Exxon Valdez Oil Spill
Restoration Project Final Report

Otolith Marking of Pink Salmon in Prince William Sound Salmon Hatcheries

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Study History: Hatchery and wild stock contributions to commercial Prince William Sound salmon fisheries have, until recently, been assessed by an extensive coded wire tagging program administered largely through EVOS Trustee Council projects after 1989 by projects F/S 3 (Sharr et al., 1995a), R60A (Sharr et al., 1995b), R93067 (Sharr et al., 1995c), R94320B (Sharr et al., 1995d), R95320B (Riffe et al., 1996), R96186 (Riffe and Evans, 1997), R97186 (Riffe and Evans, 1998) and R98186 (Riffe and Evans, 1998) with funding from EVOS, ADF&G and Private Nonprofit Hatchery operator funding. As a result of the expense of applying coded wire tags and questions regarding assumptions about tag loss, a thermal mass marking technique was developed, where specific patterns are laid down on the otoliths of incubating fish The otolith thermal mark program was supported through projects R95320C (Joyce et al., 1996), R96188 (Joyce et al., 1997), R97188 (Joyce and Evans, 1998), and R98188. This report, R99188, summarizes the work documented in R95320C, R96188, R97188 and R98188.

Abstract: In the fall of 1995, 1996, and 1997, thermal marks were applied to otoliths of all hatchery pink salmon in Prince William Sound (PWS). The marks were highly visible on voucher samples taken from hatchery fry in the spring of 1996, 1997 and 1998. For brood year 1996 and 1997 pink salmon, accessory thermal marks, applied after the fry hatched, allowed identification of within-hatchery treatment groups. Double-blind tests were conducted to assess the ability of laboratory personnel to correctly identify hatchery otolith marks laid down in brood years 1995-1997 salmon. The tests indicated that the probability of a successful identification between hatchery and wild pink salmon was 99.6%, 99.7% and 99.3% for brood years 1995-1997, respectively. Catch-sampling and estimation protocols were used to estimate the contribution of hatchery fish to PWS 1997 and 1998 pink salmon commercial fisheries. Preliminary estimates of the stock composition of an area-time specific catch were available within 24 hours after fishery closures. Otolith marks also allowed assessment of some of the assumptions used in the PWS coded wire tagging program, such as those pertaining to composition of the brood pond, and allowed estimation of the proportion of stray hatchery fish in selected wild stock streams.

Key Words:
Commercial harvest, hatchery, *Oncorhynchus gorbuscha*, otolith, pink salmon, Prince William Sound, straying, thermal mark, voucher sample, wild stock.

Project Data:
Data pertaining to the double blind test are stored in Microsoft Excel™ worksheets, ASCII files, and a Microsoft Access™ database. Data pertaining to hatchery contribution estimates are stored in Excel™ worksheets and an Access™ database. Software code used to analyze the data (SAS™, Gauss™) is available in ASCII format.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

This report documents Restoration Study 99188, one of the projects designed to restore the pink salmon *Oncorhynchus gorbuscha* resource of Prince William Sound to its pre-spill status. Four broad objectives were outlined for this study. The first objective, to apply unique and distinct thermal marks to the otoliths of developing pink salmon embryos at all four pink salmon hatcheries in Prince William Sound, was met starting in the fall of 1995, using equipment purchased and installed in 1995. The second objective, to measure the quality of otolith marks was met upon completion of the double-blind tests involving otoliths from brood years 1995, 1996 and 1997; laboratory personnel successfully distinguished between otoliths of hatchery and wild origin about 99.5% of the time. The third objective, to accurately and precisely estimate stock composition of commercial catches of pink salmon using thermal marks, was met during the 1997 and 1998 seasons and through experiments conducted to assess appropriate sampling methodologies. The fourth objective, to evaluate the quality of stock estimation procedures, was met upon analysis of the precision of estimates of stock contribution, of the availability of the estimates to managers, and of the success of otolith identification methods. Usefully narrow confidence intervals for estimated hatchery contribution to an area-time stratum were obtained, and the estimates were made available to fishery managers within 24 hours of the closure of the fishery. The negligible error encountered upon reading recovered otoliths and the effort spent in obtaining a representative sample contributed significantly to the managers' acceptance of the method, and hence its use in management of the fishery.

INTRODUCTION

Between 1961 and 1976, when hatcheries were absent from Prince William Sound, the commercial seine harvest of wild pink salmon *Oncorhynchus gorbuscha* averaged about 3.4 million fish (Randall et al, 1983). In the early 1970's, run failures led to an aggressive enhancement program that included construction of hatcheries. By 1986, five hatcheries were operating: Solomon Gulch hatchery (SGH), producing pink and coho salmon *O. kisutch* and briefly also chum *O. keta* and chinook salmon *O. tschawytscha*; A. F. Koernig hatchery (AFKH), producing pink salmon and later for a brief period chum salmon; Wally Noerenberg hatchery (WNH), producing pink, chum and coho salmon and briefly chinook salmon; Cannery Creek hatchery (CCH), producing pink salmon and briefly chum salmon; and Main Bay hatchery which produced chum and presently raises sockeye salmon *O. nerka* (Figure 1). From the late 1980's to the present, these facilities have contributed about 19 million fish to the annual pink salmon return to Prince William Sound (Morstad et al., 1998).

Hatchery parent stocks were selected from populations indigenous to Prince William Sound, resulting in a similar migratory timing of adult hatchery and wild runs. Furthermore, all of these stocks migrate to their natal streams or hatcheries through corridors in the southwestern and western areas of Prince William Sound. The similar run-timing and migratory corridors of the large hatchery runs and the much smaller wild runs put the wild stocks at risk of over exploitation. Indeed, shortfalls in wild escapements occurred in more than half of the 15 years prior to hatchery production, when the average exploitation rate was 42%, a figure considerably lower than the 80% considered appropriate for today's returning hatchery salmon.

To protect wild stocks in the mixed-stock fishery, managers needed information pertaining to the temporal and spatial distributions of hatchery and wild salmon. In 1986, a coded wire tagging program was initiated by the Alaska Department of Fish and Game and the Private Non-Profit Hatchery operators in Prince William Sound for hatchery releases of pink salmon, with the first recoveries of tagged, returning adults in the commercial and cost recovery fisheries beginning in 1987. Such tag recovery data enabled managers to obtain estimates of hatchery and wild contributions to catches from selected temporal and spatial strata within the fishery.

The March 24, 1989, *Exxon Valdez* oil spill exacerbated the problems faced by fishery managers. The spill contaminated tidal portions of streams where most wild pink salmon stocks in western Prince William Sound spawn as well as the marine waters traversed by juvenile salmon on their migration seaward. Detrimental effects have been found from oil contamination upon pink salmon embryos, pre-emergent fry, and juvenile salmon in wild populations (Bue et al., 1996, Willette and Carpenter, 1994). Fishery management decisions suddenly became more complex as they now affected wild populations injured by the oil spill.

The coded wire tagging program was continued after the spill and was funded by Natural Resource Damage Assessment study F/S 3 through 1991 (Sharr et al., 1995a). During this period, the program continued to provide information pertaining to the stock composition of the commercial salmon catch. The pink salmon tagging program was supported from 1992 through 1997, by Restoration Studies R60A (Sharr et al. 1995b), R93067 (Sharr et al. 1995c), R94320B (Sharr et al. 1995d), R95320B (Riffe et al. 1996), R96186 (Riffe and Evans, 1997) and R98186 (Riffe and Evans, 1998), along with contributions from the Prince William Sound Aquaculture Corporation, Valdez Fisheries Development Association and the State of Alaska.

Coded wire tag hatchery contribution estimates are based on several assumptions. The most contentious of these pertain to an adjustment factor used to account for differential mortality and tag-shedding. They are: 1) salmon milling adjacent to a hatchery and used as hatchery broodstock originated at that hatchery and 2) for a given cohort, the proportion of fish with tags in the broodstock is equal to that experienced in the commercial fishery. Sharr et al. (1995c) believed that wild fish invaded brood ponds of certain hatcheries, and Habicht et al. (1998) presented evidence that coded wire tags cause pink salmon to stray. It became clear that hatchery contribution estimates based on coded wire tags may be flawed and an alternative marking technology was sought.

Munk et al. (1993), Mosegard et al. (1987) and Volk et al (1990) have found that chinook, coho, sockeye, chum, pink, and Atlantic salmon *Salmo salar* otoliths can be marked through carefully controlled changes in the temperature of incubation water. The technology was subsequently incorporated into a mixed stock fisheries assessment program by Hagan et al. (1995). The technique has myriad advantages over the coded wire tag program. The cost of applying marks is relatively low, tag loss and differential mortality are non-existent, and the required adult sampling effort is lower by an order of magnitude since all of the fry released from a hatchery carry a unique identifying mark. A significant caveat, however, is the need for representative sampling.

In 1995, 1996, 1997 and 1998 thermal marks were applied to the otoliths of all pink salmon incubating in Prince William Sound hatcheries, with support from R95320C, R96188, R97188, and R98188, respectively. In 1996, emergent pink salmon fry were also coded wire tagged providing one year (1997) in which returning adults would contain both coded wire tags and otolith thermal marks. This report documents application of thermal marks on hatchery pink salmon; presents an early assessment of mark quality for those marks; reports results of blind tests of readability of marks laid down in brood years 1995, 1996, and 1997; details diagnostic studies of a proposed sampling methodology; and records the first use by fishery managers of otolith-generated estimates of pink salmon stock composition in Prince William Sound.

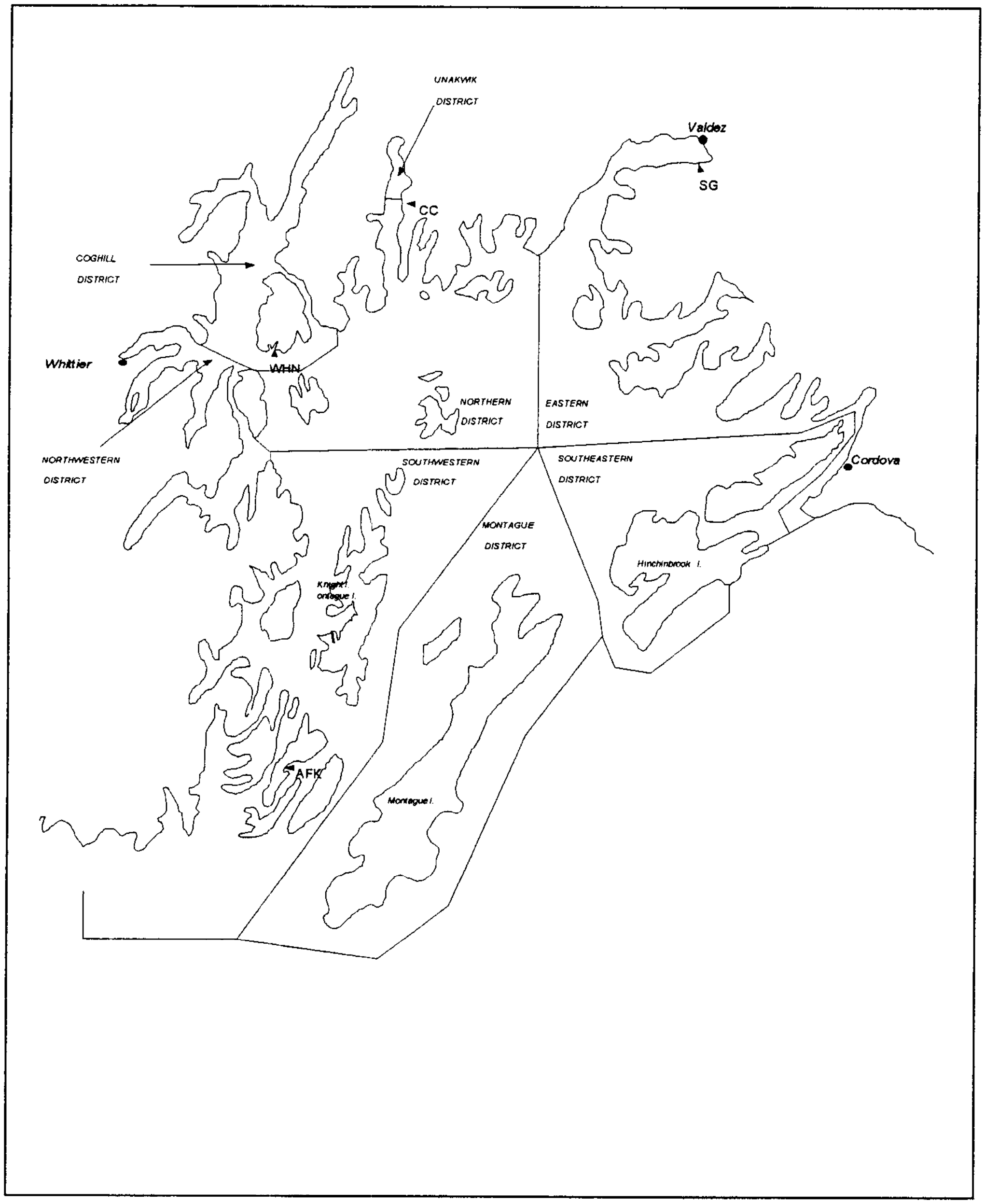


Figure 1. Fishing districts and hatcheries of Prince William Sound, Alaska. Pink salmon hatcheries: W.H.N.=W.H. Noerenberg, SG=Solomon Gulch, CC=Cannery Creek, AFK=A.F. Koernig.

OBJECTIVES

1. To apply unique and distinct thermal marks to the otoliths of pink salmon embryos incubating at all four pink salmon hatcheries in Prince William Sound.

2. To measure the quality of otolith marks, and to identify problems pertaining to specific mark assignments.

3. To use thermal mark recoveries to estimate the stock composition of the commercial catches and hatchery broodstocks in 1997 and 1998.

4. To evaluate the quality of stock-estimation procedures.

METHODS

Application of Thermal Marks to Pink Salmon

Thermal base marks that differentiated hatchery of origin were laid down after the primordial stage of otolith development (approximately 275 TU) or, equivalently, at the 'eyed' stage of embryo development. Methods followed those of Munk et al. (1993). For pink salmon of brood year 1996 (BY96), accessory marks were applied at WNH and AFKH after hatching to distinguish different release treatments. At AFKH, the accessory mark was applied to those salmon released early into plankton blooms, while the base mark was applied to salmon released later and at a higher body weight. At WNH, the accessory mark was applied to the late-release salmon and the base mark to the early-release salmon Each ring within a mark was created by a temperature-induced modification of the rate of deposition of otolith material. The modification involved raising the ambient temperature of the incubation water for 24 hours by 4 °C, and then rapidly returning it to its original value, where it remained for another 24 hours before instigation of the next ring. Later in the season as the ambient temperature dropped, 36-hour, alternating cycles were used at the CCH and WNH hatcheries to insure proper spacing between rings. Marking schedules were staggered for pairs of incubators so that the oil-fired boilers ran continuously. This schedule marked the maximum number of embryos in the shortest time.

The thermal marks were classified according to a "Region, Band, and ring" (RBr) code, written numerically as 'R:B.r' (Munk and Geiger, 1998). Thermal mark codes are shown in Table 1.

Voucher samples were taken at the time of emergence from each lot at each hatchery so that thermal mark codes could be verified, and confounding marks, laid down during the incubation period, documented.

Table 1 Thermal mark codes and associated thermal schedules (H=Warm, C=Cold, X=number of cycles, "+" = Accessory Mark applied after hatch, "," = separation of at least two ring widths within one band) used at Prince William Sound hatcheries

Hatchery	Schedule		R:B.r	Ring pattern	
AFKH[a]	Base	(4X) 24H:24C	1:1.4	IIII	
	Accessory	(3X) 24H:24C	1:1.4+2.3	IIII	III
CCH	Base	(3X) 24H:24C, (1X) 72H: 36C, 2(X)24H:24C	1:1.3,2.3	III III	
WNH[a]	Base	(8X) 24H:24C	1:1.8	IIIIIIII	
	Accessory	(3X)24H:24C	1:1.8+2.3	IIIIIIII	III
SGH	Base	(6X)24H:24C	1:1.6	IIIIII	

a WNH Base =Early/Plankton Release; WNH Accessory = Late/Large Release

AFKH Base =Late/Large Release; AFKH Accessory=Early/Plankton

Determination of the Readability of Otoliths

Our ability to successfully determine the origin of otoliths extracted from brood year 1995 (BY95), BY96 and BY97 emergent pink salmon fry was measured through double blind tests conducted at the Alaska Department of Fish and Game (ADF&G) laboratories in Juneau and Cordova. The extent to which readers agreed with each other regarding mark assignments was also measured, and an identification matrix was constructed to highlight specific misclassification tendencies. Agreement between Cordova and Juneau readers on the identification of otoliths from returning adult pink salmon (BY95) was also assessed.

Sample Collection

In the spring of 1996 (BY95), 1997 (BY96) and 1998 (BY97), a minimum of 400 pink salmon fry were collected from incubators at each Prince William Sound hatchery, and from several streams located in Prince William Sound. An equal number of samples were collected randomly from each bank of incubators at each hatchery to insure that all mark variations were represented. Sagittae otoliths were extracted and mounted, sulcus side up, on a petrographic glass slide with thermoplastic glue. Otoliths were ground to the midsaggittal plane using a LabaPol-5 grinder with 500-grit silicon carbide paper (Struers A/S, Westlake, OH) and then viewed under a compound microscope and transmitted light at 200X or 400X . Mounted otoliths were placed in slide boxes labeled by origin and sent to personnel at the ADF&G Anchorage office, where slides were coded and mixed. For the BY95 test, 12 boxes of 100 slides each were sent to the Juneau laboratory for identification. For BY96 and BY97 tests, four boxes of one hundred coded slides were shipped to the Cordova otolith laboratory for identification. Coded information was not made available to any laboratory personnel until results of the tests had been collected.

Experimental Design

For the BY95 study, four readers were assessed in four different mark interpretation events (Table 2). In the first event, the twelve boxes containing100 mounted, but unground, slides were assigned to readers in a random fashion with the restriction that each reader grind an equal number of slides. Once a slide had been ground, no further grinding by other readers was permitted. It was assumed that each reader was capable of grinding an otolith to the degree that an interpretation was possible. In the subsequent three events, time and funding constraints limited analyses to four boxes randomly chosen from the twelve original boxes.

Table 2 Experimental layout for test of otolith-reading laboratory. Numbers differentiate slide boxes

First Event				Second Event				Third Event				Fourth Event			
Reader				Reader				Reader				Reader			
A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
3	4	7	11	10	10	6	7	7	10	6	10	7	10	6	6
1	2	5	10	6	6	3	3	6	6	10	3	6	7	3	3
9	1	6	8	7	7	10	10	10	7	7	7	3	3	10	7
6	10	2	12	3	3	7	6	3	3	3	6	10	6	7	10
11	7	3	2												
10	5	1	7												
4	3	10	5												
5	11	9	4												
8	6	12	6												
2	1	8	3												
12	8	11	1												
7	9	4	9												

The BY96 blind test was scaled down such that the test was administered to the principal inseason reader, and two inexperienced readers assigned to other projects, one of which was involved to some extent in identifying BY96 otoliths for inseason management purposes. The principal inseason reader ground all otoliths. The BY97 test was only administered to the principal inseason reader. Upon completion of the tests, all determinations were sent back to the Anchorage office for analysis.

Data Analysis

The overall ability of readers to correctly identify otoliths was determined by comparing readers' interpretations of marks to known origins. Agreement between readers and trends in misclassifications were also examined.

Success Rates in Otolith Identification-BY95 (Fry)

For BY95 salmon, it was not clear which readers would be responsible for inseason identification of returning adults in 1997, and the aim of the test was to estimate the expected identification success rate for a group of 100 otoliths selected from the population of otoliths consisting of those marked in the fall of 1995 and their wild counterparts for any reader at any time. Success rates, $\hat{p}_i$,were estimated as the mean of 96 (12x4 + 4x4x3) proportions (see Table 2), each proportion being defined as the proportion of otoliths in the relevant box-reader-event combination that were successfully identified in a 'hatchery *i*' versus 'not-hatchery *i*' determination. Index *i* has values:, SGH, WNH, AFKH, CCH and 'Hatcheries Combined'. For example, a p'_{SGH} of 0.95 means that over the 96 reader-box-event combinations, the average proportion of otoliths identified correctly according to the the "SGH' or 'Not SGH' determination was 0.95. An overall success rate, $\hat{p}$, was also estimated as the mean of the 96 proportions, each defined as the proportion of otoliths in the relevant-box-reader-event combination that were successfully identified, regardless of otolith origin.

Variance estimates of $\hat{p}_i$ and $\hat{p}$ were estimated by modeling p_{ijkl} with a random effects model with reader (*k*) and box (*j*) as crossed effects and time (*l*) nested within reader by box combinations. For p_{ijkl} :

$$p_{ijkl} = \mu_i + B_{ij} + R_{ik} + BR_{ijk} + T(BR)_{l(ijk)} \quad (1)$$

with $V(B_{ij})=\sigma^2_{B_i}$, $V(R_{ik})= \sigma^2_{R_i}$, $V(BR_{ijk})= \sigma^2_{BR_i}$ and $V(T(BR)_{l(ijk)})=\sigma_i^2$

SAS Proc Mixed (SAS, 1996) was used to estimate variance components, which were then used to estimate $V(\hat{p}_i)$ and $V(\hat{p})$. Approximate 95% confidence intervals were calculated as Estimate +/- $(1.96*\hat{V}^{1/2})$.

Variance component estimates were also used to estimate the variance of an individual reading $(V(p_{ijkl}) = \sigma^2_{B_i} + \sigma^2_{R_i} + \sigma^2_{BR_i} + \sigma_i^2)$, which allowed calculation of an approximate prediction interval for the success rate of a reader selected at random who was given a random selection of 100 otoliths at any given time.

Success Rates in Otolith Identification-BY96, BY97 (Fry)

Tests involving brood year 1996 salmon were scaled down considerably, and one principal reader, known to be responsible for identifying otoliths during the 1998 return, was tested once, along with two other less experienced readers, one of whom participated in the identification of adult otoliths in the 1998 return. Success rates for the principal inseason reader were estimated in a manner similar to those described for BY95, with the exclusion of subscripts denoting reader and time. Estimated variances of $\hat{p}_i$ and $\hat{p}$ were calculated using variance components associated with box and time within box (reader treated as a fixed component).

The blind test associated with brood year 1997 was administered only to the principal inseason reader and only point estimates were calculated.

Success Rates in Otolith Identification-BY95, BY96 (Adults)

For BY95 adults, blind tests were conducted using known origin adults (identified using coded wire tag information). Otoliths of known origin were seeded into the routine inseason estimation procedure. The otolith reader was not aware which trays of otoliths contained test otoliths.

For BY96 adults, no coded wire tag information was available, and a latent class models (LCM) approach was adopted (Blick and Hagan, 1998). Latent class models provide a method of estimating misclassification rates in the absence of a known standard that allows the true state the otolith to be determined. The approach is based on the presumption that there exists unobservable or 'latent' variables about which information can only be obtained through measurements on observable or 'manifest' variables. It provides an alternative to indices that measure agreement such as percent agreement and Cohen's kappa, that can sometimes be difficult to interpret. In the formulation of Blick and Hagan (1998) the manifest variables are found in the classification matrix formed from otolith thermal mark determinations of hatchery and wild salmon by at least two readers. The method uses a likelihood approach to estimate each reader's detection rate for wild and hatchery fish as well as an estimate of the true proportion of hatchery fish in a collection of samples. If only paired readings from one collection of otoliths is available the number of parameters to estimate can exceed the degrees of freedom. For that reason Blick and Hagen (1998) recommend using three or more readers to examine a sample of otoliths, or alternatively used paired readings but from multiple collections in which there is difference in the underlying proportion of hatchery fish. With extra degree of freedom goodness-of-fit tests can be used as a check on the model assumptions. In addition, the variance due to misclassification error can be estimated as the amount variance in the parameter estimate which exceeds the variance that would be due to sample size alone under the assumption of perfect accuracy.

Reader Agreement

While perfect agreement between readers (precision) can occur simultaneously with complete failure in identification (accuracy), the degree of consistency among readers is nevertheless an important parameter. Cohen's kappa was used to assess agreement between readers for both BY95 (first reading only) and BY96 tests on fry. This statistic compares the observed agreement to that expected if the ratings were independent, and thus accounts for agreement occurring by chance alone. For $\Gamma_o = \sum \hat{\pi}_{ii}$ and $\Gamma_e = \sum \hat{\pi}_{i+}\hat{\pi}_{+i}$, where π_{ii} is the probability of a classification in category i by both readers, and π_{+i} is the marginal probability for category i for one of the readers and π_{i+} for the other reader, Cohen's kappa is calculated as

$$\kappa = \frac{\Gamma_o - \Gamma_e}{1 - \Gamma_e} \qquad (2)$$

The ratio is a measure of the agreement in excess of that expected by chance to the excess under perfect agreement. The distribution of κ is asymptotically normal for multinomial sampling , and 95% confidence intervals were calculated as κ +/-(1.96*standard error) (see Agresti, 1990 for variance formula).

Cohen's kappa was also used to assess reader agreement between Cordova and Juneau readers for adult otoliths extracted in 1997 (BY95) and 1998 (BY96). An identification matrix was also produced.

Identification Matrices

An identification matrix was produced in order to identify trends in errors. A 5x5 matrix was constructed with true and observed origin describing rows (i) and columns (j), respectively. For the BY95 test, a quasi-independence model was fitted to the data, whereby the main diagonal of the matrix was fitted perfectly, and a test of independence conducted in the off-diagonal portions of the matrix. The model assumes that, conditional on disagreement, odds ratios among all rectangularly formed 2x2 tables equal 1.0.

The appropriate model is:

$$\log \mu_{ij} = \lambda + \lambda_i^T + \lambda_j^O + \delta_i I(i,j) \qquad (3)$$

where $I(i,j) = 1$ when $i = j$ and 0 otherwise. μ_{ij} represents the mean count in cell ij of the matrix, λ represents an overall mean count, λ^T represents the variable associated with the true identification of the otolith, and λ^O represents that associated with the observed identification. If significant lack-of-fit existed when this model was fitted, Fisher's exact test of independence was used in 2x2 tables formed in the off-diagonal areas of the matrix.

Development of Catch-Sampling Technique

Two fin-clipping experiments were undertaken to help design and test an otolith sampling technique that would yield unbiased estimates of the proportion of hatchery fish in a sampled catch. The first examined the degree to which a tender mixes its load, and provided information regarding the type of sampling scheme required. The second experiment tested whether the proposed systematic sampling scheme provided unbiased results.

Assessment of Degree of Mixing within a Tender

During the commercial fishery of 1995, the pectoral fins were removed from approximately 2,000 pink salmon at each sampling event. These fin-clipped fish were added to each of two tenders at a hatchery in the Southwestern District (AFKH) during cost recovery harvests and to one tender at Payday Point in the Unakwik District. The clipped fish were added *en masse* at one of three different loading stages. Stratified random samples of the tender loads were subsequently taken from the processing belt at the North Pacific processing plant in Cordova and the number of fin-clipped fish recovered during procesing was recorded. A lap-top computer using a random-sampling algorithm, was used to indicate when a fish should be selected from the belt and examined for a missing pectoral fin.

A χ^2 -test of independence between the mark variable (two levels, marked and unmarked) and the stratum variable was conducted. The question addressed was "Is the ratio of marked to unmarked fish independent of the stratum number?".

A linear logit model was also fitted to the data, with the marked/unmarked variable as the binary response, and sampling-stratum number as the explanatory variable. The appropriate model is:

$$\log\left[\frac{Marked_i}{Unmarked_i}\right] = \alpha + \beta X_i \qquad (4)$$

where X_i is an ordinal explanatory variable indicating stratum number. The model fits one parameter to describe differences between strata, and assumes that the log-odds ratio between adjacent strata is constant:

$$\beta = Log\left[\frac{\frac{\Pi_{m,i+1}}{\Pi_{u,i+1}}}{\frac{\Pi_{m,i}}{\Pi_{u,i}}}\right] \quad (5)$$

A full and reduced (β=0) model were fitted, and a likelihood ratio test used to determine whether the linear component explained a significant amount of variation in the data.

Field Test of Proposed Sampling Technique

A field test of a proposed pseudo-systematic sampling technique was made by comparing sample estimates of the proportions of salmon bearing an external mark to known population proportions. Bias in the sampling scheme was assessed by examining the proportion of the (1-α) confidence intervals containing the known population proportions. The exercise was also designed to field-test a sample selection device.

During a 1996 cost recovery fishery in the Eastern District, pectoral fins were removed from known numbers of salmon as they were loaded into the holds of six tenders delivering to the Peter Pan processor in Port Valdez, Alaska. Four independent pseudo-systematic samples were taken from each tender at the conveyor belt during delivery to the processor. An electronic wrist-watch with a 'count-down' feature served as the signal for technicians to sample a salmon. Salmon were sampled in this manner until the tender was unloaded. Each technician sampled approximately 500 to 600 salmon.

An estimate of the population proportion associated with the i^{th} tender derived from the j^{th} sample ($\hat{p}_{ij}$) was calculated as:

$$\hat{p}_{ij} = \frac{m_{ij}}{n_{ij}} \quad (6)$$

where, n_{ij} = number of salmon examined for a missing pectoral fin from the i^{th} tender by sampler j and, m_{ij} = number of marked fish found in n_{ij}.

An estimate of the population proportion associated with the i^{th} tender over the four systematic samples was calculated as

$$\hat{\bar{p}}_i = \frac{1}{4}\sum_{j=1}^{4}\hat{p}_{ij} \quad (7)$$

The variance of $\hat{\bar{p}}_i$ was estimated as $s^2_i/4$, where s^2_i (multi-start systematic sampling variance estimate) was calculated as

$$s_i^{\,2} = \frac{\sum_{j=1}^{4}(\hat{p}_{ij} - \hat{\bar{p}}_i)^2}{3} \quad (8)$$

A 50% confidence interval was calculated for each $\bar{p}_i$ as

$$\hat{\bar{p}}_i \pm t_{0.25,3df} * \sqrt{\frac{s^2_i}{4}} \quad (9)$$

For each of the six independent confidence intervals, an assessment was made to determine whether the interval included the corresponding population mean. Under the null hypothesis that samples were unbiased, the number of times coverage was achieved, x, is a realization of binomial random variable, X, with parameters n=6 and p=0.5. A p-value for the null hypothesis was calculated as $2P(X < x)$ for $x < np$ and $2P(X > x)$ for $x > np$.

Another test was performed in which two pairs of systematic sample means were chosen from each group of four means associated with each tender. For each pair of means, one estimate was made of the population proportion associated with the tender, along with an estimate of its variance. The calculations are similar to those described by Equations 8, 9 and 10. A total of twelve proportions and corresponding variances were independently estimated from the six tenders. Confidence intervals were calculated in a manner identical to that above, except that the t parameter was associated with 1 degree of freedom (each s^2 was based on two means). A determination was made of the number of times the corresponding population mean was included within the twelve intervals, and the hypothesis test described above was conducted under the assumption that the random variable was binomial ($n=12$, $p=0.5$). The question regarding the construction of the pairs of means was solved by averaging the number of coverage instances over all 3^6 (=729) possible constructions.

Simulation study

Computer simulation studies were also undertaken to determine the influence of structured populations on the precision of the estimated proportion of hatchery salmon caught in a fishery opening. It was hypothesized that in structured populations, the systematic sampling methodology would lead to estimates that were more precise than those obtained under random sampling. For example, in an extreme case, a systematic sample of ten salmon taken from a load of 10,000 salmon, would consist of one salmon from each contiguous set of 1,000 salmon. If 5,000 hatchery salmon were unloaded first, followed by 5,000 wild salmon, the variance of the estimated proportion of hatchery salmon in the load is zero. The variance of an estimate derived from a random sample would be of hypergeometric form, and would be greater than zero (about 0.025). The simulation examined the degree to which the precision of estimates based upon random sampling theory might be underestimated in the presence of structured populations. Details of the simulation are provided in Appendix B.

Comparison of Hatchery Contributions Among Processors

For periods three and four during the 1998 season, processors receiving fish from the Southwestern District were sampled at an enhanced rate in order to accumulate otoliths sufficient to make among-processor comparisons of hatchery contributions. Six processors were sampled during each of periods three and four and a total of 839 and 692 otoliths were collected, respectively. The proportion of hatchery fish in the catch delivered to each processor was calculated.

Catch-Sampling Methodology

Recovering otoliths

At the conclusion of a common property or cost recovery fishing period, otoliths were recovered by systematically sampling all available tender loads delivered to processors. The systematic samples were collected by removing otolith pairs from salmon removed from processor belts at set intervals. The time intervals used by technicians at each processor depended upon the number and speed that pink salmon were processed. Each technician used a timing device with a count-down feature that set off an audible alarm after a pre-set time had elapsed. The entire tender was sampled in this manner so that a sample was taken throughout the load. The otoliths gathered from each tender were placed in order of selection into a numbered plastic tray. If possible, all tenders participating in the district-period stratum were sampled.

For each district-period opening, a weighted sample of 96 otoliths (one otolith from each of 96 pairs) was selected from all otoliths collected after the opening. A proportional allocation scheme was invoked, where the tender's load dictated its contribution to the overall sample of 96. Selection of otoliths from within a tray associated with a tender was made systematically to maintain the representative nature of the sample. Another sample of 96 otolith pairs formed in a similar manner was taken and stored for possible postseason analysis with the Bayesian sampling algorithm of Geiger (1994). Catch statistics pertaining to a given period were obtained from the ADF&G fish ticket system.

The left otolith from the recovered sample of 96 otolith pairs was mounted on a glass slide for microscopic examination at the Cordova otolith laboratory and bar-coded using a system developed by the Statewide Laboratory in Juneau. After the origin of an otolith was determined, a bar-code scanner was used to transfer the identity to an Access™ computer database. Upon completion of identification of the inseason sample, hatchery contributions were estimated. Otoliths were recovered in a similar manner from hatchery broodstocks and were identified as described above. A total daily count of the pink salmon spawned was used in place of the catch, and a weighted sampled of 300 - 500 otoliths was eventually taken from each hatchery broodstock.

Preliminary hatchery contribution estimates in a district-period stratum were generated from the first reading of the 96-otolith sample. A second independent reading was made on these otoliths blind to the first reading approximately two weeks later at the Statewide Laboratory in Juneau. In cases of discrepancy between the two readings, the Juneau laboratory supervisor made a third read to determine the correct identification. Any reading errors found in the quality control process were corrected in the database and the contribution number recalculated postseason.

Estimating Hatchery Contributions with Otoliths

The otolith-derived estimate of the contribution of hatchery *h* to district-period stratum *i*, C_{hi} was made as follows:

$$\hat{C}_{hi} = \frac{o_{hi}}{n_i} N_i \qquad (10)$$

where,

o_{hi}	=	Number of otoliths from hatchery *h* in sample n_i
n_i	=	Number of otoliths sampled from stratum *i* (usually 96)
N_i	=	Number of fish caught in stratum *i*.

Otolith-derived estimates of the contribution of hatchery *h*, C_{Sh}, to all sampled common property, cost recovery, and special harvests and broodstocks, were calculated as follows:

$$\hat{C}_{Sh} = \sum_{i=1}^{Q} C_{hi} \qquad (11)$$

where,

Q = Number of recovery strata associated with common property, cost recovery, broodstock, and special harvests in which otoliths from hatchery h were found.

An estimate of the contribution by hatchery h to unsampled fishery strata, $\hat{C}_{Uh}$, was made in a manner similar to that for the coded wire tagging program (Riffe et al., 1996).

An estimate of the contribution by hatchery h to all strata, sampled and unsampled, is given by

$$\hat{C}_h = \hat{C}_{Sh} + \hat{C}_{Uh} \qquad (12)$$

A variance estimate for $\hat{C}_h$ is given by:

$$\hat{V}(\hat{C}_h) = \sum_{i=1}^{Q} \frac{N_i^2 o_{hi}}{n_i^2}\left(1 - \frac{o_{hi}}{n_i}\right) \qquad (13)$$

Because there were very few unsampled strata the variance associated with $\hat{C}_{Uh}$ was assumed negligible.

For any sampled stratum, the sample size was such that the estimate of the proportion of the catch comprised of hatchery fish was made such that there is at least a 95% chance that it is within 10% of the true proportion. When combined over strata, or if the proportion of hatchery salmon differs from 50%, then the precision of the estimated hatchery contribution improves.

Estimation of Survival Rates

An estimate of the survival rate for a pink salmon cohort h, S_h, was made from otolith recoveries as follows:

$$\hat{S}_h = \frac{\hat{C}_{Sh} + \hat{C}_{Uh}}{R_h} \qquad (14)$$

where,

R_h = Number of pink salmon released in cohort h

An approximate variance of $\hat{S}_h$ is given by:

$$\hat{V}(\hat{S}_h) = \frac{\sum_{i=1}^{Q} \frac{N_i^2 o_{hi}}{n_i^2} \left(1 - \frac{o_{hi}}{n_i}\right)}{R_h^2} \quad (15)$$

Preliminary Hatchery Composition Estimates using on-grounds samples

In 1998, otoliths were sampled from test fisheries conducted before the first commercial openings of the season. The R/V Montague collected otolith pairs from approximately 100 pink salmon from three different locations in the Southwestern District (Foxfarm, Squirrel Bay, and Pt. Elrington) daily on nine different occasions beginning on 29 July. Otoliths were extracted from these fish and flown from the grounds to the otolith laboratory in Cordova where estimates of hatchery proportions were made. For three test fish events, a commercial fishery also occurred and estimates of hatchery proportions obtained from the test fishery were compared to the routine, more intensive processor-sampling estimates.

Comparison of Estimates Generated by Otolith Marks and Coded Wire Tags

In 1997, returning pink salmon adults were marked by both coded wire tags and otolith thermal marks, and comparisons were made of hatchery estimates from the otolith program and the coded wire tag program. In addition, thermal mark data gathered from hatchery brood ponds were used to investigate assumptions regarding adjustment factors used in the coded wire tag program to account for tag loss and differential mortality. Specifically, the assumption regarding the utility of the adjustment factor derived from the W.N. hatchery brood pond was investigated.

Estimation of the Proportion of Hatchery-Reared Pink Salmon in Stream Escapement.

Escapement Sampling

Pink salmon entering 12 streams in the southwestern region and two streams in the northern region of Prince William Sound were sampled for otoliths throughout the spawning migration of 1997 (Figure 1). Stream selection was dictated by a separate study, not reported here, to investigate the influence of coded wire tags on straying. Consequently, we tried to include streams from which we could recover relatively large numbers of coded wire tags from salmon.

Three streams sampled, Abercrombie, Jonah and O'Brien Creeks, are within five kilometers of large production hatcheries, and nine of the remaining eleven streams selected were chosen based on coded wire tag recoveries reported by Sharr et al. (1995a).

The goal was to sample each stream twice a week for four weeks from August 15, 1997 through September 15, 1997. At each sampling event, 48 otolith pairs were extracted from recently spawned carcasses. All carcasses present at the time of sampling were counted and removed from the streambed to avoid duplicate counting at the next sampling event. In streams where very large escapements were encountered, it was impossible to remove all salmon. In these instances, only fresh carcasses were sampled and live salmon in the stream were counted. Pink salmon counts were used to weight weekly estimates of the proportion of hatchery-released salmon in a given stream.

Estimating the Proportion of Hatchery Salmon in Stream Escapements

The estimated proportion of hatchery-released salmon in the escapement to stream s in week i, p_{si}, was calculated as:

$$\hat{p}_{si} = \frac{o_{si}}{n_{si}} \qquad (16)$$

where n_{si} is the number of otoliths mounted and identified from stream s in week i and o_{si} is the number of otoliths from hatchery-released salmon found in sample n_{si}.

Estimates of the proportion of hatchery-released salmon in the total escapement to stream s, were calculated by weighting weekly estimates by the size of the population from which the otolith sample was taken:

$$\hat{p}_S = \sum_{i=1}^{Q_s} \frac{N_{si}}{\sum_{i=1}^{Q_s} N_{si}} \hat{p}_{si} = \sum_{i=1}^{Q_s} w_{si} \hat{p}_{si} \qquad (17)$$

where Q_s is the number of weeks over which stream s was sampled, and N_{si} is the size of population from which p_{si} was estimated. A variance estimate for $\hat{p}_s$ is given by:

$$\hat{V}(\hat{p}_s) = \sum_{i=1}^{Q_s} w_{si}^2 \frac{o_{si}}{n_{si}^2} \left(1 - \frac{o_{si}}{n_{si}}\right) \qquad (18)$$

Sample sizes were chosen such that for a given sampling event, the proportion of the escapement comprised of hatchery-released salmon was estimated within approximately 10% of the true proportion with 95% probability.

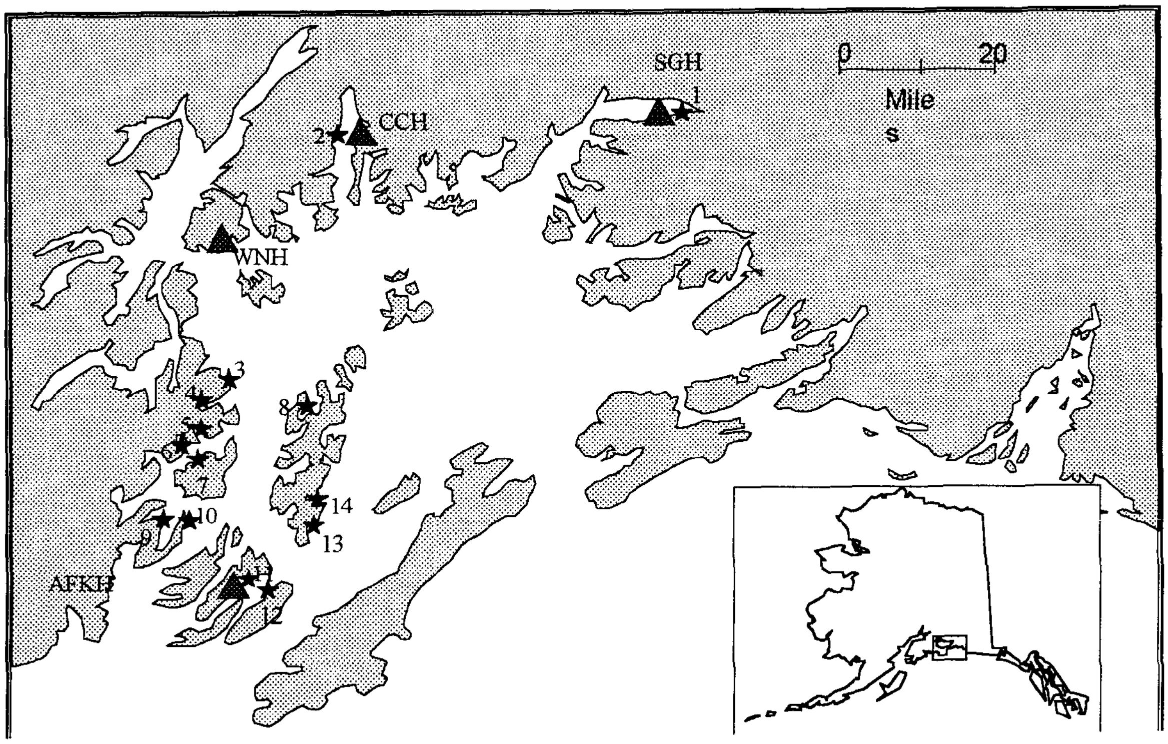


Figure 2 Location of sampled streams and pink salmon hatcheries, Prince William Sound, Alaska. Stream names: 1=Abercrombie; 2=Jonah Bay; 3=Loomis; 4=Elishansky; 5=Paddy; 6=Erb; 7=Totemoff; 8=Herring; 9=Claw; 10=Pt. Countess; 11=O'Brien; 12=Hayden; 13=Hogan; 14=Snug Harbor.

RESULTS

Application of Thermal Marks to Pink Salmon

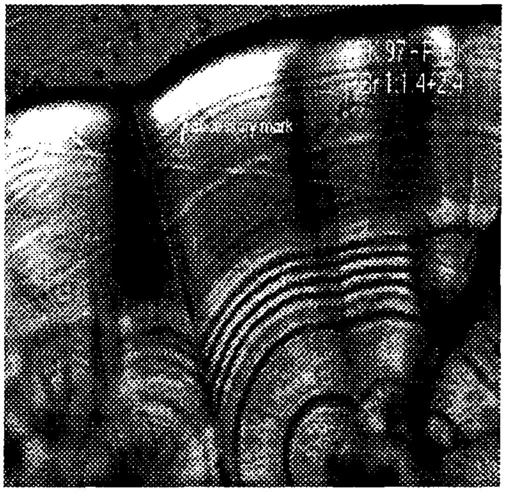
Incubation water temperatures were maintained at 3.8° to 4.0°C above ambient at all of the Prince William Sound hatcheries when required by the marking schedule. When marking system problems occurred, they were fully documented by hatchery staff and the Statewide Laboratory was notified. Modifications to mark schedules were made when appropriate, resulting in only minor variations to base marks. None of these modifications compromised mark integrity of any hatchery base mark.

The number of fry marked and released for each of the four Prince William Sound pink salmon hatcheries are shown in Table 3. Samples taken three weeks after completion of the marking process revealed that high quality thermal marks had been laid down at each of the four hatcheries. Representative thermal marks laid down in brood year 1997 are shown in Figure 3.

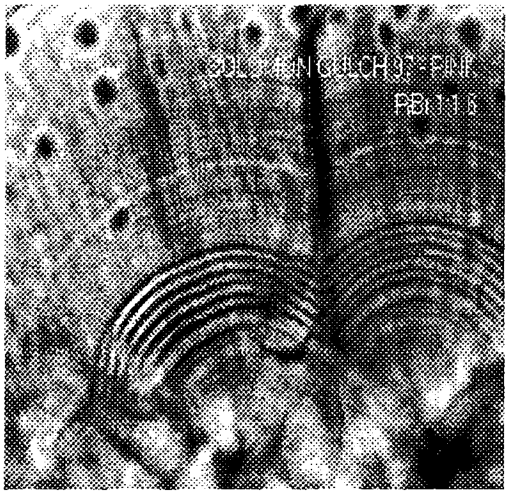
Table 3 Number of fry marked and released from Prince William Sound pink salmon hatcheries (BY95 and BY96).

Facility	Fry Marked and Released (millions)		
	BY95	BY96	
		Base Mark[a]	Accessory Mark[a]
SGH	223.1	188.9	None
CCH	140.5	136.8	None
WNH	169.5	75.9	30.6
AFKH	108.6	35.9	16.5

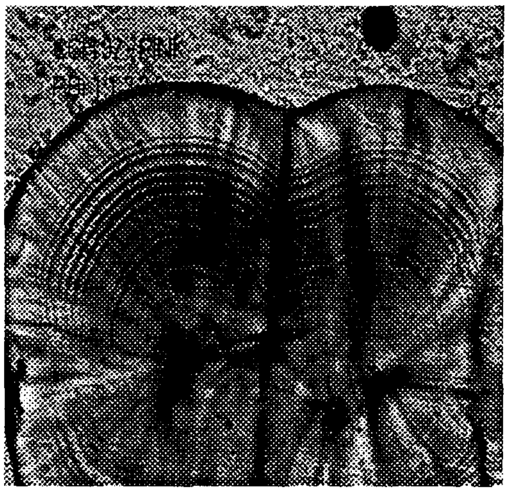
a WNH Base =Early/Plankton Release; WNH Accessory = Late/Large Release
AFKH Base =Late/Large Release; AFKH Accessory=Early/Plankton



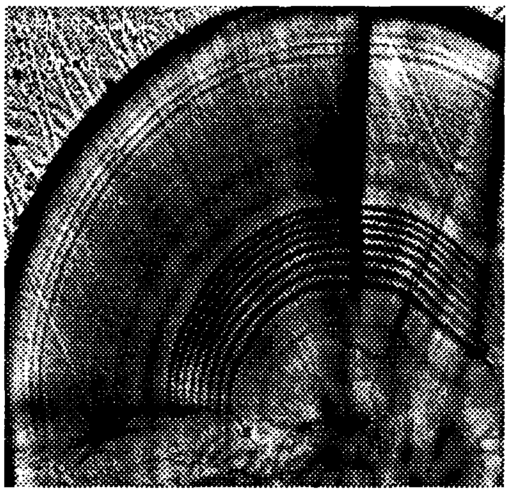
A.F.Koernig – 97 with accessory mark



Solomon Gulch – 97



Cannery Creek – 97



W.H. Noerenberg – 97 with accessory mark

Figure 3 Thermally-marked pink salmon otoliths sampled from Prince William Sound hatcheries in (BY97)

Determination of the Readability of Otoliths

Success Rates for BY95, BY96 and BY97 Blind Tests (Fry)

Estimated mean success rates are presented in Table 4. Success rates $\hat{p}_i$ and $\hat{p}$ and defined previously. The highest success rates were obtained with the $\hat{p}_i$ variable, where the success count is based on grouping all but one of the i^{th} otolith origins. The highest success rate for this variable was 1.0 for SGH, AFKH, CCH and WNH for the BY96 test and for CCH and WNH for the BY97 test. The lowest rate was 0.993 for the Hatchery-Wild distinction for the BY97 test. For the $\hat{p}$ variable, which measures overall success, regardless of otolith origin, success rates were lower, ranging from 0.987 for BY95 to 0.995 for BY96. All approximate confidence intervals contained values that would be considered acceptable in the sense that they would allow a workable contribution estimation program to function.

Success Rates for BY95 and BY96 Blind Tests (Adults)

Circumstances prevented completion of the adult blind test planned for BY95 pink salmon returning in 1997. Results of the LCM analysis for BY96 adults are presented in Table 5. The data are composed of paired readings from otoliths collected in four commercial fishing districts. The first reader was in Cordova and the second in Juneau. The readers disagreed only on five out of 3,309 samples as to whether the otolith was from a hatchery or wild fish. The LCM estimate confirms that both readers were highly accurate. For instance the accuracy rate of reader 1 for a identifying hatchery thermal mark is $\pi_{H|H}^{(1)} = 0.9996$. The rates for each reader are not significantly different from each other, and, with the exception of reader 2's rate for identifying wild fish, they are not significantly different than perfect accuracy rate of 1.0. With eight parameters and 12 df, there are 4 df available for a goodness-of-fit test. Pearson's chi-square yields 3.06, which with 4 df, has a p-value of 0.55, thus indicating an acceptable model fit. For each group examined the amount of variance associated with misclassification error contributes less than 1.6% of the total variance.

Reader Agreement

Measures of agreement between readers ranged from 0.962 to 0.996 for the BY95 blind test (measurements pertain to the first event), and from 0.982 to 0.989 for the BY96 blind test (Table 6).

Identification matrices

The identification matrix for all readers for the first event of the BY95 test indicated that errors most often occurred among the off-diagonal cells SGH/CCH, WILD/AFKH and CCH/WNH.

The number of otoliths involved in the BY96 test was smaller, and the only errors found occurred for the cells SGH/WNH and WNH/Wild

Table 4 Success rates and 95% Confidence Bounds[a] for BY95 and BY96 blind tests.

Success Variable		BY95		BY96		BY97
		Success Rate	95% CI [a]	Success Rate	95% CI [a]	Success Rate
$\hat{p}_i$						
i = Hatchery	(vs Wild)	0.996	(0.993, 0.999)	0.997	(0.989, 1)	0.993
i = SGH	(vs Rest)	0.994	(0.985,1)	1	NA	1
i = AFKH	(vs Rest)	0.997	(0.992, 1)	1	NA	0.995
i = CCH	(vs Rest)	0.991	(0.983, 1)	1	NA	1
i = WNH	(vs Rest)	0.996	(0.994, 0.999)	1	NA	1
$\hat{p}$		0.987	0.978	0.995	0.989	0.989

a Not simultaneous bounds.

Table 5. Estimates of accuracy, π, and the proportion of hatchery fish, P, as estimated by a latent class model for two readers and four fishing districts. H=hatchery fish; W=wild fish. The standard error (SE) of each parameter and the differences between each reader's accuracy rate is shown.

	Statistical Area			
	221	222	223	226
HH	169	575	1014	757
HW	1	0	1	0
WH	2	0	1	0
WW	694	115	27	34
n	866	690	1043	791

LCM Parameter	Estimate	SE	Reader Difference	SE
$\pi_{H\vert H}^{(1)}$	0.99963	0.00037	0.00003	0.000009
$\pi_{H\vert H}^{(2)}$	0.99960	0.00040		
$\pi_{W\vert W}^{(1)}$	0.99886	0.00114	0.00124	0.000036
$\pi_{W\vert W}^{(2)}$	0.99762	0.00179		
P_{221}	0.19532	0.024		
P_{222}	0.83333	0.020		
P_{223}	0.97391	0.010		
P_{226}	0.95702	0.011		

Table 6 Agreement between readers for BY95 and BY96 Blind Tests (fry). Single entries are values of Kappa. 95% confidence bounds are in parentheses.

BY95 Test	Reader	B	C	D
	A	0.964	0.963	0.962
		(0.951,0.977)	(0.950,0.976)	(0.948,0.975)
	B		0.992	0.993
			(0.985,0.998)	(0.987,0.999)
	C			0.996
				(0.992,1.000)
BY96 Test	A	0.986	0.989	
		(0.973, 1.0)	(0.977, 1.00)	
	B		0.982	
			(0.967, 0.998)	

Table 7 Identification matrix for BY95 (all readers) and BY96 (inseason reader) tests.

BY95 Test			OBSERVED			
	ORIGIN	AFK	CCH	SGH	WNH	WILD
	AFK	574	0	2	0	0
	CCH	2	529	0	17	0
TRUE	SGH	0	20	624	0	0
	WNH	0	3	3	642	4
	WILD	14	4	0	0	2358
BY96 Test	ORIGIN	AFK	CCH	SGH	WNH	WILD
	AFKH	49	0	0	0	0
	CCH	0	50	0	0	0
TRUE	SGH	0	0	93	1	0
	WNH	0	0	0	50	1
	WILD	0	0	0	0	148

For the BY95 data, a significant lack-of-fit of the quasi-independence model was found (χ^2=107.5 with 11 df; p=0), suggesting the existence of dependencies among the rectangularly-formed 2x2 tables in the off-diagonal areas of the matrix. The interpretation of the dependencies is as follows: Given that a mistake has been made in identification of an otolith, the assignment of the otolith origin is dependent on its true identification. Inspection of Table 7 suggests that the contributions to the lack of fit derive from 2x2 tables such as that with diagonals formed from the cells corresponding to SGH (True):CCH (Observed) and Wild (True):AFKH (Observed). A Fisher-exact test yields a p-value of 0 for the hypothesis of independence for this table. If a mistake is made identifying a SGH otolith, it is most likely to be classified as a CCH otolith while a misidentified otolith from a wild salmon is most likely to be classified as an AFKH otolith. Another similar example exists in the misidentification of CCH otoliths as WNH otoliths.

1997 and 1998 Agreement (Adults)

During the 1997 pink salmon season, 10,660 otoliths were identified at the Cordova otolith laboratory. Out of this total, 7,426 otoliths were read a second time at the Juneau Statewide Laboratory as a quality control measure. A total of 54 discrepancies (0.7%) were found and later confirmed by a third experienced reader. The most common error involved misidentification of a CCH otolith by Cordova readers as a WNH otolith (Table 8). Cohen's kappa for the Juneau-Cordova comparison is 0.991 (0.988, 0.993).

Table 8 Identification matrix for the Cordova *vs.* Juneau readers for 1997 adults

		Juneau				
	Origin	AFKH	CCH	SGH	WNH	WILD
	AFKH	1033	2	1	2	0
Cordova	CCH	0	1227	0	1	2
	SGH	4	1	2390	5	2
	WNH	0	19	3	2181	1
	WILD	2	0	7	1	542

During the 1998 pink salmon season, 12,697 otoliths were identified at the Cordova otolith laboratory. Out of this total, 8,137 otoliths were read a second time at the Juneau Statewide Laboratory as a quality control measure. A total of 93 discrepancies (1.1%) were found and later confirmed by a third experienced reader. Only 16 (0.2%) errors were made among hatchery vs. wild identifications and 7 (0.1%) hatchery to hatchery errors were made. The most common error involved misidentification of the accessory mark at the WNH and AFKH hatcheries (Table 9). Cohen's kappa for the Juneau-Cordova comparison is 0.986 (0.983, 0.989).

Table 9 Identification matrix for the Cordova *vs.* Juneau readers for 1998 adults[a]

		Juneau						
	Origin	AFKH	AFKH+	CCH	SGH	WNH	WNH+	WILD
	AFKH	658	21	3	1	0	0	0
	AFKH+	1	259	0	0	0	0	0
Cordova	CCH	0	0	1250	0	0	0	0
	SGH	0	0	0	1107	1	0	5
	WNH	1	0	0	1	1123	34	0
	WNH+	0	0	0	0	14	863	1
	WILD	2	1	1	4	1	1	2784

a + indicates accessory mark

Development of Catch Sampling Program

Assessment of Degree of Mixing within a Tender

Descriptions of the three marking and sampling events are given in Table 10, and results pertaining to found marks in Table 11.

A χ^2 analysis of the null hypothesis of independence between loading stage and recovery stratum yielded P values for Loading Events 1, 2 and 3 of 0.25, 0.033 and 0, respectively. For the logit analysis, the linear component β that describes adjacent odds ratios, was insignificant for the loading event in which fin-clipped fish were added to the middle of the tender. For the loading events in which fin-clipped fish were added to the beginning and end of the loads, the parameter estimate was positive and negative, respectively (Table 12).

Field Test of Proposed Sampling Technique

Mark and sample data from the study are presented in Table 13. The number of coverage events for the 50% confidence interval was 3. A p-value of 1.0 was calculated for the null hypothesis that an unbiased sample estimate was obtained. When a similar exercise was performed for two-at-time selections (twelve trials), the average number of coverage events was seven out of twelve over all 729 contingencies (p=0.81). There was no evidence that samples were biased.

Table 10 Marking and sampling scenarios for Loading Events 1 through 3.

	Loading Event		
	1	2	3
Load (# fish)	31,805	43,000	25,820
Loading Site/District	AFKH/SW	Payday Point/N	AFKH/SW
Marks Added	1,948	2,300	2,242
Loading Stage at Mark Addition	27% Complete	0% Complete	100% Complete
Distance to Processor (mi)	85	60	85

Table 11 Found marks for Loading Events 1 through 3

		Sampling Stratum					
		I	II	III	IV	V	Total
Loading Event 1	Marked	7	12	3	a	a	22
	Unmarked	168	150	87	a	a	405
	Total Sampled	175	162	90	a	a	427
Loading Event 2	Marked	4	8	18	a	a	30
	Unmarked	116	110	136	a	a	362
	Total Sampled	120	118	154	a	a	392
Loading Event 3	Marked	15	9	1	4	1	30
	Unmarked	78	74	109	91	109	461
	Total Sampled	93	83	110	95	110	491

a Fish delivered in first two loading events

Simulation Study

For randomly-mixed populations, simulated measures of precision (*d* values) were close to theoretical values (Table 14). When order was imposed on the populations, the simulated *d* values decreased. For a mixing factor of 0.7, the average *d* value was approximately half the value derived from calculations that assumed random populations and a 50:50 mix of hatchery and wild salmon.

Table 12 Parameter estimates and *P* values for linear logit model..

	Sampling Event		
Parameter Estimates:	1	2	3
α	-2.969	-3.98	-0.909
β	0.031	0.656	-0.732
P value for test H_o:β=0	0.910	0.007	0

Table 13 Mark and sample data for finclip experiment

Tender	Load (#fish)	# Marks	Mark Rate	Estimate	50% C.I.	Coverage[a]
1	18,070	1,363	0.075	0.089	0.084, 0.094	0
2	15,174	2,047	0.135	0.140	0.131, 0.149	1
3	33,568	2,769	0.082	0.077	0.072, 0.081	0
4	25,935	2,159	0.083	0.071	0.066, 0.076	0
5	20,777	1,903	0.092	0.095	0.090, 0.099	1
6	25,628	2,226	0.087	0.089	0.084, 0.094	1
Total						3

a 1 if confidence interval contains population proportion.

0 if confidence interval does not contain population proportion

Table 14 Effect of ordered populations upon precision of estimates

Population Structure		Min/Max d^{a} value over 29 openings		Average d value over 29 openings
		Min(d)	Max(d)	
Random				
Theoretical		0.026	0.080	0.063
Simulated		0.025	0.091	0.066
Ordered				
Level[b]	0.1	0.028	0.095	0.062
	0.3	0.023	0.082	0.060
	0.5	0.026	0.077	0.055
	0.7	0.019	0.062	0.045

a d is defined : $P(p\text{-}d < Estimated\ (p) < p+d) = 0.95$, where p = Population proportion

b A level of 0.3 means that 30% of the fish in the tenders were ordered, *i.e.* 70% of the fish were randomized among the ordered fish.

Comparison of Hatchery Contributions Among Processors

Sampling data and estimated proportions of hatchery salmon by processor are presented in Table 15. By-facility estimates are plotted in Figure 4.

Table 15 Sampling data and estimated proportion of hatchery salmon for processor-comparison study

Processor	Period 3		Period 4	
	Otoliths	Proportion	Otoliths	Proportion
N.P.P.	243	0.90	250	0.91
St. Elias	255	0.95	62	0.94
Peter Pan	174	0.84	88	0.85
SeaHawk	91	0.87	62	0.89
Icicle	57	0.86	163	0.91
Nautilus	19	0.95	67	0.85

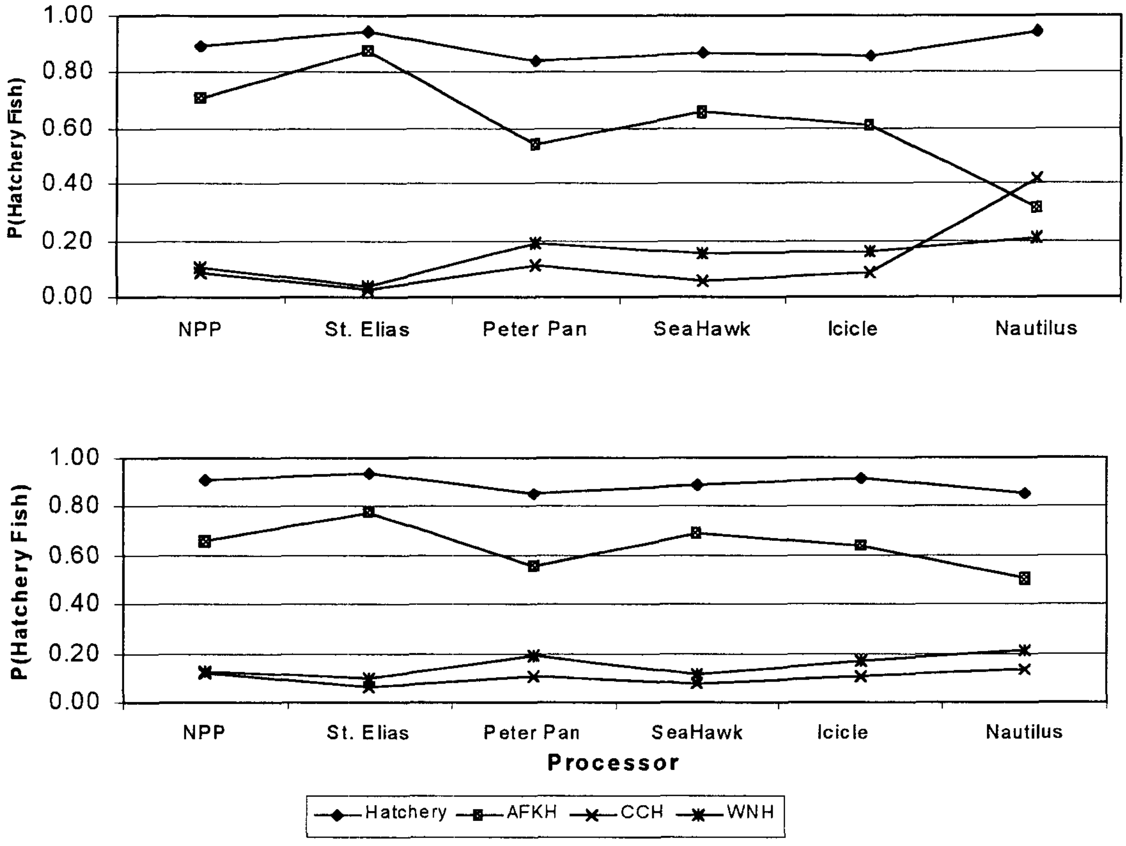


Figure 4 Estimated proportions of hatchery pink salmon delivered to six processors from district 226 during periods 3 (top) and 4 (bottom) in 1998.

Estimating Hatchery Contributions with Otoliths

General

The estimated pink salmon return to Prince William Sound in 1997 and 1998, including the Copper and Bering River Districts was 28.31 and 30.81 million fish, respectively. Contribution estimates derived from otolith marked pink salmon indicated that 90.8% and 83.1% of the pink salmon return to Prince William Sound was of hatchery origin for each respective year.

Common Property Harvest

All otolith-derived contributions to the common property harvest were calculated by district and period. In 1997, pink salmon produced by SGH comprised the largest portion of the common property harvest while in 1998 this hatchery comprised the smallest portion (Table 16). The remaining common property harvest was produced, in order of abundance in both years, by AFKH, CCCH, and WNH. Production from wild systems was the smallest component of the return. In general, the largest contributor to a district was the nearest hatchery producing pink salmon. Appendix A lists the hatchery contribution to the common property catch by district and period for 1997 and 1998. The hatchery contribution estimates presented in all appendices include those adjusted with post season samples.

Cost Recovery Harvest

Daily harvests were not sampled in all cases, so a number of daily strata had to be combined. In general, contributions to cost recovery harvests from hatcheries other than the one of origin were small. Main Bay hatchery was a notable exception. Since Main Bay hatchery produces only sockeye salmon, any pink salmon sold in their cost recovery operation originated from other locations. Table 16 lists the contribution to this fishery by facility. Detailed cost recovery harvests are presented Appendix A.

Broodstock Harvest

Only three hatcheries used on-site broodstocks in Prince William Sound in 1997 while four hatcheries used on-site broodstocks in 1998. In 1997, embryos incubated at AFKH were spawned at the WNH and later transferred after reaching the "eyed" stage of development. Hatchery broodstocks included all fish that were processed at the hatchery, and included fish in which the roe was removed for sale rather than incubation (Table 16).

Table 16 Pink salmon contribution by hatchery to Prince William Sound fisheries and broodstocks (millions of fish) for 1997 and 1998.

Harvest	1997	95% CI	1998	95% CI
Common Property				
SGH	4.005	3.94, 4.07	1.227	1.17, 1.28
CCH	3.608	3.49, 3.72	4.923	4.73, 5.12
WNH	3.464	3.33, 3.60	4.824	4.60, 5.05
AFKH	3.815	3.68, 3.95	5.038	4.79, 5.28
Wild	1.089	0.99, 1.19	3.689	3.52, 3.86
Cost Recovery				
SGH	2.428	2.41, 2.45	3.077	3.04, 3.12
CCH	1.852	1.83, 1.88	1.305	1.28, 1.33
WNH	2.321	2.30, 2.35	2.427	2.41, 2.45
AFKH	3.139	3.10, 3.17	1.582	1.56, 1.61
Wild	0.075	0.042, 0.107	0.139	0.092, 0.186
Broodstock				
SGH	0.356	0.354, 0.359	0.335	0.334, 0.335
CCH	0.319	0.316, 0.323	0.305	0.304, 0.306
WNH	0.409	0.406, 0.413	0.264	0.261, 0.268
AFKH	0	--	0.344	0.343, 0.345
Wild	0.0029	0.0005, 0.0053	0.0037	0.0005, 0.007

Estimation of Survival Rates

Pink salmon survival rates are listed in Table 17. For BY96, the survival rates for salmon released from the two hatcheries located in western Prince William Sound (WNH and AFKH) were approximately twice those of BY95. The survival rate for BY96 salmon released from the northerly-located hatchery (CCH) remained about the same as that for BY95 salmon, while for SGH, located in the eastern part of Prince William Sound, the survival rate for BY96 salmon was slightly lower than for BY95 salmon.

Table 17 Pink salmon percentage survival estimate by hatchery by year

Hatchery	BY95	95% C.I.	BY96	95% C.I.
SGH	3.0	3.0,3.1	2.5	2.4, 2.5
CCH	4.1	4.0,4.2	4.8	4.6, 4.9
WNH[a]	3.7	3.6,3.7	5.4	5.1, 5.7
WNH (Accessory)			11.4	10.7, 12.0
AFKH [a]	6.4	6.3,6.5	13.6	12.9, 14.3
AFKH (Accessory)			11.9	10.7, 13.1

a WNH Base =Early/Plankton Release; WNH Accessory = Late/Large Release
AFKH Base =Late/Large Release; AFKH Accessory=Early/Plankton

Preliminary Hatchery Contribution Estimates Using On-Grounds Samples

On-ground and processor-based estimates are depicted in Figure 4. Close agreement between processor-based and on-grounds estimates was observed for all origins.

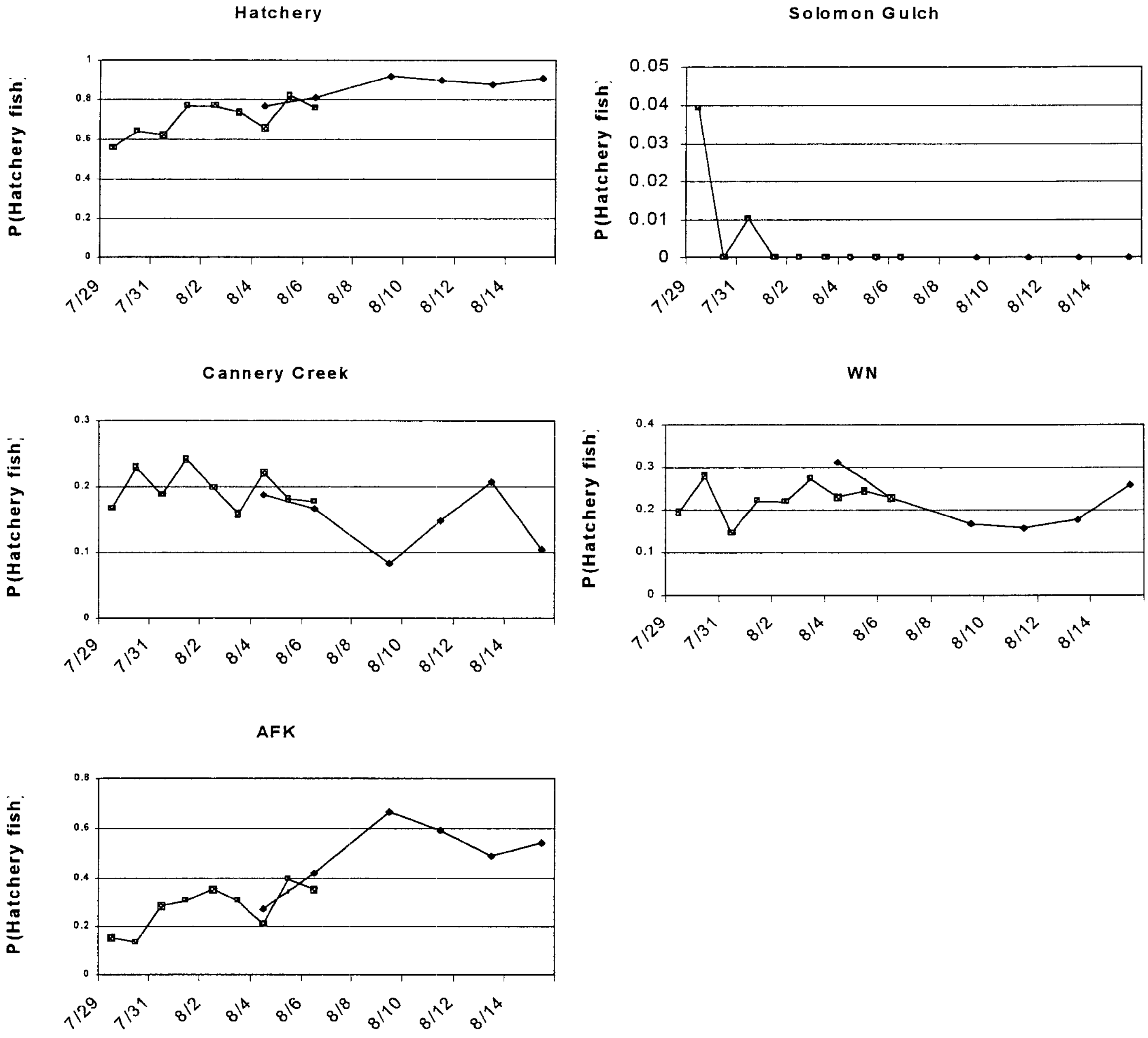


Figure 5 Comparison of on-grounds sample estimates(■) with processor-based samples (◆) for 1998.

Comparison of Estimates Generated by Otolith Marks and Coded Wire Tags

A comparison of the estimates of hatchery contributions derived from the coded wire tagging program with those from the otoltih thermal marking program for 1997 is presented in Table 18. Estimates agree relatively well, with no consistent trends. Confidence intervals, however are considerably wider for the coded wire tag-derived estimates. The wider confidence intervals are also reflected in the % relative precision (Table 19) of the coded wire tag and otolith estimates (1.96*Standard error(Estimate)/Estimate*100). Those for the otolith program are considerably more consistent and range from about 1% to 2%, while those associated with the CWT program vary widely, ranging from about 6% to 25%.

Table 18. Estimates of hatchery contributions to the common property and cost recovery harvests derived from the coded wire tag program and the otolith marking program for 1997. (Estimates are in millions of fish).

	Common Property		Cost Recovery		Total[a]		Total[a]	
Facility	CWT	Otolith	CWT	Otolith	CWT	95% CI	Otolith	95% CI
SGH	4.33	4.00	2.43	2.42	7.01	6.51, 7.49	6.79	6.72, 6.86
CCH	3.14	3.61	1.14	1.85	4.16	3.82, 5.21	5.78	5.66, 5.89
WHN	3.07	3.46	2.14	2.32	5.62	5.05, 6.20	6.19	6.05, 6.33
AFK	3.42	3.82	3.19	3.14	6.61	4.94, 7.20	6.95	6.81, 7.09
Hatchery	13.95	14.89	8.90	9.73	23.75	22.2, 25.3	25.71	25.5, 25.9
Wild	1.93	0.99	0.911	0.085	3.03	1.5, 4.6	1.17	0.98, 1.36

a Includes broodstock

Table 19 Comparison of relative precision between hatchery contribution estimates (all harvest types) provided by the CWT and otolith marking programs (1997).

	Relative Precision (95%)	
Facility	CWT	Otolith
SGH	6.9	1.0
CCH	25.2	1.9
WHN	10.3	2.3
AFK	8.9	2.0
Hatchery	6.4	0.97

Wild stock contributions to broodstocks were minimal (Appendix A) and were only found in the Solomon Gulch hatchery broodstock in 1997, where they comprised less than 1%. In 1998, wild stocks were found only in the WNH and AFKH broodstocks and comprised less than 1% of the brood.

Estimating the Proportion of Hatchery-Released Pink Salmon in Stream Escapements

Two systems, Claw and Elishansky Creeks, were only sampled over two weeks because of logistical problems, while Loomis, O'Brien and Abercrombie Creeks were sampled over four weeks. The remaining creeks were sampled over three weeks. Sampling in Abercrombie Creek began at least 10 days after post spawning mortalities were available in the system because heavy rains prevented access. The long spawning period at Jonah Creek caused sampling to occur during the later part of that run. Otolith recoveries showed that every stream contained hatchery-released salmon at every sampling event, and that the proportion of hatchery-released salmon increased through the spawning migration for all streams except Abercrombie Creek, where the proportion was close to 1.0 from the outset (Figure 5). The proportion of hatchery-released salmon found during the last sampling event ranged from 0.29 for Snug Harbor Creek to 0.96 for Abercrombie Creek. Abercrombie Creek had the greatest overall proportion of hatchery-released salmon, while Snug Harbor Creek had the lowest (Table 20).

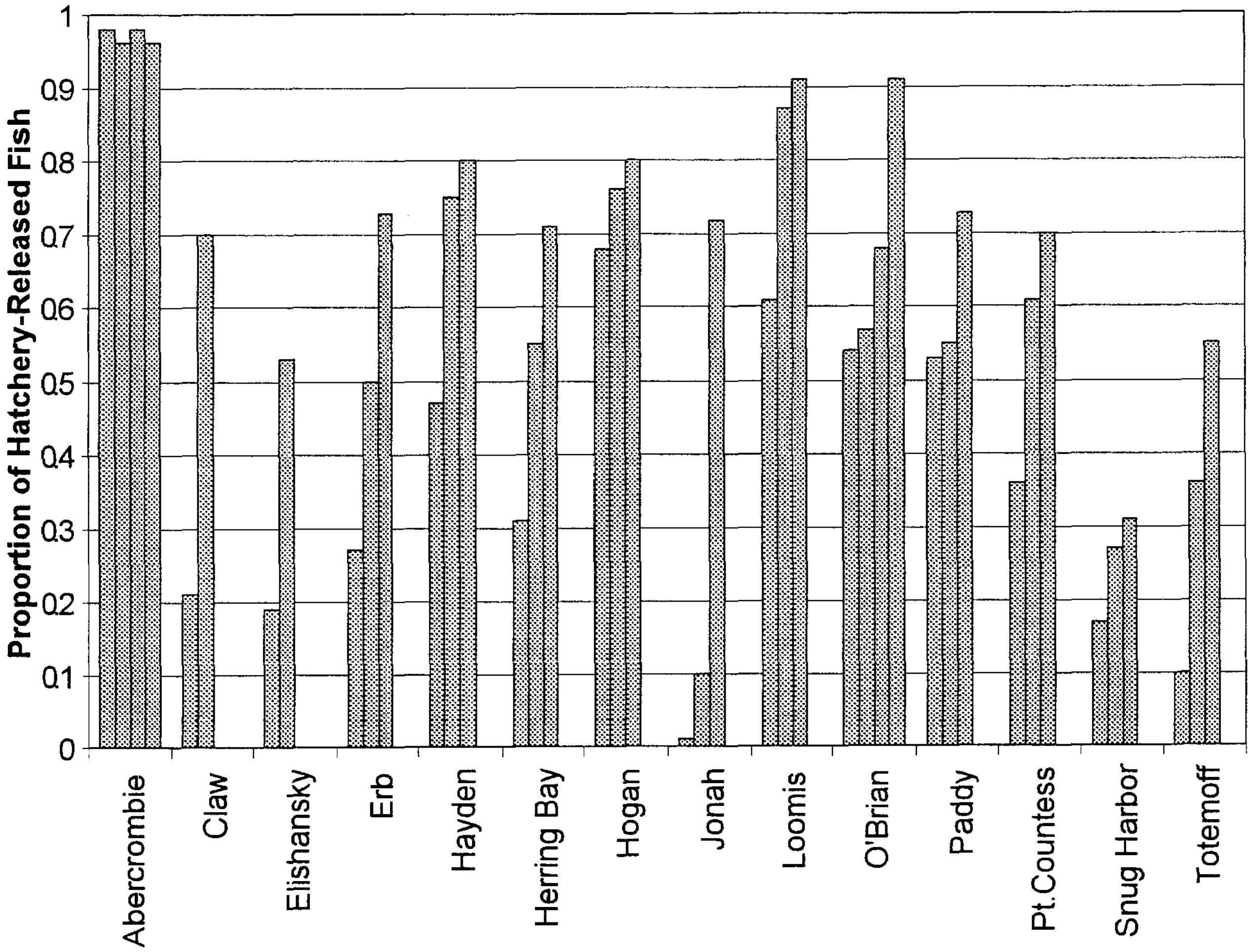


Figure 6 Proportion of hatchery-released pink salmon in wild pink salmon spawning stream escapements, southwestern Prince William Sound, Alaska, 1997. Bars within a stream reflect temporal progression of spawning migration (left to right).

Table 20 Estimated proportion of stream escapements composed of hatchery-released pink salmon, Prince William Sound, Alaska, 1997.

Creek	Estimated Proportion	95% CI	Number of Salmon-
Abercrombie	0.97	0.95, 0.99	28,200
Claw	0.59	0.52, 0.66	3,300
Elishansky	0.46	0.38, 0.54	600
Erb	0.61	0.54, 0.67	4,200
Hayden	0.75	0.70, 0.81	10,300
Herring Bay	0.61	0.55, 0.68	4,700
Hogan	0.78	0.72, 0.83	9,800
Jonah	NA		
Loomis	0.88	0.84, 0.93	7,400
O'Brien	0.86	0.81, 0.91	22,700
Paddy	0.65	0.59, 0.72	4,400
Pt_Countess	0.66	0.59, 0.73	8,400
Snug	0.26	0.21, 0.31	5,800
Totemoff	0.42	0.37, 0.47	4,800

The proportion of pink salmon from WNH and AFKH, which contributed most stray salmon to stream escapements, was greatest in streams closest to these hatcheries (Figure 6; p=0.01 and p=0.002, respectively). No such relationship was detected for stray salmon from the Cannery Creek hatchery (p=0.85).

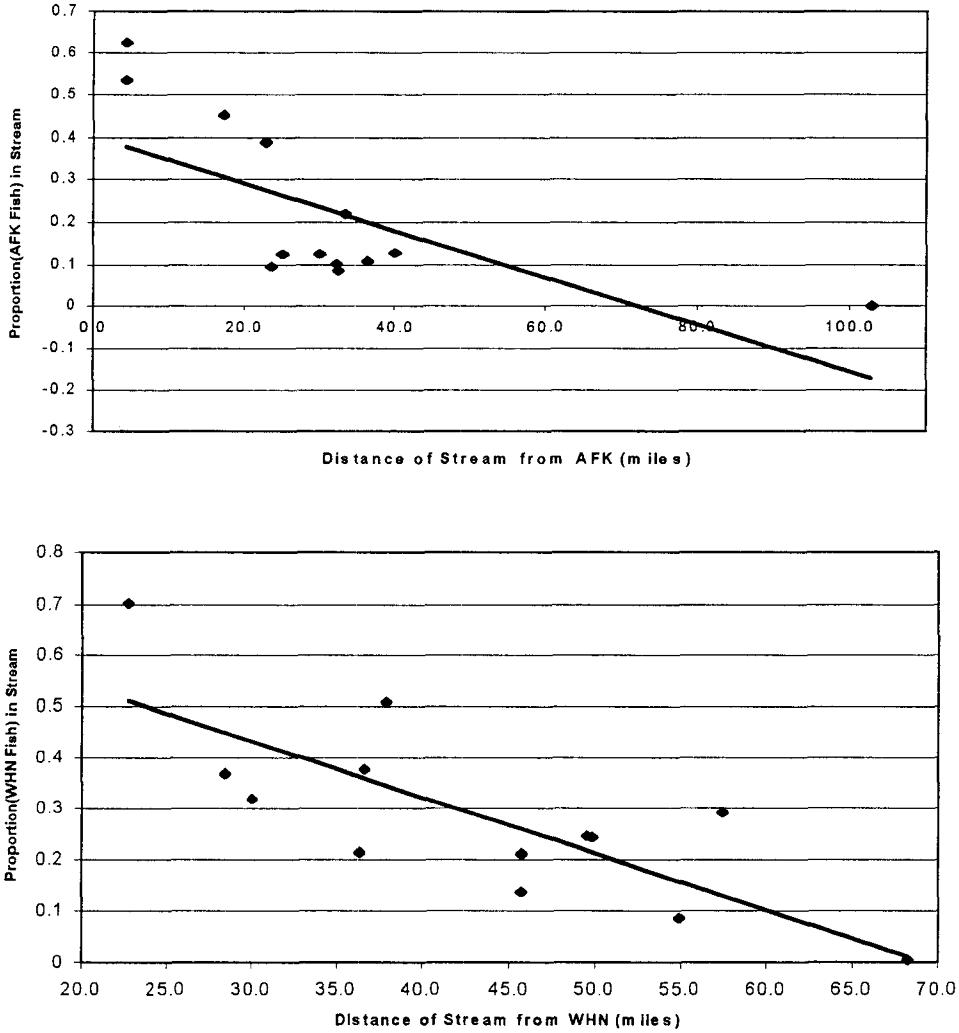


Figure 7 Relationships between proportion of hatchery-raised pink salmon in wild pink salmon streams and distance of streams from the AFKH and WNH, Prince William Sound, Alaska, 1997

DISCUSSION

Application of Thermal Marks to pink salmon

High quality marks are one of the prerequisites to the successful implementation of an otolith marking program intended to separate hatchery and wild stocks. Sampling of otoliths at the time of swim up has indicated that such marks were indeed placed on the otoliths of all brood years of pink salmon embryos produced by Prince William Sound hatcheries since the program began. Continued sampling of post mark and swim-up fry from each hatchery from each brood year will provide advance indications of mark quality and of any potential problems.

Determination of the Readability of Otoliths

With regards to BY95 and BY96 pink salmon, it was reassuring to find that reader success rates approached 100% regardless of which of the two measures of success were used. The BY95 study also showed that variability among readers and among times within readers was such that expected future performance of a randomly selected reader given a set of 100 otoliths at any given time was predictably good. Consistent with successful otolith identification rates, reader agreements were high. Also interesting is that readers with no previous experience were highly successful at identifying otoliths. On hatchery-wild distinctions, the inexperienced readers were capable of identifying otoliths 99.7% of the time.

Identification matrices indicated thermal patterns that caused difficulties in the blind test and were used to help readers improve their performance in identifying otoliths extracted from returning adults. A prediction made from the brood year 1995 blind test (Joyce et al., 1997), appears to have been pessimistic; the test indicated that the most likely identification errors associated with returning adults in 1997 would be the misidentification of fish from SGH for fish from CCH, wild fish for those from AFKH and CCH fish for WNH fish. Comparison of inseason readings made by Cordova readers with those made by more experienced readers at the Code Wire Tag and Otolith Laboratory in Juneau suggested, however, that the CCH/WNH error was the only one of any significance. Unfortunately, circumstances were such that the adult blind test could not be completed as planned, and so no absolute success rates for adults could be determined.

One possible explanation for greater than expected success in identifying adults in 1997 is that readers became familiar with the marks and their permutations quickly and were able to identify marks that would have been misidentified early in the season, or in a blind test setting. Supporting this notion is the fact that a third of the errors in first-read identification, as determined from reader agreement assessment, occurred in the first two fishing periods.

The success rates for marks established in BY96 were as high or higher than those laid down for brood year 1995 pink salmon. Blind tests on BY96 fry indicated few errors would be encountered in the 1998 adults, and in fact, there was little disagreement in hatchery vs. hatchery and hatchery vs. wild decisions made by Cordova and Juneau readers. The blind test did not, however, measure the error between base marks and accessory marks within the same hatchery, and it was among decisions regarding these marks that disagreement between Cordova and Juneau readers occurred most frequently.

The results of the blind test provide us with a high degree of confidence that accurate estimates of the contribution of hatchery pink salmon to the commercial fishery can be made from identification of recovered otoliths. While success rates in identification have been very high to this point, there is no guarantee that this will always be the case, and it is stressed that blind testing of marks should be conducted each year.

Development of Catch-Sampling Technique

One of the attractions of the thermal mark program is that it potentially allows precise and accurate estimation of the composition of a district-period catch from a much smaller sample than did the coded wire tagging program. A caveat is that the required sample size (about 100 otoliths) is so small, that there is a danger of non representative sampling. The coded wire tag program, on the other hand, involved recovery of tags applied at a rate of about 1 in 600 and consequently required sample sizes in the thousands. Such large sample sizes were necessarily spread through the catch. From the outset it was decided that sampling effort be distributed among processors and tenders within processors. How an individual tender was to be sampled was answered by the results of the tender-mixing study. It was found that fish were not necessarily randomized within the hold of a tender, and a pseudo-systematic sampling technique was developed to ensure representative sampling. The technique was tested in the field and with a computer simulation. It was shown that if order did in fact exist within the tender then the predicted precision of composition estimates would be underestimated. Over both the 1997 and 1998 seasons, the chosen sampling methodology proved to be easily implemented and the bar-code otolith tracking system developed by the Coded Wire Tag and Otolith Laboratory in Juneau operated flawlessly.

Otolith–Derived Estimates of Hatchery Contributions to the Pink Salmon Harvest

Otolith-derived estimates of hatchery contributions to the common property and cost recovery fisheries were more precise, were available sooner, and were viewed with greater confidence than those ever provided by the coded wire tag program. For some important strata, test fisheries provided information that resulted in fishery openings that would not have occurred under the sample-intensive coded wire tagging program.

The rapid turn-around time from the end of a fishing period to provision of an estimated hatchery contribution to the manager was largely a function of the proximity of the inseason otolith laboratory to the site of otolith collection. Otoliths sampled from a fishery were routinely read at the Cordova laboratory within a matter of hours. For the coded wire tag program, estimates formed from facility-specific expansions were only available after tags were shipped to Juneau and decoded in the Statewide Laboratory. Fully adjusted estimates from the coded wire program were only available postseason, when broodstocks had been sampled, and account taken of tag loss and differential mortality.

The high degree of confidence associated with otolith-derived estimates originates in large part from the assumption-free nature of the estimation procedure. The nonintrusive, permanent thermal mark has eliminated the need for the controversial adjustment factor used in the coded wire tag program; thermal marks cannot be shed and the fact that all fry are marked precludes the problem of differential mortality and any concerns over mark-induced straying. Another attractive feature of the otolith program is the highly efficient data-tracking mechanism built into the project. The data-management facilities, incorporated into the local system by personnel from the Statewide Laboratory in Juneau, functioned extremely effectively and data summaries and updates were executed with few problems.

While there are few assumptions associated with the marking aspect of the program, it should be emphasized that the otolith program will only generate unbiased estimates if representative samples are taken from the fishery. Since useful estimates can be generated from as few as 100 fish, constant attention to the sampling methodology used to derive them is needed. Close attention was paid to the estimates obtained from test fisheries conducted in areas having special significance, such as those that had historically been closed because of insufficient stock-identification data. Loosely structured sampling designs were used with the result that the associated estimates were highly susceptible to bias caused by structure in the population. Few differences were found when the test fishery estimates were compared to the more comprehensive processor-based estimates. In line with this notion are the results of the processor comparison study that indicated that the proportions of hatchery fish did not differ greatly between processors. The fact that the estimates derived from the oportunistic samples taken by the test fishery were similar to those provided from the highly representative processor samples and that there are few differences among processors suggests that there is little order in the populations examined. If this is a pervasive condition in the Prince William Sound pink salmon fishery, much less effort need be spent in sampling. It is reiterated, however, that relatively few comparisons are available to date and significantly more data is needed before the sampling effort is relaxed.

One area where the otolith program is inferior to the coded wire tagging program is in its ability to track many individual hatchery release groups. Under the coded wire tagging program, an almost unlimited number of codes were available to hatchery managers interested in experimenting with different rearing strategies. With the otolith program, such within-facility tracking is limited to the number of accessory marks available. Both the WNH and AFKH hatcheries did, however, use an accessory mark to distinguish long-term from short-term reared fish that were released into the peak plankton bloom. The recovery of the otolith marks in the returning adults provided information on the survival of these different release strategies.

Estimating the Proportion of Hatchery-Released Pink Salmon in Stream Escapements

Study streams were inundated by stray hatchery-released fish. These observations constitute some of the highest rates of straying by artificially-propagated salmon into wild pink salmon populations so far reported. The most obvious explanation for the large contribution of hatchery salmon to these escapements lies in the numerical dominance of hatchery over wild salmon runs, and the selection of streams considered most likely to contain stray hatchery salmon. The observation that the proportion of pink salmon from AFKH and WNH in stream escapements was highly correlated with distance of the stream from the facility is not surprising, and is consistent with salmon concentrating in the vicinity of their natal stream, which in this case are hatcheries. The ratio of the estimated number of stray WNH and AFKH pink salmon to stray CCH pink salmon was approximately 5 to 1. The Department's catch-sampling program indicates that differential returns do not play a role in this discrepancy. The reason for the disparity could be that a distance-straying frequency relationship also exists for CCH salmon, and the extra 30 miles that the facility is distant to the sampled streams, over WNH, may explain the lower number of detected stray CCH salmon. Another explanation for the disparity may lie in the fact that the broodstock for WNH pink salmon was obtained from pink salmon spawning streams located at considerable distances from the facility, while the CCH stock was obtained from Cannery Creek. If a genetic component to homing fidelity in pink salmon exists, as suggested by Bams (1976), salmon reared at CCH may home more effectively, perhaps through more effective imprinting.

More information is needed before the significance of data collected in our 1997 study can be assessed. First, we need to know whether the observed straying event was unique in time and space, perhaps due to the large disparity between hatchery and wild pink salmon runs in 1997, or if it is a pervasive, chronic phenomenon. Otolith sampling in randomly selected streams over time can easily answer this question. Second, we need to assess the effects of hatchery salmon straying on wild salmon populations. To achieve this task, we need to determine whether domestication-selection has occurred and whether hatchery salmon enter streams in which barriers to gene flow between wild populations exist (allozyme/mitochondrial DNA data). Finally, the ecological effect of straying salmon on wild salmon needs to be investigated. For example, do stray hatchery salmon successfully reproduce? Do they mate with wild salmon? Do their eggs and progeny survive as well as those produced by wild salmon? Answers to these questions are needed to properly understand the impacts of stray hatchery salmon on natural populations.

Other Studies

Besides their use in the management of adult returns, otolith thermal marks were also integral to the success of other projects conducted in Prince William Sound and the Gulf of Alaska. The salmon predation study (97320E), part of the Sound Ecosystem Assessment program, used otolith-marked juvenile salmon to determine growth and condition of hatchery and wild fish. It is possible that information obtained from that study would eventually be used in a forecast model being developed by project 97320J. A study conducted by the National Marine Fisheries Service to investigate the range and movement of salmon in the Gulf of Alaska has also has used otolith marks in its endeavors.

CONCLUSIONS

The major objective of this project was to apply unique and distinct thermal marks to all pink salmon embryos produced in Prince William Sound hatcheries and then to use such marks to identify hatchery salmon in mixed harvests of hatchery and wild salmon. Samples taken three weeks after marking indicated that unique and distinct marks had been applied in BY95, BY96 and BY97. Results of a double blind test on the readability of BY95, BY96 and BY97 otoliths indicated that laboratory readers had few problems in successfully differentiating hatchery otoliths from those obtained from wild populations, and also in differentiating hatchery-specific otoliths. Field recoveries of thermally marked adults occurred for the first time in the 1997 season and the sampling methodology developed in 1996 proved simple to use and provided a timely stock composition information to the management biologist. The postseason samples applied to some fishing periods did not result in any significant changes in estimates of hatchery contributions. After two years of use, otolith thermal marking has become the tool of choice for managing the Prince William Sound pink salmon return, and also for *ad hoc* studies, such as the straying study, that must identify hatchery-reared pink salmon from relatively small samples.

ACKNOWLEDGMENTS

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APPENDICES

Appendix A Hatchery contributions by district and period to commercial and brood stock harvests of 1997 and 1998.

For A1-6, *=Previous period used to apportion catch **=Following period used to apportion catch

Appendix A1 Pink salmon hatchery contributions to Prince William Sound common property fisheries of 1997 by district and period.

District:	221		Facility				
Date	Period	SGH	CCH	WNH	AFKH	Wild	
7/3	1	588,493	0	0	0	6,261	
7/7	2	715,587	5,148	0	0	20,592	
7/12	3	463,042	0	0	0	4,874	
7/15	4	449,429	0	0	0	33,403	
7/17	5	353,050	0	0	0	18,039	
7/19	6	306,881	4,910	2,455	0	39,281	
7/21	7	185,192	0	0	0	28,491	
7/23	8	184,634	5,430	1,810	1,810	65,165	
7/25	9	169,990	6,219	4,146	0	68,411	
7/28	10	190,396	2,164	0	0	15,145	
8/6	18	13,868	0	0	0	1,541	
8/7	19	24,191	0	0	0	255	
8/8	20	32,480	0	0	0	1,048	
8/9-8/10	21	69,164	2,280	0	0	1,520	
8/11-8/12	22	33,900	8,030	10,705	0	33,008	
8/13	23	18,060	1,389	1,042	0	12,850	
8/14	24	39,455	3,035	2,276	0	28,073	*
8/15	25	26,685	11,674	1,112	556	13,343	
8/16	26	7,847	3,433	328	163	3,923	*
8/17	27	11,369	13,762	2,393	0	8,975	**
8/18	28	18,713	22,653	3,940	0	14,774	
8/19	29	13,658	16,533	2,875	0	10,783	*
8/20	30	7,048	8,532	1,484	0	5,564	*

8/21	31	1,427	1,727	300	0	1,127	*
8/22	32	1,258	1,384	503	0	1,257	**
8/23	33	1,355	1,491	542	0	1,354	**
8/24	34	1,629	1,792	652	0	1,629	**
8/26	36	1,087	1,195	435	0	1,087	
TOTAL		3,930,002	122,906	37,043	2,529	441,885	

District:	222		Facility				
Date	Period	SGH	CCH	WNH	AFKH	Wild	
7/28	1	2,645	232,733	5,289	0	13,223	
8/5	8	0	74,929	0	0	788	**
8/6	9	0	316,638	0	0	3,333	
8/7	10	0	318,151	0	0	3,349	
8/9	11	0	279,895	165,799	0	14,027	
8/10	12	0	0	173,617	0	0	
8/11	13	0	108,910	4,951	0	4,951	
8/13	14	0	3,186	144,951	1,593	3,186	
8/21	15	4,965	326,694	130,774	1,530	9,553	
8/22	16	0	310,870	13,665	0	3,416	
8/23	17	0	60,472	0	0	0	
8/24	18	0	95,563	7,351	0	2,100	
8/25	19	0	64,077	4,929	0	1,408	*
8/26	20	0	32,618	2,509	0	717	*
8/27	21	0	21,915	1,685	0	482	*
8/28-8/29	22,23,24	0	104,358	9,075	0	1,512	
9/10-9/13	25-29	0	74,440	0	0	0	
TOTAL		7,610	2,425,449	664,595	3,123	62,045	

District:	223		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
6/26-6/27	5	24	0	0	0	28
6/28-6/29	6	28	0	0	0	33
6/30-7/1	7	41	0	0	0	48
7/3-7/5	8	55	0	0	0	64
7/7-7/8	9	668	0	0	0	780
7/10-7/12	10	173	87	3,556	0	1,908
7/14-7/15	11	319	160	6,542	0	3,511
7/17-7/19	12	493	247	10,109	0	5,425
7/21-7/22	13	1,699	850	34,830	0	18,689
7/24-7/26	14	0	0	145,775	0	6,160
7/28-7/28	15,16	0	986	19,718	986	9,859
8/1	19	0	7,316	21,947	0	7,316
8/5	23	0	630	10,297	0	0
8/6	24	0	9,848	16,179	0	2,110
8/7	25	0	6,015	75,788	1,203	2,406
8/8	26	1,365	2,730	122,833	0	6,193
8/15	27	0	40,021	44,675	931	3,723
8/16	28	0	77,947	10,393	0	0
8/21	29	0	58,117	32,117	0	0
8/22	30	1,401	33,628	96,679	1,401	1,401
8/23	31	2,025	48,595	139,707	2,025	2,025
8/24	32	2,129	36,195	161,811	0	4,258
8/25	33	0	55,956	83,933	0	6,583
8/26	34	0	15,936	23,904	0	1,875
8/27	35	0	4,288	6,432	0	504
8/28	36	0	1,057	1,586	0	124
8/29	37		2,346	20,173	0	
8/30	38	0	62	537	0	0
8/31-9/2	39	0	17,715	152,349	0	0
9/3-9/6	40	0	4,150	195,029	0	0
9/7-9/9	41	0	865	59,691	0	0
9/10-9/13	42	0	89	6,162		
TOTAL		10,420	425,836	1,502,752	6,546	85,032

District:	225+		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
6/30-7/1	1	18	0	0	0	29
7/3-7/4	2	107	0	0	0	174
7/7-7/8	3	300	0	0	0	489
7/10-7/11	4	0	269	3,358	0	134
7/14-7/15	5	0	24	301	0	12
7/17-7/18	6	0	79	982	0	39
7/21-7/22	7	0	287	3,587	0	143
7/24-7/25	8	0	890	11,131	0	446
7/28-7/29	9	0	1,474	18,430	0	737
7/31-8/1	10	0	3,127	25,329	0	1,563
8/4-8/5	11	0	299	24,507	0	3,885
8/11-8/12	12	235	469	20,420	235	1,174
8/18-8/19	13	0	0	37,521	0	3,263
8/21-8/22	14	0	477	18,139	477	2,625
8/25-8/26	15	0	509	19,338	509	2,799
8/28-8/29	16	0	277	10,518	277	1,522
TOTAL		660	8,181	193,561	1,498	19,034

+ 38% of catch prior to July 10 attributed to Solomon Gulch

District:	226		Facility				
Date	Period	SGH	CCH	WNH	AFKH	Wild	
7/28	1	14,165	6,666	6,666	15,831	10,831	
7/30	2	3,569	1,680	1,680	3,988	2,729	*
8/1	4	3,254	1,531	1,531	3,637	2,489	*
8/4	7	3,570	1,680	1,680	3,990	2,730	*
8/6	9	0	8,001	4,001	372,059	0	
8/7	10	0	12,027	42,095	222,500	12,026	
8/8	11	13,346	50,046	63,392	146,803	40,037	
8/9	12	6,485	45,391	67,007	168,598	28,100	
8/10	13	2,743	19,199	52,110	172,787	16,456	
8/15	14	0	14,792	81,359	647,172	33,283	
8/16	15	0	78,541	121,874	322,290	51,457	

8/21	16	0	57,849	73,919	163,907	12,855	
8/22	17	0	40,675	189,817	338,959	27,117	
8/23	18	3,269	29,419	75,182	303,997	52,301	
8/24	19	0	29,434	54,663	134,554	21,025	
8/25-8/26	20,21	0	63,777	54,666	168,552	40,999	
8/27	22	0	32,749	28,071	86,550	21,053	*
8/28	23	0	20,499	17,571	54,176	13,176	*
8/29	24	0	21,161	24,185	33,254	4,535	**
8/30-9/2	25,26	0	76,922	87,911	120,878	16,483	
9/3-9/6	27	0	0	0	249,352	8,044	
9/7-9/9	28				30,556	986	*
9/10-9/13	29				33,540	1,082	*
TOTAL		50,401	612,039	1,049,380	3,797,930	419,794	

District:	227		Facility				
Date	Period	SGH	CCH	WNH	AFKH	Wild	
6/16-6/17	7	39	0	0	0	81	**
6/23-6/24	10	163	0	0	0	340	**
6/25-6/27	11	160	0	0	0	335	
6/30-7/1	13	25	0	0	0	52	*
7/2-7/4	14	124	0	0	0	261	*
7/5-7/6	15	70	0	0	0	147	*
7/7-7/8	16	27	0	0	0	55	*
7/9-7/11	17	20	0	0	0	42	*
7/12-7/13	18	58	0	0	0	122	*
7/14-7/15	19	348	0	0	0	729	*
7/21-7/21	22	0	0	0	0	6,389	
8/11-8/12	23	550	3,852	3,852	550	3,303	
8/13	24	101	710	710	101	608	*
8/14	25	1,038	7,260	7,260	1,038	6,224	*
8/17	28	461	307	769	154	1,077	**
8/18	29	1,805	1,203	3,009	602	4,212	
8/19	30	794	529	1,323	265	1,853	*
TOTAL		5,783	13,861	16,923	2,710	25,830	

District:	228		Facility				
Date	Period	SGH	CCH	WNH	AFKH	Wild	
7/21	1	0	0	0	0	6,252	
7/23	2	0	0	0	0	8,781	
7/25	3	0	0	0	794	10,327	
8/8	14	0	0	0	106	1,383	*
8/9-8/10	15	0	0	0	19	243	*
8/20	24	0	0	0	10	125	*
TOTAL		0	0	0	929	27,111	

Appendix A2 Pink salmon hatchery contribution to Prince William Sound common property fisheries of 1998 by district and period.

District	212		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
6/22-6/23	12	0	0	0	0	3
6/26-6/26	13	0	0	0	0	6
6/29-6/29	14	7	0	0	0	27
7/2-7/3	15	19	0	0	0	76
7/6-7/7	16	36	0	0	0	146
7/9-7/11	17	33	0	0	0	133
7/13-7/14	18	217	0	0	0	870
7/16-7/18	19	224	0	0	0	2,158
7/20-7/21	20	77	0	0	0	747
7/23-7/25	21	120	0	0	0	1,165
7/27-7/28	22	130	65	0	0	2,013
7/30-8/01	23	46	93	93	46	4,181
8/03-8/04	24	0	0	0	0	6,082
8/6-8/8	25	0	16	49	16	1,352
8/10-8/11	26	0	0	0	0	399
8/13-8/14	27	0	0	0	0	100
8/17-8/18	28	0	0	0	0	56
8/20-8/21	29	0	0	0	0	28
TOTAL		909	174	142	62	19,542

District:	221		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
7/8	1	74,937	0	0	0	51,273
7/12	2	49,663	0	0	0	37,707
7/16	3	438,014	0	0	0	45,053
7/18	4	112,381	0	0	0	67,429
7/22	5	151,638	2,166	0	0	54,157
7/22-7/24	6	80,827	3,149	0	0	16,795
7/25	7	21,079	11,857	0	0	93,536
7/27	8	4,537	1,134	0	0	103,208
7/29	9	43,261	1,803	0	3,605	124,375
7/31	10	26,480	8,148	2,037	0	167,024
8/02	11	6,993	4,662	0	0	177,153
8/04	12	1,422	8,533	0	0	122,304
8/06	13	0	0	0	0	60,280
8/09	14	0	0	0	0	15,316
8/11	15	0	0	0	0	14,828
8/13	16	0	504	252	252	10,835
8/15	17	0	0	0	0	0
8/17	18		257	129	129	5,533
8/19	19		86	43	43	1,842
8/20-8/21	20		19	9	9	398
8/22-8/23	21		78	39	39	1,679
8/24-8/25	22		5	2	2	105
8/26-8/27	23				0	8
TOTAL		1,011,232	42,401	2,511	4,079	1,170,838

District:	222		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
7/12	1	108,083	0	0	0	40,329
7/16	2	9,617	401	0	0	16,830
7/18	3	21,106	1,919	0	0	69,075
7/22	4	12,232	26,910	0	0	78,285
7/25	5	13,148	1,143	2,287	0	54,876

7/27	6	12,839	0	11,005	0	47,686
7/29	7	9,366	12,488	0	0	78,048
7/31	8	0	14,266	6,713	0	59,580
8/02	9	1,509	58,864	19,621	0	57,356
8/04	10	0	58,142	4,689	0	22,507
8/06	11	2,848	458,547	25,633	0	54,114
8/09	12	2,225	307,096	48,957	0	35,606
8/11	13	0	252,399	40,709	0	4,071
8/13	14	6,300	548,095	25,200	0	0
8/15	15	0	573,428	0	0	12,201
8/17	16	0	549,064	71,901	0	6,537
8/19	17	0	296,393	0	0	3,120
8/20-8/21	18	0	373,556	141,498	5,660	22,640
8/22-8/23	19	0	23,273	2,618	291	1,745
8/24-8/25	20	0	11,572	1,302	145	868
8/26-8/27	21	0	18,047	2,030	226	1,353
8/28-8/29	22	0	8,510	957	106	639
8/30-8/31	23	0	20,096	2,261	251	1,507
9/1-9/2	24	0	24,018	2,702	300	1,802
9/3-9/4	25	0	19684	2214	246	1477
9/5-9/6	26	0	11,218	1,262	140	842
TOTAL		199,273	3,669,129	413,559	7,365	673,094

District:	223		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
6/15-6/16	1	0	0	0	0	1
6/19-6/19	2	0	0	0	0	0
6/22-6/22	3	0	0	0	0	3
6/25-6/26	4	0	0	0	0	76
6/29-6/30	5	0	0	0	0	394
7/02-7/03	6	0	0	0	0	1,476
7/06-7/07	7	0	0	0	0	4,252
7/09-7/10	8	0	0	0	0	6,302
7/23-7/24	9	2,102	1,051	4,205	0	93,552

7/27-7/28	10	0	5,299	86,553	0	77,722
7/31-7/31	11	0	2,342	5,856	2,342	26,936
8/06-8/06	12	0	1,025	2,563	1,025	11,787
8/09-8/09	13	3,791	26,540	367,765	3,791	37,915
8/11-8/11	14	0	31,368	254,861	7,842	19,604
8/13-8/13	15	0	29,377	243,831	0	8,813
8/15-8/15	16	0	22,723	213,031	8,521	28,405
8/17-8/17	17	0	16,861	65,335	2,108	8,430
8/19-8/19	18	0	12,447	117,560	1,383	0
8/20-8/21	19	0	1,454	51,627	727	2,182
8/22-8/23	20	0	23,942	82,599	1,197	7,182
8/24-8/25	21	0	11,275	122,618	1,409	0
8/26-8/27	22	0	0	174,629	1,878	3,755
8/28-8/29	23	0	0	113,132	0	0
8/30-8/31	24	0	0	148,643	0	0
9/1-9/2	25	0	0	130,265	1,371	0
9/3-9/4	26	0	0	159,982	0	0
9/5-9/6	27	0	0	115,424	1,215	0
9/7-9/8	28	0	0	80,339	0	0
9/9-9/10	29			50,342		
TOTAL		5,893	185,704	2,591,160	34,809	338,787

District:	225		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
7/30-8/01	1	0	747	5,015	640	3,414
8/03-8/04	2	0	1,968	13,212	1,687	8,995
8/06-8/8	3	0	559	3,752	479	2,555
8/10-8/11	4	0	2,465	16,548	2,113	11,266
8/13-8/15	5	0	1,023	17,390	1,023	5,114
8/17-8/18	6	0	0	15,881	1,513	3,025
8/20-8/22	7	0	209	9,594	2,503	2,294
TOTAL		0	6,971	81,392	9,958	36,663

District:	226		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
8/04	1	0	57,693	90,661	100,963	76,237
8/06	2	0	80,462	108,860	184,588	80,461
8/09	3	0	61,480	101,002	597,231	83,437
8/11	4	2,981	83,456	89,417	396,415	65,572
8/13	5	0	109,025	119,928	242,582	59,964
8/15	6	3,823	80,292	141,467	432,048	76,469
8/17	7	0	103,438	145,579	417,583	65,128
8/19	8	0	75,310	103,999	426,756	82,482
8/20-8/21	9	0	93,060	257,285	624,053	76,638
8/22-8/23	10	0	175,718	313,782	684,046	62,757
8/24-8/25	11	0	52,052	134,466	316,647	30,363
8/26-8/27	12	0	10,386	41,543	147,479	0
8/28-8/29	13	0	12,578	16,172	129,379	14,376
8/30-8/31	14	0	5,005	18,770	91,347	5,005
9/1-9/2	15	0	0	0	119,151	0
9/3-9/4	16	0	0	14,978	41,606	0
TOTAL		6,804	999,955	1,697,909	4,951,874	778,889

District:	227		Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
6/29-6/30	13	0	0	0	0	2
7/1-7/3	14	651	0	0	0	12,155
7/4-7/5	15	254	0	0	0	4,746
7/6-7/7	16	3	0	0	0	56
7/8-7/10	17	10	0	0	0	199
7/11-7/12	18	38	0	0	0	747
7/13-7/14	19	519	0	0	0	10,330
7/15-7/17	20	727	0	0	0	14,463
7/18-7/19	21	366	0	0	0	7,273
7/22-7/22	22	0	0	0	0	
8/02-8/02	23	0	12,744	35,683	22,939	173,316
8/04-8/04	24	0	4,995	999	5,994	82,914

8/06-8/06	25	0	883	177	1,060	14,662
TOTAL		2,568	18,622	36,859	29,993	320,863

District: 228			Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
7/22	5	0	0	0	0	8,230
7/25	6	0	0	0	0	5,211
7/27	7	0	0	0	0	25,532
7/29	8	0	0	0	0	29,667
7/31	9	0	0	0	0	93,698
8/02	10	0	689	0	0	64,760
8/04	11	0	0	0	0	94,531
8/06	12	0	289	0	0	27,157
TOTAL		0	978	0	0	349,103

District: 229			Facility			
Date	Period	SGH	CCH	WNH	AFKH	Wild
7/12	2	0	0	0	0	1
7/16	3	0	0	0	0	1
7/18	4	0	0	0	0	37
7/22	5	0	0	0	0	10
7/25	6	0	0	0	0	80
7/27	7	0	0	0	0	791
7/29	8	0	0	0	0	450
7/31	9	0	0	0	0	562
TOTAL	14	0	0	0	0	1,932

Appendix A3 Pink salmon hatchery contribution to Prince William Sound cost recovery fisheries of 1997.

District	221	Facility			
Dates	SGH	CCH	WNH	AFKH	Wild
6/18-6/21	8,525	0	0	0	89
6/22-6/25	170,884	0	0	0	7,430
6/26-6/28	254,015	0	0	0	0
6/29-6/30	344,441	0	0	0	0
7/01-7/02	242,849	0	0	0	2,556
7/03-7/05	318,799	0	0	0	0
7/06-7/09	478,982	0	0	0	5,042
7/10-7/11	360,992	0	0	0	0
7/12-7/14	219,016	0	0	0	2,305
8/22-9/3R	14,808	0	0	0	274
TOTAL	2,413,311	0	0	0	17,696

District:	222	Facility			
Dates	SGH	CCH	WNH	AFKH	Wild
7/29-8/02	0	336,323	7,311	0	7,311
8/03-8/05	0	567,353	0	0	5,972
8/06-8/09	0	404,136	0	0	4,541
8/10-8/13	0	141,312	0	0	0
8/14-8/16	0	252,515	0	0	2,806
8/17-8/21	0	128,074	0	2,784	2,784
9/22	0	9,271	0	0	0
TOTAL	0	1,838,984	7,311	2,784	23,414

District:	223	Facility			
Dates	SGH	CCH	WNH	AFKH	Wild
7/13-7/26	0	0	8,792	0	0
7/27-7/28	2,038	0	46,885	0	2,038
7/29-8/02	3,525	0	296,126	0	3,525
8/03-8/05	0	0	290,363	0	0
8/06-8/09	0	0	260,776	0	0

8/10-8/13	0	0	555,901	0	0
8/14-8/16	0	0	247,148	2,686	0
8/17-8/19	0	0	261,302	0	0
8/19-8/21	0	2,378	225,931	0	0
9/16	0	0	8,896	0	0
9/18	0	0	12,996	0	0
9/19	0	0	13,335	0	0
9/22	0	0	14,021	0	0
9/23	0	0	7,460	0	0
TOTAL	5,563	2,378	2,249,932	2,686	5,563

District:	225+	Facility				
Dates	SGH	CCH	WNH	AFKH	Wild	
6-Jul	0	0	0	0	23	
27-Jul	0	0	1,107	0	0	**
31-Jul	0	0	672	0	0	**
8/3-8/9	0	0	13,894	0	0	
16-Aug	0	0	22,560	301	301	
TOTAL	0	0	38,233	301	324	

+ Eshamy CPF used to apportion cost recovery catch

District:	226	Facility			
Dates	SGH	CCH	WNH	AFKH	Wild
7/24-7/26	0	0	0	206,374	0
7/27-7/29	0	0	0	412,332	0
7/30-8/02	0	0	0	430,845	9,167
8/03-8/09	0	0	0	560,772	0
8/10-8/13	0	4,126	4,126	387,814	0
8/14-8/16	0	3,447	0	324,082	3,447
8/17-8/18	3,382	3,382	10,145	287,439	3,382
8/19-8/22	5,754	0	11,508	523,624	11,508
TOTAL	9,136	10,955	25,779	3,133,282	27,504

Appendix A4 Pink salmon hatchery contribution to Prince William Sound cost recovery fisheries of 1998.

District:	221	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
6/20-6/29	124,311	0	0	0	0
6/30-7/03	415,016	0	0	0	8,830
7/04-7/06	577,181	0	0	0	12,280
7/07-7/10	927,776	0	0	0	19,740
7/11-7/13	525,356	0	0	0	16,947
7/14-7/17	397,464	0	0	0	0
7/18-7/21	109,841	0	0	0	6,035
TOTAL	3,076,945	0	0	0	63,832

District:	222	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
7/29-8/02	0	105,913	0	0	5,819
8/03-8/05	0	384,181	0	0	4,044
8/06-8/08	0	359,501	0	0	0
8/09-8/10	0	243,427	0	0	13,375
8/18-8/19	0	199,413	0	0	2,099
TOTAL	0	1,292,435	0	0	25,337

District:	223	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
7/17-8/01	0	0	114,990	0	4,600
8/02-8/05	0	4,898	225,322	0	2,449
8/06-8/8	0	0	392,850	0	0
8/9-8/12	0	0	646,888	0	0
8/13-8/15	0	0	462,353	0	0
8/16-8/19	0	6,081	577,658	0	0
TOTAL	0	10,979	2,420,061	0	7,049

District:	226	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
7/29-8/01	0	1,730	0	159,162	5,190
8/02-8/04	0	0	0	219,215	17,242
8/05-8/07	0	0	2,607	234,585	13,033
8/08-8/11	0	0	0	301,299	0
8/12-8/15	0	0	0	249,328	2,625
8/16-8/19	0	0	4,452	418,449	4,452
TOTAL	0	1,730	7,059	1,582,038	42,542

Appendix A5 Pink salmon hatchery contribution to Prince William Sound broodstocks of 1997.

District:	221	Facility			
Period	SGH	CCH	WNH	AFKH	Wild
7/21-7/25	52,093	0	0	0	548
7/28-8/01	81,361	0	0	0	855
8/3-8/8	55,937	0	0	0	589
8/10-8/16	45,972	0	0	0	0
8/17-8/23	57,911	0	0	0	950
8/7-8/9R	47,649	0	0	0	0
8/8R	14,311	0	0	0	0
8/20R	813	0	0	0	0
9/13R	224	0	0	0	0
TOTAL	356,271	0	0	0	2,942

District:	222	Facility			
Period	HSG	CCH	WNH	AFKH	Wild
8/24-9/6	0	94,499	995	0	0
9/7-9/13	0	131,740	1,387	0	0
9/14-9/17	0	91,692	0	0	0
TOTAL	0	317,931	2,382	0	0

District:	223	Facility			
Period	SGH	CCH	WNH	AFKH	Wild
8/22-8/30	0	0	40,150	0	0
8/31-9/6	0	1,398	132,842	0	0
9/7-9/13	0	0	159,889	0	0
9/14-9/15	0	0	42,541	0	0
9/16-9/28	0	0	31,651	0	0
TOTAL	0	1,398	407,073	0	0

Appendix A6 Pink salmon hatchery contribution to Prince William Sound broodstocks of 1998.

District:	221	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
7/23-7/24	16,631	0	0	0	0
7/27-7/31	66,122	0	0	0	0
8/3-8/8	92,072	0	0	0	0
8/9-8/15	86,056	0	0	0	0
8/19-8/21R	35,199	0	0	0	0
8/24-9/3 R	24,243	0	253	0	0
8/19-9/8M	14027	0	0	0	0
9/9-9/20M	201	0	0	0	0
TOTAL	334,551	0	253	0	0

District:	222	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
8/28-8/29	0	21,026	934	0	0
8/30-9/05	0	93,008	0	0	0
9/06-9/12	0	90,011	0	0	0
9/13	0	100,900	0	0	0
TOTAL	0	304,945	934	0	0

District:	223	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
8/22-8/29	0	0	98,815	0	2,102
8/30-9/5	0	0	104,386	0	0
9/6-9/7	0	0	31,164	0	636
9/08	0	0	28,143	0	574
TOTAL	0	0	262,508	0	3,312

District:	226	Facility			
Date	SGH	CCH	WNH	AFKH	Wild
8/24-8/29	0	0	448	42,150	448
8/30-9/05	0	0		54,298	0
9/06-9/12	0	0		95,497	0
9/13-9/17	0	0		57,033	0
9/18	0	0		95,000	0
TOTAL	0	0	448	343,978	448

Appendix B Simulation Study of Effect of Ordered Populations on Precision of Estimates.

Pink salmon fishery statistics from 1996 were used as the framework for the simulation study, which was conducted in the following manner.

1) Catches and coded wire tag estimates of hatchery proportions were obtained for each of 29 major harvest-district-week openings occurring in 1996.

2) For each harvest-district-week openings, a group of tender loads was selected which was representative of those delivered in that stratum. Loads were randomly selected from this group until the total accumulated load approached the catch associated with the stratum. Any difference between the catch and the accumulated load was split equally among the selected tenders, so the total selected load and catch were equal. The tenders were selected only once during the simulation and are a representative realization of the 1996 fishery.

3) For each selected tender load, a specific structure was imposed on the population of fish moving along the processor conveyor belt. The nature of the population was determined by a 'mixing factor' which controlled the degree to which hatchery and wild fish were mixed. Only one mixing factor was used within each simulation. The mixing algorithm operated as follows:

A) Each salmon population within a tender was first ordered (e.g. all hatchery salmon, then all wild salmon).

B) For a mixing factor of 0.7, a random sample of 70% of the ordered population was selected and randomized within itself . A mixing factor of 0.0 indicated that the final population was completely ordered while a mixing factor of 1.0 indicated it was arranged randomly.

C) The randomized salmon were returned to the positions in the population from which the ordered sample had been taken.

4) For each iteration of the simulation, a systematic sample of s=100 salmon was taken from each tender load, N. The group of starting points required for the set of systematic samples taken from each tender was randomly selected without replacement from all possible N/s starting points.

5) For the t tenders associated with each harvest-district-week stratum within an iteration, a composite sample of 150 salmon were randomly selected from the group of t samples of size s in a manner proportional to the loads aboard the tenders. The proportion of hatchery salmon in this final sample was calculated and stored until completion of the simulation.

6) After all iterations had been completed, the standard deviation was calculated for the simulated proportions of hatchery salmon for each harvest-district-week stratum. It was then compared to theoretical values obtained with random sampling assumptions. The simulation was conducted using GAUSS^{TM} (Aptech Systems Inc) code is presented in Appendix E.

7) The exercise was repeated for five mixing factors, with fifty iterations conducted for each factor.