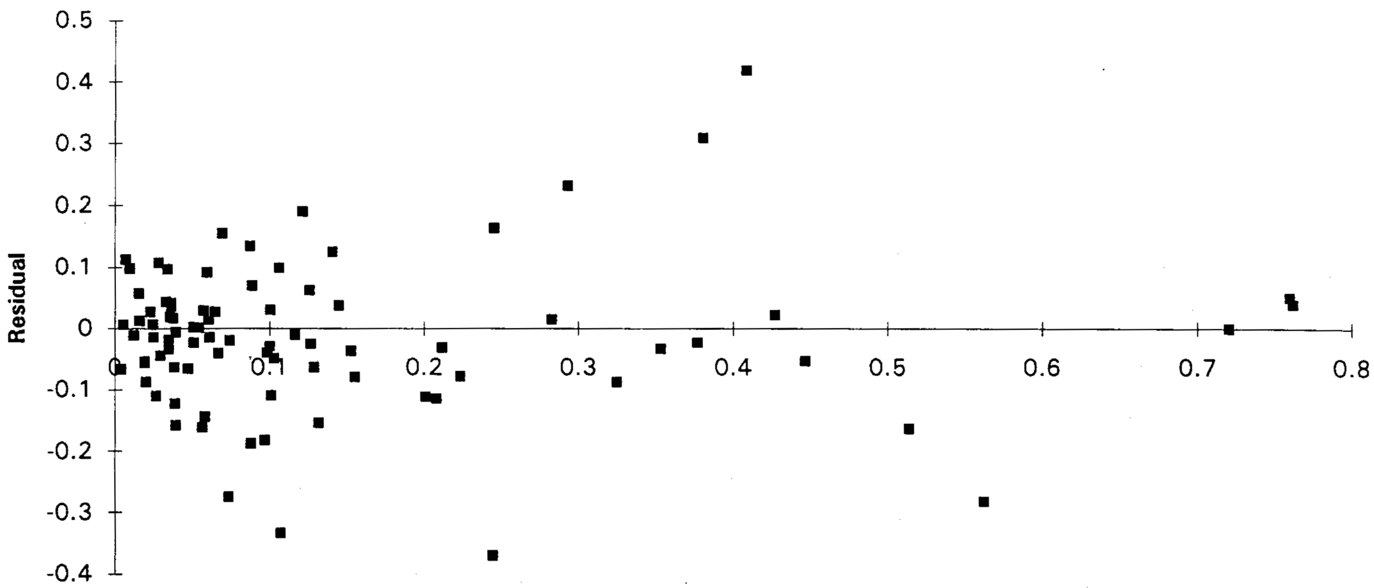


Marginal Distribution of Residuals (Year)



Marginal Distribution of Residuals (Age)

Residual vs Estimated Proportion



Residual Distribution for: Agecomp