Exxon Valdez Oil Spill
State/Federal Natural Resource Damage Assessment Final Report

Coded Wire Tag Studies on Prince William Sound Salmon, 1989-1991

Fish/Shellfish Study Number 3
Final Report

Samuel Sharr
Carol J. Peckham
Daniel G. Sharp
Larry Peltz
Jodi L. Smith
T. Mark Willette
David G. Evans
Brian G. Bue

Alaska Department of Fish and Game
Commercial Fisheries Management and Development Division
333 Raspberry Road
Anchorage, Alaska 99518

November 1995

Coded Wire Tag Studies on Prince William Sound Salmon, 1989-1991

Fish/Shellfish Study Number 3
Final Report

Study History: 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. In the early 1970's, run failures led to an aggressive enhancement program during which numerous hatcheries were built and five facilities were operating by 1986. By 1987, the estimated combined contribution of three facilities alone to the pink salmon fishery was approximately 10 million fish (40% of the total catch). In 1989, the juvenile pink salmon from both wild and hatchery origin emigrated from Prince William Sound in the presence of the *Exxon Valdez* oil spill and the commercial fisheries were disrupted. This study is one of an integrated group studies conducted to quantify the damage inflicted upon the Pacific salmon *Oncorhynchus sp.* resource of Prince William Sound by the spill. This study (with F/S 4) was designed to document effects of the spill at various stages in the life cycle of pink salmon and to provide information on the number of wild and hatchery pink salmon captured in various fisheries as well as to provide marked fish of known origin for use in other pink salmon studies.

Abstract: Following the *Exxon Valdez* oil spill, wild and hatchery juvenile pink salmon were coded wire tagged to evaluate damages and improve management strategies. Tagging rates were sufficiently high to allow adequate numbers of marks to be recovered in the fishery catches, brood stock, and streams. Results indicated that 5.3 million (24%) of the 22.5 million pink salmon caught in 1989 were of wild origin. In 1990, it was estimated that 13.1 million fish (29%) of the 44.9 million catch were of wild origin, and in 1991, that 7.4 million fish (19%) of the 38.4 million catch were of wild origin. There were no significant differences in survival rates for pink salmon originating from oiled and unoiled streams in 1990 or 1991 (P=0.7 and P=0.65).

In addition to meeting damage assessment objectives, the coded wire tagging program has furnished information critical to management decisions associated with restoration of damaged wild salmon stocks. For example, during 1992, tag data were used to estimate proportions of wild fish in district and period-specific catches which were then used by fisheries managers to direct the commercial fleet towards more abundant hatchery returns.

Key Words: Coded wire tagging, commercial fisheries, damage assessment, *Exxon Valdez* oil spill, hatcheries, *Oncorhynchus gorbuscha*, pink salmon, Prince William Sound.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

EXECUTIVE SUMMARY

This study is one of an integrated group of Natural Resource Damage Assessment Fish/Shellfish Studies (F/S 1,2,3,4,28) conducted to quantify the damage inflicted upon the Pacific salmon *Oncorhynchus sp.* resource of Prince William Sound by the *Exxon Valdez* oil spill. The egg and fry mortality study (F/S 2), the early-marine survival study (F/S 4), and this study (F/S 3), were designed to document effects of the spill at various stages in the life cycle of pink salmon *O. gorbuscha*. Fish/Shellfish study 3 was also fashioned to provide information on the number of wild and hatchery pink salmon captured in various fisheries as well as to provide marked fish of known origin for use in other pink salmon studies. Fish/Shellfish Study 1 was designed to provide information for use in estimating the number of pink salmon returning to individual streams to spawn. The Run Reconstruction and Life History Modelling Study (F/S 28) will integrate results from studies 1 through 4 to provide stock-specific estimates of post-spill population size for oil-impacted stocks and identify population level damages.

Coded wire tags were applied to pink, chum *O. keta*, coho *O. kisutch*, and chinook salmon *O. tshawytscha* fry at four Prince William Sound hatcheries in 1988, 1989, 1990 and 1991. Tags were also applied to wild pink salmon fry at three oil-contaminated and three control streams and to wild sockeye salmon *O. nerka* smolt at two oil-contaminated and one control stream in 1990 and 1991.

Tagging rates were sufficiently high to allow adequate numbers of marks to be recovered in the fishery catches, brood stock, and streams. Hatchery pink salmon were tagged at rates of approximately 1 tag per 600 fish. Wild pink salmon were tagged at rates ranging from 1 tag per 5 fish to 1 tag per 20 fish. Coded wire tags were recovered from the commercial and cost-recovery fisheries, from brood stock at the four hatcheries, and from salmon carcasses examined at the wild-tagging streams. All tags were decoded at the Coded Wire Tag Processing Laboratory in Juneau.

Results indicated that 5.3 million (24%) of the 22.5 million pink salmon caught in Prince William Sound in 1989 were of wild origin. In 1990, it was estimated that 13.1 million fish (29%) of the 44.9 million catch were of wild origin, and in 1991, that 7.4 million fish (19%) of the 38.4 million catch were of wild origin.

There were no significant differences in survival rates for pink salmon originating from oiled and unoiled streams in 1990 or 1991 (P=0.7 and P=0.65). Survival rates for sockeye salmon could not be estimated due to incomplete returns.

In addition to meeting damage assessment objectives, the coded wire tagging program has furnished information critical to management decisions associated with restoration of damaged wild salmon stocks. For example, during 1992, tag data were used to estimate proportions of wild fish in district and period-specific catches which were then used by fisheries managers to direct the commercial fleet towards more abundant hatchery returns.

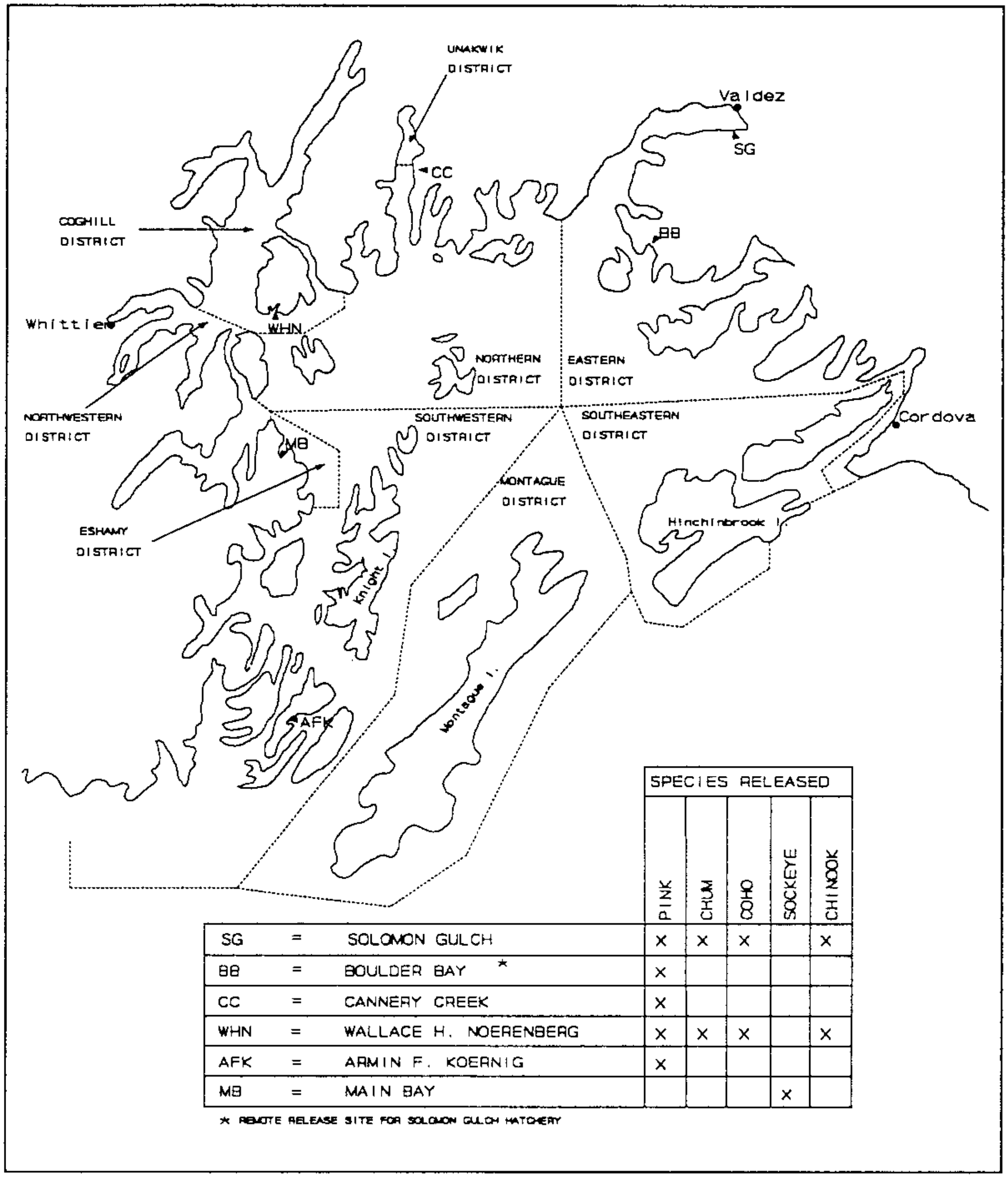
INTRODUCTION

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. In the early 1970's, run failures led to an aggressive enhancement program during which numerous hatcheries were built. Five facilities were operating by 1986 (Figure 1): the Solomon Gulch hatchery, producing coho salmon *O. kisutch*, and later, pink, chum *O. keta*, and chinook salmon *O. tschawytscha*, the A. F. Koernig hatchery, producing pink salmon, the W. Noerenberg hatchery, producing pink salmon, and later, chum, coho and chinook salmon, the Cannery Creek hatchery, producing pink salmon, and the Main Bay hatchery which produced chum and presently raises sockeye salmon *O. nerka*. Geiger (1990a) estimated that by 1987, the combined contribution of the A.F. Koernig, W. Noerenberg, and Cannery Creek facilities to the pink salmon fishery was approximately 10 million fish (40% of the total catch), with hatchery contributions expected to increase in the following years as fish reared at the Solomon Gulch facility returned. Significant numbers of sockeye, coho, chum and chinook salmon have also been produced.

Parent stocks for Prince William Sound hatchery production were selected from native populations in the Sound with the consequence that the migratory timings of adult hatchery and wild returns coincided. Furthermore, virtually all these salmon stocks migrate to their natal streams or hatcheries through corridors in the southwestern and western areas of the Sound. The coincident timing and location of the large hatchery return and the considerably smaller wild returns lead to the danger of over-exploitation of the latter by the commercial fishery. Indeed, an exploitation rate of 70% is considered appropriate for returning hatchery fish, while examination of historical data indicates shortfalls in escapements for pink salmon in more than half of the fifteen years prior to hatchery production when exploitation rates averaged only 42%, and did not exceed 69%. Clearly, the sustainability of the wild salmon resources of Prince William Sound must suffer if it is subjected to harvest rates appropriate for returning hatchery fish.

To protect wild stocks in a hatchery-dominated fishery, managers needed information pertaining to the temporal and spatial distributions of hatchery and wild fish. To meet this requirement, a coded wire tagging program was initiated in 1986 with recovery of tagged returning adults in commercial and cost-recovery fisheries beginning in 1987. Tag recovery data enabled managers to estimate hatchery and wild contributions to catches from temporal and spatial strata within the fishery. The tagging program was developed for use in Prince William Sound by Peltz and Geiger (1990) and Geiger and Sharr (1990).

On March 24, 1989, the *Exxon Valdez* spilled 11 million gallons of Alaskan crude oil into the Sound (Figure 2). An assessment of damage to the Prince William Sound Pacific salmon resource was needed and a series of Natural Resource Damage Assessment



			SPECIES RELEASED				
			PINK	CHUM	COHO	SOCKEYE	CHINOOK
SG	=	SOLOMON GULCH	X	X	X		X
BB	=	BOULDER BAY *	X				
CC	=	CANNERY CREEK	X				
WHN	=	WALLACE H. NOERENBERG	X	X	X		X
AFK	=	ARMIN F. KOERNIG	X				
MB	=	MAIN BAY				X	

* REMOTE RELEASE SITE FOR SOLOMON GULCH HATCHERY

Figure 1. Fishing districts and hatcheries of Prince William Sound, Alaska.

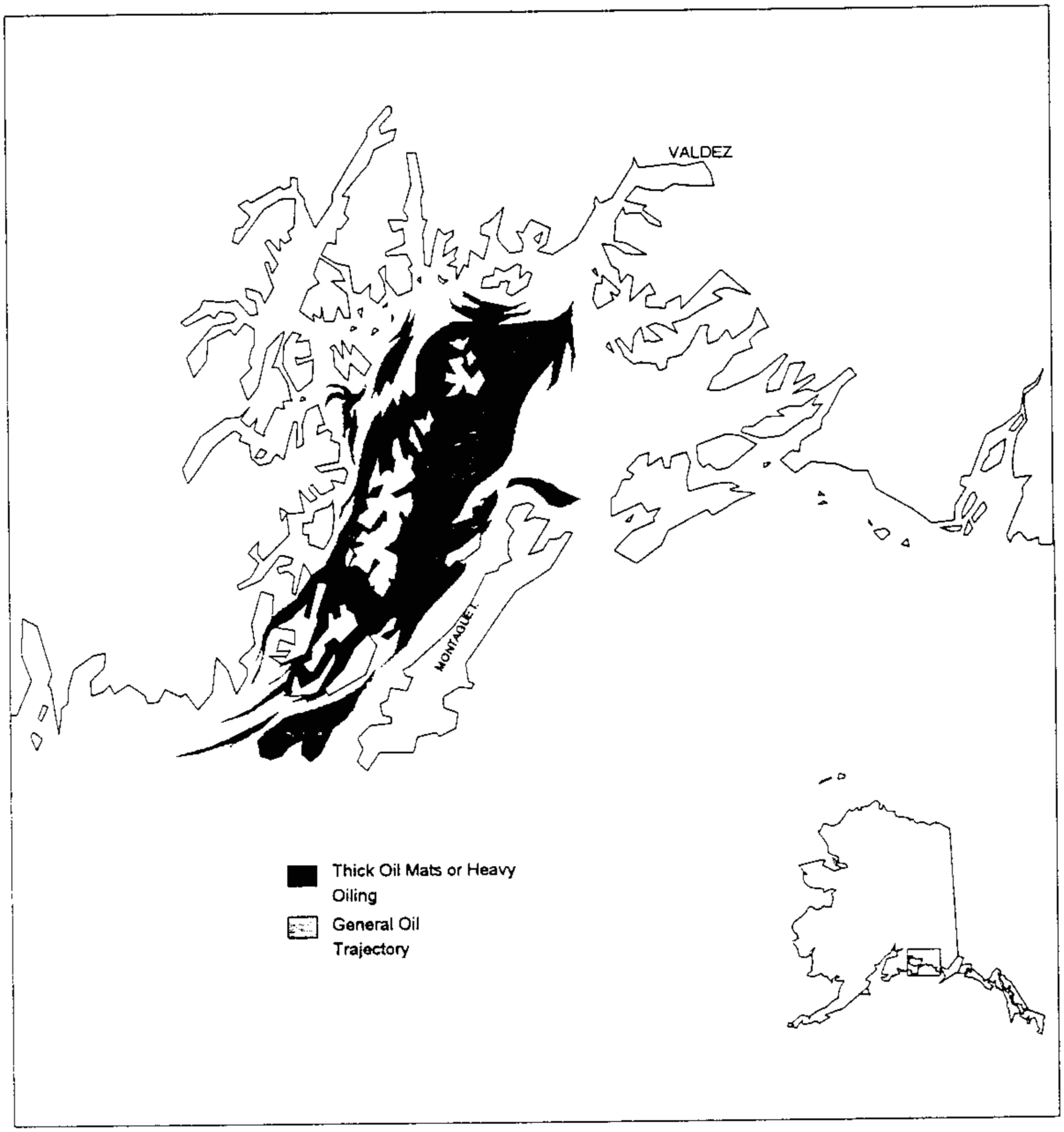


Figure 2. Trajectory of oil plume across Prince William Sound, Alaska, 1989.

Fish/Shellfish studies was implemented (F/S 1, 2, 3, 4 and 28). The egg and fry mortality study (F/S 2), the early-marine survival study (F/S 4), and this study (F/S 3) were designed to detect and document effects of the spill at various stages in the life cycle of pink salmon. This study was also fashioned to provide information on the number of wild and hatchery pink salmon captured in various fisheries as well as to provide marked fish of known origin for use in other pink salmon studies. Fish/Shellfish Study 1 was designed to provide information for use in estimating the number of pink salmon returning to individual streams to spawn. The Run Reconstruction and Life History Modelling Study (F/S 28) will integrate results from studies 1 through 4 to provide stock-specific estimates of postspill population size for oil-impacted stocks and identify population level damages.

In addition to playing an indispensable role in the integrated package of damage assessment studies referred to above, the coded wire tag program allowed other *ad hoc* comparisons to be made, such as those between the survival rates of salmon originating from hatcheries located within and outside the path of the oil plume. Tagging of wild sockeye salmon from oiled and unoiled watersheds allowed an assessment of the effects of oiling upon this species.

This report summarizes the activities and results of the coded wire tagging program through the years 1989, 1990 and 1991 as documented in the Natural Resource Damage Assessment Status Reports of Fish/Shellfish Study 3. Some tag recovery data collected in 1992 are also summarized.

OBJECTIVES

1. Estimate catch and survival rates of pink, sockeye, coho and chinook salmon released from five hatcheries in Prince William Sound: two hatcheries in heavily oiled areas, and three in lightly or unoiled areas.

2. Estimate survival rates of wild pink salmon from three streams with contaminated estuaries and three streams with uncontaminated estuaries using fry outmigration, and adult catch and escapement data.

3. Estimate survival rates of wild sockeye salmon from two watersheds with contaminated estuaries and one watershed with an uncontaminated estuary using fry outmigration, and adult catch and escapement data.

4. Provide marked salmon of known origin and oil exposure history for recovery by researchers studying early marine life and migration of juvenile salmon.

5. Identify relevant injuries for which methods of restoring lost use, populations, and habitat must be developed.

METHODS

Tagging

Hatchery Tagging

Tagging of pink salmon occurred at the three Prince William Sound Aquaculture Corporation (PWSAC) facilities (W. Noerenberg, Cannery Creek, and A. F. Koernig hatcheries) and at the Valdez Fisheries Development Association (VFDA) facility (Solomon Gulch hatchery). Tagging and recovery efforts were such that contribution estimates were sufficiently precise to allow fishery managers to make meaningful inseason decisions and to allow detection of oil-induced effects. Assuming a sampling rate of approximately 20% of all commercial and cost recovery harvests and following an analysis of the performance of previous tagging studies (Peltz and Miller 1990; Peltz and Geiger 1990; Geiger and Sharr 1990), an overall tagging rate of approximately 0.00167 tags per fish was chosen. A different tag code was given to each release group, a release group representing a batch of fish subjected to a certain feeding regimen (early feeding, late feeding or no feeding) and release timing. An effort was made to keep tagging rates as uniform as possible between hatcheries and between release groups within hatcheries.

Pink salmon fry to be tagged were randomly selected as they emerged from incubators. Fry were anesthetized in a 1 ppm solution of MS-222 prior to removal of adipose fins and application of tags. Half-length coded wire tags were applied with a Northwest Marine Technology tag injector (model MKII). Adipose fin-clipped and tagged fish were passed through an electronic quality control device to test for tag retention. Rejected fish were held and retested later. If rejected a second time, they were sacrificed to minimize the number of untagged clipped fish in the release. Fry which retained tags were held overnight to determine short-term mortality and tag-loss. Overnight mortality rates were determined by counting the number of fish floating on the surface (floaters) 24 hours after tagging. An overnight tag-loss rate was estimated by randomly selecting 200 fish and testing them with the quality control device before release into saltwater rearing pens. Tag placement was checked periodically, but not quantified.

Methods of handling tagged fry after the overnight holding period and prior to release differed slightly among hatchery facilities and years. In 1989, fry tagged at the Solomon Gulch hatchery were held in salt water for three days in pens positioned within larger pens holding their unmarked cohorts. A short-term saltwater mortality was determined and used to discount the total number of tagged fry released. At PWSAC facilities, tagged fry were released directly into saltwater pens containing unmarked fry in 1989. In 1990, tagged fry from PWSAC hatcheries were treated identically to those tagged in 1989, whereas at the Solomon Gulch facility, only 500 marked fry were assessed for short-term saltwater mortality, the remainder being introduced directly into pens containing unmarked fish. In 1991, all tagged fry from all hatcheries were introduced into saltwater pens located within larger pens holding their unmarked cohorts, allowing determination of short-term saltwater mortalities for all facilities. One difference between facilities in 1991 was that fry tagged at Solomon Gulch were held in freshwater incubators until all tagging within a single tag code was completed, whereas fry tagged at PWSAC hatcheries were released into saltwater pens immediately after their 24 hour waiting period. Tagged fry at PWSAC facilities were thus introduced to salt water in a staggered fashion. Unmarked fry entering the large saltwater rearing pens were counted with electronic fry counters at PWSAC hatcheries, while the number of unmarked fry entering saltwater net pens at the Solomon Gulch hatchery were estimated from egg counts with appropriate adjustments for egg mortality.

The number of fry released with tags of tag code t (Tr_t) was estimated for each release group by deducting both the overnight tagging and saltwater rearing mortalities from the number of fry initially tagged, and then adjusting the result with an overnight tag-loss estimate:

$$\hat{Tr}_t=(T_t-Mo_t-Msw_t)(1-\hat{Lo}_t), \tag{1}$$

where

T_t	=	total number of tagged (t) fish,
Mo_t	=	number of deaths during overnight holding period among tagged (t) fish,
Msw_t	=	number of deaths during saltwater rearing period among tagged (t) fish, and
Lo_t	=	proportion of tagged (t) fish that lost tags during the overnight holding period.

The inclusion of Msw_t is appropriate for those facility/year instances where such a parameter could be estimated/determined.

All other salmon species reared in Prince William Sound hatcheries were also tagged. Tagging practices for chum salmon fry were identical to those for pink salmon. Sockeye, coho, and chinook salmon smolt were also tagged in a similar manner to that described for pink salmon fry, except that full-length tags were used due to the larger size of fish being tagged. After tagging, smolt were returned to freshwater raceways before being transferred to either saltwater pens or remote release locations.

At all facilities, pink and chum salmon fry mortalities were estimated visually immediately prior to release. These estimates were applied equally to tagged and untagged fish to obtain final release estimates. Fry and smolt releases were timed to coincide with peak plankton abundances near the hatcheries.

Wild Stock Tagging

Wild pink salmon fry were tagged at six streams in the western portion of Prince William Sound during 1990 and 1991 (Figure 3). Three of the streams (Hayden, Herring, and Loomis

Creeks) were contaminated with oil spilled from the *Exxon Valdez* and three streams were not contaminated (O'Brien, Totemoff, and Cathead Creeks). Wild fish were tagged at a considerably higher rate than hatchery fish. Tagging rates ranged from 0.071 to 0.4 and were largely functions of the rates at which field crews could work.

Wild pink salmon successfully spawn in the intertidal as well as upstream portions of streams in Prince William Sound. Successful intertidal spawning occurs in portions of stream channels more than 1.8m above mean low tide (Kirkwood 1962; Bailey 1966; McCurdy 1979). Total enumeration and tagging of wild pink salmon fry from streams required installation and maintenance of weirs capable of trapping fish as small as 27mm in length in an estuarine environment with 3m tidal fluctuations. This was accomplished by placing 3m x 3m fyke nets with nylon mesh wings at the 1.8m tide level at each stream. Each net emptied into a floating box from which fry were removed for tagging and fin clipping. Tagging at each site was temporally stratified, depending upon the magnitude and duration of the run. On each tagging day, a sample of fry was removed from the trap for tagging. Fry to be tagged were anesthetized in an MS-222 solution, had their adipose fins clipped, and were injected with a half-length coded wire tag. Recirculating freshwater systems were used to minimize osmoregulatory stress to fry during tagging. Short-term tag loss and mortality rates were determined in a manner similar to that described for fry tagged at hatcheries. Tag placement was also checked each day. After tag retention checks, fry were introduced into saltwater net pens and held for up to 24 hours prior to release. Untagged fry were enumerated and transferred from the floating live box into the stream below the weir.

The number of wild stock fry released with tag code t (Trw_t) was estimated as:

$$\hat{Trw}_t = (T_t - Mo_t)(1 - \hat{Lo}_t), \qquad (2)$$

where

T_t	=	total number of tagged (t) fish,
Mo_t	=	number of overnight deaths among tagged (t) fish, and
Lo_t	=	proportion of tagged (t) fish that lost tags during the overnight holding period.

Tag codes referred to stream identity. An upstream weir was operated at Herring Creek in conjunction with an intertidal weir in 1991, different tag codes being used at each weir to allow the origin of fish within the stream to be determined upon recovery.

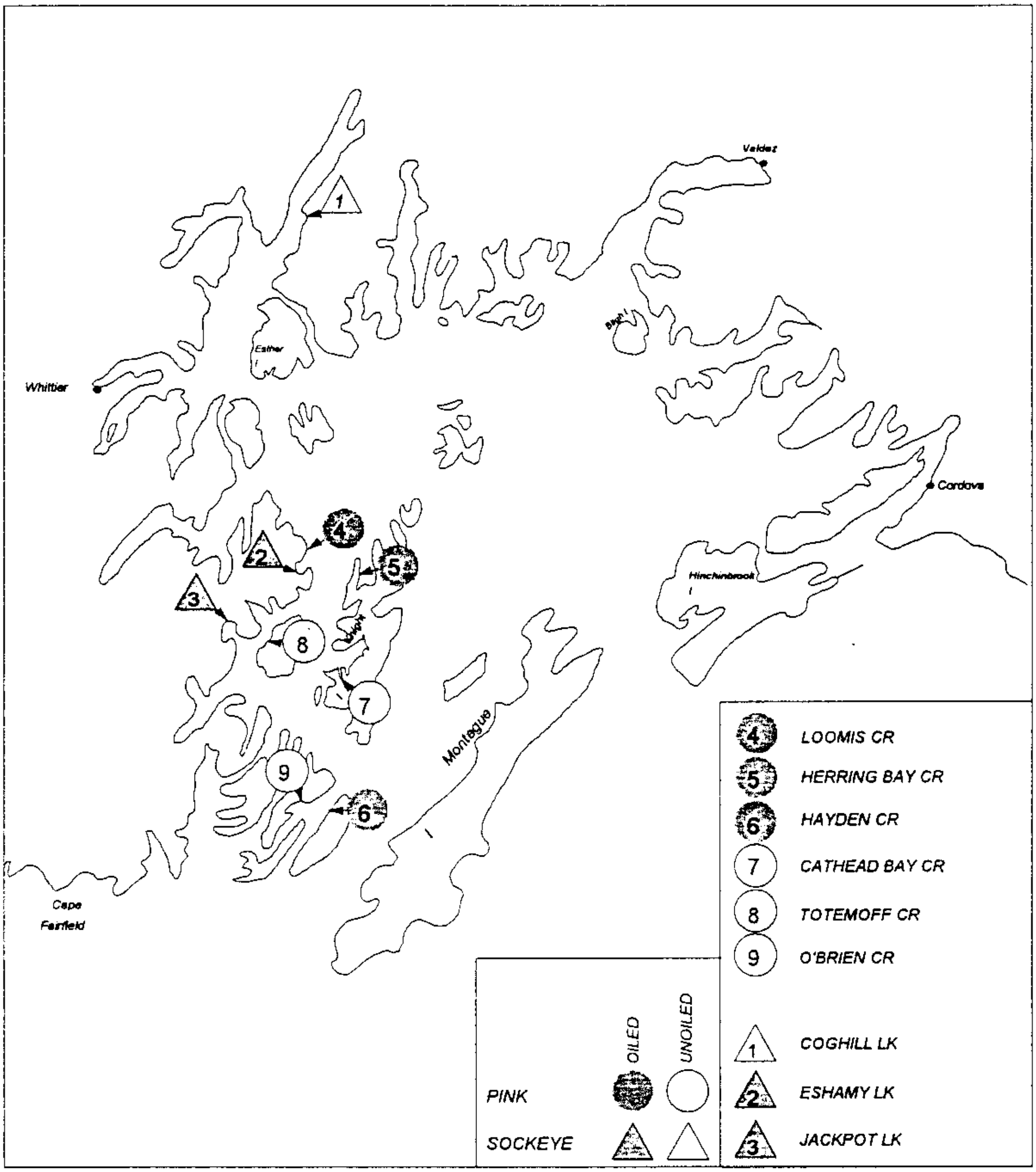


Figure 3. Pink and sockeye salmon weir sites, Prince William Sound, Alaska.

Sockeye salmon smolt were tagged at the Coghill and Eshamy weirs during 1989, at the Jackpot and Eshamy weirs during 1990 and at the Coghill, Jackpot and Eshamy weirs during 1991. The intertidal areas adjacent to the Eshamy and Jackpot watersheds were contaminated with oil whereas areas immediately adjacent to the Coghill watershed were not impacted. An incline plane trap was used to trap smolt at Coghill and Jackpot and a 1.22m x 1.22m fyke net was used at Eshamy. Half-length coded wire tags were used at Coghill during 1989 and Jackpot during 1990 due to the small size of the outmigrating smolt. A quality control device was used to test all smolt for tag presence immediately after tag application; this test was repeated on 200 smolt after a 24 hour holding period. The number of tagged and clipped fish actually released was calculated in a manner similar to that used for wild pink salmon fry (Equation 2).

Tag Recovery

Commercial and Cost-Recovery Harvests

Recoveries were stratified by district, week, and processor. This stratification was chosen as a result of the findings of Peltz and Geiger (1990), who detected significant differences between the proportions of some tag codes among such strata. The differences indicate that processors tend to receive catches from only certain parts of a district and is believed to be the result of traditional tendering patterns.

Recoveries of pink salmon tags from commercial and cost-recovery harvests were made after each fishery opening as fish were pumped from tenders onto conveyor belts at land-based processors located in Cordova, Valdez, Seward, Anchorage, Whittier, Kenai, Kodiak, and aboard floating processors. Fish were sampled by one or two technicians standing alongside the belt. In the case where two technicians scanned the belt, measures were taken to ensure that fish were not sampled twice. Each sampled fish was subjected to a visual and tactile examination for a missing adipose fin. In most cases technicians were unable to census a complete tender load. However, a complete census of some tenders was possible, and when this occurred, a Chi-square test of independence was used to compare the rate of occurrence of adipose finclips in the census with that observed in a random sample from the load.

Data recorded for each tender included harvest type (i.e. commercial or cost-recovery catch), fishing district(s) from which the catch was taken, catch date, processor, and the number of fish examined. Catch data associated with each tender were later obtained from fish tickets.

Heads of fin-clipped fish were excised, identified with a uniquely-numbered cinch tag, bagged, frozen and shipped along with sample data to the Alaska Department of Fish and Game, Coded Wire Tag Processing Laboratory (Tag Lab) in Juneau. Tag Lab staff processed the heads and entered tag code and sample data into a database that was accessible to biologists in Cordova.

Tag recoveries were made in a similar fashion for chum, coho, sockeye, and chinook salmon. Sample storage, processing, and data entry were also made in a similar manner to that for pink salmon.

Brood Stock Harvests

Tag shedding from release to return and differential mortality between tagged and untagged fish can lead to discrepancies between marking rates at release and recovery. Hatchery pink salmon brood stocks were scanned for tags in order to estimate adjustment factors which could be used to account for the loss of tags from the population. Three assumptions inherent in the use of the brood stock for this purpose are a) the brood stock consists only of fish reared at the hatchery, b) the tendency for a tagged fish to lose a tag or to die is similar for all fish marked at the same hatchery, and c) there is no influence of an implanted tag on homing fidelity. If it was believed that the first of these assumptions had been violated, adjustment factors were generated from cost-recovery harvests. With respect to the second assumption, tagging practices vary little within a facility, and it is believed that the rate of tag loss and tag-induced mortality were similar for all fish tagged within a hatchery. No direct evidence exists to refute the third assumption, although some histological evidence to this end is referenced in the discussion.

The adjustment factor for hatchery h, a_h, was estimated as the ratio of sampled fish in the brood stock to the expanded number of fish based on tags found in the sample :

$$\hat{a}_h = \frac{s_h}{\sum_i^T \frac{x_i}{p_i}}, \quad (3)$$

where

T	=	number of tag codes released from hatchery h,
p_i	=	tagging rate at release for tag code i (defined as number of tagged fish released with code i divided by the total number of fish in release group i),
x_i	=	number of tags of code i found in s_h, and
s_h	=	number of brood stock fish examined in hatchery h.

The factor is 1.0 when there is no tag loss or differential mortality, and there are no violations of the closed population assumption.

The adjustment factor was used to adjust contribution estimates (Equation 4) if it could be shown that it was significantly greater than 1.0 at the 90% level. An appropriate test of the hypothesis : $Ho : a_h \leq 1.0$ is given in Appendix B.

Brood stock samples were taken during hatchery egg-take operations. Approximately 95% of the brood stock was examined through visual and tactile means for missing adipose fins. The number of fish sampled was recorded daily. When adipose-clipped fish were found, the heads were excised and shipped on a weekly basis along with sample data to the Tag Lab.

An assumption inherent with the use of the above adjustment factors for species with variable marine residencies (sockeye, chum, chinook) is that the tendency for a fish to shed its tag, or for a tag to induce death is independent of time spent in the ocean. Implicit here is the notion that the majority of tags are lost from the population only during a short period after release from the hatcheries.

Stream Recoveries

Pink salmon carcasses were sampled for coded wire tags at all six wild stock tagging locations (Loomis, Cathead, Herring, Totemoff, O'Brien, and Hayden) in 1991 and 1992, and at any additional streams surveyed as part of NRDA F/S 1 (40 in 1991 and 18 in 1992). Only carcasses with a visible adipose region were sampled. The total number of carcasses sampled was recorded on a daily basis for each stream surveyed. Heads were removed from carcasses found to lack adipose fins, soaked in a brine solution, bagged, and sent to the Tag Lab along with sample data. Estimates of adjustment factors were generated in a manner similar to that for hatchery fish (Equation 3, with h indexing streams). Assumptions equivalent to those needed for valid hatchery adjustment factors are also required for derivation of meaningful stream adjustment factors.

Hatchery Contributions and Survival Rates

The contribution of release group t to the sampled common property, cost-recovery, brood stock, escapement and special harvests, C_t , was estimated as:

$$\hat{C}_t = \sum_{i=1}^{L} x_{it} \left(\frac{N_i \, \hat{a}_{h(t)}}{s_i \, p_t} \right) , \tag{4}$$

where

x_{it}	=	number of group t tags recovered in ith stratum,
N_i	=	total number of fish in ith stratum,
s_i	=	number of fish sampled from ith stratum,
p_t	=	proportion of group t tagged,
$a_{h(t)}$	=	adjustment factor associated with hatchery h, and
L	=	number of recovery strata associated with common property, cost-recovery, brood stock, special harvests and escapement in which tag code t was found.

The contribution of release group t to unsampled strata, Cu_t, was estimated from contribution rates associated with strata which were sampled from the same district-week openings as the unsampled strata:

$$\hat{Cu}_t = \sum_{i=1}^{U} \left[N_i * \left(\frac{\sum_{j=1}^{S} \hat{C}_{tj}}{\sum_{j=1}^{S} N_j} \right) \right] , \tag{5}$$

where

U	=	number of unsampled strata,
N_i	=	number of fish in ith unsampled stratum,
S	=	number of strata sampled in the period in which the unsampled stratum resides,
C_{tj}	=	contribution of release coded with tag t to the sampled stratum j, and
N_j	=	number of fish in jth sampled stratum.

When a district-week opening was not sampled at all (an infrequent occurrence), the catch from that opening was treated as unsampled catch of the subsequent opening in the same district.

An estimate of the contribution of the release group coded with tag t to the total Prince William Sound return for a year was obtained through summation of contribution estimates for sampled and unsampled strata. An estimate of the total hatchery contribution to the Prince William Sound return was calculated through summation of contributions over all release groups.

A variance approximation for $\hat{C}_t$, derived by Clark and Bernard (1987) and simplified by Geiger (1990b) was used:

$$\hat{V}(\hat{C}_t) = \sum_{i=1}^{L} x_{it} \left[\frac{N_i\, \hat{a}_{h(t)}}{s_i\, p_t}\right]\left[\frac{N_i\, \hat{a}_{h(t)}}{s_i\, p_t} - 1\right]. \qquad (6)$$

Assuming that covariances between contributions of different release groups to a stratum could be ignored, summation of variance components over all tag codes provided an estimate of the variance of the total hatchery contribution. Inspection of the formula given by Clark and Bernard (1987) for the aforementioned covariances shows them to be negligible for large N and s, and to be consistently negative, so that when ignored, conservative estimates of variance are obtained. Variances associated with contribution estimates made for unsampled strata were ignored. In an attempt to assess the consequences of this, a parametric bootstrap analysis of the 1991 recoveries was performed. The distribution of the bootstrap survival estimates was also assessed to determine the applicability of normal theory to confidence interval calculations. Details of the analysis are presented in the Appendix A.

The survival rate of the release group coded with tag t (S_t), was estimated as:

$$\hat{S}_t = \frac{\hat{C}_t + \hat{Cu}_t}{R_t}, \qquad (7)$$

where

C_t	=	contribution of release coded with tag t to sampled strata,
Cu_t	=	contribution of release group coded with tag t from unsampled strata, and
R_t	=	total number of fish in release group coded with tag t released from hatchery.

Assuming the total release of fish associated with a tag code is known with negligible error, and that the cumulative variance contributions associated with contribution estimation for unsampled strata are small, a suitable variance estimate for $\hat{S}_t$ is given by:

$$\hat{V}(\hat{S}_t) = \frac{\sum_{i=1}^{L} x_{it} \left[\frac{N_i \hat{a}_{h(t)}}{s_i p_t}\right]\left[\frac{N_i \hat{a}_{h(t)}}{s_i p_t} - 1\right]}{R_t^2} . \tag{8}$$

Wild Salmon Contributions and Survival Rates

Contribution and survival estimates for tagged wild salmon were derived in a manner similar to those for tagged hatchery fish (Equations 4, 5 and 7), as were the estimates of variances of the contribution and survival rates (Equations 6 and 8). An estimate of the contribution of the release group coded with wild stock tag t to the total Prince William Sound return was obtained from the summation of estimates of contributions to the common property, cost-recovery and special harvests and of the estimates of the returns to all surveyed streams.

Analysis of variance was used to determine the effect of oil upon survival rates of wild pink salmon. The analysis reflected the completely randomized nature of the design. The survival rates (Y_{ij}) were analyzed with the effects model as:

$$Y_{ij} = \mu + oil_i + \epsilon_{ij} , \tag{9}$$

where

i = 1 or 2 for oiled and unoiled, respectively, and
j = 1, 2 or 3.

RESULTS

Tagging

Hatchery Tagging Data

Pink salmon fry were released from the A.F. Koernig, W. Noerenberg, Cannery Creek, and Solomon Gulch hatcheries over the years 1986 through 1991 (Table 1). Releases of pink salmon were by far the largest among those of the different salmon species cultivated at the Prince William Sound hatcheries. Numbers of pink salmon fry released range from 235 million from the W. Noerenberg hatchery in 1990 to 31 million from the Cannery Creek facility in 1986. The median release was 125 million. Tagging rates for pink salmon fry over the years 1988 through 1991 ranged from 0.00143 at the W. Noerenberg hatchery in 1988 to 0.00243 at the Solomon Gulch hatchery in 1989, with a median rate of 0.0019. The largest number of tag codes applied by hatcheries occurred in 1991, when 58 different codes were used. The smallest number of codes used over the years 1988 through 1991 occurred in 1988 when 12 different codes were released.

Chum salmon fry were released from the Main Bay, Solomon Gulch and W. Noerenberg hatcheries (Table 1). Releases of this species were the next most numerous. Releases ranged from 76.8 million from the W. Noerenberg hatchery in 1991 to 1.7 million from the Solomon Gulch facility in 1991 with a median of 4 million. Tagging rates used for chum salmon fry were larger than those used for pink salmon fry, ranging from 0.00143 at the Main Bay hatchery in 1987 to 0.04 at the Main Bay hatchery in 1986. The median tagging rate was 0.0109.

Coho salmon smolt were released from the Solomon Gulch and W. Noerenberg hatcheries (Table 1). Releases ranged from 231 thousand from Solomon Gulch in 1986 to 4.3 million from the W. Noerenberg hatchery in 1991, with a median release of 787 thousand. Tagging rates ranged from 0.0162 to 0.06667. The median tagging rate was 0.0313.

Sockeye salmon smolt were released only from the Main Bay hatchery with releases ranging from 330 thousand in 1988 to 4.1 million in 1991 (Table 1), and with a median of 3.33 million. Tagging rates ranged from 0.0256 in 1989 to 0.125 in 1988, with a median of 0.0313.

Chinook salmon smolt were released from the Solomon Gulch and W. Noerenberg hatcheries in 1990 and 1991 (Table 1). Releases ranged from 142 thousand to 241 thousand fish, with tagging rates ranging from 0.0526 to 0.25. The median tagging rate was 0.125.

Table 1.Hatchery tagging data by year, species and facility, Prince William Sound, Alaska.

	RELEASE YEAR	NUMBER			
		RELEASED	TAG CODES	TAGGED	TAGGING RATE
SOCKEYE SALMON					
MAIN BAY	1988	330,025	4	41,528	0.125
	1989	3,925,026	4	100,434	0.0256
	1990	2,744,595	10	138,663	0.05
	1991	4,133,421	9	135,621	0.0323
CHUM SALMON					
MAIN BAY	1984	6,538,611	2	109,647	0.0167
	1985	4,197,186	2	84,317	0.02
	1986	2,953,962	3	119,091	0.04
	1987	76,537,024	2	109,726	0.00143
SOLOMON GULCH	1987	3,420,288	2	35,217	0.0103
	1989	2,921,414	1	28,991	0.0099
	1990	3,104,288	1	35,820	0.0115
	1991	1,736,374	2	20,720	0.0119
W. NOERENBERG	1990	47,495,780	5	110,543	0.00233
	1991	76,834,313	4	178,392	0.00232
CHINOOK SALMON					
SOLOMON GULCH	1991	192,945	1	10,326	0.0526
W. NOERENBERG	1990	141,939	2	36,841	0.25
	1991	241,348	1	30,772	0.125
COHO SALMON					
SOLOMON GULCH	1986	231,538	1	10,556	0.0454
	1987	314,751	2	21,087	0.0667
	1988	826,424	2	13,248	0.0162
	1989	980,000	2	30,561	0.0313
	1990	787,137	1	33,957	0.0435
	1991	1,956,869	3	36,679	0.0189
W. NOERENBERG	1989	2,599,937	1	100,529	0.0385
	1990	2,460,620	2	69,783	0.0286
	1991	4,341,698	4	72,588	0.0167
PINK SALMON					
A.F. KOERNIG	1986	111,266,808	2	207,756	0.00187
	1987	116,117,645	0	0	0
	1988	110,036,728	3	209,063	0.00190
	1989	160,486,843	4	323,030	0.00201
	1990	113,843,914	8	202,265	0.00178
	1991	115,762,047	16	201,835	0.00174
W. NOERENBERG	1986	34,525,575	2	220,369	0.00636
	1987	75,932,715	0	0	0
	1988	195,607,839	2	280,479	0.00143
	1989	159,713,663	3	313,004	0.00196
	1990	235,378,496	11	467,587	0.00199
	1991	214,941,068	18	395,313	0.00184
CANNERY CREEK	1986	31,115,388	2	218,436	0.00699
	1987	42,600,000	0	0	0
	1988	95,571,232	3	172,591	0.00181
	1989	58,969,539	3	125,869	0.00213
	1990	143,662,511	8	248,193	0.00173
	1991	141,519,850	14	244,204	0.00172
SOLOMON GULCH	1987	59,822,967	9	178,461	0.00299
	1988	130,827,285	4	277,365	0.00212
	1989	128,499,680	7	312,196	0.00243
	1990	122,242,297	5	210,854	0.00172
	1991	131,295,093	10	250,051	0.00191

Wild Stock Tagging Data

Seaward migrations of pink salmon from the six study streams in 1990 ranged from approximately 154 thousand to 714 thousand, with a median of 327 thousand (Table 2). Tagging rates for pink salmon fry ranged from 0.071 to 0.256, with a median of 0.125. Two tag codes were applied at each stream. In 1991, seaward migrations ranged from 152 thousand to 510 thousand, with a median of 306 thousand. Tagging rates ranged from 0.098 to 0.667, with a median of 0.2.

Seaward migrations of sockeye salmon in 1989 ranged from 388 thousand from the Eshamy system to 245 thousand from the Coghill system (Table 2). Tagging rates were 0.121 and 0.179, respectively. In 1990, the seaward migration from the Eshamy system was 682 thousand, while that from the Coghill system was 20 thousand. Tagging rates were 0.03 and 0.23, respectively. In 1991, three, one and two tag codes were applied at the Eshamy, Jackpot and Coghill systems, respectively. Tagging rates ranged from 0.066 to 0.37 during 1991.

In 1990, wild pink salmon fry migrated from the six study streams from mid-April to early June (Figures 4 and 5). Tagging was terminated in mid-May, recorded tagging rates being adjusted for the untagged portion of the outmigration. In 1991, tagging was extended for an additional month and pink salmon fry were observed migrating from the three oiled streams and two unoiled streams (Cathead and O'Brien Creek) from mid-April through mid-June. Migration timing at the remaining unoiled stream (Totemoff) was essentially the same in 1991 as in 1990.

Tag Recoveries

Sampling Rates

Approximately 15, 11 and 13% of the pink salmon captured in the common property fisheries and 14, 12 and 30% of those captured in the cost-recovery harvests were sampled during 1989 through 1991, respectively (Table 3). These sampling rates were functions of the magnitude of the catch (average of 30 million fish), the number of samplers and the short time period the fish were accessible to the samplers. The proportion of the pink salmon brood stock sampled was 73, 90 and 93% in 1989, 1990 and 1991, respectively. Approximately 90% of the pink salmon carcasses found in ground survey streams were scanned for tags. For the other salmon species, higher sampling rates were possible, in many instances reaching 42% in the common and cost-recovery fisheries (Table 3).

Table 2. Wild stock tagging data by year, species, stream and tag code, Prince William Sound, Alaska.

TAGGING YEAR	SALMON SPECIES	SYSTEM	DATE OF RELEASE	SEAWARD MIGRATION	TAG CODE	NUMBER TAGGED	NUMBER FISH PER TAG
1989	SOCKEYE	ESHAMY	5/12 - 6/01	388,512	311840	46,771	8.3
		COGHILL	5/13 - 6/03	244,939	1301010403	43,935	5.6
1990	SOCKEYE	ESHAMY	5/12 - 6/05	682,521	311910	20,794	32.8
		JACKPOT	5/18 - 5/28	20,076	1301010911	4,601	4.4
	PINK	HAYDEN	4/25 - 5/30	365,037	1301010802 1301010803	44,082	8.3
		HERRING	4/26 - 6/05	393,413	1301010801 1301010715	45,987	8.6
		LOOMIS	4/22 - 6/03	203,315	1301010707 1301010708	46,313	4.4
		CATHEAD	4/28 - 5/24	154,377	1301010709 1301010710	39,998	3.9
		O'BRIEN	4/28 - 5/28	289,708	1301010712 1301010711	31,379	9.2
		TOTEMOFF	4/25 - 5/29	714,459	1301010713 1301010714	50,926	14.0
1991	SOCKEYE	ESHAMY	5/13 - 7/01	460,816	311951 311957 311956	46,152	10.0
		JACKPOT	5/14 - 6/15	22,311	311955	8,384	2.7
		COGHILL	5/14 - 7/16	110,941	1301020102 1301020101	7,347	15.1
	PINK	HAYDEN	4/19 - 6/20	388,739	1301011407 1301011408 1301011409	61,683	6.3
		HERRING	4/26 - 6/27	261,751	1301011313 1301011315 1301011515 1301011312	57,953	4.5
			6/02 - 6/27[a]	11,457	1301011311	7,614	1.5
		LOOMIS	4/18 - 6/20	152,446	1301011401 1301011402 1301011403 1301011514	60,393	2.5
		CATHEAD	4/23 - 6/09	234,998	1301011404 1301011405 1301011406	36,376	6.5
		O'BRIEN	4/13 - 7/08	347,576	1301011410 1301011411 1301011412 1301011314	63,077	5.5
		TOTEMOFF	4/19 - 5/27	510,213	1301011309 1301011310 1301011308	49,817	10.2

a Denotes upstream tagging

Table 3. Overall sampling rates (percent) of Prince William Sound coded wire tag recovery programs for 1989 through 1991.

RECOVERY YEAR	SALMON SPECIES	HARVEST TYPE		
		COMMON PROPERTY	COST-RECOVERY	BROOD STOCK
1989	Pink	15.4	13.6	73.0
	Sockeye	38.8	--	100.0
	Coho	27.3	100.0	100.0
	Chum	9.7	36.6	--
	Chinook	7.3	--	--
1990	Pink	11.1	11.5	89.7
	Sockeye	30.6	--	100.0
	Coho	34.6	68.4	19.1
	Chum	22.3	11.7	47.8
	Chinook	4.1	--	--
1991	Pink	12.5	29.9	92.7
	Sockeye	39.7	--	100.0
	Coho	36.5	30.9	97.2
	Chum	29.1	15.1	90.2
	Chinook	42.4	--	73.0

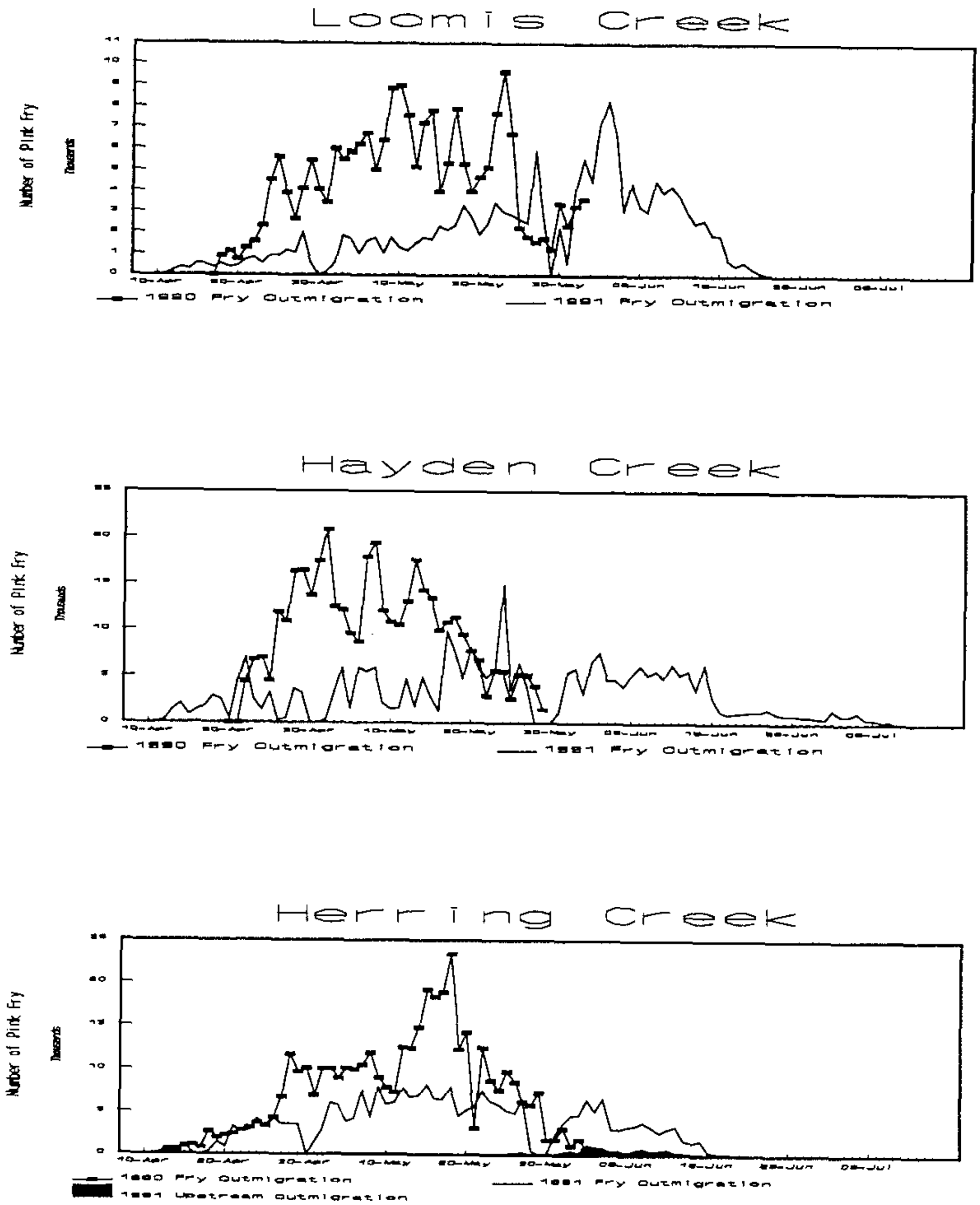


Figure 4. Timing and magnitude of pink salmon fry outmigrations from three oiled streams in Prince William Sound during 1990 and 1991.

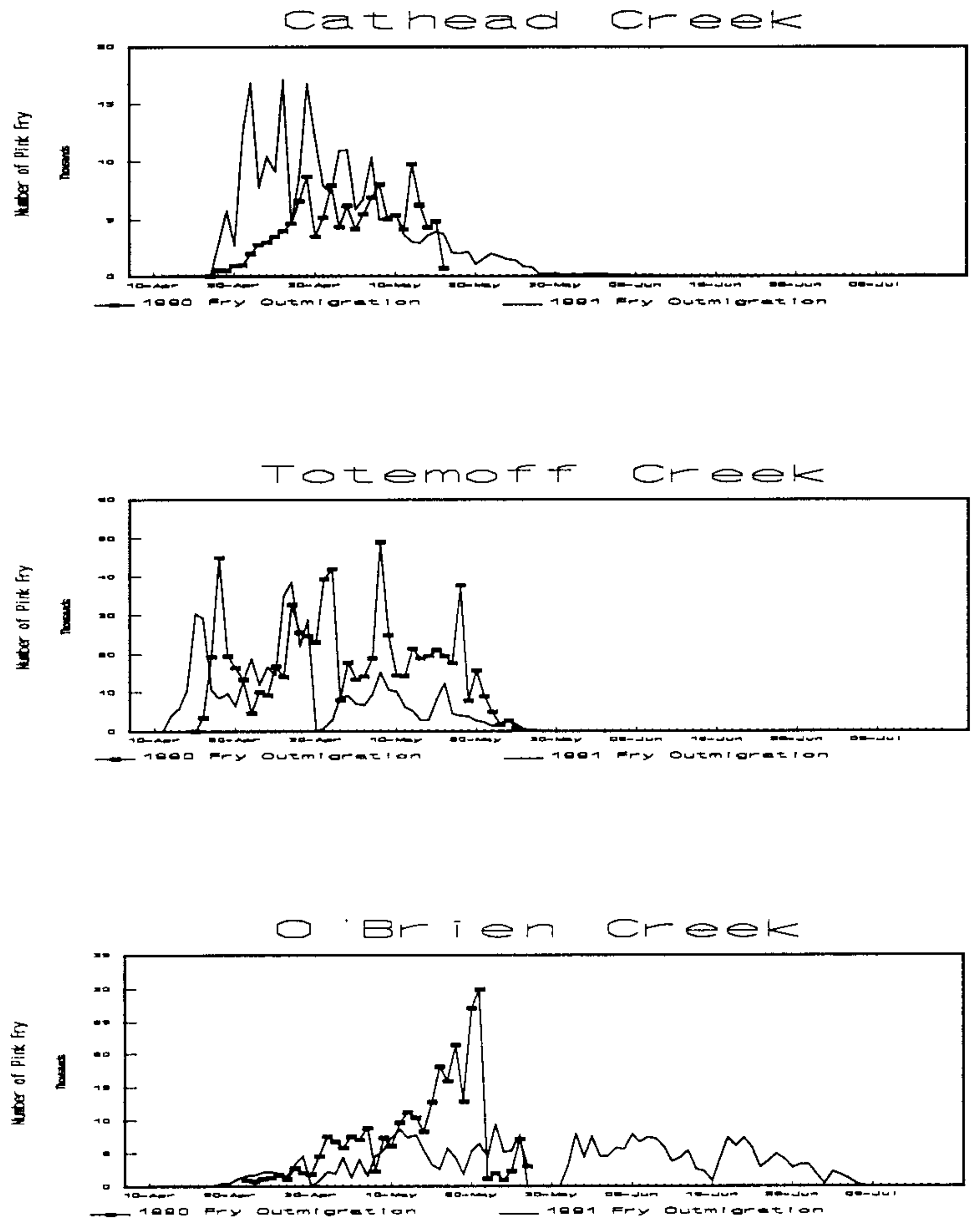


Figure 5. Timing and magnitude of pink salmon fry outmigrations from three unoiled streams in Prince William Sound during 1990 and 1991.

Hatchery Recoveries

Contributions and survival rates. Tags of hatchery origin were recovered in the common property, cost-recovery and brood stock harvests. Some hatchery tags were also recovered during surveys of the pink salmon spawning streams.

In 1989, hatcheries contributed 17.2 million pink salmon (76%) to the Prince William Sound catch of 22.5 million. The W. Noerenberg hatchery, contributing 5.7 million fish (25%), was the largest producer among the four hatcheries cultivating pink salmon in the Sound. In 1990, hatcheries contributed 31.8 million fish (71%) to the Sound-wide catch of 44.9 million pink salmon. Again, the W. Noerenberg hatchery was the largest contributor (13.6 million, 30%). In 1991, the hatchery contribution to the total catch of 38 million fish was 31 million fish (81%). The W. Noerenberg hatchery produced 11.7 million of these fish (30%), and was the largest contributor. Contribution data are presented in Table 4.

Hatchery production of sockeye salmon increased from 2600 (1.9% of total catch) in 1989 to 13 thousand in 1990 (20% of catch) and to 453 thousand in 1991 (84% of catch) (Table 5). Contributions of chum, chinook and coho salmon are presented in Table 5.

Survival rates of pink salmon returning to hatcheries in 1989 ranged from 2.39% (A.F. Koernig) to 5.8% (Cannery Creek). No significant differences (at α=0.05) in survival rates of pink salmon released from the A.F. Koernig, Solomon Gulch and W. Noerenberg hatcheries were found. The survival rates associated with these hatcheries were found to differ significantly (P<0.001) from that associated with Cannery Creek hatchery. For the 1990 recovery year, a significant difference (P<0.001) in survival rate was detected between the A. F. Koernig hatchery (4.24%) and both the Solomon Gulch (6.95%) and W. Noerenberg hatcheries (8.48%). No difference (at α=0.05) was detected between rates associated with the A. F. Koernig and Cannery Creek (4.30%) hatcheries. For 1991, the only significant differences in survival rates (P<0.0001) occurred between Cannery Creek (5.93%) and the other hatcheries, A.F. Koernig (4.52%), W. Noerenberg (4.99%) and Solomon Gulch (4.67%). Survival data are presented in Table 6 and Figure 6.

A bootstrap analysis showed the survival estimates to be approximately normally distributed, and that the variability associated with unsampled strata was negligible. There was little difference in the estimated standard error of a survival rate for adults returning in 1991 as determined analytically (variance associated with estimation of contributions from unsampled strata ignored) and by the bootstrap analysis (aforementioned variance accounted for) (Figure 7).

An analysis of the tag-code specific survival data generated for pink salmon from the PWSAC hatcheries was effected. In this analysis, hatchery treatment was controlled

Table 4. Summary of hatchery and wild stock contributions to the Prince William Sound pink salmon catch for 1989 through 1991 (millions of fish).

RECOVERY YEAR		FACILITY[a]	COMMON PROPERTY	COST-RECOVERY	SPECIAL[b]	BROOD STOCK	TOTAL CONTRIBUTION	95 % BOUNDS	% OF TOTAL CATCH
1989	Hatchery Contribution	AFK	0.03	2.47	N/A	0.12	2.62	2.25, 2.99	11.64
		WN	3.21	2.12	N/A	0.39	5.72	5.19, 6.25	25.42
		CC	4.91	0.50	N/A	0.13	5.54	4.86, 6.22	24.62
		SG	2.41	0.67	N/A	0.21	3.29	3.03, 3.55	14.62
		TOTAL	10.56	5.76	N/A	0.85	17.17	16.19, 18.14	76.31
	Wild Stock Contribution		3.24	2.09	N/A	0.00	5.33	4.36, 6.30	23.68
1990	Hatchery Contribution	AFK	5.39	1.30	N/A	0.12	6.81	6.33, 7.29	15.17
		WN	10.28	2.99	N/A	0.28	13.55	12.63, 14.46	30.18
		CC	1.85	0.49	N/A	0.19	2.53	2.26, 2.80	5.64
		SG	6.86	1.91	N/A	0.15	8.92	8.29, 9.55	19.87
		TOTAL	24.38	6.69	N/A	0.74	31.81	30.57, 33.05	70.86
	Wild Stock Contribution		11.04	2.04	N/A	0.00	13.08	11.84, 14.32	29.14
1991	Hatchery Contribution	AFK	3.88	0.65	0.34	0.24	5.11	4.76, 5.46	13.30
		WN	7.79	0.96	2.48	0.46	11.69	11.13, 12.25	30.43
		CC	6.71	0.69	0.75	0.35	8.50	7.95, 9.05	22.13
		SG	2.52	2.90	0.00	0.27	5.69	5.35, 6.03	14.81
		TOTAL	20.90	5.20	3.57	1.32	30.99	30.06, 31.92	80.68
	Wild Stock Contribution		5.99	0.92	0.51	0.00	7.42	6.49, 8.35	19.32

a AFK = A.F. Koernig, WN = W. Noerenberg, CC = Cannery Creek, SG = Solomon Gulch
b Specifies donated and dumped fish (1991 only).

Table 5. Summary of estimable[a] hatchery and wild stock contributions to the Prince William Sound sockeye, chum and coho salmon catches for 1989 through 1991.

RECOVERY YEAR	SPECIES/ FACILITY[b]	COMMON PROPERTY	COST-RECOVERY	BROOD STOCK	TOTAL CONTRIBUTION	95% BOUNDS		% OF TOTAL CATCH
1989								
	HATCHERY							
	Sockeye/MB	2,030	NH[c]	580	2,610	2,430	2,800	1.89
	Coho/WN	NA[d]	NA	0				
	Coho/SG	19,320	32,330	1,100	52,750	47,680	57,810	25.90
	Chum/MB[e]	1,440	43,360	0	44,800	38,680	50,920	4.64
	WILD STOCK							
	Sockeye	135,490	NH	-[f]	135,490	135,300	135,670	98.11
	Coho	NA	NA	-				
	Chum	NA	NA	-				
1990								
	HATCHERY							
	Sockeye/MB	4,760	NH	8,380	13,140	12,310	13,980	19.91
	Coho/WN	121,090	1,540	2,290	124,920	113,300	136,530	50.24
	Coho/SG	21,630	8,230	12,230	42,080	38,770	45,930	16.93
	Chum/MB	153,260	NH	NH	153,260	24,370	182,150	16.42
	WILD STOCK							
	Sockeye	52,860	NH	-	52,860	52,020	53,690	80.09
	Coho	77,220	4,430	-	81,650	69,410	93,880	32.84
	Chum	NA	NH	-				
1991								
	HATCHERY							
	Sockeye/MB	420,890	NH	31,960	452,850	422,340	483,310	83.94
	Coho/WN	73,740	12,260	1,640	87,640	105,730	150,240	59.05
	Coho/SG	2,480	36,400	1,470	40,350	28,830	51,870	27.19
	Chum/MB[e]	134,530	NH	NH	134,530	100,800	168,260	42.27
	WILD STOCK							
	Sockeye	86,640	NH	-	86,640	56,190	117,100	16.06
	Coho	16,470	3,960	-	20,430	0	84,080	13.76
	Chum	183,750	NH	-	183,750	150,020	217,480	57.73

a Chinook, Chum/SG and Chum/WN are not estimable due to returning untagged releases
b AFK = A.F. Koernig, WN = W.Noerenberg, CC = Cannery Creek, SG = Solomon Gulch
c NH = No Harvest
d NA = Not Available due to returning untagged hatchery fish
e Unadjusted contributions due to unavailable brood stock data
f Brood stock assumed to consist solely of fish reared at the hatchery

Table 6. Survival rates of pink salmon returning to Prince William Sound hatcheries for 1989 through 1991.

RECOVERY YEAR	FACILITY[a]	OILING STATUS	SURVIVAL RATE (%)	95 % BOUNDS
1989	AFK	OILED	2.39	(2.06,2.72)
	WN	PARTIALLY	2.93	(2.65,3.20)
	CC	UNOILED	5.80	(5.09,6.51)
	SG	UNOILED	2.52	(2.32,2.72)
1990	AFK	OILED	4.24	(3.95,4.54)
	WN	PARTIALLY	8.48	(7.91,9.06)
	CC	UNOILED	4.30	(3.84,4.75)
	SG	UNOILED	6.95	(6.46,7.44)
1991	AFK	OILED	4.52	(4.15,4.89)
	WN	PARTIALLY	4.99	(4.70,5.29)
	CC	UNOILED	5.93	(5.51,6.35)
	SG	UNOILED	4.67	(4.39,4.95)

a AFK = A. F. Koernig, WN = W.Noerenberg, CC = Cannery Creek, SG = Solomon Gulch

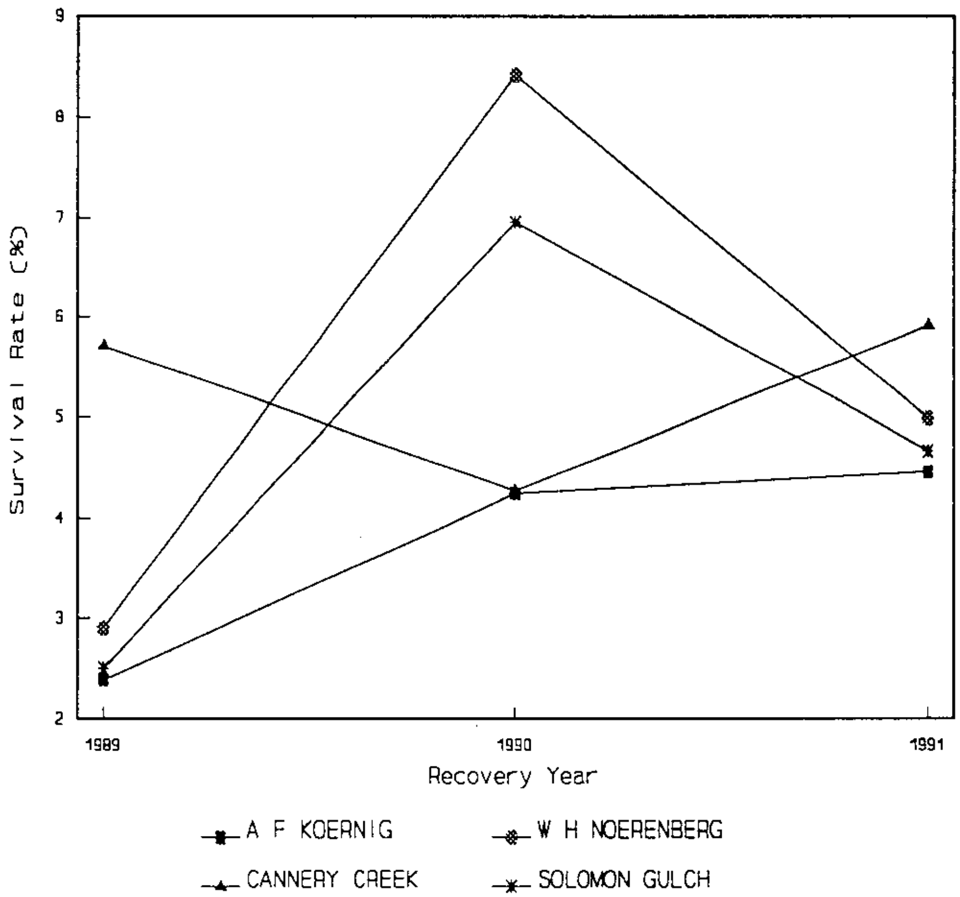


Figure 6. Survival rates of hatchery pink salmon in Prince William Sound for 1989 through 1991.

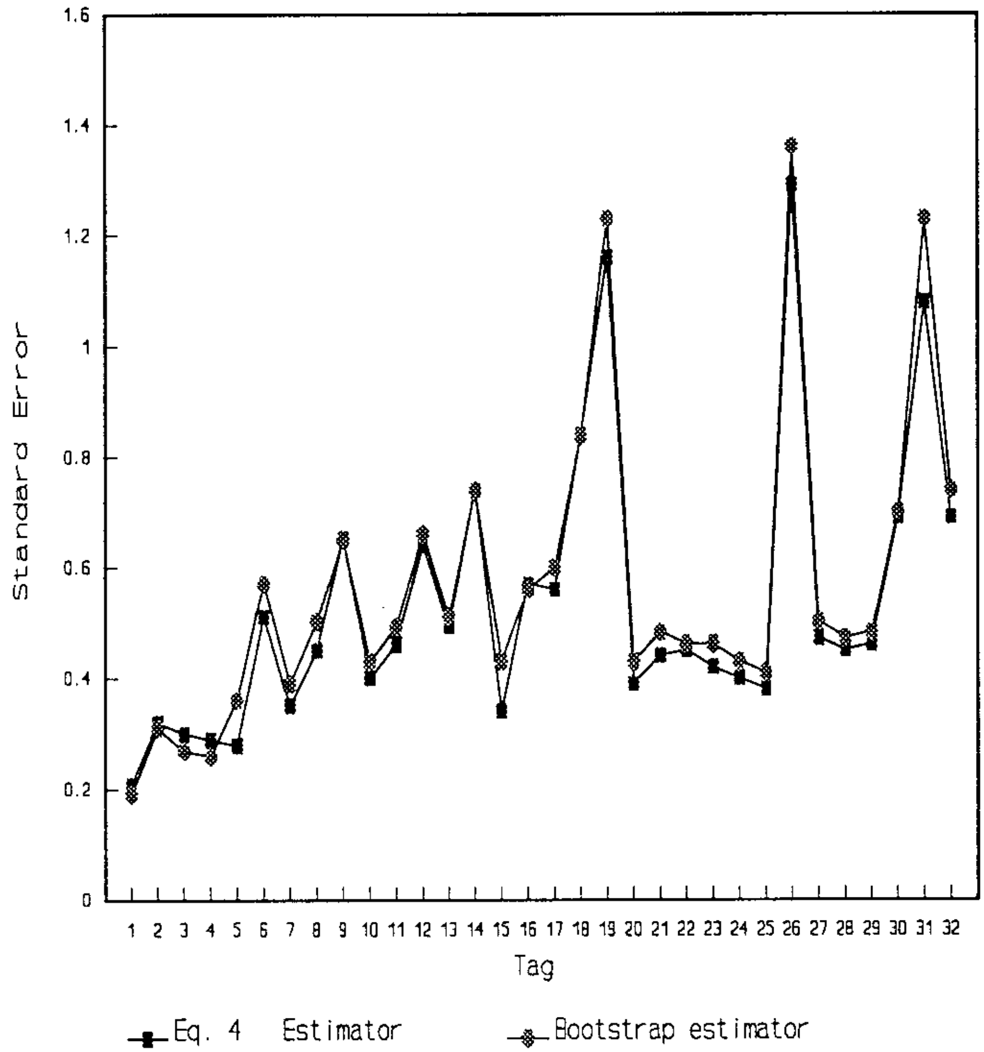


Figure 7. Standard errors of survival rates calculated from bootstrap and analytical methods using 1991 recovery data.

(treatments consisted of different feeding regimes, such as early and late feeding) so comparisons between hatcheries but within treatments could be made. For 1990 and 1991 returns, only those release groups which outmigrated during the plankton bloom were compared. For 1989 returns, only one release group outmigrated during the plankton bloom and so comparisons were made between groups released outside this period. Results were inconclusive. While for one of the treatments (feeding regimes) the survival rate of fish released from the A.F. Koernig hatchery (oiled facility) was higher than that for fish released from the Cannery Creek and W. Noerenberg hatcheries during 1988 (prespill) and lower for fish released during the year of the spill, the opposite was true for other treatments.

Chum, sockeye and chinook salmon have variable marine residence times; consequently, returns of tagged fish are incomplete and survival rates of these release groups cannot be determined at present.

Adjustment factors. Adjustment factor estimates for pink salmon returning to the W. Noerenberg and A.F. Koernig facilities were generated from brood stocks, and ranged from 1.28 for the former hatchery for the 1990 recovery year to 1.82 for the same facility for the 1991 recovery year (Table 7). The adjustment factor estimates for the Cannery Creek and Solomon Gulch hatcheries (Table 7) were based upon cost-recovery fish because of concerns over the straying of wild fish into the brood and a consequential overestimation of the adjustment factor. The estimates based upon cost-recovery sampling ranged from 1.11 for the Solomon Gulch facility in 1989 to 1.97 for the Cannery Creek facility in 1991. The brood stock estimates (not used) were: Cannery Creek: 2.12 (1989), 1.96 (1990), 2.28 (1991); Solomon Gulch: 1.13 (1989), 1.82 (1990) and 1.94 (1991). All adjustment factor estimates were found to be significantly greater than 1.0 (see Table 7 for P values and standard errors). The frequency of adipose clips in returning hatchery fish lacking tags is also reported in Table 7. In ten of twelve cases, this quantity was greater than the naturally-occurring rate.

Sampling diagnostics. Some significant differences (at $\alpha=0.05$) in the proportions of pink salmon tags found at different processors within district-week strata were found for each year. An example of one of the more extreme cases in which proportions of tags were found to differ between processors within a district-week stratum is depicted in Figure 8. Chi-square tests of the null hypothesis that the proportion of tags in the population sampled by the technicians at the unloading belt was the same as that found in a census of that load were performed for each year. The tests suggested that the null hypothesis be accepted, i.e. no evidence was gathered to suggest that samplers were missing fish with clipped adipose fins on the belt.

Table 7. Adjustment factors, standard errors, *P* values and clip frequency in tagless fish calculated from pink salmon brood stock or cost-recovery harvests for 1989 through 1991.

RECOVERY YEAR	FACILITY	ADJUSTMENT FACTOR	STANDARD ERROR (ADJUSTMENT FACTOR)	*P* VALUE FOR Ho:A.Factor <=1.0	CLIP FREQUENCY IN TAGLESS HATCHERY FISH **
1989	A. F. Koernig	1.36	0.0989	0.00014	0.00185
	W. Noerenberg	1.73	0.1434	0	0.00065
	Cannery Creek*	1.81	0.1610	0	0.00097
	Solomon Gulch*	1.11	0.0605	0.035	0.00067
1990	A. F. Koernig	1.58	0.0862	0	0.00077
	W. Noerenberg	1.28	0.0578	0	0.00042
	Cannery Creek*	1.71	0.1030	0	0.00090
	Solomon Gulch*	1.23	0.0374	0	0.00030
1991	A. F. Koernig	1.45	0.0827	0	0.00122
	W. Noerenberg	1.82	0.0827	0	0.00159
	Cannery Creek*	1.97	0.1473	0	0.00098
	Solomon Gulch*	1.55	0.0442	0	0.00033

* Adjustment factors and standard errors calculated from cost-recovery harvests.

** Estimated frequency of naturally-occurring adipose clips is 0.00042 (Peltz and Miller, 1990).

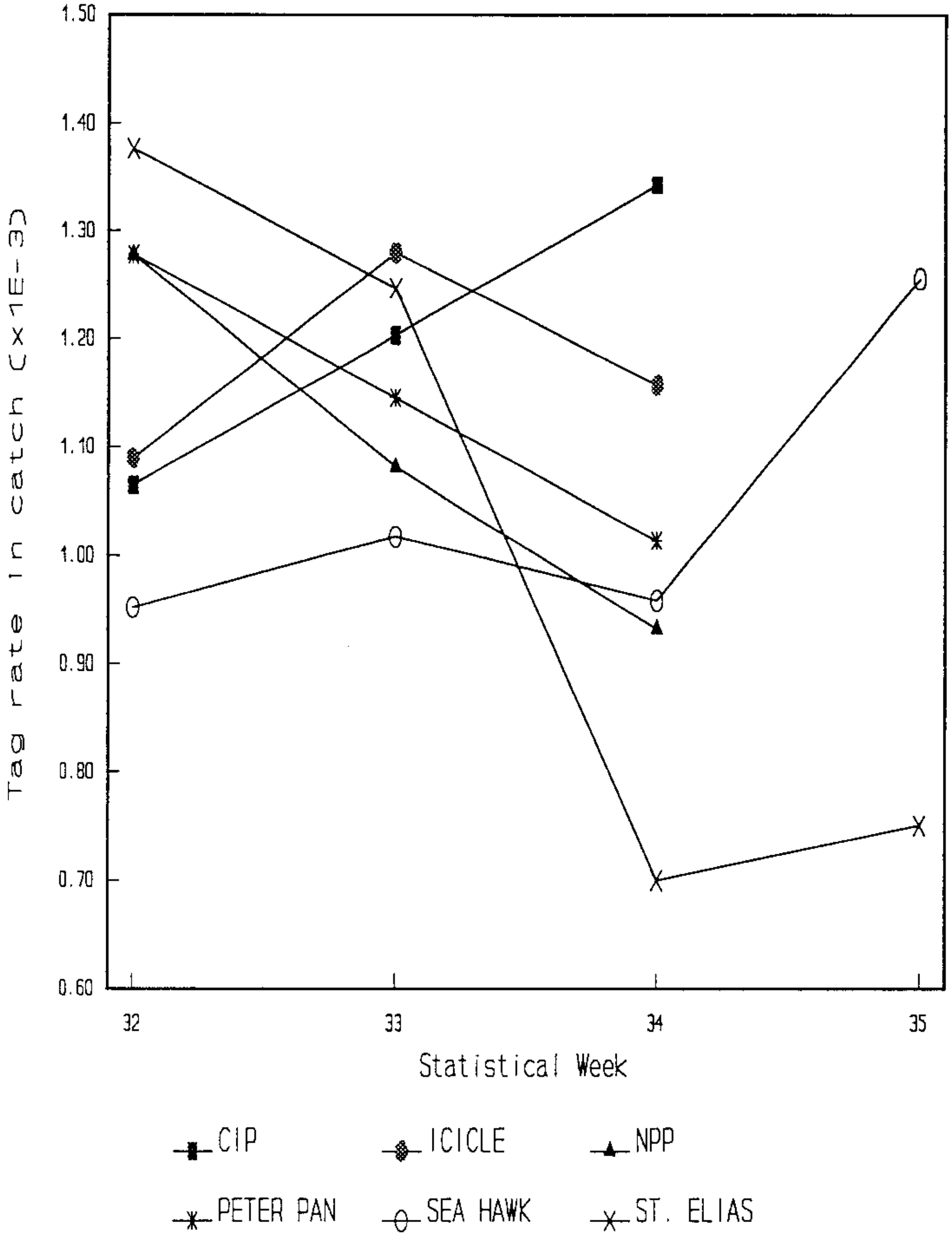


Figure 8. Tagging rates found in sampled common property catches from District 226 in 1991 as influenced by processor and week.

Wild Stock Tag Recoveries

Contributions and survival rates Wild stock recoveries were made in the common property and cost-recovery harvests and in the surveyed streams. The incidence of tag recoveries in all surveyed streams by stream or hatchery of origin is shown in Table 8. Estimates of wild stock contributions to the Prince William Sound pink salmon harvest have ranged from 19% in 1991 to 29% in 1990 (Table 4). As hatchery-produced fish were found in spawning streams, some tagged wild fish were observed in hatchery brood stocks (one Cathead tag at the Solomon Gulch hatchery, one Totemoff tag at the W. Noerenberg facility, and one Hayden tag at the A.F. Koernig hatchery).

No significant differences in survival rates of pink salmon returning to oiled and unoiled streams in 1991 or 1992 were found (P=0.70 and 0.65, respectively). For 1991 recoveries, the mean adult survival rates were 2.27% for oiled streams and 2.03% for unoiled streams. For 1992 recoveries, the mean survival rates were 0.24% and 0.36% for oiled and unoiled streams respectively (Table 9)

The estimates of percent wild stock contribution to the total harvests of other salmon species have decreased as hatchery production has increased (Table 5). Most notable is the decrease in percent contribution from sockeye salmon, when in 1989, 98% of the harvest was of wild origin, compared to 16% in 1991.

Adjustment factors. Estimated adjustment factors for the tagged wild stocks were found to be high. Values of 18, 24, 22, 60, 82, and 20 were calculated for 1991 returns to Loomis, Herring, Totemoff, Cathead, O'Brien, and Hayden Creeks, respectively and values of 52, 18, 7, 102, 216, and 74 were calculated for 1992 returns (account was taken of estimated numbers of stray fish in the streams for both years, as indicated by the presence of stray tags). The generated estimates were not used and a_h was set to 1.0 in Equations 4, 6, and 8.

Table 8. Tags recovered from pink salmon wild stock streams in Prince William Sound by hatchery or stream of origin in 1991.

RECOVERY STREAM[c]	TAG ORIGIN										
	WILD STOCK STREAM						HATCHERY[a]				TOTAL TAGS[b]
	LOOMIS	TOTEMOFF	O'BRIEN	HAYDEN	HERRING	CATHEAD	AFK	CC	WN	SG	
225 30 15060 (LOOMIS)	150	2	0	0	14	0	1	1	18	0	36
226 20 16210 (TOTEMOFF)	3	109	0	0	3	8	1	1	6	0	22
226 40 16660 226 40 16665 (O'BRIEN[d])	0	1	29	3	1	0	10	0	5	1	21
226 40 16770 226 40 16768 (HAYDEN[d])	0	0	0	86	1	1	5	1	2	0	10
226 10 16982 (HERRING)	2	0	0	0	55	1	1	0	3	0	7
226 20 16990 (CATHEAD)	0	0	0	0	0	37	0	0	1	0	1
226 20 16949	0	0	0	0	2	3	0	0	1	0	6
225 10 15000	0	0	0	0	1	0	0	0	0	0	1
225 30 15070	0	1	0	0	0	0	0	0	0	0	1
225 30 15080	1	3	0	0	21	3	3	0	3	0	32
225 30 15100	1	4	0	0	1	2	0	2	4	0	14
225 30 15110	0	1	0	0	3	2	0	1	1	0	8
225 30 15150	0	0	0	0	1	0	0	0	2	0	3
225 30 15160	2	1	1	0	2	0	0	0	5	0	11
226 20 16010	0	1	0	0	2	1	1	0	4	0	9
226 20 16020	0	1	0	0	1	1	0	1	1	0	5
226 20 16040	1	11	0	0	1	5	0	0	2	0	20
226 20 16120	0	1	0	0	0	0	0	0	0	0	1
226 20 16130	1	0	0	0	4	0	1	0	1	0	7
226 20 16230	0	3	1	0	0	3	1	1	2	0	11
226 20 16280	0	0	0	0	1	1	1	2	2	0	7
226 20 16360	1	0	0	0	0	0	0	0	0	0	1
226 40 16650	0	0	0	1	3	0	3	0	1	0	8
226 40 16700	0	0	0	1	0	1	1	0	0	0	3
226 40 16730	0	0	1	2	0	0	1	1	0	0	5
226 40 16780	1	0	0	0	0	0	1	0	0	0	1
226 20 16950	0	0	0	1	2	2	0	1	0	0	6
226 20 16970	0	0	0	0	0	1	0	0	1	2	4
221 40 10760	0	0	0	0	0	0	1	0	0	2	3
221 40 10800	0	1	0	0	0	0	0	0	0	1	2
221 40 10930	0	0	0	0	0	0	0	0	0	3	3
221 40 10940	0	1	0	0	0	0	0	0	0	0	1
Total[b]	13	32	3	8	64	35	32	12	65	9	

a AFK = A.F. Koernig, WN = W.Noerenberg, CC = Cannery Creek, SG = Solomon Gulch.
b Excluding tags from the stream of origin.
c From Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes, 1990, Alaska Department of Fish and Game, Habitat Division, Juneau, Alaska.
d Recovery area covers two stream systems

Table 9. Survival rates of wild pink salmon migrating from oiled and unoiled streams in 1990 and 1991.

RECOVERY YEAR	OILING STATUS	STREAM OF ORIGIN	SURVIVAL RATE (%)	95% CI (LOWER, UPPER)
1991	OILED	Hayden	2.08	(1.67, 2.49)
		Herring	2.42	(1.99, 2.85)
		Loomis	2.32	(1.87, 2.77)
	UNOILED	O'Brien	1.25	(0.70, 1.80)
		Totemoff	1.66	(1.36, 1.96)
		Cathead	3.17	(2.66, 3.68)
1992	OILED	Hayden	0.07	(0.044,0.096)
		Herring	0.47	(0.399,0.581)
		Herring[a]	0	
		Loomis	0.19	(0.152,0.226)
	UNOILED	O'Brien	0.02	(0.003,0.036)
		Totemoff	0.70	(0.592,0.806)
		Cathead	0.35	(0.229,0.459)

a Denotes upstream tagging

DISCUSSION

Contributions and Survival Rates

Contribution of Hatchery and Wild Fish to the Commercial Catch

One of the stated objectives of this study was to accurately and precisely assess the contributions made to the Prince William Sound returns by hatchery and wild fish. Examination of the confidence intervals for the contributions (Tables 4, 5) shows that the coded wire tagging program has indeed furnished precise estimates of these quantities, and it appears that the tagging and sampling rates were adequate. The accuracy of the estimates depends upon whether certain assumptions, discussed later, were met.

Survival Rates of Hatchery Fish

The survival rate for pink salmon from the unoiled Solomon Gulch hatchery increased from 2.52% for the 1989 recovery year to 6.95% for the 1990 recovery year, while survival for the oiled A.F. Koernig hatchery increased only from 2.39% to 4.24% (Figure 6). While this trend is consistent with the notion of an oiling effect, the observation that survival rates of fish from the Cannery Creek hatchery, an unoiled facility, actually decreased from 5.80% to 4.30% between the 1989 and 1990 recovery years leaves the question of the existence of an oiling effect upon hatchery survival rates unanswered. It should be born in mind when considering such comparisons that there are many factors such as hatchery practices and non-oil-related environmental conditions which contribute to intra and interannual variabilty, and which confound the oiling contrasts.

Since combining survival data over all tag codes for each facility may have masked oiling effects, an analysis was effected whereby the variable tracked by the tags (feeding regime) was controlled. For one of the treatments, the survival rate of fish released from the A.F. Koernig hatchery in 1989 was found to be lower than those of fish from other PWSAC hatcheries released in the same year, while for fish released in 1988, a pre-spill year, the survival of fish from the A.F. Koernig hatchery was higher. Comparisons made for other treatments exposed opposite trends, however. The inability to show that the relative survival of fish released from the A.F. Koernig hatchery (*i.e.* compared to fish released from unoiled hatcheries) in pre-spill years did not decrease for post-spill years for all treatments means few conclusions can be drawn with respect to oiling effects upon survival.

Chum, sockeye and chinook salmon have variable marine residence times; consequently, returns of tagged fish are incomplete to date and survival rates of these release groups have not been determined. Whether survival rates of these species will be estimated will depend upon the availability of resources to conduct tag-recovery programs over the next few years.

Survival Rates of Tagged Wild Fish

Estimated survival rates of the tagged wild stocks returning in 1991 were considerably lower than those of the hatchery fish returning in the same year, and is probably a result of the improved nutritional status of outmigrating hatchery fry. A similar trend is found for those fish returning in 1992 (C.J. Peckham, Alaska Department of Fish and Game, Cordova, personal communication).

There was very little evidence of an oiling effect on survival rates of adult pink salmon returning to the six tagged streams in southwestern Prince William Sound in 1991 and 1992. It should be noted, however, that the small size of the experiment (three replicates) in conjunction with the inherently large variability of natural systems precluded detection of all but near-catastrophic effects of oiling on survival rates. It is estimated that in order to detect a difference in survival rates between oiled and unoiled streams, the populations from the former would have had to have been almost wiped out. Some mention should also be made regarding the effect of the lack of randomization of 'treatment' application to experimental units (streams) on any interpretations made from analysis of survival rates. Streams which became oiled tended to lie on the eastern side of islands in the southwestern part of Prince William Sound with the result that the oiling effect became confounded with geological and environmental factors. Another problem with the analysis pertains to the generation of unreasonably high estimates of adjustment factors for the streams in question (see below). Rather than use these estimates, it was decided to set the adjustment factors to 1.0 for all streams. The calculated survival rates are therefore underestimated. It is not thought that this action compromises treatment comparisons, however, since the underestimation is likely to be similar for all treatments (tagging methods were similar at all streams). Finally, it should be noted that no fry migrating from the streams during the year of the spill were tagged, and therefore no estimate is available to assess the influence of a direct exposure of wild fry to oil in the water.

Estimates of survival rates associated with tagged wild sockeye salmon cannot be made to date due to incomplete returns. Whether survival rates of wild sockeye salmon will be determined will depend upon the availability of resources to conduct tag-recovery programs and to operate weirs over the next 2 to 3 years.

Some Theoretical Issues of the Coded Wire Tagging Program

Assumptions

Although estimation of contributions and survival rates using coded wire tags in Prince William Sound is a complex problem, unbiased estimates can be obtained if the following assumptions are met:

1. The tagging rate is known exactly.
2. The number of fish in the fishery (or each recovery stratum) and the number of fish in the fishery sample are known exactly.
3. The tagged sample is a simple random sample (i.e. every fish in the collection of fish has an equal probability of selection independent of every other fish in the sample).
4. All marks in a sample are observed and all tags decoded.
5. The sample of the fishery is a simple random sample.
6. The use of adjustment factors is valid.

Most assumptions appear to have been met in the present study, although some improvements can be made in the future. The validity of each assumption is discussed below.

Assumption 1: Tagged and untagged fish were passed through electronic fry counters at the PWSAC hatcheries. Such devices are considered to be reliable and to yield estimates which are precise enough to be considered constants. The situation at the Solomon Gulch hatchery may be different; releases are estimated from estimates of egg counts, and the validity of treating these estimates as constants is debateable.

Assumption 2: Fish ticket data was used to estimate the number of fish on each tender as well as the total number of fish caught. For statistical purposes, these estimates were considered constants.

Assumption 3: A truly random sample can never be taken; however, the sampling procedure used to collect fish for tagging at all hatcheries and streams led to a sample which was as close to random as was practically possible.

Assumption 4: Chi-square tests showed that the proportion of clips observed in the sample agreed well with that observed in a near-census conducted at the mechanical heading device.

Assumption 5: The concept of obtaining a truly random sample from a processor is unrealistic. Efforts were made to limit bias, although the chances of obtaining a random sample from all fish aboard tenders unloading at a particular processor would be improved if a proportional sampling scheme was invoked, whereby each tender is sampled at an intensity related to its load (see below).

Assumption 6: There is little doubt that tags are lost from the population after tagging. Evidence for tag shedding derives from the observation that in the great majority of cases, the frequency of clip rates in returning hatchery fish possessing no tags is greater than the clip rate found in natural untagged populations (Peltz and Miller (1990), this report (Table 7)). While there is no direct evidence for elevated mortality of tagged fish, it is difficult to believe that it too does not contribute to the loss of tags from the population. Tags are thus lost from the population after application via tag-loss and possibly differential mortality and some correction for this is required if the estimation of hatchery contributions is to be unbiased.

Accounting for such losses through the use of adjustment factors will only be valid if the assumptions outlined earlier (Methods) have not been violated, namely that the pool of fish (brood stock, cost recovery or stream) from which adjustment factors are calculated consist only of fish reared in the hatchery or stream in question, that the tendency for tag loss is similar for all fish tagged at the same hatchery/stream, and that implanted tags do not induce straying.

In the present study, some very large adjustment factors were calculated for the tagged wild stocks (ranging from 7 to 216; median of 38). If the size of these adjustment factors is a reflection of tag shedding and/or differential mortality, then they should be used as determined. It is for such events that the adjustment factor was developed. Since adjustment factors calculated from hatchery brood stocks rarely exceeded 2.5, and tag shedding and differential mortiality are likely to be of the same magnitude for the wild tagging and hatchery tagging programs, it is believed that the above values are far too large to be accounted for by loss of tags from the population. Some alternative explanations are offered below.

One possibility is that the third assumption outlined in the Methods section, namely that tagging does not affect homing ability, has been violated. Morrison and Zajac (1987) found that implantation of half-length coded wire tags into the snouts of chum salmon (1500 fish/kg) resulted in visible damage to olfactory nerves in 18 of 44 fish studied. It may be argued that damage to pink salmon would be more severe, considering the increase in relative size of the invading tag (~4000 fish/kg). No direct evidence is available at this time, however, to indicate that olfactory damages were sustained by fish tagged in the current studies or to link such damage to changes in fish migratory behavior. In an attempt to further examine this phenomenon, Alaska Department of Fish and Game staff in Cordova plan to examine the placement of tags in fish returning in 1992 through X-ray imaging. A comparison will be made between the locations of tags in fish that had strayed and those found in fish that did not stray. A large-scale dual marking experiment is needed to definitively answer this question. One proposed experiment would mark fish with coded wire tags and also with a noninvasive mark, such as that produced on otoliths with thermal banding (Munk and Smoker 1990). Marks would be recovered at the hatcheries and streams, and a comparison between tag ratios in hatchery returns and those in returns to nonnatal areas would determine the effect of tagging upon homing ability. Against this hypothesis are the large differences in the calculated adjustment factors for the streams and hatchery brood stocks. Tagging methods are similar for the two programs, and any effect of tagging on homing ability might be expected to manifest itself equally in tagged hatchery and tagged wild fish, and therefore to lead to similar adjustment factors.

Another perhaps more acceptable hypothesis is that straying in the pink salmon populations of Prince William Sound is significant enough to cause the inflated adjustment factors (note that the estimates made for the streams were adjusted for the presence of hatchery fish, indicated by the presence of hatchery tags). Examination of Table 8 reveals that in 1991, non-native wild fish were found in 29 of the 32 surveyed streams. While the adjustment factors calculated from the Solomon Gulch and Cannery Creek brood stocks were not of the same magnitude as those derived for the streams, it is known that a significant spawning area for wild fish exists in the outlet streams at these facilities. For this reason, adjustment factors were calculated from cost-recovery harvests, in which it was rationalized that wild stocks would be more dispersed.

Finally, problems with fry enumeration techniques will manifest themselves in aberrant adjustment factor estimates. This potentially applies to the Solomon Gulch facility, where outmigrating fry were estimated from egg counts. Electronic fry counters were used at all other facilities.

Sampling Stratifications

The finest level of stratification used in this study was that of the processor. Differences between processors with respect to proportions of hatchery and wild fish arriving aboard tenders during specific district-week openings were detected (Figure 8) and stratification at the processor level appeared warranted.

It has been assumed that variability within the district-week processor stratum is low, and that stratification at the tender level is unnecessary. This has not been tested, however. A modification of the current sampling scheme is proposed which will accommodate the contingency that significant variability exists within strata (i.e. between tenders within processors). It is suggested that for future tag recovery programs, a proportional sampling strategy be implemented, whereby a set proportion of each tender's load is sampled. Currently, tenders are sampled on an "available effort" basis, so that sampling rates vary widely among tenders. This change would require little modification to current sampling procedures and database management practices.

While the proportional sampling strategy would solve problems associated with variability within a district-week-processor stratum, it is also desirable if in fact there is little variability within a stratum. Assumption 5 states that a random sample of fish is taken from all fish arriving at a processor. On average, a truly random sample will distribute itself approximately according to tender load. It follows that a proportional sample will tend to mimic a true random sample to a greater extent than one obtained with current methods.

Variance Estimation and Survival Estimate Distribution

Through comparisons with results from bootstrap techniques, Geiger (1990b) showed that the variance estimator defined in Equation 6 performed well. In the current study, samples could not be taken from every harvest-district-week-processor stratum because of resource limitations, although most such strata were sampled. Tag recoveries had to be estimated for unsampled strata, using data from strata sampled during that week. The variance estimate defined in Equation 6 ignores the variability associated with this estimation and a bootstrap analysis was conducted in which the variability of unsampled strata was accounted for. Little difference was found between standard error calculations based upon estimates of variances of contributions from Equation 6 and from the bootstrap analysis (Figure 7), suggesting that the estimator defined in Equation 6 was adequate. Frequency histograms of the bootstrap survival estimates revealed little evidence of non-normality and therefore classical normal-theory confidence intervals were considered appropriate.

Fisheries Management and the Coded Wire Tagging Program

The coded wire tagging program was originally developed to furnish data needed to estimate total wild and hatchery returns, as well as to facilitate direction of fishing effort towards more abundant hatchery stocks. While such functions are not directly related to damage assessment, some discussion of these roles is warranted when it is realized that amelioration of oil-induced damages to pink salmon populations must involve improved management of the exploitation of hatchery and wild stocks. The need for enhanced management is evident from the findings that over the three years covered by this study, at least 70% of the total pink salmon return was of hatchery origin (Table 4). Such a pattern inevitably leads to public pressure to open the fishery, and hence expose already-weak wild stocks to further risk.

There are two obvious ways coded wire tag data may be used in the management of a fishery. The first is to build a historical database in which the within-season spatial and temporal contributions of wild and hatchery fish to the commercial catch are recorded from year to year. While the interannual variability in hatchery contributions to the various time-space strata is significant, knowledge of trends in wild and hatchery contributions in specific areas at specific stages of a run helps managers make the day to day decisions necessary in the operation of the fishery. The coded wire tag data collected in 1989, 1990 and 1991 were used in this manner.

The second, and more desirable approach, is to assimilate coded wire tag data as it is collected during the fishing season. For this to be possible, highly efficient sampling, tag processing and data analysis are required. Only then will estimated hatchery contributions from area/time strata be meaningful on a real-time basis.

Experience in the use of coded wire tag data on an inseason basis was gained during the 1992 fishery (Restoration Study R60A). While this period is beyond the scope of this report, it is felt that the lessons learned would be valuable in future work, and are worth reporting here. It was hypothesized that the most readily available estimate of hatchery contributions could be obtained solely from adipose-clip data, with appropriate assumptions being made about natural clip occurrences. Indeed, a highly significant regression of number of tagged fish on number of adipose-clipped fish was obtained from historical data ($r^2 = 0.97$), which did not appear to depend upon year, fishery type (common property vs. cost-recovery), district or week. Through comparisons of contribution estimates made by this method to those made from actual tag data, it soon became apparent, however, that the method was inappropriate. While much of the variation in historical tag occurrences could be explained by clip counts, tag prediction intervals for 1992 were unacceptably wide, primarily due to the low numbers of clips recovered from the processors. The problems of the imprecision of the tag to clip regression were overcome by waiting for the Tag Lab to provide actual tag numbers. This method also performed poorly, however, probably due to the presence of wild stock tags within the Sound. Without complete tag decoding, wild tags were counted as hatchery tags and inflated the calculated proportion of hatchery fish. Thus for the 1992 fishery, only tag data associated with a complete analysis by the Tag Lab was useful. Such data did take longer to procure, but it was considered the only data upon which management decisions should be made. Future inseason estimates may be made more expediently since the necessity for complete tag decoding will no longer exist, due to the termination of the wild stock tagging program in 1991.

Whether such a program will in fact function in future years is dependent upon assignment of *Exxon Valdez* settlement monies. Without the program, managers will have little indication as to the composition of catches, and their ability to protect oil-injured wild stocks from exploitation will be severely compromised.

CONCLUSIONS

Coded wire tagging of hatchery salmon in Prince William Sound proved to be an effective method of partitioning the commercial catch into wild and hatchery-produced fish. For pink salmon, the most numerous and most commercially and ecologically important species, it is estimated that from 1989 through 1991, hatcheries contributed 17.2 (76%), 31.8 (71%) and 31 (81%) million fish to the commercial catch. Precise estimates of marine survival rates of hatchery-reared pink salmon were made and ranged from 2 to 8.5% over the years examined. No correlation was found between the location of hatcheries with respect to the oil plume and survival rate. Marine survival rates of tagged wild stocks were considerably lower than those of hatchery fish, and ranged from 0.02% to 3.17%. No significant differences in survival rates were detected among wild stocks originating from oiled and unoiled streams, although confounding environmental factors made it difficult to draw strong conclusions. Sockeye salmon survival rates cannot be calculated until 1995, when all brood years have returned and is contingent upon funding for tag recovery. Sufficient numbers of tags were applied for use in the juvenile salmon survival study (F/S 4).

The coded wire tagging program has functioned as a restoration tool since 1990. Fishery managers have used the information provided by this study to reduce exploitation of damaged wild pink salmon stocks by curtailing fishing in areas where large numbers of wild fish are harvested. This fishing effort was often redirected to areas where large numbers of hatchery fish are present.

LITERATURE CITED

Bailey, J.E. 1966. Effects of salinity on intertidal pink salmon survival *In* Proceedings of the 1966 Northeast Pacific Pink Salmon Workshop Oct. 3, 1966 pp. 12-15.

Clark, J.E. and D.R. Bernard. 1987. A compound multivariate binomial-hypergeometric distribution describing microwire tag recovery from commercial salmon catches in southeast Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Information Leaflet 261 Juneau.

GAUSS System, Version 3.0, 1992. Aptech Systems, Inc., 23804 S.E. Kent-Kangley Road, Maple Valley, WA 98038.

Geiger, H, J. 1990a. Pilot Studies in Tagging Prince William Sound Hatchery Pink Salmon With Coded-Wire Tags. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 90-02.

Geiger, H, J. 1990b. Parametric bootstrap confidence intervals for estimating contributions to fisheries from marked salmon populations. American Fisheries Society Symposium 7:667-676.

Geiger, H.J. and Sharr, S. 1990. The 1988 tag study of pink salmon from the Solomon Gulch Hatchery in Prince William Sound, Alaska, *In* Pilot studies in tagging Prince William Sound hatchery pink salmon with coded-wire tags. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 90-02 Juneau.

Kirkwood, J.B. 1962. Inshore marine and freshwater life history phases of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) in Prince William Sound, Alaska. Ph.D. Thesis. University of Louisville, 300 pp. Louisville, Kentucky.

McCurdy, M.L. 1979. Prince William Sound general districts 1979 pink and chum salmon forecasts, background, methods, and thoughts. Alaska Department of Fish and Game, Prince William Sound Management Area Data Report No. 14-1979.

Morrison J, and Zajac, D. 1987. Histologic effect of coded-wire tagging in chum salmon. North American Journal of Fisheries Management 7:439-441.

Munk, K.M. and W.W. Smoker. 1990. Temperature-induced marks in otoliths of pink salmon embryos. Juneau School of Fisheries and Ocean Sciences Report 90-01. University of Alaska, Juneau, Alaska.

Peltz, L. and Geiger, H.J. 1990. A tagging study of the effects of hatcheries on the 1987 pink salmon fishery in Prince William Sound, Alaska, *In* Pilot studies in tagging Prince William Sound hatchery pink salmon with coded wire tags. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 90-02 Juneau.

Peltz, L. and Miller, J. 1990. Performance of half-length coded wire tags in a pink salmon hatchery marking program. American Fisheries Society Symposium 7:244-252.

Rbase Version 4.0a, 1992. Microrim, Inc., 15395 S.E. 30th Place, Bellevue, WA 98007.

APPENDIX A

Bootstrap Standard Error of Survival Rates

The following describes the procedures used in generating bootstrap standard errors of the survival rates of release groups originating from pink salmon hatcheries in Prince William Sound in 1989. Standard errors based upon the variance estimator of Clark and Bernard (1987) (Equation 7) were also computed for comparison.

The following variables were transferred from an Rbase (1992) database to an ASCII file, loaded into GAUSS (1992) and sorted by tag code:

-tag code
-number of tags found
-harvest
-contribution of release group associated with tag code to catch
-district
-week
-catch
-sample size

The following manipulations were then performed on a tag code basis:

a) Strata (i.e. harvest, district, week, processor combinations) were divided into sampled strata, unsampled strata (which are, of course, the same for all tag codes) and escapement strata (i.e. instances where tags were recovered from surveyed streams).

b) From the sampled strata, bootstrap samples were taken. The following describes the selection of one such sample.

For each sampled stratum, the contribution estimate was used as the '*C*' parameter in the binomial distribution:

$$f\,(m|C,r/H) = \binom{C}{m}\left(\frac{r}{H}\right)^{m}\left(1 - \frac{r}{H}\right)^{C-m}, \qquad \text{(A1)}$$

(i.e. equation 1.2 of Geiger (1990))
where

C	= number of hatchery fish in catch,
r/H	= tagging rate (rate found in brood used) and,
m	= number of tags in catch.

A binomial random variable was generated from this distribution which was then used as the *M* parameter of the hypergeometric distribution:

$$f\,(x|M,N,s) = \frac{\binom{M}{x}\binom{N-M}{s-x}}{\binom{N}{s}}, \qquad \text{(A2)}$$

(i.e. equation 2.1 of Geiger (1990))

where

M = number of tags in catch,
N = number of fish in catch,
s = number of fish in sample and,
x = number of tags in sample.

The vector x̲ (over all sampled strata) represents one bootstrap realization of the sampled strata. Contributions were then calculated in the manner described above.

c) For each bootstrap sample, an estimate was then made of the contributions made by the unsampled strata. For each unsampled stratum, the contribution was calculated as follows:

$$Contrib = \left(\frac{catch\ in\ unsampled\ stratum}{Total\ \#\ sampled^{*}}\right) \text{X}\ \#\ tags^{*}\ \text{X}\ \frac{1}{tagging\ rate^{+}}\,. \qquad \text{(A3)}$$

* in the harvest, district, week stratum in which the unsampled processor lay.
\+ From brood, i.e. adjusted rate

The contribution from the escapement strata is measured without sampling error since virtually all fish in a surveyed stream are ultimately scanned.

For each bootstrap sample, survival estimates were calculated as follows:

$$Sv = \frac{\sum_{i=1}^{L} contributions_i}{H} \qquad \text{(A4)}$$

where

L = total number of strata from which tag code was recovered plus unsampled strata, and
H = total number of fish in the group labelled with tag code (i.e # released).

A bootstrap standard error of the survival estimates associated with a tag code was then calculated from the vector of n bootstrap Sv's.

APPENDIX B

A Statistical Test for the Adjustment Factor, a_h, (i.e of H_o: $a_h \leq 1.0$).

An estimate of the adjustment factor for hatchery h, ($\hat{a}_h$) is generated by:

$$\hat{a}_h = \frac{s_h}{\sum_i^T \frac{x_i}{p_i}}, \tag{B1}$$

where

T	=	number of tag codes released from hatchery h,
s_h	=	brood stock sample size associated with hatchery h,
p_i	=	tagging rate at release for tag code i, (defined as number of tagged fish released with code i divided by the total number of fish in release group i, and
x_i	=	number of tags of code i found in sample of size s_h.

To conduct a test of *Ho*: $a_h \leq 1.0$, an estimate of the standard error of the estimated adjustment factor is required, together with the assumption that the adjustment factor estimates are approximately normally distributed.

An assumption made in order to derive an approximate standard error for the estimated adjustment factor is that all tags released from a given hatchery are applied at the same rate (examination of release data reveals this to be a reasonable assumption).

With this assumption, Equation B1 becomes:

$$\hat{a}_h = \frac{s_h}{\frac{x_h}{p_h}} \tag{B2}$$

where

x_h	=	total number of tags found in the brood stock of hatchery h, and,
p_h	=	common tagging rate at release for hatchery h.

The variance of $\hat{a}_h$ is:

$$V(\hat{a}_h) = (s_h\, p_h)^2\, V\left(\frac{1}{X_h}\right) . \qquad \text{(B3)}$$

The random variable which represents the number of tags appearing in the brood stock (X_h), is generated by a binomial process, binomial (s_h, $p_h^/$), where $p_h^/$ is the proportion of returning hatchery fish bearing a tag. The variance of X_h is given by:

$$V(X_h) = s_h\, p_h^/ \,(1 - p_h^/) . \qquad \text{(B4)}$$

To derive the variance of $\frac{1}{X_h}$, the δ method was used:

$$V\left(\frac{1}{X_h}\right) \approx \frac{(1 - p_h^/)}{(s_h\, p_h^/)^3} , \qquad \text{(B5)}$$

leading to:

$$V\,(\hat{a}_h) \approx \frac{p_h^2\,(1 - p_h/)}{s_h\, p_h/3} . \qquad \text{(B6)}$$

The parameter $p_h/$ is unknown, and must be estimated from the data as $\frac{x_h}{s_h}$. The estimated variance of the estimated adjustment factor is then:

$$\hat{V}\,(\hat{a}_h) = \frac{p_h^2\left(1 - \left(\frac{x_h}{s_h}\right)\right)}{s_h\left(\frac{x_h}{s_h}\right)^3} , \qquad \text{(B7)}$$

with the estimated standard error:

$$\hat{SE}\,(\hat{a}_h) = p_h \sqrt{\frac{\left(1 - \left(\frac{x_h}{s_h}\right)\right)}{s_h\left(\frac{x_h}{s_h}\right)^3}}\ . \qquad \text{(B8)}$$

To make use of the above estimated standard error, the estimated adjustment factors must be assumed to be normally distributed. This assumption was assessed through an examination of the distribution of 1000 simulated adjustment factors. One thousand binomial outcomes were generated from a binomial distribution using values of 150,000 for s_h, and 0.002 for both p_h and $p_h/$ (null distribution). These are realistic values for the brood stock sample and the tagging proportion. Associated adjustment factors were calculated according to Equation B2. A frequency histogram for the generated adjustment factors (Figure B1) shows there to be little evidence of non-normality.

In addition to demonstrating the normality of the adjustment factor estimates under the null distribution, the simulation also provided a check of Equation B7. The estimated variance according to Equation B7 = 0.003326, while $s^2 \left(=\Sigma(a_i - \bar{a})^2/999\right)$, calculated from the vector of 1000 adjustment factors = 0.003349.

Though the adjustment factor appears normally distributed under the null hypothesis, Equation B7 nevertheless shows that the variance of the adjustment factor estimate is dependent upon its mean. The adjustment factor estimate cannot therefore be strictly normally distributed, and a log transformation may be warranted before the test described earlier is conducted. No such transformation was performed in this report.

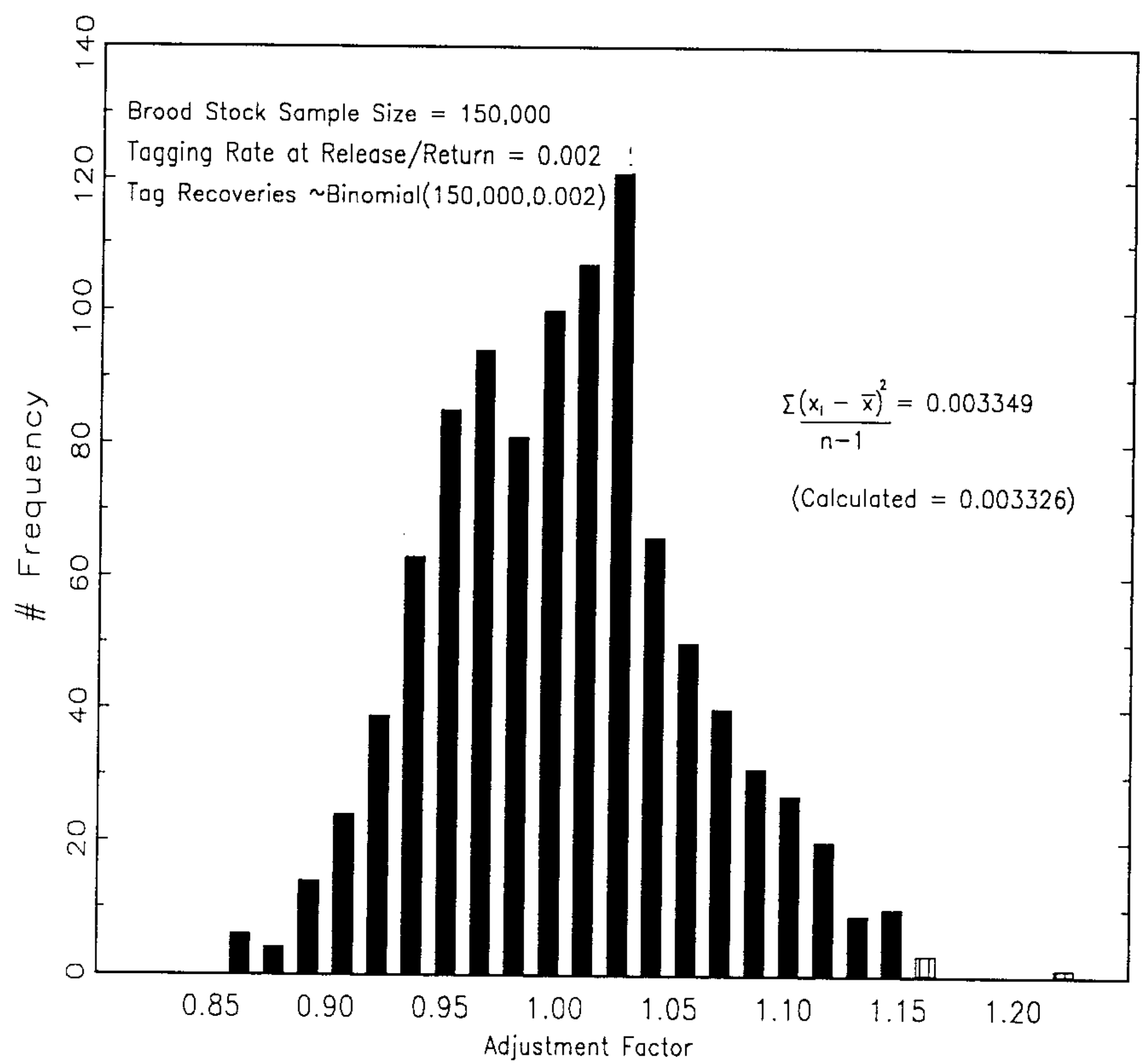


Figure B1. Frequency histogram of 1000 generated adjustment factors