PACIFIC HERRING SPAWNING GROUND SURVEYS FOR PRINCE WILLIAM SOUND, 1988, WITH HISTORIC OVERVIEW

By

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ABSTRACT

A herring spawn deposition survey program employing underwater techniques, similar to the survey program in Southeast Alaska(Blankenbeckler, 1987), was reimplemented in Prince William Sound in 1988. Surveys of this kind had not been conducted in the Sound since 1983 and 1984, when feasibility studies had been completed. The program was reinitiated due to an increase in funding and a need for an increase in accuracy of herring biomass forecasting in Prince William Sound.

The Sound was divided into four areas (Figure 1) and biomass estimates were calculated for each area. Survey transects were randomly selected from mapped spawning areas derived from aerial surveys. Quadrants of 1/10th m2 within each transect were haphazardly sampled for egg density every 5 meters along the transect; the contents of 38 quadrants were collected for determination of diver estimate correction factors or diver calibration. It was discovered from the Prince William Sound data and from Southeast Alaska data (Funk, 1988) that diver error is not a constant and is affected by substrate type and egg density; a model was derived to employ as diver error correction that takes into account substrate, year, diver, and density effects. Fecundities were determined from 315 weighed females over a range of 10 mm lengths in order to provide egg numbers per female as a parameter in the biomass estimate model. A-W-L samples representative of the timing of spawn for each area examined were selected to obtain average fish weight and sex ratio; the numbers were then employed for back-calculation of spawner biomass. In addition, a skiff survey was conducted in two of the four areas to examine the accuracy of mapping from aerial surveys and major discrepancies were discovered.

In 1988, a total of 166.3 miles of spawn was mapped, with an average spawner density of .56 million pounds of spawners per mile. The resulting spawner biomass estimate for the Sound was 43,581 tonnes or 48,047 short tons. With the commercial catch of 11,731 short tons, the total herring pre-spawning biomass was estimated at 59,778 short tons which is 17,778 tons over the Prince William Sound stock threshold of 42,000 tons. The resulting exploitation rate for 1988 was approximately 19.6%.

KEY WORDS: Pacific herring, *Clupea harengus pallasi*, spawn deposition surveys, biomass, diver calibrations, fecundity, aerial survey

INTRODUCTION

There is no need to express the economic importance of the spring herring populations to the various fishery user groups in the State of Alaska and British Columbia, Canada. Due to the historic pressure exerted on various herring stocks by the user groups, precision in management has become imperative and lack of it can cost the industry millions of dollars and/or result in damage to the stocks lasting several years afterwards.

British Columbia biologists and managers in Southeastern Alaska have adopted underwater spawn deposition surveys as the major management tools in determining spawning stock biomass (Haegele, Humpreys, and Hourston, 1981 and Blankenbeckler and Larson, 1987). Aerial and hydroacoustical surveys are used in conjunction with and in addition to the spawning ground diver surveys. Historically, in Prince William Sound, herring biomass estimates have been derived primarily from aerial surveys which typically exhibit considerable variability from year to year and within seasons due to differences in observers, weather, water visibility, varying school depths and varying spawning potential of the biomass due to differences in age structure.

In British Columbia historic spawn biomass estimates were based on aerial and ground surveys, until it was discovered that in many areas, especially on mixtures of vegetation types versus eelgrass beds, the majority of spawn was sublittoral (Haegele, et. al., 1981 and Schweigert and Fournier, 1982). Biomass estimates derived from diver surveys were found to be lower in general than biomass estimates based on aerial and ground counts, even though previous surveyors tended to underestimate the widths of the spawn (due to the majority being subtidal), (Schweigert and Stocker 1988). The overestimate on the part of the aerial or ground surveyors may have been due to lack of ability to observe "patchiness" in the actual spawn areas only measurable from diver surveys. Rosenthal (1976) found that in Prince William Sound, most of the herring spawn was observed in a zone that extended from the intertidal to 35 feet in depth. In view of the information available, it would seem that in Prince William Sound, as with other areas in the Pacific Northwest, underwater surveys of the spawning areas is the most promising way to accurately measure the reproductive strength of a herring stock in any given year.

Feasibility studies of diver surveys were conducted in Prince William Sound by Jackson and Randall (1983, 1984) and concluded that directly measuring spawn deposition was a more precise method of estimating spawning biomass than aerial surveys, which were based on peak visible biomass. Spawn deposition surveys were not conducted in years following due to funding constraints, however, in 1988 increased budgets for herring management in the Sound allowed reimplementation of the diver survey program. Since much of the ground work had previously been achieved with the 1983 and 1984 feasibility studies, a complete spawn deposition survey covering all the major spawning areas in the Sound was conducted.

Historically, the area utilized by spring spawning herring in Prince William Sound has expanded and contracted over the years to various locations. In 1988, the major areas of spawning included the west shore of Montague Island north of Hanning Bay to Rocky and Zaikof Bays and Green Island, Valdez Arm and Tatitlek Narrows including Boulder Bay, Galena Bay, Sawmill Bay and Bligh Island, the North Shore area including Chamberlain Bay on Glacier Island and Fairmont, Granite and Cedar Bays and finally on portions of Lone Island, south Storey Island and Naked Island (see Figure 1.). From 1956 and 1961-64, observers peported moderate to heavy spawning in the southwestern sector of the Sound at Crab Bay, Evans Island and Dangerous Passage, in 1956, very heavy spawning in Macleod Harbor, Montague Island (Rosenthal, 1978 and W. Noerenberg, Alaska Department of Fish and Game, Cordova, personal notes on observations, 1956-66), which are areas that have not been utilized to any extent in previous years. Noerenberg reported areas utilized in pre-earthquake years, in addition to areas utilized currently, to included Pigot Bay, Port Wells with spawning schools observed at Port Ethches and Anderson Bay on Hinchinbrook Island and Windy Bay on Hawkins Island. Brady (1987) summarized use of different areas in the Sound by percent of total annual mile-days of spawn and total miles of spawn over ten years. Total miles of spawn has changed dramatically from a low of 47.4 on 1978 to the maximum of 166.3 in 1988. While some areas such as Simpson and Sheep Bays, Hawkins and Hinchinbrook and Port Gravina seemed to have been utilized less since 1978, other areas such as Valdez Arm, Granite Point to Esther Passage, Naked Island, and Montague Island have either increased in utilization or remained steady.

Egg densities and mean spawn width varied significantly from area to area as revealed by the diver surveys. These differences in egg coverage affect the final spawner biomass estimate from diver surveys in a way that aerial spawner biomass estimates from each area cannot discern. This "fine-tuning" of the spawner biomass estimate by area is what will increase the accuracy of the expected return and quota set for future years and allow pre-season summaries to be distributed to managers and industry alike.

METHODS

Biomass Estimation

The 1988 Prince William Sound spawn deposition survey was patterned after similar surveys in southeastern Alaska (Blankenbeckler 1987, Blankenbeckler and Larson 1982, 1985, 1987) and British Columbia (Schwiegert et al. 1985). The objective of the spawn deposition survey was to estimate the biomass of the spawning population from estimates of the total number of eggs deposited on the spawning grounds, incorporating additional sampling estimates of average fecundity, average weight, and sex ratio of the spawning population. The overall biomass estimator is:

(1) $B = T \cdot B' \cdot (1 - R)$

where:

- B = Estimated spawning biomass in tonnes
- T = Estimated total number of eggs (billions) deposited in an area
- B' = Estimated tonnes of spawning biomass required to produce one billion eggs
- R = Estimated proportion of eggs disappearing from the study area from the time of spawning to the time of the survey.

The estimates for T and B′ are derived from separate sampling programs and are thus independent. Ignoring the unknown variability in R, the estimated variance for the product of the independent random variables T and B′ is (Goodman 1960):

(2) $\hat{Var}(B) = (1-R)\ [T\ Var(B') + B'\ Var(T) - Var(T)\ Var(B')]$

where Var(B′) is an unbiased estimate of the variance of B′ and Var(T) is an unbiased estimate of the variance of T.

Survey Areas

Areas potentially containing herring eggs were delineated either from aerial surveys of milt locations or from skiff surveys. Aerial surveys were flown throughout the herring spawning migration, from April 18 to May 9, at least once per day during the peak spawning periods when weather permitted. During each aerial survey, observers recorded the position and length of milt sightings on 1:63360 U.S.G.S. charts of Prince William Sound. Prior to the egg deposition survey, summary maps containing the cumulative locations of all herring milt observed during the aerial surveys were prepared. These locations were used to stratify the Prince William Sound shoreline into areas potentially containing herring spawn and areas not containing spawn. Shoreline areas where no milt sightings were recorded were assumed not to contain any herring eggs and were not sampled. The shoreline areas where milt was sighted tended to be somewhat larger than the area actually containing herring eggs, due to the milt drifting in tidal currents. In addition, the milt sighting areas were expanded by a small amount to ensure that areas near the endpoints of the milt sighting that might contain herring eggs were included in the potential egg-containing strata. Skiff surveys were used to further refine the potential spawn-containing strata in some areas, prior to the diving surveys. Observers in skiffs would travel through shallow waters at low speeds (2-3 knots) during low tide, recording spawning bed locations and occasionally grappling for eggs on subtidal vegetation with grappling hooks.

In 1988, a total of 166.3 shoreline miles of herring milt was mapped as a result of the aerial surveys flown from April 18 through May 9. Four major spawning areas were logically apparent after mapping the spawn:

Montague/Green Islands, Valdez Arm/Tatitlek Narrows, North Shore including Glacier Island, Fairmont, Granite and Cedar Bays, and Naked Island (Fig. 1). Potential spawn-containing shoreline in Port Gravina, Knowles Head, and St. Matthews Bay included in the nearby Valdez Arm area and the spawn-containing shoreline on Lone, Storey, Knight and Olsen Islands, was included with the Naked Island area. Biomass was estimated separately for each of the four areas.

Total Number of Eggs (T)

The total number of eggs deposited in an area was estimated from a two-stage sampling program with random sampling at the primary stage, followed by systematic sampling at the secondary stage, using a sampling design similar to that described by Schwiegert et al. (1985). Transects placed perpendicular to shore were the primary sampling stage, with quadrats placed along the transect comprising the second stage. The scale of the aerial survey charts on which potential spawn-containing shoreline was recorded limited transect assignments to 0.1 miles, so that 832 unique transect assignments were possible within the 166.3 shoreline miles of the potential spawn-containing stratum. A random number table was used to select 86 of the 832 possible transect assignments. Transect locations were selected without replacement because the sampling procedures involved occasional egg collection. Constraints on the number of divers available and the sampling time available between egg deposition and hatching precluded sampling more transects. The specific site for the 0.32 meter wide transect strip within the randomly selected 0.2 mile wide shoreline segment was selected haphazardly. The dive team leader would select a specific transect starting point along the shoreline from a distance as the diving vessel approached the pre-selected 0.2 mile shoreline segment, before shoreline features or subtidal vegetation were evident. Transects were oriented perpendicular to shore from this starting point. Of the total of 86 transects, 31 were located in the Montague area, 27 in the Valdez area, 22 in the North Shore area and 6 in the Naked Island area. Figures 2-7 show the transect locations in each area.

Because of the logistic constraints of sampling underwater, random sampling along transects is not feasible (Schweigert, et. al., 1985), so that systematic sampling was employed for the second stage, using 5 m sampling intervals and a 0.1 m quadrat size. The first quadrat location was selected haphazardly within the first 5 meters of spawn if the spawn began above the water level in the intertidal zone. If the first spawn was underwater, the divers began measuring 5 m intervals along the transect course from the water's edge. This method approximates the random starting point requirement of true systematic sampling. Divers followed compass courses perpendicular to shore, measuring 5 meter intervals with 1 meter arm spans. Individual divers practiced placing arm spans at 1 meter intervals using a measuring tape prior to the survey. The specific site for placing the 0.1 m sampling frame was selected haphazardly by casting the sampling frame approximately 0.5 m ahead as the diver was midway through the fifth 1 m arm span and allowing the frame to settle to the bottom.

In computing variances based on the systematic second stage samples it is assumed that eggs are randomly distributed in spawning beds with respect to the 0.1 m sampling unit. While this assumption was not examined, in practice the variance component contributed by the second sampling stage was much smaller than that contributed by the first stage, so that violations of this assumption would have little effect on the overall variance.

For each quadrat, divers recorded the vegetation type, substrate type, depth, distance from the start of the transect, and an estimate of the number of eggs in the quadrat. To estimate egg numbers, divers would visually examine the area within the sample quadrat, observing the amount of surface area of vegetation and bottom substrate, the per cent of the surface area covered by herring eggs, and the number of egg layers. Divers then visually integrated the number of egg layers and the per cent of the surface covered by eggs to estimate the number of eggs in the quadrat, using the reference standard that 40,000 eggs in one layer would uniformly cover the 0.1 m quadrat surface. Diver's estimates were later adjusted using a model with parameters derived from calibration samples which were counted in laboratory procedures, so that the actual sampling design involves three stage estimates. Sampling along the transect continued until the end of the spawning bed was reached. Divers usually travelled at least 25 m beyond the end of the spawn when transects were placed along shallow depth profiles, or to at least 30 feet when transects were placed along steeper profiles. Herring eggs were only very rarely observed below a depth of 30 feet.

The total number of eggs (T), in billions, in an area was estimated as:

(3) $$T = N \hat{y} \quad 10^{-6}$$

where

$N = L/ 0.1$ = the total number of possible transects

L = the shoreline length of the spawn containing stratum in meters

$0.1 = 0.3162$ m = width of transect strip

$\hat{y}$ = average estimated total number of eggs (thousands) per transect

10^{-6} = conversion from thousands to billions of eggs

The average total number of eggs per transect strip (in thousands) was estimated as the mean of the total eggs (in thousands) for each transect strip using:

(4) $$\hat{y} = \frac{\sum_{i=1}^{n} \hat{y}_i}{n}$$

where

$$\hat{y}_i = M_i \cdot \bar{y}_i$$

n = number of transects actually sampled

i = transect number

$M_i = w_i / 0.1$ = number of possible quadrats in transect i

w_i = transect width in meters

$\bar{y}_i$ = average quadrat egg count in transect i (in thousands of eggs)

The average quadrat egg count within a transect $\bar{y}_i$ was computed as:

$$(5) \quad \bar{y}_i = \frac{\sum_{j=1}^{m_i} y_{ij}}{m_i}$$

where

j = quadrat number within transect i

m_i = number of quadrats actually sampled in transect i

y_{ij} = adjusted diver-estimated egg count (in thousands of eggs) from the diver calibration model for quadrat j in transect i.

The variance of T is similar to that given by Cochran (1963 p. 277) for three stage sampling with primary units of equal size, although in this case the expression is modified because the primary units (transects) do not contain equal numbers of secondary units (quadrats), and the variance term for the third stage comes from the general linear model used in the diver calibration samples:

$$(6) \quad Var(T) = N^2 (10^{-6})^2 \left[\frac{(1-f_1)}{n} s_1^2 + \frac{f_1(1-f_2)}{\sum_{i=1}^{n} m_i} s_2^2 + \frac{f_1 f_2}{\sum_{i=1}^{n} m_i} s_3^2 \right]$$

where $$s_1^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \hat{y})}{n-1} = \text{variance among transects}$$

$$s_2^2 = \sum_{i=1}^{n} M_i^2 \sum_{j=1}^{m_i} \frac{(y_{ij} - \bar{y}_i)^2}{n(m_i - 1)} = \text{variance among quadrats}$$

$$s_3^2 = \sum_{i=1}^{n} \sum_{j=1}^{m_i} Var(y_{ij})$$ = sum of the variances of the individual predicted quadrat egg counts from the diver calibration model.

$$f_1 = \frac{n}{N}$$ = proportion of possible transects sampled

$$f_2 = \frac{m_i}{M_i}$$ = proportion of quadrats sampled within transects (same for all transects)

Diver Calibrations

During the spawn deposition survey, eggs from 38 quadrats (2.5% of the total quadrats) were removed for later enumeration in the laboratory (Table 1). For each of these quadrats, the two divers in the survey team recorded independent estimates of the number of eggs in the quadrat. The vegetation and eggs within the quadrat were then removed with knives and placed in individually numbered mesh sample bags. Any eggs remaining in the quadrat which could not be removed, e.g. attached to rocks or loose, were then estimated and recorded. These estimated numbers were later added to the laboratory-enumerated counts. The average estimated proportion of eggs remaining in the 38 enumerated quadrats was 13.3% .

After completing the dive, samples were transferred to zip-lock plastic bags and labeled with date, diver names, type of substrate, transect number, and diver estimated egg counts. Gilson's solution was then added to the bags as a preservative. The Gilson's solution consisted of formalin, glacial acetic acid, 70/70 nitric acid, ethanol and water. The project operational manual contains a more detailed explanation of the lab procedure and chemicals used in processing (Biggs, 1988).

In the laboratory, each sample was drained of Gilson's solution and placed in a potassium hydroxide solution to dissolve the kelp and loosen the eggs from any remaining substrate. Soaking time in the potassium hydroxide depended on the type of vegetation, with eelgrass and fucus taking the longest and filamentous and hair kelps taking the least amount of time. Repeated fresh water washings of the eggs, with the use of an appropriately sized sieve, was often necessary to completely remove all substrate. The clean eggs were then soaked in a 1.0 Normal saline solution to assure standardized volumetric displacement. After 24 hours the eggs from each sample were removed from the saline solution for volumetric enumeration. A standard reference displacement was determined from the average displacement of subsamples of 1000 eggs selected haphazardly from every third sample. The total number of eggs in the sample could then be back-calculated by simple proportion from the measured total sample volume and known volume of the 1000 egg subsample.

Quadrat samples were classified into four primary vegetation categories based on structural and phylogenetic similarities of the vegetation and substrate: eelgrass, fucus, hair kelp, and large brown kelp (Table 2). In addition, a fifth "mixed" category was created for a mixture of vegetation types commonly encountered on rocky substrates.

In developing a model for calibrating diver estimates, the diver observations were assumed to be approximately proportional to laboratory-enumerated counts, but systematic biases were allowed for in the diver estimates that could be accounted for by vegetation type or individual diver effects. The basic form of models used to describe these effects was:

(7) $$Y_{ijk} = e^{\alpha} e^{D_j} e^{V_k} X_{ijk}^{\beta_{jk}} e^{\varepsilon}$$

where α is a constant, D_j are parameters representing the effect of j^{th} diver, V_k are parameters representing the effect of the k^{th} vegetation type, β_{jk} are parameters controlling the functional form of the relationship between the diver estimate and laboratory-enumerated egg count for diver j in vegetation type k, Y_{ijk} is the i^{th} laboratory egg count in the vegetation-diver stratum jk, X_{ijk} is the i^{th} diver estimate in vegetation-diver stratum jk, and ε is a normally distributed random variable with mean 0 and variance σ^2.

A multiplicative-effect model was chosen because relative estimation errors were expected to change with egg density. In addition, initial examination of the diver estimates and laboratory-enumerated counts revealed that the variability of the egg counts increased with increasing egg numbers, and that the distribution of laboratory-enumerated egg counts for a given diver estimate was positively skewed. The logarithmic transformation used to estimate the parameters of the multiplicative-effect model stabilized the variance and corrected the skewness of the egg density estimates. After a logarithmic transformation model 2 becomes:

(8) $$\log_e(Y_{ijk}) = \alpha + D_j + V_k + \beta_{jk} \log_e(X_{ijk}) + \varepsilon$$

The parameter β_{jk} now becomes the slope of the relationship between the logarithm of the diver estimate and the logarithm of the laboratory-enumerated egg count. In logarithmic form, the model comprises a linear analysis of covariance problem with 2 factor effects (vegetation and diver) and 1 covariate (diver-estimated egg number). The SAS procedure for general linear models (SAS 1987) was used to obtain least squares estimates of parameters and evaluate variance components. In addition to the two factor effects and one covariate, terms for diver-vegetation group interactions, density-vegetation group interactions and density-diver interactions were considered in the analysis of covariance for a total of six effects. Three-way and higher level interaction effects were not considered because the objective was to derive a simple model with a relatively small number of parameters.

Backward stepwise procedures were used to determine subsets of the six effects which would explain the maximum amount of variability in the data with the smallest number of parameters. During the backward stepwise procedures, effects were included or eliminated from the model based on the probability level of F ratios for partial sums of squares.

Translation of the predicted values from the logarithmic model (3) back to the original scale (2) required a correction for bias. The bias in the expected value of Y_{ijk} is exp( ) when the true variance of Y_{ijk}, , is known, and Laurent (1963) gives an exact expression for the bias correction which incorporates additional terms when is estimated from a sample. For the diver calibration data, the biases in estimating from a sample were less than 0.05%, so expected values for Y_{ijk} were estimated from:

$$(9) \qquad E(Y_{ijk}) = e^{\alpha} \cdot e^{D_j} \cdot e^{V_k} \cdot X_{ijk}^{\beta_{jk}} \cdot e^{\frac{1}{2} s^2}$$

where s was the mean squared error from the general linear model. The variance of individual predicted Y_{ijk} was estimated from:

$$(10) \qquad Var(Y_{ijk}) = [e^{(2Y_{ijk} + \sigma^2)}] \cdot [e^{\sigma^2} - 1]$$

This expression is appropriate when is known (Laurent 1963), although in the present study s was used for without correction for bias, because the bias introduced into estimates of the mean when s was used for were found to be small.

Spawning Biomass per Billion Eggs (B′)

Catch sampling programs were used to estimate the relationship between spawning biomass and egg deposition. The tonnes of spawning biomass required to produce one million eggs (B′) was estimated as:

$$(11) \qquad B' = \frac{\overline{W} \cdot S}{F(\overline{W}_f)} \cdot 10^3$$

where

$\overline{W}$ = Estimated average weight in grams of all herring (male and female) in the spawning population in an area

S = Estimated ratio of total spawning biomass (male and female) to female spawning biomass

$F(\overline{W}_f)$ = Estimated fecundity at the average weight of females in the spawning population in an area, in numbers of eggs

$$10^3 = \text{units conversion factor} = \frac{10^{-6}}{10^{-9}} = \frac{\text{conversion from grams to tonnes}}{\text{conversion from eggs to billions}}$$

Because average weight, sex ratio and fecundity are all estimated from essentially the same sampling program, the estimates are not independent. The variance of B′ is approximately:

$$\begin{aligned}(12)\ Var(B') = (10^3)\ \{ & [S/F(\overline{W}_f)]^2\, Var(\overline{W}) \\ & + [\overline{W}/F(\overline{W}_f)]^2\, Var(S) \\ & + [\overline{W}S/F(\overline{W}_f)^2]^2\, Var(F(\overline{W}_f)) \\ & + 2Cov(\overline{W},S)\ [S/F(\overline{W}_f)]\ [\overline{W}/F(\overline{W}_f)] \\ & - 2Cov[\overline{W},F(\overline{W}_f)]\ [S/F(\overline{W}_f)]\ [\overline{W}S/F(\overline{W}_f)^2] \\ & - 2Cov[S,F(\overline{W}_f)]\ [\overline{W}/F(\overline{W}_f)]\ [\overline{W}S/F(\overline{W}_f)^2]\ \}\end{aligned}$$

Because S was estimated from pooled AWL samples, and in two of the areas S was estimated from a single AWL sample, it was not possible to estimate the covariance terms containing S, $Cov(\overline{W},S)$ and $Cov[S,F(\overline{W}_f)]$, so these terms were not included in the estimate of Var(B′). These covariance terms probably contribute a negligible amount to Var(B′), because the term involving $Cov[\overline{W},F(\overline{W}_f)]$ was very small.

Mean Weight and Sex Ratio

Mean weight and sex ratio were estimated from age-weight-length (AWL) samples collected either from the commercial catch or from test fishing conducted before or after commercial openings by ADF&G or by commercial vessels. Only purse seine samples were used in order to avoid gillnet size selectivity.

Attempts were made to obtain AWL samples representative of the spawning population in each area. The approximate timing of peak herring spawning in each area was determined from aerial survey summaries of milt sightings (Appendix D). All fish from AWL samples taken during the time of peak spawning in each area were then pooled to obtain estimates of mean weight and sex ratio for each area. Average weights and sex ratios for all of Prince William Sound were estimated as a weighted average of the estimates from each of the areas, weighting by the estimated biomass (B) from (1) in each area. Table 3 summarizes the samples collected during periods of peak spawning that were used in estimating average weights and sex ratios. Appendix D describes each of the AWL samples in detail.

The sex ratio estimate, S, is computed as the ratio of the number of fish of both sexes in the AWL samples to the number of females. The binomial distribution is applicable to estimating the proportion, p, of females in AWL samples, where $S = 1/p$. The variance of S is then given by:

$$(13) \quad Var(S) = \frac{S^2(S-1)}{n}$$

where n is the number of fish in the AWL sample.

Egg Loss

Prior to the extensive use of diving surveys of herring egg deposition, estimates of herring egg loss between the time of spawning and the time of egg deposition were relatively high. Montgomery (1958) estimated that in Southeast Alaska egg loss was 25 to 40%, and similar high egg losses were used in the early studies of egg deposition in Southeast Alaska (Blankenbeckler and Larson 1987). However, Haegele et. al. (1981) argued that these estimates were high due to the fact that most spawn was thought to be intertidal prior to the advent of diving surveys and that intertidal predation and wave loss is probably higher than subtidal. Haegele et. al. (1981) estimate egg loss to be approximately 10%, primarily due to predation and wave action loosening the eggs from the substrate during storms. Since the timing of diver surveys following spawning is similar in British Columbia, Southeastern Alaska and Prince William Sound, the 10% egg loss used in British Columbia and Southeast Alaska (W. Blankenbeckler, Alaska Department of Fish and Game, Ketchikan, personal communications, 1988) was used for the 1988 Prince William Sound egg deposition survey.

Fecundity

AWL samples were subsampled in selected areas to obtain fish for fecundity enumeration. Five separate samples were collected from AWL samples from five areas. Ten fish were sampled in each of twelve 10 mm length intervals from 140 to 260 mm standard length (refer to PWS Herring AWL Sampling Manual, Crawford and Sharr, 1988) as available in each length class. A total of 315 samples were collected. The ovarian sacs from each sample were individually labelled, bagged in zip-lock plastic bags, and frozen.

After the season, individual samples were thawed, each ovary was weighed, a subsample of from 0.5 to 1.0 grams was cut in a haphazardly located area from each ovary, and weighed to the nearest 0.01 grams. The eggs from each subsample were allowed to soak in Gilson's solution until the eggs were opaque and loose from the skein. The eggs were then counted under magnification and total fecundity was estimated using gravimetric expansion.

Fecundity-weight relationships have been reported both as power curves (Tanasichuk and Ware 1987), and as linear functions (Ware 1985). Examination of residuals from linear regressions fit to the 1988 Prince William Sound fecundity data indicated that a linear regression was a reasonable model. Data from all areas were pooled for estimating the fecundity-weight relationship.

Average fecundity for each area was estimated from the fecundity-weight relationship using the average female weight in the AWL samples from each area (Table 3). The variance of estimated average fecundities was approximated by the variance of predicted means from the fecundity-weight linear regression:

$$(14) \quad Var[F(\bar{W}_f)] = s^2\left[\frac{1}{n} + \frac{1}{q} + \frac{(\bar{W}_f - \bar{W}_x)^2}{\sum(W_x - \bar{W}_x)^2}\right]$$

where s^2 is the residual mean square from the fecundity-weight linear regression, n is the total number of females in the fecundity sample, q is the total number of females in the AWL sample, $\bar{W}_x$ is the mean weight of females in the fecundity sample, and W_x are the weights of individual females in the fecundity sample.

RESULTS

In 1988, a total of 166.3 miles of spawn was mapped as a result of the aerial surveys flown from April 19th through May 9th. Four major spawning areas became logically apparent after mapping the spawn (Figure 1) and they were split out as follows: Montague and Green Islands, Valdez Arm and Tatitlek Narrows general area, North Shore including Glacier Island, Fairmont, Granite and Cedar Bays, and finally, Naked Island. The spawn in Port Gravina, Knowles Head, and St. Matthews Bay was lumped with the Valdez Arm area and the spawn on Lone, Storey, Knight and Olsen Islands, was lumped with the Naked Island area. Naked Island was considered seperately from the North Shore area because no commercial harvest was allowed and comparison between a harvested versus an unharvested area may result in different mean egg density estimates and therefore, affect final biomass estimates.

In 1988, 35 % of the total miles-days of spawn was on Montague, 20.6 % was in the Point Freemantle to Granite Point area, 19.8 % was in the Valdez Arm area, 11.9 % was in the Granite Point to Esther Passage area, and 7.9 % was in the Naked Island area(Appendix E, Table E.2).

A total of 86 transects were completed in Prince William Sound with 31 in the Montague area, 27 in the Valdez area, 22 in the North Shore area and 6 in the Naked Island area. Figures 2-7 show the randomly selected transects in each area and Tables 4-7 summarize transect information.

Biomass Estimates

Mean densities, transect widths, maximum depths reached per transect, spawn widths and mean density of the actual width of spawn for each transect in each area is summarized in Tables 4-7. Biomass estimates resulting from the data collected in each area is summararized in Table 8.

Significant differences between areas become apparent immediately. It is interesting to note that in the Montague area, about a third of the transects were zeros or showed no actual spawn, versus about a quarter of the transects in Valdez area, one zero in the North Shore area and no zeros Naked Island area. There are several possible explanations for this occurrance that will be discussed further later in the report.

Bottom characteristics such as substrate type and slope vary greatly from one transect to another, as well as from one area to another. These differences become apparent if one examines the transect widths versus the spawn widths, which are outlined on the bottom of Tables 4-7. In general, transects that covered areas with gradual slopes were longer than those with steep slopes mainly due to the fact that the majority of the spawn is laid down from a 35 foot depth to the intertidal zone. Areas with gradual slopes could have patchy coverage over a long range and the divers had to cover more area to make sure all the spawn along a given transect was sampled, resulting in longer average transects in those areas. Montague Island is known for its wide shelves on which extensive kelp beds abound. The average transect width of 121 meters is considerably longer than any of the other areas. Naked Island also had relatively wide shelves with thick kelp coverage. If transect widths were used in the biomass estimate, a large amount of zero quadrats would enter into the calculations for the mean densities and therby increase variance. To reduce variance, and allow managers to picture true widths of actual spawn in one area or another, spawn width is used which only considers quadrats sampled that included some spawn. Even in patchy spawn areas, as was found on Montague and Valdez areas, spawn is effectively compressed and between area comparisons are not clouded by differences in substrates and slopes.

Montague and Valdez areas recieved spawn to average depths of 25.7 and 24.8 feet respectively, resulting in part from wide shelves, shallow depths, and patchy or sparse spawn. In contrast, the North Shore and Naked Island areas recieved spawn to deeper average depths of 33.4 and 38.7 feet reflecting, in part, the narrow shelves, as well as the extensive and continuous spawn those areas recieved. On Naked Island spawn was found in one area at 60 feet and deeper and the survey had to be terminated due to diver decompression problems associated with diving at depth.

Naked Island was clearly the area with the most complete coverage with an average spawn width of 54.2 meters and mean area density of 44.5 thousand eggs/0.1 m_2. Even though Naked Island recieved only 11% of the 166.3 total shoreline miles of spawn, it contributed 23.9% of the total estimated spawning biomass in the entire Sound(Table 8). The North Shore may have been similar to Naked Island had it not been exploited by the fisheries, however, that point is one left up to speculation.

The average size of the herring, especially the females, may have affected the differences in spawn coverage from one area to another. Females in the Montague and Valdez areas were generally smaller than those sampled in the North Shore or Naked Island areas(Table 3), resulting in lower fecundities (since fecundity is positively correlated with weight) for the former two. While a population of smaller females when viewed from the air, may look similar to a population of slightly larger females, they would not have the reproductive strength in egg numbers that the larger fish would.

The resulting biomass estimate of active herring spawners in Prince William Sound for 1988 is 43,581 tonnes(metric tons) or 48,047 short tons(Table 8). When added to the commercial fisheries harvest of 11,731 short tons (Brady, 1988), a total pre-spawning stock biomass can be estimated at 59,778 short tons which is 17,778 tons over the Prince William Sound stock threshold of 42,000 short tons. The resulting exploitation rate for 1988 was approximately 19.6%.

Diver Calibrations

A total of 38 calibration samples were collected in 1988 to adjust diver estimated egg counts for systematic biases (Table 1). Laboratory processing time was the limiting factor in determining diver calibration sample size as only one week for laboratory time was available and only 6-8 samples could be processed per day.

Model (7) with parameters and only, without regard to vegetation type, explained 80% of the variability in the log-transformed laboratory-enumerated egg counts. Adding in all six effects explained a total of 89% of the variability. Backwards step-wise procedures were used to define submodels containing fewer parameters that would account for as much of the variability as possible. With a probability level of .001 used as a stopping criterion for removing effects from the model, the final model contained parameter and a vegetation group-specific parameter ${}_k$, and has expected values given by:

$$(15) \quad E(Y_{ik}) = e^{\alpha} \cdot X_{ik}^{\beta_k} \cdot e^{\frac{1}{2}s^2}$$

where s is variance of an individual predicted observation. This model explains 86% of the variability in the log-transformed data, and requires the estimation of six parameters.

In general, divers tend to underestimate quadrat egg counts at low egg densities and overestimate quadrat egg counts at high egg densities, except in the hair kelp vegetation type (Figs. 12-17). Calibration sample sizes and model fits in comparison to the range of diver estimates actually encountered are reasonable predictors of egg density only for the large brown kelp and hair kelp vegetation types (Figs. 15 and 16). For the other three vegetation types, a model estimated with a pooled parameter over all vegetation types is more appropriate for predicting egg densities (Fig. 12).

Parameter estimates used for calibrating diver observations are given in Table 9.

Fecundity

Figures 8-11 show fecundity-length and fecundity-weight relationships for both normal and log-transformed observations. Because the linear model between fecundity and weight is the simplest model and fits the available data as well or better than the other models, the linear model (Fig. 10) was used to describe the fecundity-weight relationship. The estimated slope of the regression was 172.1, with an intercept of -3,179.8, and a residual mean square of 4,392.4.

The average egg size was 0.0014 g, over all fecundity samples, with an average egg count per gram female weight of 140. Appendix B., Figures B.1-7, break the fecundity relationship out by ages. Even though no further analysis was completed of fecundity to weight by age class, it is interesting to compare the results and may be a topic for future examination with a larger sample size to draw from for the various age classes.

Skiff Surveys

After completing several of the initial transects on Montague Island, it became apparent that the maps drawn from the aerial surveys were not entirely representative of the actual spawn laid down. As a result, an attempt was made, on a small scale, to survey the beaches from a skiff and map the extent of the actual spawn areas with the maps derived from the aerial surveys.

Figures 5, 6, and 7 show the skiff surveyed areas versus the aerially mapped areas. It is interesting to note that in the North Shore area, the spawn area was actually increased by "connecting the dots" so to speak of the intermittant mapped patches of spawn. T. Minicucci (Alaska Department of Fish and Game, Ketchikan, personal communications, 1988) stated that this was a common occurrence with aerially mapped spawn due to the lack of continuity (areas are not surveyed every day and a spawn occurrance can be missed). In contrast, skiff surveys on Lone and Storey Islands actually decreased the area of actual spawn; drift of milt with the wind and ocean currents could be the cause of the inconsistency.

Miles of spawn mapped from aerial surveys were used in the biomass estimate calculation, and not the revised miles that the skiff surveys revealed since only small portions of the mapped areas were actually examined from the skiff. However, the skiff surveys do reveal the need for a map of actual spawning areas and how aerial drawn maps can introduce error in the calculation of actual spawn.

DISCUSSION

Upon examining the total miles of spawn coverage in Prince William Sound in 1988, the initial reaction is impressive. However, when one takes a closer look at the actual egg densities and substrate coverage, it is realized that the coverage was disappointing and resulted in lower spawn biomass estimates than one might expect from 166.3 miles of spawn. Although the 1988 biomass estimate of 59,778 short tons, including the commercial catch, represents a ten year high when compared to the peak aerial estimates in the past, the spawner density (Table 10, (4)) was lower than in previous years with similar biomass estimates (1980, 1981, and 1984).

Spawner density expressed in units of millions of pounds per mile is a convenient way to compare and express data graphically and is used extensively by the Southeast Alaska staff in assessing herring spawn biomass on an inseason, and year to year basis. The convenience occurs because the number is generally 1 (Mil. lbs./mile)in areas with "normal" egg densities and typical coverage, and as a rule, 1 million lbs./mile is the guideline spawner density used in Southeast Alaska(W. Blankenbeckler, Alaska Department of Fish and Game, Ketchikan, personal communications, 1988). The latter part of Table 8 shows the spawner density in the four areas in the Sound expressed in millions of lbs/mile, with Naked Island spawn coverage coming closest to this density goal. However, the overall density for the Sound was only .56 million lbs./mile. Table 10 is a summary of biomass estimates of herring spawning populations in Prince William Sound since 1978, mainly derived from aerial survey techniques. Spawner density estimates vary dramatically from one year to the next from a low of .39 million lbs./mile in 1986, to a high of 2.20 in 1984 (from diver surveys). The 1988 density approached the ten year minimum and is a little over half of the desired spawner density, if Prince William Sound were to adopt 1 million lbs./mile of spawners as a guideline.

Based on aerial surveys, total biomass estimates of herring have varied from 9,228 short tons in 1978 to a high of 51,090 in 1981 (Table 10). In 1988 the peak aerial estimate was 34,270 short tons which is a thousand tons higher than the ten year average. Biomass estimates from diver surveys for the first two years they were conducted varied considerably from the aerial estimates, ranging to an area-wide ten year high of 79,710 short tons in 1984. In 1988, the area-wide diver estimate exceded the aerial estimate by approximately 14,000 short tons if one compares the spawner biomass estimate alone. If one compares the aerial estimate to the spawner plus commercial catch biomass estimate, the diver survey number exceeds it by 25,500 short tons.

In examining biomass summaries by area, the discrepancies between aerial and diver surveys can be defined more closely. The Montague area estimates varied considerably 26,580 short tons versus 13,480 (Appendix E.1, peak aerial estimates by area) for diver versus aerial surveys. It is likely that the schools that produced the particularly heavy spawn on the north end of the island (and comprising a large part of the total spawner biomass estimate) were not included in the peak aerial survey, since spawn in this area was mapped by personnel other than the usual herring surveyors (i.e., biomass estimates were not calculated). In the Valdez area, 5,973 short tons versus 5,830 for diver versus aerial surveys is surprisingly close unless one considers the 1600 tons that were removed by the commercial fisheries and not included in the diver estimate. In the North Shore area, divers estimated 4,327 short tons while aerial techniques resulted in an estimate of 12,300 short tons; this discrepancy can be explained by the commercial catch of 7,856 tons of roe herring which is included in the aerial estimate, but not counted in the diver estimate. The North Shore area survey results probably coincide the closest of the four areas probably due to the frequent aerial surveys flown in that area. In the Naked Island area, divers estimated 11,167 short tons of herring spawners, while the aerial surveyers only recorded 1,450; aerial surveys in that area were not conducted as often or as regularly as in the North Shore area and this lack of information probably caused the discrepancy. In areas that were surveyed aerially on a regular basis, both types of survey methods seem to result in similar estimates.

For purposes of historic comparisons, since conditions and regularity of aerial surveys for each particular year are basically unknown and unmeasurable, indexing past results would be a hard task if not impossible.

One would expect the aerial survey to be conservative because of the inability to see the true flux of spawners through any given area, however, considering that the aerial estimates include the harvested fish, one would expect the estimate to exceed the diver estimate. Since survey conditions change so much from year to year, and since historic aerial survey results cannot be validated, it is difficult to index aerial estimates based on actual ground surveys. In addition, other factors affecting a spawner biomass estimate enter into the picture. From the air, it is difficult to gage the density of egg coverage that so significantly affects the final biomass estimate. As historic data shows, density of spawners and eggs in any given area can change radically from year to year (J.A. Brady, Alaska Department of Fish and Game, Cordova, 1988 Prince William Sound herring season summary memorandum and Randall and Jackson, 1983 and 1984). Age structure of the population strongly influences its "egg production" potential and is a factor adding considerable variability to a biomass estimate that does not really test the true reproductive strength of a given population. It may be possible to index the aerial estimates with the diver estimates, however, considering all the variables, it could turn out to be a formidable task. In any case, several more years of data will be necessary to enable researchers to visualize any kind of pattern emerging.

Skiff Surveys

The surveys conducted experimentally in 1988 exhibited the discrepancies in mapping that can occur if just aerial information is taken into account. Several factors affect the accuracy of mapping spawn from the air:

- aerial surveys are flown only once per day and can only represent the extent of spawning at the specific time of the flyover

- current and tidal drift can carry milt to shoreline areas that have recieved no spawn,

- if surveys are not carried out on a regular basis, areas recieving spawn can be left unmapped,

- it is possible that with populations consisting of younger fish, males may be releasing milt in the water, but no spawn occurs because the females are not laying down eggs.

On Montague and Green Islands, it is believed that two of these factors occurred. Zero transects occurred from Hanning Bay northward, which was probably due to drift. On Green Island, even though thick milt was seen from the air, there was virtually no spawn; this might have been due to younger fish and "false spawn". In the Naked Island area, both Lone and Storey Islands recieved less actual spawn than was mapped and this was probably, once again, due to drift of milt or "false spawn". In the North Shore area, even though in reality a continuous band of spawn existed from Cedar Bay to Fairmont Bay, only discontinuous sections were mapped, probably due to intermittant aerial surveys.

All of these results suggest the need for a mapping method that preceeds the diver surveys, and accurately shows the actual spawning areas. Skiff surveys, 2 or 3 days ahead of the divers could correct aerial maps and add accuracy to the biomass estimate. Conducting transects only in areas of actual spawn would reduce sampling variance and should result overall, in a better biomass calculation statistically.

Survey Design

The Canadians have reported an optimal survey design that results in a standard error of less than or equal to 25%. By sampling 5 quadrats per 100 meters of transect and by spacing transects 250-400 meters apart along the length of the spawn (or 2-5% of each transect and 3-4 transects/km), error occurring in stimates leveled off (Schweigert et. al., 1985). In Prince William Sound in 1988, 700 transects would have had to be completed in order to achieve that kind of standard error. The Sound was, in reality sampled every 2.02 miles or 3000 meters. As a result, other methods for reducing error must be sought.

Increased accuracy in mapping, as mentioned previously, may reduce some error. In addition, using larger scale maps would allow more accurate placement of the randomly selected transects by allowing a smaller unit of length for selection. In order to successfully implement two stage sampling, randomness must be assured. Even though the second stage of the sampling process is systematic, random placement of the quadrat within the first 5 meters of spawn observed would assure increased statistical validity.

Schweigert et. al. (1985) found that by eliminating zero quadrats within a particular transect with patchy egg or kelp coverage, variance within and between transects could be reduced. This method was adopted in analysis of the 1988 data as well to reduce variance and to exhibit a truer picture of actual spawn width and density in an area.

In general, error in estimating could be reduced by sampling more area or more transects. The budget and time constraints are the limiting factors in this case, however, a compromise that is consistent with the results of Schweigert et. al. (1985) would be to conduct more transects, but sample fewer quadrats per transect. Travel time and increasing frequency of diver entries and exits, as would occur with more transects, would probably take more time than would be saved by decreasing the amount of quadrats sampled, and as a result, sampling fewer quadrants per transect may or may not be a reasonable solution. In any case, depending on miles of spawn mapped in 1989, transect coverage should be maximized.

Diver Calibrations

Schweigert and Fournier (1982) revealed variations in egg counts depending on egg layers, percent cover and vegetation type that have significant effects on diver estimates. They found, that largely due to patchy egg deposition, egg counts based on counting egg layers and expanding the estimate respectively, resulted in egg estimates that were higher than expected. These results suggest a non-linear relationship between diver error and egg density. Funk (1988) conducted an analysis on nine years worth of diver calibration data on the Southeast survey divers, and found a non-linear relationship of diver estimates versus actual lab counts with an increase in error(overall) at the low and high end of the range of egg densities encountered(Figs. 12-17).

The Canadian reseachers also found a significant difference in egg estimates between vegetation types, splitting out into three basic types:

- sea grasses, brown algaes and filamentous reds were not markedly different,

- large brown kelps(Laminaria spp.) and foliose red algaes had substantially fewer eggs at a given percent cover and number of egg layers, than the preceeding and following groups,

- and finally, rockweeds(Fucus sp.) had substantially more eggs at a given percent cover and number of eggs than either of the two preceeding groups (Schweigert and Fournier, 1982).

Funk (1988) also discovered this substrate type effect, with four major groupings of vegetation types:

- eelgrass was found to have significant "substrate effect", resulting in a increase in the predicted egg number,

- while hair kelps and fucus had similar effects resulting in little change in the predicted egg number,

- with large brown kelps (LBK) having a significant effect, resulting in decreasing the predicted egg number,

- mixed kelp made up the fourth group with variable effect.

These results reveal the need to break calibration corrections down by substrate type, with perhaps 3 groupings and an additional group for spawn on mixed kelp or substrate that does not fit with eelgrass, hair kelps and fucus, or LBK.

Funk (1988) stated that the use of the same divers from year to year is crutial to calibration accuracy due to the learning process which causes variability in calibration factors for the first 2 or 3 seasons. With practice and experience, Southeast individual diver calibration variation decreased and calibration factors stablized. Because calibration factors improve statistically with more samples and the year effect is not significant following the training period, all prior years data are employed in reaching an individual's correction factor (with the year effect as a parameter). Funk (1988) recommends that diver estimates should be checked annually, due to the potential for a divergence in trends and to insure that the pooled year model is still valid. Introducing new divers adds variability and inaccuracy to biomass estimate corrections, if their estimates are employed in the overall biomass estimates.

Since the Prince William Sound program has relatively new estimaters, there were few calibration samples used to analyze any effects due to individuals or vegetation. However, because of the significant effects of substrate on the Southeast diver estimates, substrate effects were also examined in the Sound. A separate model was employed for hair kelps and large brown kelps (LBK) with the other substrate types (Table 2 and 9) getting pooled in a single mixed kelp model. In following years, with more calibration data for the Sound, more specific substrate effects may emerge and the correction models may change accordingly. In any case, more samples will definitely increase accuracy in correction and in the final resulting biomass estimate.

The standard error for each calibration factor is a good way to gage how well an individual estimates. Considering it was the first year for divers EB and DN and how few samples were included, the standard errors of .01 and .02 respectively (Table 1) with less than 20% off actual density values are highly acceptable(W. Blankenbeckler, Alaska Department of Fish and Game, Ketchikan, personal communications, 1988). The lower than expected errors associated with first year divers are probably due to cross-training from the Southeast team; the Sound divers did not have to experience the same learning process as the Southeast divers did when their program was initiated.

The goal for 1989 with respect to diver calibrations should include:

1.) employ as many second season divers as possible that already have estimating experience and if new divers are utilized, have them be the second estimater (the primary estimate coming from the experienced diver) so that calibration samples can be collected for them, 2.) collect as many calibration samples as would be possible to process, increasing available lab time and technician time, as necessary to work up the samples,

3.) collect at least 20 samples from each of the four vegetation types, eelgrass, hair kelps and fucus, LBK, and mixed algaes.

Fecundity

In 1988, the linear relationship between $_w$eight and $_f$ecundity was chosen to derive fecundities to be used in the calculation of biomass for each area. Researchers in the past have examined fecundity in Prince William Sound and found a power curve regression equation to work well using length as the dependent variable(Paulson and Smith, 1977). Nagasaki(1958) plotted fecundity logarithmically with length broken out by age and found differences in growth rates between ages affected the relationship slightly. However, Hourston, et. al. (1981), found that the most accurate estimate of fecundity was derived from a relationship between all three characters (age, weight and length), followed closely by the relation to weight and age, and thirdly weight alone. Length alone was not as accurate as the three mentioned above. The observed annual variations in fecundity reflected differences in growth rates and regional differences and explain why body weight is the best indicator for fecundity estimates and why estimates are improved if age and length are taken into account(Hourston, et. al., 1981). Because there were not enough data points to do a complete analysis of fecundity by weight and age, and for simplicity, the linear relationship between weight and fecundity was chosen, as it seemed like a reasonable fit to the data.

Regional differences in fecundity have been documented by Canadian and U.S. researchers alike. While Nagasaki (1958) recorded a decrease in fecundity going from north to south and west to east in British Columbia, while Paulson and Smith (1977) recorded a general decline in fecundity per unit female body weight with increasing latitudes, but an increase in mean length and fecundity of female spawners with increasing latitude. In comparing the 1988 Prince William Sound fecundity data to that of Southeast Alaska data(Blankenbeckler and Larson, 1987), 1983-84 Prince William Sound data(Jackson and Randall, 1983 and 1984), it appears that the fecundities are lower per unit body weight of females, indicating that there is not only a regional effect occurring, but a year affect as well.

There is some evidence that suggests that winter sea temperature has an effect on fecundity. Tanasichuk and Ware (1986) found that while ovary weight did not vary significantly from year to year or between locations, egg size and fecundity did. They found higher overall fecundities per unit weight in fish overwintering in the warmer waters during the 1983 El Nino year. Egg size was found to be the compensating factor, which decreased as fecundity increased. They theorized that egg size should decrease and fecundity increase with temperature when the larval growth rate was less than the mortality rate. The average egg size measured in the Sound in 1988 was .0014 g which is the egg size that coincides with a sea temperature during incubation of 7 degrees C(44.6 degrees F) in the Canadian data (Tanasichuk and Ware, 1986). At the time of the spawn survey, sea surface temperatures in the eastern and southern areas were running 42-43 degrees F and in the northern district, 39-40 degrees F; however, water temperature was increasing rapidly and could have reached a temperature close to 44 degrees by incubation time. In any case, the compensation for growth and larval mortality associated with different temperatures may explain the regional and annual differences in fecundity in Alaska and deserves a closer examination and analysis.

In British Columbia, it was found that in general, fecundity could be broken down into a number of eggs per unit body weight of females. Sshweigert, et. al.(1985) utilized 200 eggs per gram weight of females in the analysis and calculation of biomass estimates. The average in the Sound for 1988 was found to be 140 eggs per gram of female weight based on an average length of 200 mm and an average weight of 115 grams. Jackson and Randall (1983) found an increasing number of eggs per gram with an increase in fecundity and fish size. In general a fecundity of 12,608 associated with an 88.7 gram female had 142.1 eggs/gram whereas as the top of the scale, a fecundity of 29,797 associated with a 165.3 gram female had 180.3 eggs per gram of weight. If this number were relatively constant, it could be employed in the biomass estimate equation, eliminating a calculation step; however, there are some doubts concerning the validity of using this number, since fecundity and weight, especially on larger individuals, may not have a simple proportional relationship. The estimate of 140 eggs/gram is lower than the Canadian estimate of 200 eggs/gram, again, possibly indicating a regional difference in fecundity per unit body weight of females.

The topic of fecundity of herring in Prince William Sound could be a separate study in itself and once a good data base is established, should be examined more closely. It would be of value to conduct a statewide examination of fecundity comparing regional differences in fecundity and egg size from Norton Sound to Southeast. Understanding parameters affecting herring egg production would be of value by adding accuracy to the spawning biomass estimates, that rely so heavily on accurate fecundity estimates.

RECOMMENDATIONS

1. Examination of Egg Loss: It may be possible to begin examining egg loss in the Sound more closely by laying down some index transects marked with a permanent leadline and possible an enclosed index area. These index sites would then be surveyed several times prior to the spawn survey and sampled separately for calibration. They could also be used to study incubation timing and would probably provide some interesting insights to the spawning dynamics in the Sound. Some time needs to be devoted to methodology and planning if it is going to be conducted in 1989.

2. **Skiff Survey:** The need for a skiff survey to accurately map spawning area has already been stressed in this report. If a gillnetter were to be chartered with a skipper and one biologist or technician, the cost

could probably be kept to a minimum (since those vessels are generally not in use at that time of the year) and would provide a sleeping platform as well for the extra person. The skiff survey would begin 2 or 3 days ahead of the diver survey with a revised map provided to allow placement of the randomly selected transects within the newly mapped area.

3. **Range in Depth of Spawn in the Littoral/Sublittoral Zone:** It would be of interest to further examine and analyze the depth of spawn found in the Sound by looking at the percentage of intertidal versus subtidal as a function of gradient and slope of the substrate. In addition, major or representative vegetation types associated with the particular slopes or gradients would be of interest. The position of the majority of spawn found in the Sound with regards to location within the littoral-sublittoral zone would have a profound effect on egg loss due to predation and current. Time was a limiting factor in 1988 in examining this information, but it should be considered a priority in the future.

4. **Continuation of Fecundity Sampling:** As outlined in the discussion, understanding fecundity more thoroughly may be a key feature in the improvement of spawning biomass estimations. Therefore, continuing to collect fecundity samples will increase the data base available for when a regional or statewide study is initiated.

5. **Computerization of Spawn Data and Mapping:** In addition to determining spawn profile with depth, mapping spawn areas and width graphically in a way that distinguishes spawn densities and perhaps even substrate type would be of value for visual analysis and comparison. Graphical presentation could simplify the interpretation of information as complex as 166.3 miles of spawn stretched out over an area of approximately 20,000 square miles with densities and spawn widths varying by 100%. There are several, relatively inexpensive mapping software packages available, some incorporated in existing software. Being able to not only computerize transects and spawn/habitat data, but to randomly set transects and map them prior to surveys would save considerable time and add accuracy to the sampling technique. Computerization of herring spawn on a mapping program could also provide managers with an invaluable inseason method of visualizing herring schools and spawn nearly instantaneously.

5. **Employment of Spawn Biomass Estimate in Forecasting:** Sandone (1988a and 1988b) has compiled an extensive and complete analysis of Prince William Sound herring age-class structure and dynamics and has outlined a cohort model to be utilized for biomass projections. It is recommended that the 1988 biomass estimate from spawn deposition surveys be employed in this model to obtain a workable biomass projection for 1989. This would allow a pre-season summary of the expected return in 1989 and enable managers to set quotas and industry to review status long before the season begins, as in the past, with increased accuracy. In addition, it may be of interest to examine the relationship between age class structure and spawner density (as back-calculated from spawn deposition

surveys). This may allow a prediction of not only the returning spawner biomass, but also the expected spawner/egg density and possibly even miles of spawn expected from a particular age class structure.

LITERATURE CITED

Beauchamp, J.J., and J.S. Olsen. 1973. Corrections for bias in regression estimates after logarithmic transformation. Ecology 54(6): 1403-1407.

Biggs, E.D. 1988. Herring spawn deposition survey operational plan, Prince William Sound, 1988. Alaska Department of Fisn and Game, Cordova office. 10 pp.

Blankenbeckler, D. 1987. Pacific herring *(Clupea harengus pallasi)* research in Southeastern Alaska. Alaska Department of Fish and Game Technical Data Report No. 203, Juneau, Alaska.

Blankenbeckler, D., and R. Larson. 1987. Pacific herring *(Clupea harengus pallasi)* harvest statistics, hydroacoustical surveys, age, weight, and length analysis, and spawning ground surveys for Southeastern Alaska, 1980-1983. Alaska Department of Fish and Game Technical Data Report No. 202, Juneau, Alaska.

Blankenbeckler, D., and R. Larson. 1985. Pacific herring *(Clupea harengus pallasi)* research in Southeastern Alaska, 1982-1983. Alaska Department of Fish and Game Technical Data Report No. 143, Juneau, Alaska.

Blankenbeckler, D., and R. Larson. 1982. Pacific herring *(Clupea harengus pallasi)* spawning ground research in Southeastern Alaska, 1978, 1979, and 1980. Alaska Department of Fish and Game Technical Data Report No. 69, Juneau, Alaska.

Brady, J.A. 1987. Distribution, timing and relative biomass indices for Pacific herring as determined by aerial surveys in Prince William Sound, 1978 to 1987. Alaska Department of Fish and Game, Prince William Sound Data Report No. 87-14. 37 pp.

Cochran, W.G. 1963. Sampling techniques. John Wiley and sons, Inc., publishers, New York.

Crawford, D. and S. Sharr. 1988. Prince William Sound herring A-W-L sampling manual. Alaska Department of Fish and Game, Cordova office report. 36 pp.

Goodman, L.A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

Funk, F. 1988. Estimation of herring egg densities from diver observations on Southeastern Alaskan herring spawning grounds. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau office, Draft, August 18, 1988. 18 pp.

Haegele, C.W., R.D. Humphreys, and A.S. Hourston. 1981. Distribution of eggs by depth and vegetation type in Pacific herring (Clupea harengus pallasi) spawnings in Southern British Columbia. Can. J. Fish. Aquat. Sci. 38:381-386.

Haegele, C.W. and J.F. Schweigert. 1985. Estimation of egg numbers in Pacific herring spawns on giant kelp. No. Am. J. Fish. Mngmt. 5:65-71.

Hourston, A.S., V. Haist, and R.D. Humphreys. 1981. Regional and temporal variation in the fecundity of Pacific herring in British Columbia waters. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1009. 31 pp.

Jackson, M. and R.C. Randall. 1983. Herring spawn deposition surveys in Prince William Sound, 1983. Alaska Department of Fish and Game, Prince William Sound Data Report No. 83-6. 15 pp.

Jackson M. and R.C. Randall. 1984. Herring spawn deposition surveys, Prince William Sound, 1984. Alaska Department of Fish and Game, Prince William Sound Data Report 84-16. 15 pp.

Laurent, A.G. 1963. Lognormal distribution and the translation method: description and estimation problems. Journal of the American Statistical Association 58: 231-235.

Montgomery, D.T. 1958. Herring spawning surveys if Southeastern Alaska. USFWS. Bur. of Comm. Fish. Fish. Marine Fish. Inv. Field Operations Report. 22 pp.

Nagasaki, F. 1958. The fecundity of Pacific herring (Clupea pallasi) in British Columbia coastal waters. J. Fish. Res. Bd. Canada, 15(3), pp 313-330.

Paulson, A.C. and R.L. Smith. 1977. Latitudinal variation of Pacific herring fecundity. Trans. Am. Fish. Soc., 106(3):244-247.

Rosenthal, R.J. 1976. Herring spawn on kelp fishery of Prince William Sound for Alaska Department of Fish and Game. Dames and Moore, Anchorage, Job No. 6791-002-20, 12-6-76. 111 pp.

Rosenthal, R.J. 1978. An investigation of the herring egg on seaweed fishery in Prince William Sound, Alaska: estimates of standing crop, growth rates of kelps and patterns of recolonization in harvested areas for State of Alaska, Department of Fish and Game, Division of Commercial Fisheries. Alaska Coastal Research, Anchorage, Job No. Ocean-04-78, 12-09-78. 45 pp.

Sandone, G.J. 1988a. Estimated age-class contribution of Pacific herring to the commercial sac-roe harvests of Prince William Sound, 1973-1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage, Prince William Sound Area Data Report Series 88-04. 55 pp.

Sandone, G.J. 1988b. Prince William Sound 1988 herring biomass projection. Alaska Department of Fish and Game, Prince William Sound Area Data Report 88-05, 21 pp.

SAS. 1987. SAS/STAT Guide for personal computers, version 6 edition. SAS Institute, Cary, North Carolina.

Schweigert, J.F. and D. Fournier. 1982. A model for predicting pacific herring (**Clupea harengus pallasi**) spawn density from Diver Observations. Can. J. Fish. Aquat. Sci., 39:1361-1365.

Schweigert, J.F., C.W. Haegele, and M. Stocker. 1985. Optimizing sampling design for herring spawn surveys on the Strait of Georgia, B.C. Can. J. Fish. Aquat. Sci. 42:1806-1814.

Seber, G.A.F. 1973. The estimation of animal abundance. C. Griffin and Co., Ltd., London, 506 pp.

Tanasiachuk, R. W. and D. M. Ware. 1987. Influence of interannual variations in winter sea temperature on fecundity, and egg size in Pacific herring (**Clupea harengus pallasi**). Can. J. Fish. Aquat. Sci. 44:1485-1495.

Ware, D.M. 1985. Life history characteristics, reproductive value, and resilience of Pacific herring (**Clupea harengus pallasi**). Can. J. Fish. Aquat. Sci. 42:127-137.

APPENDIX A. TABLES AND FIGURES

TABLE 1. 1988 SUMMARY OF DIVER CALIBRATION SAMPLE RESULTS.

DATE	LOCATION (a)	TRANS NO.(b)	SUBSTRATE TYPE (c)		ml/1 K eggs(d)	LAB COUNT(e)	EGGS OUTSIDE:(f) NO.	% TOT	DIVERS ESTIMATES: (thousands or K), (g) EB	Lab/v	DN	Lab/v	FF	Lab/v	TM	Lab/v
5/07/88	Granite	64	Fu/Rk	*		-	1	0.83%	25		35					
5/04/88	Rocky Pt.	52	LBK	*		57.4	0	0.00%			15	3.83			8	7.18
5/02/88	Zaikof	4	Fu/Rk	*	9.0	64.9	120	48.00%	250	0.26						
5/07/88	Granite	-	LBK	*	3.8	247.0	0	0.00%	95	2.60	90	2.74				
5/07/88	Granite	66	LBK	*		5.2	0	0.00%	35	0.15	35	0.15				
5/02/88	Zaikof	2	Fu/Hr	*	12.0	26.0	0	0.00%	100	0.26						
5/04/88	Rocky Pt.	50	LBK	*			0	0.00%			60	0.00			40	
5/07/88	Granite	-	EG/Rk			66.2	0	0.00%	65	1.02	35	1.89				
5/05/88	Granite	63	Fu			48.0	0	0.00%			25	1.92				
5/04/88	Narrows	57	EG/Hr		4.8	43.8	0	0.00%	40	1.10	40	1.10				
5/05/88	Granite	62	EG		7.7	34.8	0	0.00%			80	0.43	120	0.29		
5/04/88	Rocky Pt.	51	LBK			66.3	0	0.00%			70	0.95			60	1.11
5/07/88	Granite	-	EG		5.1	77.7	0	0.00%	95	0.82	85	0.91				
5/07/88	Granite	83	LBK		5.1	63.6	0	0.00%	35	1.82	75	0.85				
5/07/88	Granite	-	Hr/Rk			389.3	0	0.00%	320	1.22	280	1.39				
5702/88	Zaikof	4	Fu/Rk		12.0	14.9	20	133.33%	15	0.99						
5/06/88	Fairmont	75	Fu & Hr/Rk		5.9	137.8	14	10.00%					140	0.98		
5/02/88	Zaikof	1	EG/Rk		6.0	262.1	120	34.29%	350	0.75						
5/06/88	Fairmont	75	Fu/Rk		11.8	5.6	0.2	5.00%					4	1.40		
5/01/88	No. Mont.	17	Hr & Fu/Rk			160.2	200	80.00%	250	0.64						
5/03/88	Galena B.	38	Hr/Red Hr		6.4	115.0	40	7.41%	160	0.72	110	1.05				
5/05/88	Granite	63	LBK		7.1	25.0	0	0.00%			25	1.00				
5/02/88	Zaikof	2	EG & Hr/Rk		5.2	326.6	160	40.00%	400	0.82						
5/07/88	Granite	-	Fu		12.0	21.7	0	0.00%	40	0.54	45	0.48				
5/03/88	Galena	38	Fu/Snd			19.4	0	0.00%	60	0.32						
5/04/88	Narrows	57	Hr			64.9	10	3.33%	70	0.93	80	0.81				
5/03/88	Galena	47	Fu/Rk		21.2	18.5	20	13.33%	35	0.53	40	0.46				
5/07/88	Granite	-	EG		4.2	100.5	10	2.33%	120	0.84	95	1.06				
5/07/88	Granite	66	Ag.		5.5	46.4	0	0.00%	110	0.42	70	0.66				
5/07/88	Granite	82	Hr/Fu		5.1	144.2	30	5.56%	150	0.96	120	1.20				
5/07/88	Granite	-	LBK		4.2	182.0	0	0.00%	160	1.14	230	0.79				
5/04/88	Rocky Pt.	48	EG			29.8	0	0.00%			40	0.75			60	0.50
5/07/88	Granite	-	LBK		6.1	55.3	0	0.00%	70	0.79	75	0.74				
5/02/88	Rocky B.	12	LBK/Rk		4.7	22.8	15	42.86%	35	0.65						
5/02/88	Zaikof	2	Hr/GF		5.5	230.8	160	35.56%	450	0.51						
5/06/88	Fairmont	78	Ag.		11.0	58.9	0	0.00%	70	0.84	70	0.84				
5/07/88	Granite	-	Hr.			245.4	0	0.00%	250	0.98	240	1.02				
5/07/88	Granite	-	LBK			98.6	0	0.00%	200	0.49	160	0.62				
			Average =		7.5		26	13.32%		0.83		0.95		0.89		0.80
			STD =		3.9		54	28.37%		0.31		0.38		0.46		0.30
			Std Error =		0.16		1	14.19%		0.01		0.02		0.15		0.15

* Samples excluded in the average because of processing problems.

(a) Location within Prince William Sound, see Figures 2-7.

(b) See Figures 2-7 for individual transect locations.

(c) Spawning substrate; Table A1 defines the substrate codes listed here.

(d) Volume in ml of 1000 eggs haphazardly selected from the sample.

(e) Actual count of eggs in thousands(K), measured volumetrically, for each sample.

(f) Number of eggs left outside the quadrant when taking a sample from the grounds (loose or on rock, etc.) and percent of eggs out of the total estimate, left outside.

(g) Diver estimates of each sample in thousands of eggs(K), followed by the ratio of the actual lab count over the individual diver's visual estimate, see Table A1 for diver identification.

Table ~~XI~~ 2. Vegetation and substrate codes used in the 1988 Prince William Sound egg deposition survey, and vegetation summary categories and codes.

Vegetation		Vegetation Summary Category		
Code	Name	Code	Number	Name
ag	**Agarum cribosum**	LBK	1	Large brown kelp
alg	Algae	FUC	4	Fucus
cob	Cobble	FUC	4	Fucus
cor	Corraline algae	LBK	1	Large brown kelp
eg	Eelgrass	EEL	2	Eelgrass
fu	Fucus	FUC	4	Fucus
gf	Filamentous green algae	HRK	3	Hair kelp
gl	Green leaf algae	HRK	3	Hair kelp
gr	Gravel	FUC	4	Fucus
hr	Hair kelp	HRK	3	Hair kelp
lbk	Large brown kelp	LBK	1	Large brown kelp
le	Loose eggs	EEL	2	Eelgrass
mix	Mixed on rock	MIX	5	Mixed on rock
mud	Mud	EEL	2	Eelgrass
rf	Red filamentous algae	HRK	3	Hair kelp
rh	Red hair kelp	HRK	3	Hair kelp
rib	Ribbon kelp	LBK	1	Large brown kelp
rk	Rock	FUC	4	Fucus
rl	Red leaf algae	LBK	1	Large brown kelp
sd	Sand	EEL	2	Eelgrass
snd	Sand	EEL	2	Eelgrass

Table 3. Summary of samples used to estimate mean weight and sex ratio for each area stratum in the 1988 Prince William Sound herring egg deposition survey.

Area	Sample Location	Gear[1]	Date	No. Fish	Mean Weight Females	Mean Weight Total	Sex Ratio (Total/Females)
Montague	Hanning Bay	TPS	4/17	568	99.2	96.0	1.78
Valdez	Galena Bay	TPD	4/16	284	106.0	102.0	1.89
	Virgin Bay	TPD	4/16	293	92.0	90.0	2.01
	Area summary[2]			577	99.0	95.7	1.95
North	Fairmont Bay	TPS	4/18	548	129.0	125.0	2.07
	North Shore	CPS	4/22	615	115.0	110.0	2.03
	Granite Bay	CPS	4/21	293	104.0	99.0	2.08
	Cedar Bay	CPS	4/21	291	113.0	109.0	2.22
	Area summary[2]			2,010	117.1	113.8	2.14
Naked I.	McPherson Bay	TPS	4/19	545	111.4	107.5	1.97
Prince William Sound Summary[3]				3,700	102.3	100.2	1.88

1 Gear Codes: TPS = test purse seine
TPD = test pound
CPS = commercial purse seine.

2 Average weights computed as the unweighted mean of all fish in stratum. Sex ratio computed from unweighted total of all fish in stratum.

3 Prince William Sound average weights and sex ratio computed as the weighted average of the average weights and sex ratio in each stratum, weighting by the estimated biomass in each stratum.

Table 4. Summary of transect information for the Montague area.

Transect No.	Date mmdd	Location	Divers 1 2	Time -In-	Time Min.	Width (m)	Depth (ft)	No. Quad. Sampled (m_i)	Mean Quad. Count y_i	Within Transect Variance Var(y_i)	Total Quadrats Possible M_i	Total Eggs Per Transect $\hat{Y}_i$
1	5 2	Zaikof Bay	TM DN	8:23	13	135	28	27	30.6	1.4E+9	426	13026
2	5 2	Zaikof Bay	TM DN	8:59	15	155	20	31	90.3	5.7E+9	490	44234
3	5 2	Zaikof Bay	TM DN	9:36	15	165	18	33	4.7	3.8E+7	521	2427
4	5 2	Zaikof Bay	TM DN	10:40	8	85	40	17	68.3	6.1E+8	268	18315
5	5 2	Zaikof Bay	TM DN	11:02	6	80	30	16	0.0	0.0E+0	252	0
6	5 2	Zaikof Bay	TM DN	11:18	6	105	30	21	0.0	0.0E+0	332	0
7	5 2	Zaikof Bay	TM DN	11:39	6	105	35	21	0.0	0.0E+0	332	0
8	5 2	Rocky Bay	EB FF	16:30	10	95	16	19	27.3	1.7E+8	300	8189
9	5 2	Rocky Bay	EB FF	16:00	13	80	18	16	17.6	1.8E+8	252	4424
10	5 2	Rocky Bay	EB FF	15:31	14	65	26	13	9.7	2.2E+7	205	1994
11	5 2	Rocky Bay	EB FF	14:51	12	105	27	21	16.0	2.1E+8	332	5313
12	5 2	Rocky Bay	EB FF	14:25	17	140	30	28	2.2	5.7E+6	442	977
13	5 2	Rocky Bay	EB FF	14:15	3	55	26	11	0.0	0.0E+0	173	0
14	4 30	N. Montague	EB DN	16:45	43	205	32	41	24.8	4.6E+8	648	16046
15	5 1	N. Montague	EB FF	17:25	45	225	20	45	31.4	8.6E+8	711	22290
16	5 1	N. Montague	EB FF	16:55	10	65	27	13	22.2	1.0E+8	205	4558
17	5 1	N. Montague	EB RI	8:45	30	70	38	14	49.1	3.4E+8	221	10851
18	5 1	N. Montague	TM FF	15:37	10	95	35	19	0.0	0.0E+0	300	0
19	5 1	N. Montague	TM FF	15:07	11	235	40	47	0.1	3.3E+5	743	83
20	5 1	N. Montague	TM	14:37	14	155	20	31	0.0	0.0E+0	490	0
21	5 1	N. Montague	TM DN	10:25	11	90	15	18	20.2	1.8E+8	284	5740
22	5 1	N. Montague	TM DN	12:01	18	205	25	41	0.4	1.4E+6	648	259
23	4 30	Green Island	TM FF	14:19	7	45	30	9	0.0	0.0E+0	142	0
24	4 30	Green Island	TM FF	14:43	11	105	30	21	0.0	0.0E+0	332	0
25	4 30	Green Island	TM FF	15:13	32	235	25	47	16.9	2.7E+8	743	12536
26	4 30	Green Island	EB DN	11:50	15	65	20	13	0.0	0.0E+0	205	0
27	5 1	N. Montague	TM DN	10:51	18	275	30	55	3.8	2.6E+8	869	3296
28	5 1	N. Montague	TM DN	11:20	19	190	15	38	4.2	2.2E+7	600	2500
29	4 30	N. Montague	EB DN	11:01	14	70	10	14	0.0	0.0E+0	221	0
30	4 30	S. Montague	TM EB	10:20	10	105	15	21	0.0	0.0E+0	332	0
31	4 30	S. Montague	TM EB	9:23	27	100	25	20	22.0	8.4E+7	316	6965

Summary Information:

Mean Transect Width = 121.0 meters
Mean Spawn Width (excluding all zero quadrants) = 33.9 meters
Maximum Depth of Transect = 25.7 feet
Mean Quadrant Density (for all non-zero quadrants) = 33.0 K eggs/.1 m2

Table 5. Summary of transect information for the Valdez area.

Tran-sect No.	Date mmdd	Location	Divers 1 2	Time -In-	Time Min.	Width (m)	Depth (ft)	No. Quad. Sampled (m_i)	Mean Quad. Count y_i	Within Transect Variance Var(y_i)	Total Quadrats Possible M_i	Total Eggs Per Transect $\hat{y}_i$
32	5 3	Valdez Arm	EB TM	8:51	17	90	21	18	26.6	1.0E+8	284	7565
33	5 3	Valdez Arm	TM FF	10:03	5	55	35	11	0.0	0.0E+0	173	0
34	5 3	Sawmill Bay	TM FF	11:04	7	70	20	14	1.3	3.7E+5	221	294
35	5 3	Valdez Arm	TM FF	11:08	4	90	35	18	1.8	3.5E+6	284	513
36	5 3	Valdez Arm	TM FF	12:26	16	95	35	19	37.0	1.1E+8	300	11101
37	5 3	Valdez Arm	TM FF	13:01	14	90	25	18	7.2	1.0E+7	284	2034
38	5 3	Galena Bay	EB DN	16:43	8	40	34	8	6.9	5.8E+6	126	872
39	5 3	Galena Bay	EB DN	17:04	5	40	34	8	0.1	2.6E+3	126	18
43	5 3	Galena Bay	EB DN	17:24	10	75	25	15	0.0	0.0E+0	237	0
44	5 3	Galena Bay	EB DN	16:28	6	15	30	3	2.6	2.9E+4	47	124
45	5 3	Galena Bay	EB DN	16:11	3	40	30	8	0.0	0.0E+0	126	0
46	5 3	Galena Bay	EB DN	15:43	14	65	30	13	16.3	1.4E+8	205	3346
47	5 3	Galena Bay	EB DN	15:22	12	35	25	7	8.9	4.1E+6	110	983
48	5 4	Rocky Point	TM DN	8:47	8	30	30	6	9.0	4.3E+6	94	850
49	5 4	Rocky Point	TM DN	8:32	9	45	30	9	4.8	1.1E+6	142	683
50	5 4	Rocky Point	TM DN	9:05	9	15	25	3	61.3	1.3E+6	47	2883
51	5 4	Rocky Point	TM DN	9:32	8	50	25	10	8.8	9.3E+6	158	1386
52	5 4	Rocky Point	TM DN	9:52	8	50	20	10	17.0	3.5E+7	158	2684
53	5 4		EB DN	13:56	10	85	19	17	1.3	7.4E+5	268	344
54	5 4		EB DN	14:16	8	90	10	18	0.0	0.0E+0	284	0
55	5 4		EB DN	15:37	8	75	31	15	0.4	1.7E+4	237	90
56	5 4	Bligh Isle	EB DN	11:34	10	40	30	8	0.1	2.6E+3	126	18
57	5 4		EB DN	14:54	21	160	20	32	6.2	5.2E+7	505	3115
58	5 4	Bligh Isle	TM DN	11:30	8	105	20	21	0.0	0.0E+0	332	0
59	5 4	Bligh Isle	TM DN	11:11	9	140	4	28	0.4	3.6E+5	442	163
60	5 4	Bugby Isle	TM DN	10:47	5	55	6	11	0.5	1.8E+4	173	89
61	5 4	Bugby Isle	TM DN	10:27	9	155	20	31	0.0	0.0E+0	490	0

Summary Information:

Mean Transect Width = 65.2 meters

Mean Spawn Width (excluding all zero quadrants) = 16.9 meters

Maximum Depth of Transect = 24.8 feet

Mean Quadrant Density (for all non-zero quadrants) = 17.4 K eggs/.1 m2

Table 6. Summary of transect information for the North Shore area.

Transect No.	Date mmdd	Location	Divers 1 2	Time -In-	Time Min.	Width (m)	Depth (ft)	No. Quad. Samp. (m_i)	Mean Quad. Count y_i	Within Transect Variance Var(y_i)	Total Quadrats Possible M_i	Total Eggs Per Transect $\hat{y}_i$
62	5 5	Granite Bay	DN FF	17:02	28	95	54	19	50.2	2.0E+8	300	15062
63	5 5	Granite Bay	DN FF	17:47	21	90	40	18	9.7	1.9E+7	284	2757
64	5 7	Granite Bay	EB DN	9:33	12	95	23	19	15.8	5.2E+7	300	4748
65	5 7	Granite Bay	EB DN	10:22	10	55	40	11	51.3	8.6E+7	173	8874
66	5 7	Granite Bay	EB DN	10:48	15	70	42	14	13.8	3.6E+7	221	3059
67	5 6	Fairmont Bay	EB DN	9:11	9	25	40	5	20.5	5.5E+6	79	1617
68	5 6	Fairmont Bay	EB DN	9:30	9	35	15	7	34.4	1.1E+7	110	3781
69	5 6	Fairmont Bay	EB DN	8:43	7	25	15	5	14.5	6.3E+6	79	1143
70	5 6	Fairmont Bay	EB DN	8:52	4	25	12	5	0.2	1.6E+3	79	18
71	5 6	Fairmont Bay	EB DN	17:40	15	110	35	22	1.0	9.8E+5	347	350
72	5 6	Fairmont Bay	EB DN	17:25	8	40	30	8	4.5	2.1E+6	126	564
73	5 6	Fairmont Bay	EB DN	16:48	8	45	30	9	24.6	2.2E+7	142	3486
74	5 6	Fairmont Bay	EB DN	16:30	8	90	13	18	10.4	9.7E+7	284	2954
75	5 6	Fairmont Bay	EB DN	16:02	15	85	35	17	2.0	1.2E+6	268	539
76	5 6	Fairmont Bay	EB DN	15:28	19	115	60	23	24.8	1.8E+8	363	8995
77	5 6	Fairmont Bay	EB DN	10:26	8	60	30	12	24.4	5.2E+7	189	4606
78	5 6	Fairmont Bay	EB DN	10:43	23	125	42	25	37.7	1.7E+8	395	14884
79	5 7	Granite Bay	EB DN	8:32	8	30	36	6	24.7	1.2E+7	94	2321
80	5 7	Granite Bay	EB DN	8:47	6	30	30	6	14.3	4.3E+6	94	1342
81	5 7	Granite Bay	EB DN	9:05	10	75	37	15	10.6	1.8E+7	237	2516
82	5 7	Granite Bay	EB DN	9:53	7	55	35	11	0.0	0.0E+0	173	0
83	5 7	Granite Bay	EB DN	11:10	7	35	40	7	14.7	8.0E+6	110	1621

Summary Information:

Mean Transect Width = 59.1 meters
Mean Spawn Width (excluding all zero quadrants) = 32.5 meters
Maximum Depth of Transect = 33.4 feet
Mean Quadrant Density (for all non-zero quadrants) = 27.5 K

Table 7. Summary of transect information for the Naked Island area.

Tran-sect No.	Date mmdd	Location	Divers 1	2	Time -In-	Min.	Width (m)	Depth (ft)	No. Quad. Samp. (m_i)	Mean Quad. Count y_i	Within Transect Variance $Var(\bar{y}_i)$	Total Quadrats Possible M_i	Total Eggs Per Transect $\hat{y}_i$
84	5 8	Outside Bay	EB	DN	8:39	16	100	37	20	55.8	3.8E+8	316	17647
85	5 8	Outside Bay	EB	DN	8:15	16	75	45	15	22.5	4.2E+7	237	5323
86	5 8	Bass Harbor	EB	DN	9:38	9	60	35	12	20.0	3.7E+7	189	3780
87	5 8	Bass Harbor	EB	DN	9:55	16	85	60	17	62.5	3.6E+8	268	16750
88	5 8	McPherson B.	EB	DN	11:50	11	100	25	20	10.9	4.0E+7	316	3434
89	5 8	McPherson B.	EB	DN	11:31	9	50	30	10	49.7	3.8E+7	158	7857

Summary Information:

Mean Transect Width = 73.3 meters

Mean Spawn Width (excluding all zero quadrants) = 54.2 meters

Maximum Depth of Transect = 38.7 feet

Mean Quadrant Density (for all non-zero quadrants) = 44.5 K eggs/.1 m2

Table 8. Summary of 1988 Prince William Sound herring egg deposition survey biomass estimates.

		Montague	Valdez	North Shore	Naked Island	All Areas
Shoreline Length in miles		72.0	60.6	15.4	18.3	166.3
Shoreline Length in meters	(L)	115,873	97,526	24,784	29,451	267,634
No. of possible transects	(N)	366,422	308,405	78,374	93,132	846,333
No. of Transects Sampled	(n)	31	27	22	6	86
Prop. Transects Sampled	(f_1)	0.0085%	0.0088%	0.0281%	0.0064%	0.0102%
Prop. Quadrats Sampled	(f_2)	6.3%	6.3%	6.3%	6.3%	6.3%
Eggs per Transect, 1,000	($\hat{y}$)	5,936	1,450	3,874	9,132	4,324
Total Eggs in billions	(T)	2,175	447	304	850	3,660
Among Transect Variance	(s_1^2)	8.8E+7	6.5E+6	1.9E+7	4.2E+7	4.6E+7
Within Transect Variance	(s_2^2)	3.5E+8	1.8E+7	4.5E+7	1.5E+8	1.7E+8
Sum Var Indiv. Pred. Obs.	(s_3^2)	3.4E+5	2.7E+4	5.9E+4	5.3E+4	9.6E+5
Variance of Total Eggs,	Var(T)	381,646	22,977	5,244	60,076	381,336
Average Weight	($\overline{W}$)	96.0	95.7	113.8	107.5	100.2
Sex Ratio	S	1.78	1.95	2.14	1.97	1.88
Fecundity of avg. female	$F(W^f)$	13,881	13,851	16,976	15,982	14,068
Variance of avg. weight	Var($\overline{W}$)	0.86	1.20	0.58	2.12	0.20
Variance of sex ratio	Var(S)	0.0043	0.0062	0.0026	0.0069	0.0008
Variance of fecundity	Var[$F(W_f)$]	72,601	72,808	62,459	63,288	81,913
Covariance of (W,F)	Cov(W,F)	326,962	279,221	390,907	390,907	312,087
Tonnes per billion eggs	(B')	12.32	13.46	14.36	13.23	12.86
Variance of B'	Var(B')	0.014	0.024	0.009	0.032	0.004
Proportion of eggs lost	(R)	10%	10%	10%	10%	10%
Biomass in tonnes	(B)	24,109	5,418	3,925	10,129	42,345
Variance of biomass est.	Var(B)	4.69E+7	0.34E+7	0.09E+7	0.85E+7	5.12E+7
Standard error of B		6,851	1,837	936	2,922	7,147
Coefficient of variation of B		28%	34%	24%	29%	17%
Lower 95% confidence limit of B		10,681	1,817	2,090	4,402	28,336
Upper 95% confidence limit of B		37,537	9,019	5,761	15,857	56,354

Table 9 M3. Parameter estimates for vegetation group-specific and pooled vegetation group diver calibration models used for predicting egg densities in the 1988 Prince William Sound herring egg deposition survey, by vegetation group.

Parameters from vegetation group-specific model:

Vegetation Type	Parameter	Estimate	Standard Error
Large brown kelp	α	0.9657	0.3897
	β_k	0.7306	0.0897
Hair kelp	α	0.9657	0.3897
	β_k	0.8143	0.0791

Mean squared error: 0.1185

Parameters from pooled vegetation group model:

Vegetation Type	Parameter	Estimate	Standard Error
Eelgrass, Fucus, Mixed	α	0.0016	0.3216
	β	0.9551	0.0709

Mean squared error: 0.1532

Table 10. Annual Prince William Sound herring biomass indicies 1978-1988.

Year	Peak Aerial Estimate(1)	Spawn Depo. Estimate(2)	Miles of Spawn(3)	Million lbs./ Mile(4)	Million lbs./ Mile(5)
1978	9,228		47.4	0.40	
1979	31,631		67.1	0.94	
1980	49,844		53.3	0.87	
1981	51,090		99.7	1.02	
1982	34,861		59.1	1.18	
1983	33,803	22,000	49.7	1.36	0.70
1984	45,655	79,710	65.8	1.39	2.20
1985	26,162		83.2	0.63	
1986	15,150		78.6	0.39	
1987	24,090		72.8	0.66	
1988	34,270	~~43,581~~ 48047 (11731) 59778 revised	166.3	0.41	0.56
Mean	32,344		76.6	0.84	
STD	12,735		32.0	0.36	
Co-variance	39.4		41.8	42.3	

(1) Largest single day aerial estimate of herring biomass in short tons

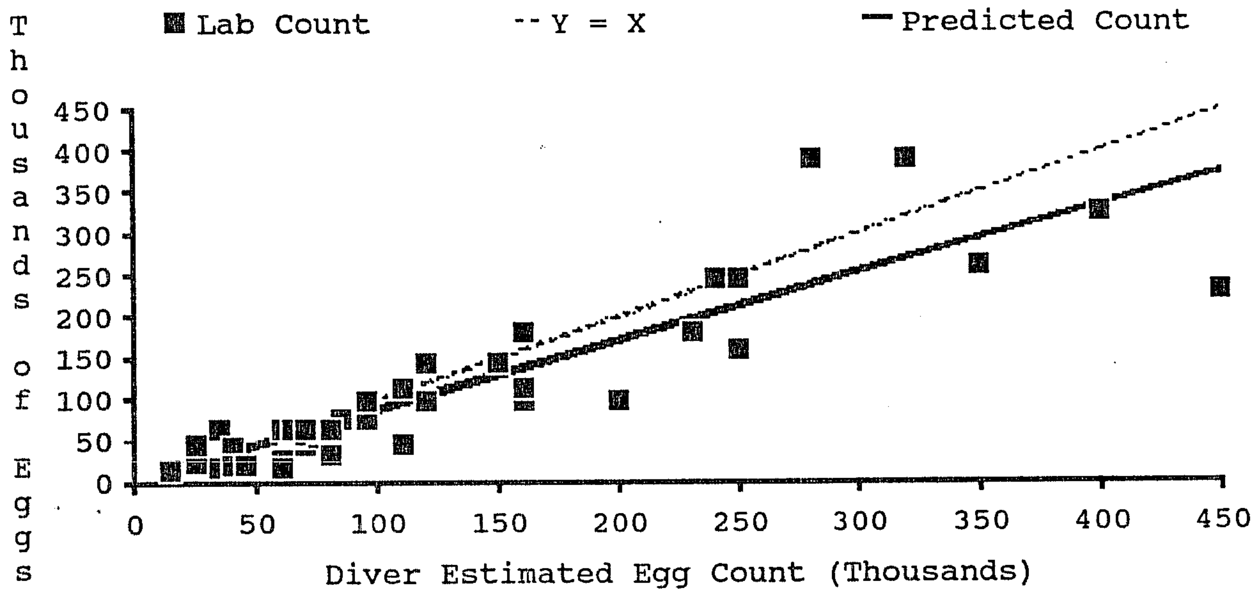
(2) Biomass estimates from spawn deposition diver surveys. 1983 estimate is expanded from a survey covering 23 linear miles. in short tons + commercial catch

(3) Total linear miles of spawn mapped from aerial surveys.

(4) Spawner density derived from aerial survey peak estimate.

(5) Spawner density derived from diver surveys.

1988 Escapement has wild Hrk (772) added back in in Forecast



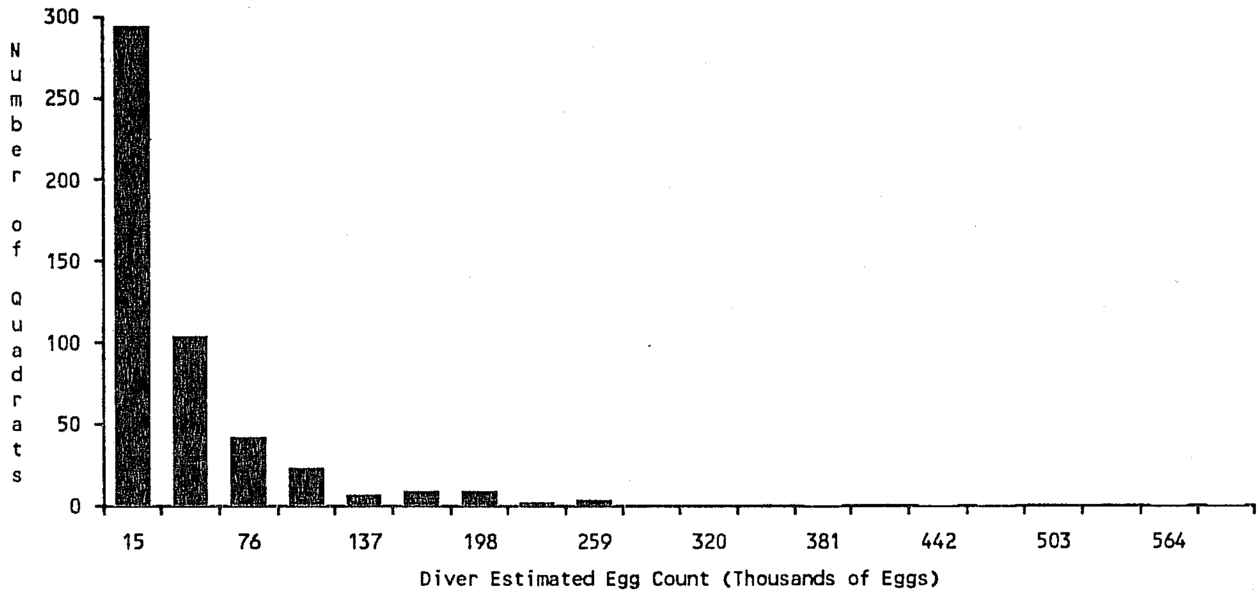


Figure 12. Laboratory enumerated egg counts and predicted values from the pooled vegetation group diver calibration model in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in all vegetation groups in the 1988 Prince William Sound herring egg deposition survey (b).

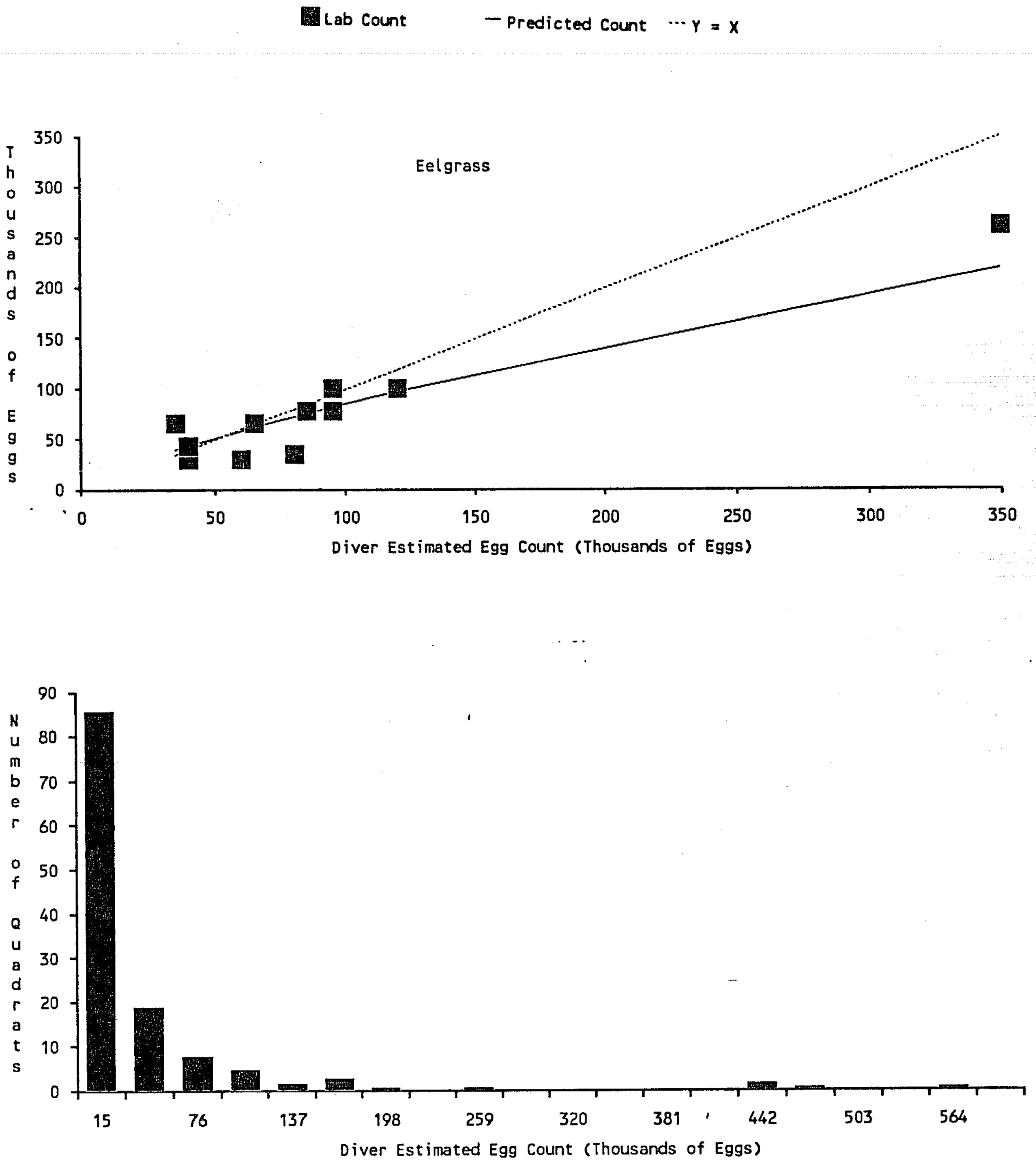


Figure 13 . Laboratory enumerated egg counts and predicted values from the vegetation group-specific diver calibration model for the eelgrass vegetation group in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in the eelgrass vegetation group in the 1988 Prince William Sound herring egg deposition survey (b).

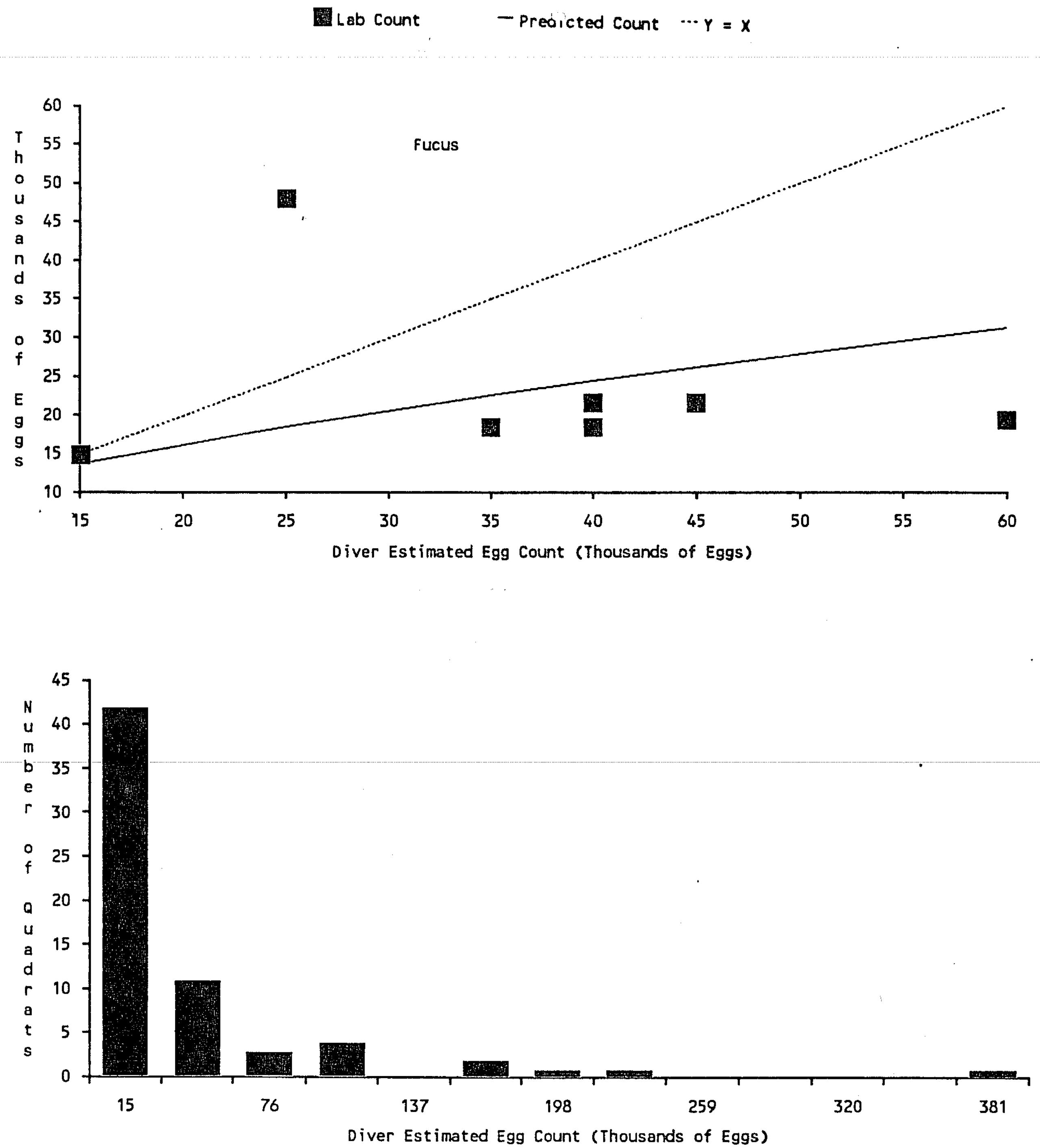
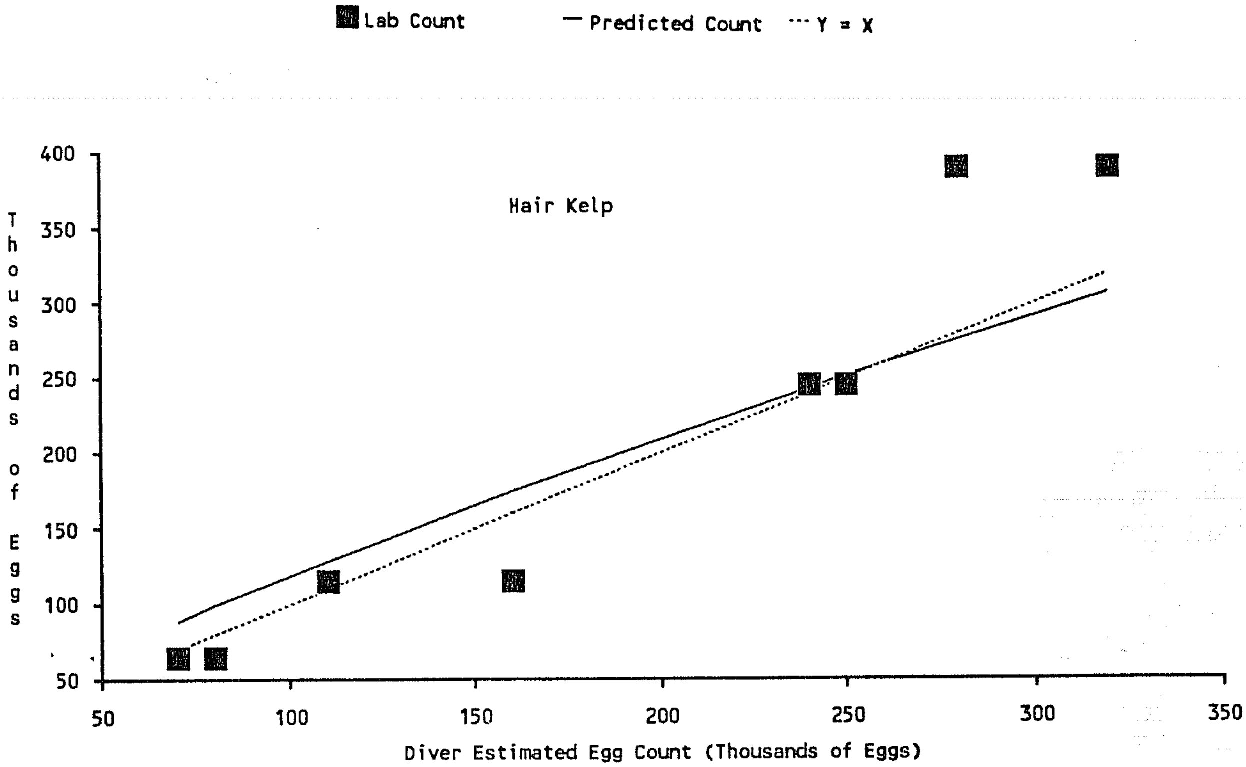


Figure 14 . Laboratory enumerated egg counts and predicted values from the vegetation group-specific diver calibration model for the fucus vegetation group in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in the fucus vegetation group in the 1988 Prince William Sound herring egg deposition survey (b).



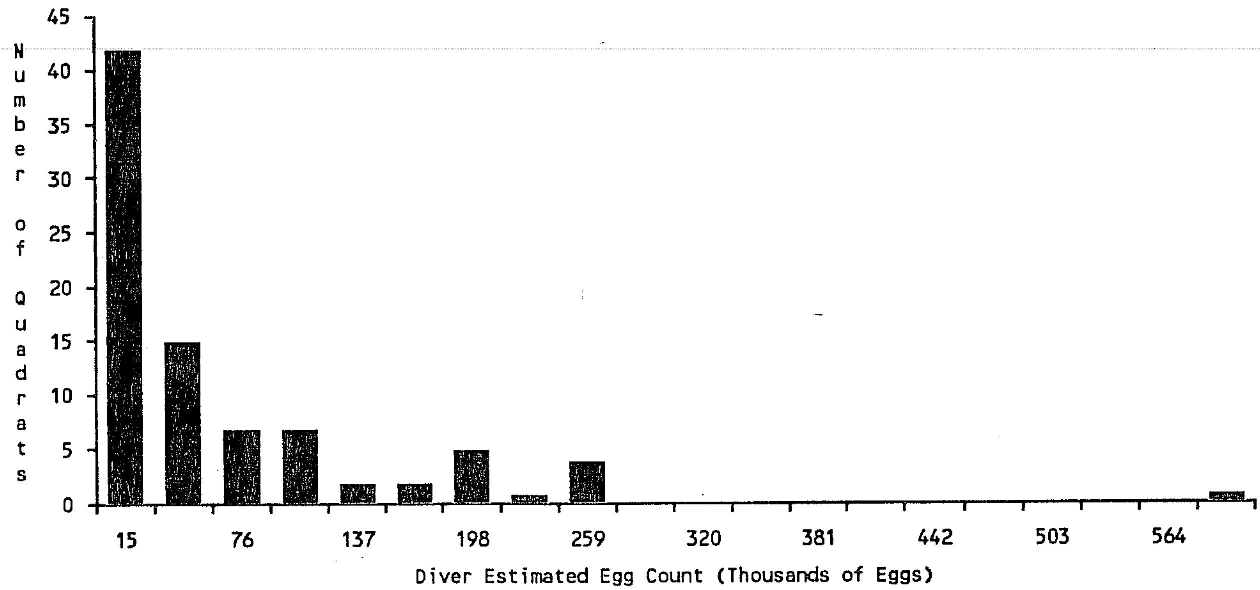


Figure 15 . Laboratory enumerated egg counts and predicted values from the vegetation group-specific diver calibration model for the hair kelp vegetation group in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in the hair kelp vegetation group in the 1988 Prince William Sound herring egg deposition survey (b).

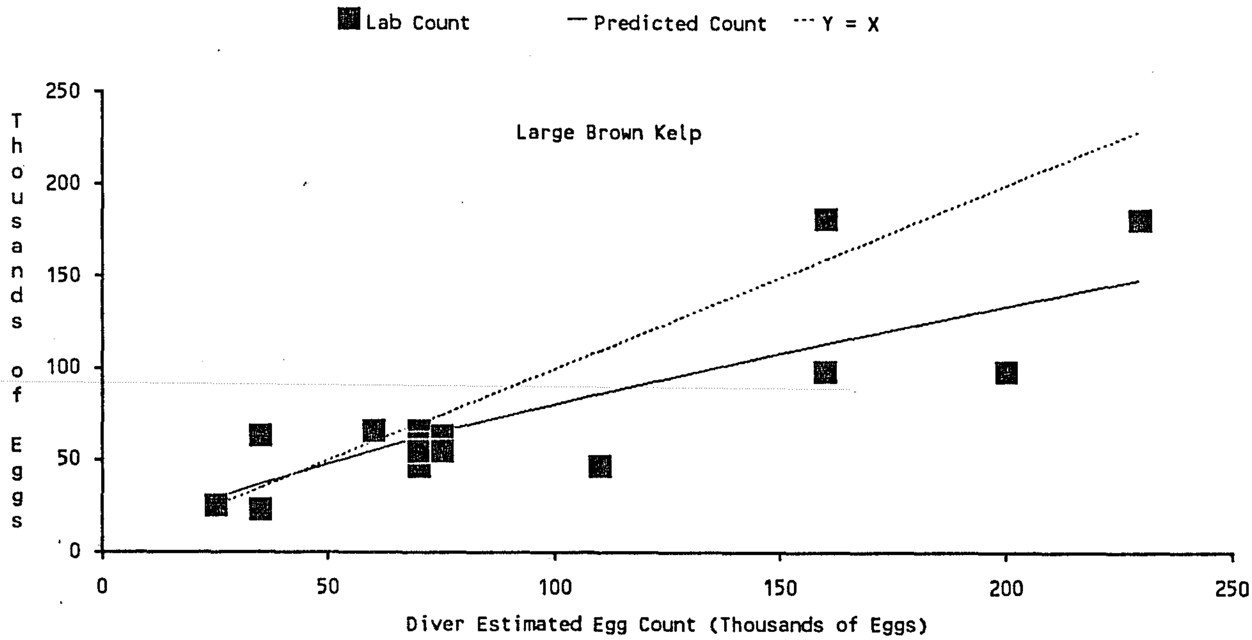
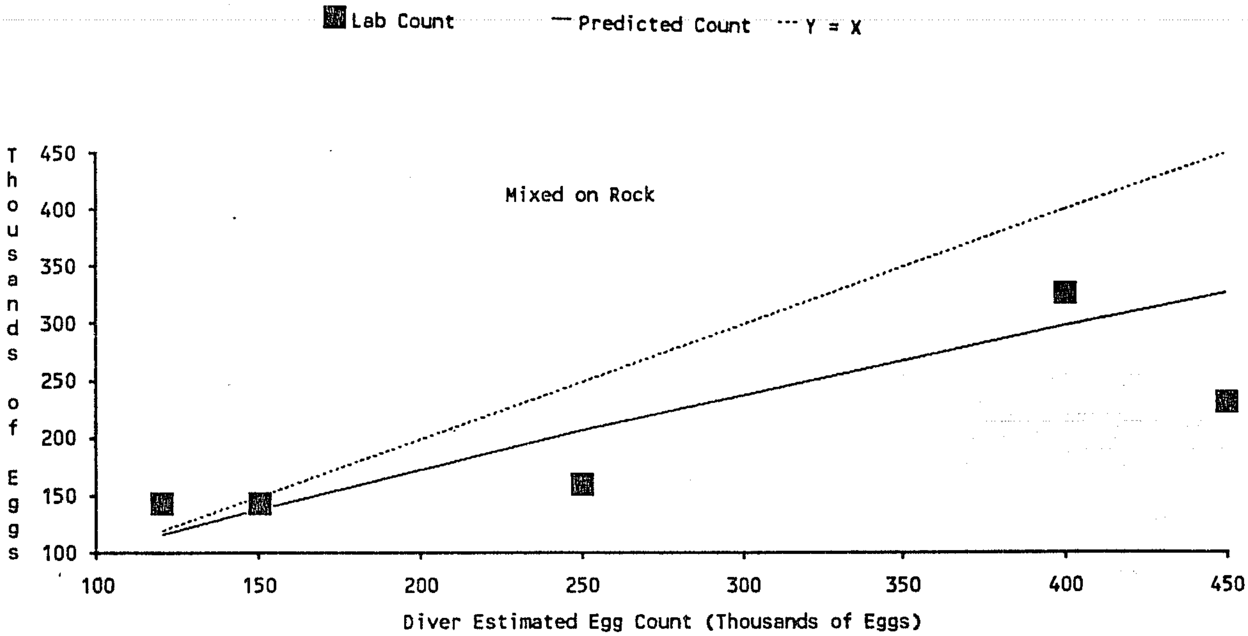


Figure 16 . Laboratory enumerated egg counts and predicted values from the vegetation group-specific diver calibration model for the large brown kelp vegetation group in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in the large brown kelp vegetation group in the 1988 Prince William Sound herring egg deposition survey (b).



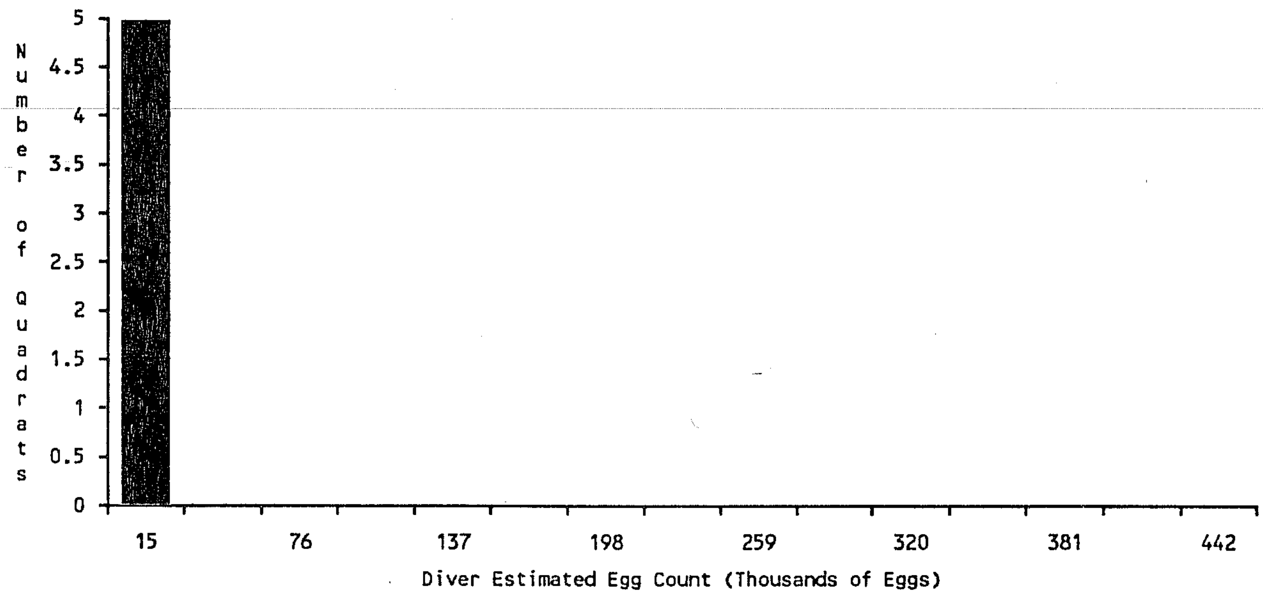


Figure 17. Laboratory enumerated egg counts and predicted values from the vegetation group-specific diver calibration model for the mixed vegetation group in the diver calibration samples (a), and the frequency distribution of non-zero diver estimated egg counts in the mixed vegetation group in the 1988 Prince William Sound herring egg deposition survey (b).

APPENDIX B. CODING, UNDERWATER SURVEY FORMS AND FECUNDITY FORM

TABLE ~~A~~B1. CODING FOR DIVER SURVEY DATA

DIVER TABLE

Initials	Diver Name
TM	Tim Minicucci
EB	Evelyn Biggs
RI	Robin Irving
DN	Dave Norman
FF	Fritz Funk

VEGETATION AND SUBSTRATE CODES

RK	Rock	
HR	Hair kelp	(Desmarestia spp. and others)
LE	Loose Eggs	
RL	Red Leaf kelp	(Porphyra sp. or Phodymenia sp.)
RIB	Ribbon kelp	(Laminaria saccharina)
AG	Agarum, or sieve or shotgun kelp	(Agarum sp.)
RH	Red Hair Kelp	(Cryptosiphonia sp. or Pterosiphonia sp.)
GL	Green Leaf	(Ulva sp. and others)
SND	Sand	
GF	Green Filamentous	(Spongomorpha spp.)
RF	Red Filamentous	(Rhodomela spp.)
MUD	Mud	
COB	Cobble	
GRV	Gravel	
COR	Corraline	(Corralina spp.)
ALG	Algae	(Misc. green and brown, small plants)
RC	Red Cup	(Constantinea sp.)
LBK	Large Brown Kelps	(Laminaria spp.)
EG	Eelgrass	(Zostera sp.)
FU	Rockweed or popwee	(Fucus sp.)

CONVERSIONS USED IN CALCULATIONS

1 metric ton = 2205 lbs.
1 short ton = 2000 lbs.
1 short ton = 907.18 kg.
1 metric ton = 1000 kg.
1 nautical mile = 1852 meters
1 linear mile = 1609 meters

Appendix B.2 Underwater sample form for diver surveys.

AREA

DATE

TRANSECT

DIVERS

COMPASS HEADING

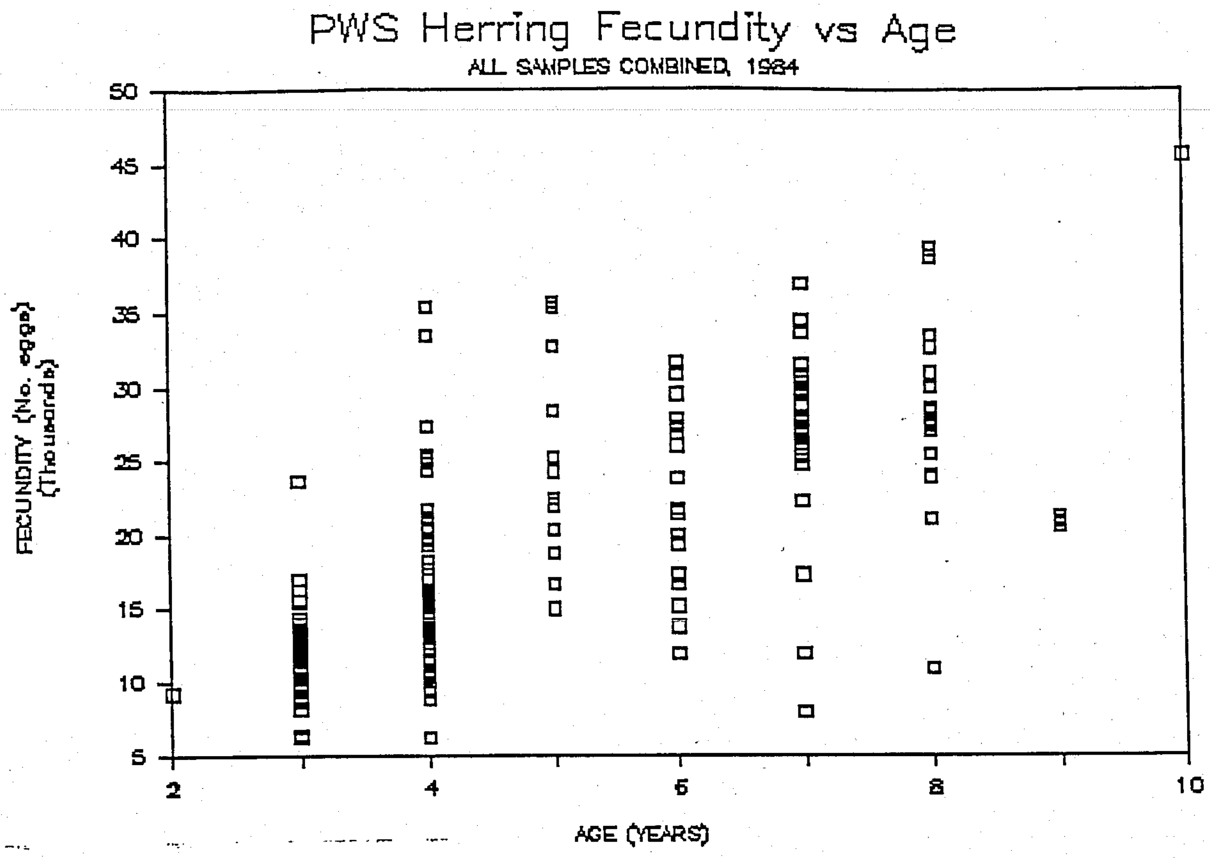
TIME IN→

TIME OUT→

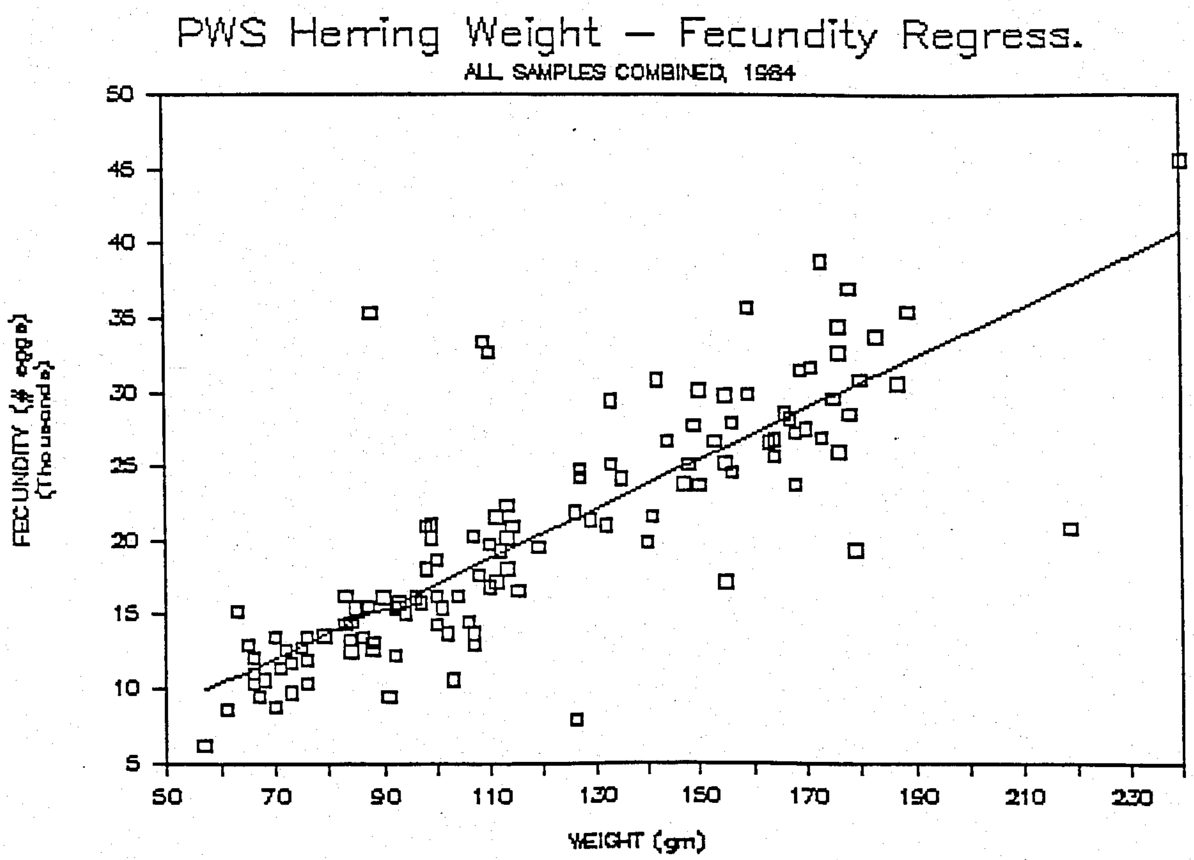
TIDE→

NO.	DEPTH	SUBSTRATE	ESTIMATES SAMPLE BAG	ESTIMATES OUTSIDE BAG	BAG#	NO.	DEPTH	SUBSTRATE	ESTIMATES SAMPLE BAG	ESTIMATES OUTSIDE BAG	BAG#
1						21					
2						22					
3						23					
4						24					
5						25					
6						26					
7						27					
8						28					
9						29					
10						30					
11						31					
12						32					
13						33					
14						34					
15						35					
16						36					
17						37					
18						38					
19						39					
20						40					

APPENDIX C. FECUNDITY DATA BY AGE



B8



$R^2 = 0.68649$

B9

63

APPENDIX D. SUMMARY TABLES FOR AWL SAMPLES USED IN THE BIOMASS ESTIMATE

Table D1.

SUMMARY TABLE : PRINCE WILLIAM SOUND HERRING POUND FISHERY, GALENA BAY TEST SAMPLE, 16 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	2	0.7	172	4	71	5	2	0.7	179	2	72	2	4	1.4	175	4	71	3
4	107	37.7	191	9	92	17	121	42.6	191	8	97	13	233	82.0	191	8	94	15
5	7	2.5	199	13	104	22	6	2.1	204	7	115	13	13	4.6	201	11	109	19
6	3	1.1	173	40	113	14	2	0.7	209	3	142	8	6	2.1	191	34	120	19
7	7	2.5	212	8	127	17	9	3.2	228	7	178	16	16	5.6	221	11	156	30
8	5	1.8	228	7	173	25	4	1.4	231	6	173	12	9	3.2	229	6	173	20
9	0	0.0	NA	NA	NA	NA	2	0.7	235	1	187	21	2	0.7	235	1	187	21
10	0	0.0	NA	NA	NA	NA	1	0.4	185	0	87	0	1	0.4	185	0	87	0
11	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
12	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	131	46.1	194	14	98	25	147	51.8	196	14	106	28	284	100.0	195	14	102	27
UNAGED	11	68.8	202	17	108	27	5	31.3	197	9	109	19	16	100.0	200	15	108	25

Table D2.

SUMMARY TABLE : PRINCE WILLIAM SOUND HERRING POUND FISHERY, VIRGIN BAY TEST SAMPLE, 16 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	3	1.0	182	7	74	7	1	0.3	162	0	56	0	4	1.4	177	10	70	10
4	127	43.3	186	11	84	19	129	44.0	188	12	91	22	256	87.4	187	12	87	20
5	6	2.0	196	18	100	31	9	3.1	195	10	97	13	15	5.1	195	14	98	22
6	2	0.7	185	1	85	3	1	0.3	162	0	56	0	3	1.0	177	11	75	14
7	2	0.7	230	8	168	10	4	1.4	220	16	146	31	6	2.0	224	14	153	27
8	6	2.0	202	20	118	38	1	0.3	198	0	98	0	7	2.4	201	18	115	36
9	1	0.3	233	0	192	0	1	0.3	183	0	84	0	2	0.7	208	25	138	54
10	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
11	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
12	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	147	50.2	188	14	88	25	146	49.8	189	14	92	23	293	100.0	188	14	90	24
UNAGED	2	28.6	179	4	70	4	5	71.4	194	5	93	10	7	100.0	189	8	86	14

Table D3.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING, HANNING BAY TEST PURSE SEINE SAMPLE, 17 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	8	1.4	175	14	68	23	6	1.1	179	16	76	26	14	2.5	176	15	71	25
4	212	37.3	192	8	89	13	283	49.8	194	9	95	15	495	87.1	193	9	93	14
5	13	2.3	198	8	98	14	12	2.1	207	11	115	18	25	4.4	202	11	106	18
6	7	1.2	215	5	137	16	6	1.1	225	11	150	29	13	2.3	219	10	143	24
7	4	0.7	210	11	113	15	7	1.2	227	14	162	34	11	1.9	221	16	144	37
8	2	0.4	220	1	148	8	4	0.7	230	5	177	14	6	1.1	227	6	167	19
9	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
10	0	0.0	NA	NA	NA	NA	1	0.2	205	0	104	0	1	0.2	205	0	104	0
11	1	0.2	188	0	81	0	0	0.0	NA	NA	NA	NA	1	0.2	188	0	81	0
12	2	0.4	245	4	218	26	0	0.0	NA	NA	NA	NA	2	0.4	245	4	218	26
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	249	43.8	193	12	92	21	319	56.2	196	12	99	23	568	100.0	195	12	96	22
UNAGED	21	65.6	192	9	88	13	11	34.4	202	17	110	37	32	100.0	195	13	96	26

Table D4.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING, FAIRMONT BAY TEST PURSE SEINE SAMPLE, 18 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	2	0.4	174	5	63	5	2	0.4	205	10	104	19	4	0.7	190	17	84	25
4	148	27.0	195	10	95	17	144	26.3	200	9	105	17	292	53.3	198	9	100	18
5	22	4.0	205	8	111	17	27	4.9	201	36	116	17	49	8.9	203	27	114	17
6	9	1.6	222	12	142	30	19	3.5	226	11	155	23	28	5.1	225	11	151	26
7	44	8.0	227	10	160	23	28	5.1	226	11	161	23	72	13.1	227	10	161	23
8	41	7.5	228	11	161	25	32	5.8	231	11	172	26	73	13.3	229	11	166	26
9	7	1.3	234	23	172	49	4	0.7	251	5	200	20	11	2.0	240	20	182	43
10	4	0.7	247	8	206	10	0	0.0	NA	NA	NA	NA	4	0.7	247	8	206	10
11	3	0.5	241	2	193	11	4	0.7	248	10	217	15	7	1.3	245	9	207	18
12	3	0.5	240	15	180	23	5	0.9	244	6	208	9	8	1.5	243	11	198	21
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	283	51.6	209	19	123	40	265	48.4	211	21	129	38	548	100.0	210	20	125	39
UNAGED	6	50.0	198	17	104	32	6	50.0	211	17	131	37	12	100.0	204	18	117	37

Table D5.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING. NAKED ISLAND (MCPHERSON PASSAGE) TEST PURSE SEINE SAMPLE, 19 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	4	0.7	171	5	65	5	6	1.1	170	9	63	7	10	1.8	170	7	63	6
4	201	36.9	191	8	91	12	196	36.0	192	8	95	16	397	72.8	192	8	93	14
5	16	2.9	203	13	110	23	22	4.0	207	9	119	17	38	7.0	205	11	115	20
6	9	1.7	216	10	136	23	8	1.5	219	9	150	19	17	3.1	218	10	143	23
7	18	3.3	222	9	152	23	21	3.9	227	11	164	24	39	7.2	225	10	158	24
8	14	2.6	229	8	163	30	14	2.6	233	10	183	17	28	5.1	231	9	173	26
9	3	0.6	234	9	182	16	8	1.5	236	5	189	19	11	2.0	236	6	187	19
10	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
11	0	0.0	NA	NA	NA	NA	2	0.4	248	2	222	3	2	0.4	248	2	222	3
12	3	0.6	246	8	221	20	0	0.0	NA	NA	NA	NA	3	0.6	246	8	221	20
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	268	49.2	197	16	104	31	277	50.8	200	18	111	36	545	100.0	199	17	107	34
UNAGED	5	33.3	199	18	109	36	10	66.7	194	12	92	19	15	100.0	196	14	98	27

Table D6.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING, CEDAR BAY COMMERCIAL PURSE SEINE CATCH SAMPLE, 21 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	4	1.4	169	8	66	7	1	0.3	176	0	76	0	5	1.7	170	8	68	8
4	109	37.5	191	7	95	12	91	31.3	192	9	100	15	200	68.7	191	8	97	14
5	14	4.8	206	11	120	21	13	4.5	203	6	122	12	27	9.3	205	9	121	17
6	8	2.7	216	6	140	14	5	1.7	221	4	150	10	13	4.5	218	6	144	13
7	14	4.8	216	11	149	22	12	4.1	225	4	167	11	26	8.9	220	10	157	20
8	6	2.1	222	6	157	7	9	3.1	227	6	177	21	15	5.2	225	7	169	19
9	2	0.7	229	3	186	13	0	0.0	NA	NA	NA	NA	2	0.7	229	3	186	13
10	1	0.3	252	0	215	0	0	0.0	NA	NA	NA	NA	1	0.3	252	0	215	0
11	1	0.3	231	0	213	0	0	0.0	NA	NA	NA	NA	1	0.3	231	0	213	0
12	1	0.3	241	0	212	0	0	0.0	NA	NA	NA	NA	1	0.3	241	0	212	0
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	160	55.0	196	14	106	28	131	45.0	198	15	113	30	291	100.0	197	15	109	29
UNAGED	5	55.6	209	11	135	25	4	44.4	214	9	145	28	9	100.0	211	11	139	27

Table D7.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING, GRANITE BAY COMMERCIAL PURSE SEINE CATCH SAMPLE, 21 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	3	1.0	172	6	63	7	2	0.7	171	2	66	7	5	1.7	172	5	64	7
4	126	42.9	189	8	88	12	112	38.1	193	9	96	12	238	81.0	191	9	92	13
5	7	2.4	206	8	119	17	10	3.4	205	8	115	18	17	5.8	205	8	116	17
6	4	1.4	214	11	135	27	4	1.4	218	9	132	22	8	2.7	216	10	134	25
7	8	2.7	213	11	131	21	7	2.4	223	7	160	16	15	5.1	217	11	144	23
8	3	1.0	225	4	146	5	5	1.7	225	5	170	12	8	2.7	225	4	161	15
9	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
10	1	0.3	243	0	191	0	0	0.0	NA	NA	NA	NA	1	0.3	243	0	191	0
11	1	0.3	245	0	165	0	1	0.3	227	0	160	0	2	0.7	236	9	163	3
12	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	153	52.0	193	14	95	23	141	48.0	197	13	104	25	294	100.0	195	14	99	24
UNAGED	3	50.0	195	4	89	7	3	50.0	198	19	105	34	6	100.0	197	14	97	26

Table D8.

SUMMARY TABLE : PRINCE WILLIAM SOUND SAC ROE HERRING. NORTH SHORE COMMERCIAL PURSE SEINE CATCH SAMPLE. 22 APRIL 1988.

	MALES						FEMALES						SEXES COMBINED					
			LENGTH		WEIGHT				LENGTH		WEIGHT				LENGTH		WEIGHT	
AGE	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD	NUMBER	PERCENT	MEAN	STD	MEAN	STD
2	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
3	6	1.0	174	6	65	10	2	0.3	182	3	76	2	8	1.3	176	6	68	10
4	225	36.6	192	9	90	13	219	35.6	195	9	97	14	444	72.2	193	9	93	14
5	15	2.4	208	7	115	14	15	2.4	212	9	129	20	30	4.9	210	9	122	19
6	6	1.0	220	10	142	20	11	1.8	221	6	145	20	17	2.8	220	8	144	20
7	32	5.2	223	8	154	16	32	5.2	226	9	161	21	64	10.4	225	8	158	19
8	18	2.9	233	7	171	16	18	2.9	237	8	182	25	36	5.9	235	8	177	21
9	4	0.7	238	2	177	11	3	0.5	242	7	206	30	7	1.1	240	5	190	26
10	3	0.5	241	3	193	11	0	0.0	NA	NA	NA	NA	3	0.5	241	3	193	11
11	3	0.5	238	6	179	32	1	0.2	247	0	243	0	4	0.7	241	7	195	39
12	0	0.0	NA	NA	NA	NA	2	0.3	252	9	217	25	2	0.3	252	9	217	25
13	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA	0	0.0	NA	NA	NA	NA
TOTAL	312	50.7	200	18	106	33	303	49.3	203	17	115	35	615	100.0	202	18	110	35
UNAGED	7	46.7	205	15	112	30	8	53.3	198	20	110	37	15	100.0	201	18	111	34

APPENDIX E. SUMMARY OF AERIAL SURVEY DATA

Table E1. Herring biomass estimates in tons from aerial surveys by area and date, Prince William Sound, 1988

DATE	SIMPSON SHEEP & ISLANDS	PORT GRAVINA	PORT FIDALGO	TATITLEK AREA	VALDEZ ARM & PORT	FREEMANTLE GRANITE PT.	GRANITE PT. ESTHER PASS.	NAKED ISLAND	KNIGHT ISLAND	MONTAGUE ISLAND	DAILY TOTAL	DATE
3/18	0	0	0	0	0	0	0	0	0	0	0	3/18
3/19	0	0	0	0	0	0	0	0	0	0	0	3/19
3/20	0	0	0	0	0	0	0	0	0	0	0	3/20
3/21	0	0	0	0	0	0	0	0	0	0	0	3/21
3/22	0	0	0	0	0	0	0	0	0	0	0	3/22
3/23	0	0	0	0	0	0	0	0	0	0	0	3/23
3/24	0	0	0	0	0	0	0	0	0	0	0	3/24
3/25	0	0	0	0	0	0	0	0	0	0	0	3/25
3/26	0	0	0	0	0	0	0	0	0	0	0	3/26
3/27	0	0	0	0	0	0	0	0	0	0	0	3/27
3/28	0	580 *	0	0	0	10	0	0	0	0	590	3/28
3/29	0	0	0	0	0	0	0	0	0	0	0	3/29
3/30	0	20	0	0	0	0	0	0	0	0	20	3/30
3/31	0	0	0	0	0	0	0	0	0	0	0	3/31
4/1	0	0	0	0	0	0	0	0	0	0	0	4/1
4/2	0	0	0	0	0	0	0	0	0	0	0	4/2
4/3	0	0	0	0	0	0	0	0	0	0	0	4/3
4/4	0	0	0	0	0	0	0	0	0	0	0	4/4
4/5	0	0	0	0	80 *	0	0	0	0	0	80	4/5
4/6	0	10	80 *	0	20	0	180	0	0	0	290	4/6
4/7	0	0	0	0	0	0	0	0	0	0	0	4/7
4/8	0	0	20	0	70	400 *	1480 *	0	0	0	1970	4/8
4/9	0	0	0	0	10	140	960	0	0	0	1110	4/9
4/10	0	0	0	0	0	0	0	0	0	0	0	4/10
4/11	0	0	0	0	0	0	0	0	0	0	0	4/11
4/12	0	0	0	0	0	0	0	0	0	0	0	4/12
4/13	0	0	0	0	0	0	40	0	0	0	40	4/13
4/14	0	0	0	80	0	0	0	0	0	4040 *	4120	4/14
4/15	0	0	0	0	0	0	0	0	0	0	0	4/15
4/16	0	0	0	0	0	0	0	80	0	705	785	4/16
4/17	0	0	0	70	0	0	0	60	0	850	980	4/17
4/18	0	0	0	0	0	0	720	200	0	1130	2050	4/18
4/19	0	0	0	80	40	0	100	1450 *	0	9440 *	11110	4/19
4/20	0	0	0	90	300	0	6720	930	0	2290	10330	4/20
4/21	0	0	0	460 *	2660	0	6760	1140	0	1770	12790	4/21
4/22	0	0	0	0	5750 *	540 *	9740 *	0	0	40	16070	4/22
4/23	0	0	0	0	0	0	3310	0	0	0	3310	4/23
4/24	0	0	60 *	0	0	0	1100	0	0	0	1160	4/24
4/25	0	0	0	0	0	0	0	0	0	0	0	4/25
4/26	0	0	0	0	0	0	0	0	0	0	0	4/26
4/27	0	0	0	0	0	0	0	0	0	0	0	4/27
4/28	0	0	0	0	0	0	0	0	0	0	0	4/28
4/29	0	0	0	30 *	0	0	110	0	0	100	240	4/29
4/30	0	0	0	0	0	0	0	0	0	0	0	4/30
5/1	0	0	0	0	0	0	130 *	0	0	0	130	5/1
5/2	0	0	0	0	0	0	0	0	0	0	0	5/2
5/3	0	0	0	0	0	0	0	0	0	0	0	5/3
5/4	0	0	0	0	0	0	0	0	0	0	0	5/4
5/5	0	0	0	0	0	0	0	0	0	0	0	5/5
5/6	0	0	0	0	0	0	0	0	0	0	0	5/6
5/7	0	0	0	0	0	0	0	0	0	0	0	5/7
5/8	0	0	0	0	0	0	0	0	0	0	0	5/8
5/9	0	0	0	0	0	0	0	0	0	0	0	5/9
AREA TOTALS	0	610	160	810	8930	1090	31350	3860	0	20365	67175	
PEAK EST. TOT.	0	580	140	490	5830	950	11350	1450	0	13480	34270 = PEAK AERIAL ESTIMATE	

* Indicates aerial estimates used in peak survey estimate.

Table E2. Estimated mile-days of herring spawn by aerial survey, P.W.S. 1988.

DATE	SIMPSON SHEEP & ISLANDS	PORT GRAVINA	PORT FIDALGO	TATITLEK AREA	VALDEZ ARM & PORT	FREEMANTLE GRANITE PT.	GRANITE PT. ESTHER PASS.	NAKED ISLAND	KNIGHT ISLAND	MONTAGUE ISLAND	DAILY TOTAL	DATE
3/18	0	0	0	0	0	0	0	0	0	0	0	3/18
3/19	0	0	0	0	0	0	0	0	0	0	0	3/19
3/20	0	0	0	0	0	0	0	0	0	0	0	3/20
3/21	0	0	0	0	0	0	0	0	0	0	0	3/21
3/22	0	0	0	0	0	0	0	0	0	0	0	3/22
3/23	0	0	0	0	0	0	0	0	0	0	0	3/23
3/24	0	0	0	0	0	0	0	0	0	0	0	3/24
3/25	0	0	0	0	0	0	0	0	0	0	0	3/25
3/26	0	0	0	0	0	0	0	0	0	0	0	3/26
3/27	0	0	0	0	0	0	0	0	0	0	0	3/27
3/28	0	2.6	0	0	0	0	0	0	0	0	2.6	3/28
3/29	0	0	0	0	0	0	0	0	0	0	0	3/29
3/30	0	1.6	0	0	0	0	0	0	0	0	1.6	3/30
3/31	0	0.3	0	0	0	0	0	0	0	0	0.3	3/31
4/1	0	0	0	0	0	0	0	0	0	0	0	4/1
4/2	0	0	0	0.2	0	0	0	0	0	0	0.2	4/2
4/3	0	0	0	0	0	0	0	0	0	0	0	4/3
4/4	0	0	0	0	0	0	0	0	0	0	0	4/4
4/5	0	0	0.3	0.6	0	0	0	0	0	0	0.9	4/5
4/6	0	0	0	0.5	0	0	0	0	0	0	0.5	4/6
4/7	0	0	0	0	0	0	0	0	0	0	0	4/7
4/8	0	0	0.5	0.2	0	0	0	0	0	0	0.7	4/8
4/9	0	0	2	0	0	0	0	0	0	0	2	4/9
4/10	0	0	0	0	0	0	0	0	0	0	0	4/10
4/11	0	0	0	0	0	0	0	0	0	0	0	4/11
4/12	0	0	0	0	0	0	0	0	0	0	0	4/12
4/13	0	0	0	1.4	0	0	0	0	0	0	1.4	4/13
4/14	0	0	0	1	0	0	0	0	0	0	1	4/14
4/15	0	0	0	0	0	0	0	0	0	0	0	4/15
4/16	0	0	0	0.8	0.5	0	0	0	0	0	1.3	4/16
4/17	0	0	0	0	0	0	0	0	0	0	0	4/17
4/18	0	0	0	1.5	1	0	0	0	0	0	2.5	4/18
4/19	0	0	0	2.2	1.2	0	0	0	0	2	5.4	4/19
4/20	0	0	0.2	2.1	4	0	1.7	1	0	7.7	16.7	4/20
4/21	0	0	0	2.4	2.5	0	2.3	4	0	10.8	22	4/21
4/22	0	0.2	0	10	8	0	0	3.3	0.6	12.7	34.8	4/22
4/23	0	0	0	15.5	15.3	0	5.7	10.4	0	17.5	64.4	4/23
4/24	0	0	0	6.2	16.4	3	11.7	0	0	4.1	41.4	4/24
4/25	0	0	0	0	0	0	0	0	0	4	4	4/25
4/26	0	0	0	0	0	0	0	0	0	0	0	4/26
4/27	0	0	0	0	0	0	0	0	0	0	0	4/27
4/28	0	0	0	0	0	0	0.6	0	0	19.7	20.3	4/28
4/29	0	0	0	0	0	0	1.3	0	0	4.4	5.7	4/29
4/30	0	0	0	1.2	0	0	1.8	0	0	0	3	4/30
5/1	0	0	0	1.2	0	0	3	0	0	0	4.2	5/1
5/2	0	0	0	0	0	0	0	0	0	0	0	5/2
5/3	0	0	0	0	0	0	0	0	0	0	0	5/3
5/4	0	0	0	0	0	0	0	0	0	0	0	5/4
5/5	0	0	0	0	0	0	0	0	0	0	0	5/5
5/6	0	0	0	0	0	0	0	0	0	0	0	5/6
5/7	0	0	0	0	0	0	0	0	0	0	0	5/7
5/8	0	0	0	0	0	0	0	0	0	0	0	5/8
5/9	0	0	0	0	0	0	0	0	0	0	0	5/9
AREA TOTAL	0	4.7	3	47	48.9	3	28.1	18.7	0.6	82.9	236.9	
% OF TOTAL	0	2.0%	1.3%	19.8%	20.6%	1.3%	11.9%	7.9%	0.3%	35.0%	100.0%	