# MARK-RECAPTURE POPULATION ESTIMATES OF COHO, PINK, AND CHUM SALMON RUNS TO UPPER COOK INLET IN 2002

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# ABSTRACT

This project estimated the total population sizes, escapements, and exploitation rates for coho, pink, and chum salmon returning to Upper Cook Inlet (UCI) in 2002 as a first step toward determining escapement levels needed to achieve sustained yields for these species. Mark-recapture techniques were used to estimate the total population sizes for each species returning to UCI as a whole. Salmon were tagged along a transect running from Anchor Point to the Red River delta on the west side of Cook Inlet during July and early August. Total population sizes for each species were estimated from recoveries of passive integrated transponder (PIT) tags in commercial fishery harvests. Recoveries of radio telemetry tags were used to estimate the total escapement of coho salmon into all UCI streams for comparison to the estimate derived from PIT tags. Radio telemetry tag data were also used to estimate coho salmon escapements into 33 streams and 5 areas around UCI. Our best PIT tag estimate of the total population size of coho salmon returning to UCI was 2.52 million (95% CI: 2.16-2.87 million). Given a commercial harvest of 0.25 million, the total escapement of coho salmon into all UCI streams was 2.27 million (95% CI: 1.91-2.62 million), and the exploitation rate in the commercial fishery was about 10%. Our radio tag estimate of the total escapement of coho salmon into all UCI streams was 1.36 million (95% CI: 0.98-1.96 million). Thus, our PIT tagging experiment estimated a population size for coho salmon entering UCI streams that was higher than the estimate obtained from radio tagging. Although, the 95% confidence intervals around the two estimates overlapped slightly, the z-test statistic indicated the two estimates were significantly different. Of the total coho salmon escapement into all UCI streams, 56% (0.76 million) returned to the Susitna and Little Susitna River drainages, 19% (0.26 million) returned to streams along the west side of UCI, 17% (0.24 million) returned to streams along Knik Arm, 5% (0.07 million) returned to streams along Turnagin Arm, and 3% (0.04 million) returned to streams on the Kenai Peninsula. However, these estimates for Turnagin Arm and Kenai Peninsula streams do not include the entire escapement, because we stopped tagging before the runs to these areas were complete. Our PIT tag estimate of the total population size of pink salmon returning to UCI was 21.28 million (95% CI: 1.60-40.96 million). However, this estimate was of questionable value due to its very low precision resulting from problems with tag recovery. Therefore, we estimated a maximum exploitation rate on pink salmon in the commercial fishery by simply summing escapements that were actually enumerated in 3 streams. Given a commercial harvest of 0.45 million, the maximum exploitation rate in the commercial fishery was about 12%. However, the actual exploitation rate must have been much lower, because we did not include escapements into numerous other streams around UCI. Our PIT tag estimate of the total population size of chum salmon returning to UCI was 3.88 million (95% CI: 3.30-4.47 million). Given a commercial harvest of 0.24 million, the total escapement of chum salmon into all UCI streams was 3.64 million (95% CI: 3.06-4.23 million), and the exploitation rate in the commercial fishery was about 6%. Despite uncertainty in our salmon population estimates, it is reasonable to conclude that exploitation rates on coho, pink, and chum salmon in the UCI commercial fishery were substantially below optimal rates in 2002.



KEY WORDS: Coho salmon, *Oncorhynchus kisutch*, pink salmon, *O. gorbuscha*, chum salmon, *O. keta*, mark-recapture, passive integrated transponder tags, radio telemetry tags, total population size, escapement, exploitation rate.

## INTRODUCTION

Commercial salmon fisheries in Upper Cook Inlet (UCI) generally target sockeye salmon, but coho, pink, and chum salmon are taken incidentally. In its 1999 meeting, the Board of Fisheries (BOF) directed the Alaska Department of Fish and Game (ADF&G) to develop a management plan for pink salmon and management strategies for chum salmon in UCI. Until that time, the BOF directed that no targeted pink salmon fishing would be allowed in UCI. The BOF further directed that no additional fishing periods would be allowed for the drift gillnet fishery outside the Kenai and Kasilof sections of the Upper Subdistrict until significant harvestable surpluses of chum salmon were available. The commercial sockeye salmon fishery in UCI in 2000 experienced a run failure. In August 2000, commercial fishermen petitioned the BOF to open fishing for pink salmon. Their request for an extended commercial fishery was denied, because of lack of escapement information for pink salmon and conservation concerns for coho salmon. At present, the ADF&G does not have a comprehensive program to estimate escapement, exploitation, and sustainable yields for coho, pink, and chum salmon in UCI. Although, escapements of these species are enumerated or partially enumerated at several weirs throughout the area, it is not known to what extent escapements in these systems represent overall production in the area.

The goal of this project was to estimate the total population size, escapement, and exploitation rates for coho, pink, and chum salmon returning to UCI. This project was a first step toward determining escapement levels needed to achieve sustained yields for these species.

Several methods have been used to assess stocks of salmon returning to UCI, but each has its limitations. Weirs have been used to enumerate salmon escaping to spawning grounds on numerous streams around UCI. While these projects can provide accurate estimates of stock size for individual small streams, escapement estimates from weirs on a small number of streams may not be representative of trends over the entire inlet. Mobile hydroacoustic surveys have been used to estimate salmon population size in UCI (Tarbox and Thorne, 1996), but these surveys only provide an estimate of the population size at the time of the survey, so multiple surveys would be required to estimate total run size and residence time would also need to be estimated. Aerial surveys provide a cost effective means to estimate salmon escapements over large areas, but the large number of occluded glacial streams in UCI preclude use of this technique in many systems. Side-scan sonars have been used to enumerate salmon migrating in several large glacial streams around UCI, but accurate estimates are difficult to obtain when species are mixed and migrating throughout the river cross section. Marine mark-recapture experiments can provide total population estimates for individual salmon species enabling escapements to be estimated after subtraction of the commercial harvest.

The methods used to estimate salmon population size by mark-recapture were initially developed in the 1930’s and 1940’s, but the correct conceptualization of analysis procedures were largely developed by Seber (1962, 1982). Historically within UCI, Thompson (1930) used mark recapture to investigate salmon migration patterns in the inlet. Likewise, Tyler and Noerenberg (1967) studied salmon migration and noted that nearly all salmon tagged north of Anchor Point were recaptured in UCI. Tarbox (1988) corroborated these findings. Since the late 1970’s, the ADF&G has conducted an offshore test fishing (OTF) project to estimate the population size of sockeye salmon returning to UCI during the fishing season. The test fishing vessel fishes a drift gillnet each day during July at 6 stations along a transect running from Anchor Point to the Red River delta on the west side of Cook Inlet (Figure 1). During 11 of the past 14 years, the catch per unit effort from the test fishing vessel has forecast the size of the sockeye salmon run into UCI to within 20% of the actual value (Shields 2003). Although, none of these studies used mark-recapture to estimate the size of salmon populations returning to UCI, they did lay the groundwork for mark-recapture population experiments by demonstrating that nearly all salmon migrating past Anchor Point were destined for streams in UCI.

Marine mark-recapture methods have been used successfully to estimate the size of salmon populations returning to Puget Sound and Kodiak Island. Eames et al (1981, 1983) tagged coho and chum salmon in northern Puget Sound to estimate returns to particular river systems in the region. They demonstrated appropriate use of stratified population estimators when multiple stocks were present and documented that short-term mortality associated with tagging these species in saltwater was insignificant. Likewise, Bevan (1962) estimated the size of sockeye salmon populations returning to Kodiak Island, Alaska, noting that the majority of the sockeye salmon returned to Karluk Lake. Bevan (1962) found that tag loss was about 10%, and that tagged fish exhibited a 48-hour lag before returning to the population. This finding was consistent with results from subsequent ultrasonic tagging studies which demonstrated that tagged salmon initially dive and remain at depth for about 48 hours before returning to the surface layer (Candy et al. 1996).

Most mark-recapture studies have used visible tags, but this approach can introduce an unknown bias into population estimates if fishermen discard tagged fish. To avoid this problem, we used Passive Integrated Transponder (PIT) tags that were injected into the fish and were not externally visible. These tags can also be detected using electronic equipment, so tag recovery in processing plants could be automated and made much less intrusive to processor operations. PIT tags are constructed with an integrated circuit chip connected to a tightly wound copper hoop antenna. The tags can be interrogated by 125 kHz signal from a scanning device. When the scanning device frequency excites the PIT tag, the tag emits a signal back to the receiver with a unique code (10-digit hexidecimal code displayed alphanumerically). The PIT tags are encapsulated in glass and are typically 12-mm long by 2.1-mm wide. PIT tags have been used extensively in research on salmonid survival (Prentice 1990; Skalski et al. 1998), movement (Prentice et al. 1990c, Hildebrand and Kirschner 2000) and behavior (Brannas et. al. 1994), as well as, crustacean research (Prentice et al. 1985; Pengilly and Watson 1994).

When properly injected in the body cavity, PIT tags have high retention rates (Prentice et al. 1990a) and mortality rates of tagged fish are low. Prentice et al. (1990a) found that tag retention rates in males (100%) were slightly higher than in females (99.7%) if egg skeins were not stripped from the fish. Prentice et al. (1990b) described a tagging method developed for Columbia River salmonid research, and Prentice et al. (1990a) noted that all wounds were closed and healing by the third day after maturing Atlantic salmon were PIT tagged. Prentice (1986) compared juvenile chinook salmon and steelhead trout that were PIT tagged with cold branding, coded wire tagging, cold branding and coded wire tagging, and a control group (handling but not tagged) at dams on the Columbia river. He noted no significant mortality of PIT tagged fish when compared to these other tagging methods. Similarly, Quinn and Peterson (1996) found no significant mortality of juvenile coho salmon that could be attributed to PIT tagging.

The fundamental assumptions of a mark-recapture experiment are: (1) the population is closed, (2) all fish have equal probability of being marked during the first sampling event, (3) tagged fish do not suffer greater mortality than untagged fish, (4) fish do not lose their marks, (5) no marks are overlooked, and (6) either marked and unmarked fish are uniformly mixed or the recaptures are a random sample (Seber 1982). Violation of these assumptions may not invalidate estimation of population size by mark-recapture, if the magnitude of the errors is known. We conducted several studies to estimate the magnitude of these sources of error and corrected for their effects on our population estimates.

We also applied radio tags to coho salmon migrating into UCI. This component of the project provided (1) a second estimate of the size of the total coho salmon population entering UCI streams for comparison to our estimate derived from recovery of PIT tags, (2) an estimate of the population size of coho salmon entering each major stream flowing into UCI, (3) estimates of the timing of various stocks of coho salmon migrating past the OTF transect, (4) estimates of the timing of various stocks of coho salmon entering their natal streams, and (5) estimates of the residence time and migration rate of coho salmon in UCI.

# OBJECTIVES

1. Estimate short-term tag mortality.
2. Apply PIT and radio tags.
3. Estimate rate of PIT tag loss.
4. Recover PIT tags at processors and estimate PIT tag detection rate.
5. Estimate salmon population sizes and evaluate sources of error.
6. Estimate escapements of coho salmon using radio telemetry.

# METHODS

*Objective 1: Estimation of short-term tag mortality*

In 2001, coho and chum salmon were captured by a chartered purse seine vessel and tagged to estimate short-term tag mortality. Dummy radio tags (n=200) were applied to coho salmon, and PIT tags (n=200) were applied to chum salmon. All tags were uniquely numbered, and the time each fish was tagged was recorded. The study on coho salmon was conducted in a lagoon near the Homer spit, and the study on chum salmon was conducted near the Wally H. Noerenberg hatchery in Prince William Sound. The methods used to handle and tag fish were similar to those used on the tagging vessels in UCI (objective 2). Tagged fish were immediately released to a floating net pen secured along side the tagging vessel and held for 48 hours. All mortalities were retrieved and the time each fish was held in the net pens prior to tagging was recorded. Mortalities were enumerated for 4 lots of 50 sequentially tagged fish, i.e. 0-50, 50-100, 100-150, and 150-200. Lots of 50 fish corresponded to holding times of about 60 mins each, since this was the time required to tag this number of fish. No control group was included in the study, because our goal was to estimate the mortality associated with handling and tagging. The survival of tagged fish in each of the lots was estimated from $S_t$=$m_t$/$T_t$, where $m_t$ was the number of live tagged fish from lot $t$ at the end of the experiment, and $T_t$ was the total number of fish tagged in lot $t$. The standard error of the estimate was calculated as described by Zar (1984).

*Objective 2: Application of PIT and radio tags*

In 2001, an approximately 52’ purse seine vessel (F/V Agave) was chartered from July 1 to July 15. This vessel fished an approximately 200-fm seine (3.5” mesh, 375 meshes deep) to capture salmon for tagging. However, the charter was terminated before the end of the project, so a second 58’ purse seine vessel (F/V Infinite Glory) was chartered from July 28 to August 4. This vessel fished an approximately 250-fm seine (3.5” mesh, 375 meshes deep). Lack of vessel support during the entire salmon run precluded our estimation of salmon population sizes in 2001. However, we were able to obtain useful information regarding catch rates, fish handling and tagging methods, tag retention rates, and some preliminary coho salmon escapement distribution data from radio tags. The methods used to capture, handle and tag fish in 2001 were generally similar to those used in 2002.
In 2002, two approximately 58’ purse seine vessels (F/V Just-in-Case and F/V Millenium) were chartered (July 2 – August 7) to capture salmon for tagging in UCI. Each vessel fished an approximately 250-fm

seine (3.5" mesh, 375 meshes deep). All salmon were tagged within about 5 km of the OTF transect that runs from Anchor Point to the Red River delta. Since, our goal was to tag a representative sample of salmon migrating into UCI, we attempted to tag fish near each of the six OTF stations each day. But, we also focused most of our fishing effort in areas along the OTF transect where salmon catches were highest, because the precision of our population estimate was dependent on the number of fish tagged and recovered. The seine was generally set in an approximate semi-circle, open into the current for 20 minutes at each station. After the seine was pursed, all jellyfish and other debris were removed from the bunt end of the seine. On board the F/V Just-in-Case, captured fish were rolled out of the seine into 1-2 totes along the port side of the vessel, and fish to be tagged were sent down a chute to a second set of totes on the starboard side of the vessel and sorted by species. On board the F/V Millenium, captured fish were generally brailed from the seine onto the deck and fish to be tagged were quickly sorted by species into a set of totes on the starboard side of the vessel. All totes used to hold fish prior to tagging were supplied with re-circulating seawater. Salmon captured in each net set were generally enumerated by species, but if a large number of a particular species was captured the number of that species was visually estimated. The start and stop time of each net set, coordinates (latitude, longitude), wind velocity, and stage of tide were recorded for each net set.

Immediately before tagging, fish were dip-netted from the re-circulating seawater tote into a clove oil bath. Clove oil was used as an anesthetic, because anesthetized fish could be harvested and consumed on the same day (Price and Powell 2000). The number of fish held in the totes and the time they were held was kept to a minimum to reduce mortality. Prior to tagging, each fish was removed from the clove oil bath, inspected to insure it had not already been tagged, measured (total length), and tagged with an individually identifiable PIT or radio tag. The time at which each fish was tagged was also recorded. PIT tags were applied to coho, pink and chum salmon, and radio tags were applied to a subsample of coho salmon each day. Radio tags were applied to coho salmon before fish were PIT tagged. We used 125 kHz cylindrical glass encased PIT tags (20 mm x 3.2 mm). A hypodermic needle was used to inject each PIT tag into the fishes' cheek muscle. The needles were periodically sterilized by immersion in a betadine solution. Radio transmitters (20 mm x 55 mm) were mounted externally on coho salmon about 3-4 cm below the dorsal fin. Two wires were passed through the fish, and the tag fixed by crimping a 2-cm diameter plastic Petersen disc tag (uniquely numbered) onto the wire. We used 729 unique transmitter codes with frequencies ranging from 150.054 – 150.963 mHz and 15 pulse codes within each frequency. Each transmitter weighed about 15 g and had a battery life of about 80 days. Each radio tag was scanned by a receiver to establish that it was transmitting before being attached to a fish. Each PIT tagged fish was scanned prior to release to establish that the tag was retained and detectable. Tagged fish were immediately returned to the sea.

We calculated the geometric mean catch per net set ($CPUE_i$) for sockeye, coho, pink, and chum salmon during five weekly (July 1-6, July 7-13, July 14-20, July 21-27, and after July 28) tag release strata (*i*) to evaluate the relative abundance of each species and their run timing across the OTF transect.

*Objective 3: Estimation of rate of PIT tag loss*

In 2001, a double-marking experiment was conducted with sockeye salmon to estimate the rate of PIT tag loss. The sockeye salmon used in this experiment were captured, handled, and PIT tagged using methods described in objective 2, but T- bar anchor/dart tags were also applied to these fish approximately 3-4 cm below the dorsal fin. Double-marked sockeye salmon were recovered by technicians in fish processing plants and by commercial and sport fishermen. An electronic PIT tag reader was used to scan each of these fish for the presence of a PIT tag. If a tag was not detected, the head was dissected to determine if the tag had been damaged and to evaluate how the tag may have been lost. The proportion of fish that retained a readable PIT tag was estimated from $c_L=m_p/m_d$, where $m_p$ was the number of double marked fish that retained a readable tag, and $m_d$ was the number of double-marked fish examined for PIT tags. The standard error of the estimate was calculated as described by Zar (1984).

*Objective 4: Recovery of PIT tags at processors and estimation of PIT tag detection rates*

Electronic PIT tag readers were installed at each major plant that processed salmon from UCI. The readers were most often installed on chutes immediately below the salmon header machines. These chutes were usually constructed of approximately 25-cm diameter PVC pipe cut longitudinally into half sections. Two hand-held racket antennas were attached to each chute using zipties to provide for redundancy in the detection of PIT tags. The two antennas were attached to the chute at different angles, because tag detection is a function of the angle of the tag in the electromagnetic field created by the antenna. The antennas were also attached as far as possible away from each other and from any metal or electric motors to reduce interference that might reduce tag detection. A PIT tag reader was attached to each antenna by a cable. The two readers needed for the installation on each chute were housed in a tote immediately below the processing line. An external 12V battery was used to power both readers. The configuration of the installation varied among processing plants depending on the design of the processing equipment. We made every effort to maximize tag detection rate given the constraints of the environment at each plant.

Technicians maintained the PIT tag readers and conducted tag detection tests at each processing plant on most days during the fishing season. Upon each visit to the plant, the technicians inspected the readers for any problems with the installation (e.g. loose antenna, error messages on the reader, water damage, etc.). The voltage on the external batteries was tested and the battery replaced with a newly charged one if the voltage dropped below 12V. Upon each visit, the technicians recorded date, time, processor, line number, PIT tag reader serial number, any problems with the reader, battery voltage, and whether the battery had been replaced.

In addition, technicians conducted tag detection tests upon each visit to each processor. These tests involved passing 50 dummy or actual salmon heads that had been previously PIT tagged past the antenna array attached to each chute. Dummy heads were constructed of styrofoam gillnet floats cut laterally in half and shaped like a salmon head. Actual salmon heads were also periodically retrieved from the heading machines, PIT tagged in the cheek and used for detection tests. Detection tests with dummy heads were conducted to monitor relative tag detection rates. Tests with actual heads were used to calibrate relative rates to actual rates. These tests were generally conducted with the processing equipment operating to replicate actual conditions during the heading operation. Detection tests were not conducted with actual heads at all times due to the extra work involved in periodically recycling these heads as they decomposed. Each set of heads used for detection tests was scanned by a PIT tag reader to create a file of the tag codes in the set. The tagged heads were tossed down the chute past the blade of the heading machine to simulate the actual heading process. After each tag detection test, the data from the two PIT tag readers attached to each chute was downloaded to a hand held computer. Later in the laboratory, the data from the hand held computer was downloaded to a desktop or laptop computer and an algorithm run to calculate detection rate. The algorithm compared the tag codes in the detection test set to the tag codes detected by the reader during the test. Tag detection was estimated for each day at each processor from $d= m_d/m_t$, where $m_d$ was the number of detected tags, and $m_t$ was the number of known tagged dummy or actual heads scanned. The algorithm calculated detection rate for each reader and for both readers combined, i.e. if a tag was detected by one reader but not the other. The algorithm wrote these three detection rates and a list of tag codes that were not detected to a file. Lists of undetected tag codes were periodically inspected to determine if specific codes were consistently not detected indicating damage to the tag.

Detection tests were conducted with dummy and actual salmon heads on the same processing lines at each plant on several different days. These data were used to calculate the difference between detection rates estimated using dummy versus actual heads. The Wilcoxon signed ranks test was used to test whether the mean difference of ranks was significantly different from zero (Conover 1999). The actual detection rate at each plant and processing line on each day of the season was estimated from tests conducted with actual heads when available. But, when only tests with dummy heads were conducted, the actual rate was estimated by adjusting the relative detection rate obtained using dummy heads by the mean difference between the rates measured using actual versus dummy heads.

An analysis of variance (ANOVA) was conducted to test whether detection rates differed among processing lines and among five tag recovery strata (July 1-6, July 7-13, July 14-20, July 21-27, July 28-August 3, and after August 4). An interaction term was included in the model, and the least-squares mean detection rate ($d_{kj}$) and standard error was estimated for each of $k$ processors\lines and $j$ recovery strata.

*Objective 5: Estimation of salmon population sizes and evaluation of sources of error*

A simple Petersen estimate of the size of the salmon population returning to UCI is given by

$$\hat{N} = \frac{n_1 \cdot n_2}{m_2} \tag{1}$$

where $n_1$ is the number of valid tagged fish released by the purse seine vessel at time 1, $n_2$ is the number of fish scanned for tags at time 2, and $m_2$ is the number of tagged fish recovered at time 2.

The Peterson estimator provides an unbiased estimate of population size when the following conditions are met: (1) all fish in the population have the same probability of being tagged, or all fish have the same probability of being caught in the second recovery sample, or tagged fish mix uniformly with untagged fish, (2) closed population, (3) no tag loss, (4) no tags overlooked, and (5) tagging has no effect on fish behavior. In the present study, we expect that assumption 1 is violated, because at a minimum fish would have to be tagged in proportion to their abundance as they cross the OTF transect, or commercial harvests would have to be randomly distributed, or fish tagged at the beginning of the run would have to mix equally with fish from the end of the run. One solution to this problem is to stratify by time.

A stratified Petersen method (Darroch estimator) was used to estimate the populations of coho, pink and chum salmon returning to UCI. We used a Stratified Population Analysis System (SPAS) software package developed specifically for analysis of data from stratified mark-recapture experiments (Arnason et al. 1996). This software allows researchers to define strata in space or time or both with the $s$ strata in which marking took place differing, if necessary, from the $t$ recovery strata. Arnason et al (1996) provided the following notation for mark-recapture experiments. The number of strata at tagging and recapture are denoted by $s$ and $t$, and statistics or parameters associated with these events are denoted by $c$ and $r$. The statistics are as follows:

$n_i^c$ number of fish marked in release stratum $i$, $i = 1 \ldots s$

$n_i^r$ number of fish taken in recovery stratum $j$, $j = 1 \ldots t$.

$m_{ij}$ the number of the $n_i^c$ recovered in stratum *j*

$u_j$ number of unmarked fish recovered in stratum *j*.

The parameters are as follows:

$N_i^c$ population size at initial (release) stratum *i*, *i* = 1…*s*

$N_j^r$ population size in final (recovery) stratum *j*, *j* = 1…*t*.

$p_i^c$ probability that a fish in the initial stratum *i* at capture time is captured in that sample; *i* = 1…*s*.

$p_j^r$ probability that an fish in final stratum *j* at recovery time is recaptured in that sample; *j* = 1…*t*.

$\theta_{ij}$ probability that a fish in stratum *i* at capture is in stratum *j* at recovery time.

$\mu_{ij}$ expected number of fish tagged in strata *i* that are recovered in strata *j*.

The above statistics and parameters can be arranged into a matrix (Table 1) with associated population parameters (Table 2). The total population at time of tagging ( $N_.^c$ ) is then given by

$$N_.^c = \sum_{i=1}^{s} N_i^c \tag{2}$$

And, total population at time of recovery ( $N_.^r$ ) is given by

$$N_.^r = \sum_{j=1}^{t} N_j^r \tag{3}$$

It is assumed that no part of the population enters recovery strata without being part of one of the tagging strata. To couple tables 1&2, the usual assumptions associated with mark-recapture experiments are required, and it is also assumed that: (1) fish behave independently of one another with respect to movement among strata, (2) all tagged fish released in a stratum have the same probability distribution of movement to recovery strata, (3) all fish in a recovery stratum behave independently in regard to being caught and all have equal probability of being caught, (4) no tags are lost, and (5) tags are recorded properly and correctly upon detection (Schwarz and Taylor 1998).

In addition, one or both of the following assumptions are made depending on whether the goal of the study is to estimate the number of fish in the tagging or recovery strata: (6a) movement pattern, death, migration rates for both tagged and untagged fish are the same in each tagging stratum (required to estimate the total population in the tagging strata), and (6b) the population is closed with respect to movement among strata (required to estimate the total population in the recovery strata). Given these assumptions the expected values of the statistics in table 1 can be written in terms of the following parameters (Table 3).

Let $\theta_{ij}$ equal the probability that a fish captured in tagging stratum *i* will survive and migrate to recovery stratum *j*, and let $N_{ij}$ be the corresponding number of fish. If the population is closed, $\theta_i$=1 for *i*=1,…,*s*. and by definition

$$q_{ij} = \frac{N_{ij}}{N_i^c}, i = 1,\ldots,s,\ j = 1,\ldots,t \tag{4}$$

There are a total of *st* + *s* + *t* parameters, the movement parameters, the initial capture probabilities, and the recovery probabilities. With these parameters certain functions can be estimated under two different scenarios (Schwarz and Taylor 1998).

First, the number of tagging strata may be less than or equal to the number of recovery strata ($s$      $t$). Given assumption 6a, (same movement patterns of tagged and untagged fish, but not necessarily closure over recovery strata), Banneheka et al. (1997) showed that fish in the population at time of tagging could be estimated.

Given this scenario, the above models can be parameterized with $st+2s$ parameters. The expected number of fish moving from tagging strata $i$ to recovery strata $j$ that are tagged and recovered ($st$ parameters) is given by

$$m_{ij} = N_i^c p_i^c q_{ij} p_j^r ; \tag{5}$$

the odds that a fish will not be captured at tagging stratum $i$ ($s$ parameters),

$$b_i = \frac{1-p_i^c}{p_i^c} ; \tag{6}$$

and the expected number of fish tagged in stratum $i$ and never recovered ($s$ parameters),

$$g_i = \sum_{j=1}^{t} N_i^c p_i^c q_{ij} \left(1-p_j^r\right). \tag{7}$$

One can describe the expected values of the observed statistics and the number of fish not seen (Schwarz and Taylor 1998).

The $\{b_i\}$ are then essentially weights that can be used to construct a linear combination of the rows of the $E[m_{ij}]$ that equals the $E[u_j]$. Thus, we can solve for the $\{b_i\}$ to minimize the sum of squares of the predictions, i.e.

$$\sum_{j=1}^{t}\left(u_j - \sum_{i=1}^{s}\hat{b}_i m_{ij}\right)^2 . \tag{8}$$

However, we used an alternative iterative maximum-likelihood technique to estimate the $\{b_i\}$, because this approach allows uncertainty in the $m_{ij}$ to be included in the estimation procedure (Plante 1990; Plante and Rivest 1995). This procedure finds estimates of the $\{b_i\}$ that best predict the $\{u_j\}$ while allowing the $\{m_{ij}\}$ to vary around their observed values in a way that is consistent with observed data but also improves the fit (Schwarz and Taylor 1998).

We also calculated the effective number of tags released in each strata (Arnason et al. 1996) by correcting for tagging-induced mortality $\{S_t\}$ and tag loss $\{c_L\}$, i.e.

$$n\_eff_i^c = n_i^c \cdot S_t \cdot c_L . \tag{9}$$

Two estimates of the coho salmon population were computed. The first estimate was corrected for short-term tag mortality, and the second estimate was corrected for long-term tag mortality. Short-term tag mortality was estimated from our net pen studies (objective 1). Long-term tag mortality was estimated from the ratio of the total number of radio tags recovered and the total number applied to coho salmon. This method provides an estimate of the minimum fraction of tagged coho salmon that survived and migrated through the recovery area (commercial fishing districts).

We further calculated the effective number of tags recovered by correcting for tag detection $d_{kj}$ at each processor ($k$) during each recovery strata ($j$), i.e.

$$m\_eff_{ij} = \frac{m_{ij}}{d_{kj}} . \tag{10}$$

Note that corrections for tag mortality, tag loss, and tag detection were made to minimize bias in the population estimates. However, these corrections add variation that was not accounted for in the standard errors and the confidence intervals for the population estimates (Arnason and Mills 1981).

We initially established weekly tagging and recovery strata (July 1-6, July 7-13, July 14-20, July 21-27, July 28-August 3, and after August 4). Once the model was fit, goodness-of-fit tests were conducted to test whether any of the following conditions were satisfied:

1. the recovery probabilities were constant across strata,
2. the (expected) ratio of marked to unmarked fish was constant across all recovery strata. This could have been achieved in one of several ways. Two possibilities were:
   (a) the proportion of each initial stratum marked was constant across all capture strata and marked and unmarked animals experienced the same migration patterns, or
   (b) the migration pattern of marked and unmarked animals across final strata was independent of their initial strata (Arnason et al. 1996).

A ‘complete mixing’ test was used to test the hypothesis that the probability of resighting a released animal was independent of its stratum of origin. An ‘equal proportions’ test was used to test the hypothesis that the ratio of marked to unmarked animals was constant across recovery strata (Arnason et al. 1996). If either test passes (i.e. $p$>0.05), it should be possible to pool strata, but this is unusual in practice (Arnason et al. 1996). In either case, failure to pass these tests does not preclude pooling, other factors must be considered (Arnason et al. 1996). Pooling strata can increase the precision of the estimate but will introduce bias if done improperly. Other than goodness-of-fit statistics, there are no formal tests to determine if one should pool or drop strata.

The $c^2$ and $G^2$ goodness-of-fit statistics were computed to evaluate model fit, i.e.

$$c^2 = \sum_{i=1}^{s}\sum_{j=1}^{t}\frac{(m_{ij}-\hat{m}_{ij})^2}{\hat{m}_{ij}} + \sum_{j=1}^{t}\frac{(u_j-\hat{u})^2}{u_j} + \sum_{i=1}^{s}\frac{(n_i^c - m_{i.} - \hat{g}_i)^2}{\hat{g}_i} \tag{11}$$

or the

$$G^2 = 2\left[\sum_{i=1}^{s}\sum_{j=1}^{t} m_{ij}\ln\left(\frac{m_{ij}}{\hat{m}_{ij}}\right) + \sum_{j=1}^{t} u_j \ln\left(\frac{u_j}{\hat{u}_j}\right) + \sum_{i=1}^{s}\left(n_i^c - m_{i.}\right)\ln\left(\frac{n_i^c - m_i}{\hat{g}}\right)\right]. \tag{12}$$

The following factors were considered when identifying strata to pool: (1) elimination of strata with E[$m_{ij}$]<5, (2) pooling of adjacent strata with similar initial capture or recapture probabilities, and (3) minimization of the standard error of the estimate. Poolings that resulted in a large change in the $G^2$ statistic or standard error of the population estimate (greater than 1 SE) were considered questionable (Arnason et al. 1996). In addition, strata were dropped if the number of tags released or recovered was very small. This was necessary to minimize the number of cells with E[$m_{ij}$]<5.

Finally, we conducted 5 analyses to evaluate sources of error in our population estimates. The first 2 analyses were focused on whether the salmon tagged in our study were exclusively migrating north into UCI. We first conducted a chi-square test of the null hypothesis that the probability of recapturing PIT tagged salmon did not differ for fish that were captured north versus south of 59.852$^o$ N latitude. Approximately, one half of the salmon PIT tagged in our study were tagged north of this latitude. Second, we conducted a chi-square test of the null hypothesis that the probability of recapturing PIT tagged salmon did not differ for fish that were captured during ebb, flood, or slack tides. Next, we conducted a chi-square test of the null hypothesis that the probability of recapturing PIT tagged salmon did not differ among three groups that were held on the tagging vessels for <30 mins, 30-60 mins, and

>60 mins. Since time was recorded when each fish was tagged, we were able to include all of our PIT tag data in this analysis. In these first 3 analyses, separate tests were conducted for each species and for all species combined. A fourth chi-square analysis was conducted to test the null hypothesis that the probability of recapturing PIT tagged salmon did not differ among six length classes (<50 cm, 50-55 cm, 55-60 cm, 60-65 cm, 65-70 cm, >70 cm). This analysis was conducted with all species combined, and the length distribution of each species was also calculated for comparison. A final chi-square analysis was conducted to test the null hypothesis that the ratio of the number of tagged to untagged salmon did not differ among seven processors in UCI. Separate analyses were conducted for each species.

*Objective 6: Radio telemetry study on coho salmon*

Radio tagged coho salmon were tracked from a fixed-wing aircraft using a receiver interfaced with a data collection computer (Advanced Telemetry Systems) and controlled by an external hand-held computer interfaced with a global positioning system. The coordinates and altitude of the aircraft were continuously logged at user defined distance intervals usually between 50 and 100 m. This system allowed tags to be quickly interrogated with data regarding frequency, pulse code, number of hits, date, time of day, and coordinates of each tag easily logged to a data file in flight. The data collection computer was set to cycle between frequencies at intervals from 1-2 seconds per frequency. In 2002, streams flowing into UCI were surveyed once each week from mid July through September. On August 22 & 29, streams south of the OTF transect were surveyed once to determine if any radio tagged coho salmon migrated southward. This survey covered streams south to Cottonwood Bay on the west side of the inlet and on the east side from Port Graham into Kachemak Bay. Only the lower portions of each watershed were surveyed during these flights to minimize cost and survey time. Later in October 2002, most of the UCI drainage basin was surveyed to document the location of tagged salmon within each watershed. Anchorage area streams and streams south of Big River were not included in these surveys of the entire drainage basin. In 2001, only one aerial survey was conducted to locate any tags that had entered the lower portions of streams flowing into the inlet. In 2001 and 2002, fixed receivers were operated on the Susitna River near Susitna Station and on the Yentna River approximately 3 miles above the Yentna sonar site. Receivers operated by the Sport Fish Division of ADF&G scanned for tags on the Kenai, Kasilof, and Swanson rivers. All of the analyses described below were conducted using data from 2002 except that a map of the distribution of radio tag recoveries around UCI was constructed using data from 2001.

We initially used our radio tag data to estimate the total population size of coho salmon entering UCI streams for comparison to our PIT tag estimate. Radio tag recoveries and coho salmon weir counts were available from five streams flowing into northern Cook Inlet (Deshka R., Little Susitna R., Fish Creek, Cottonwood Creek, and Wasilla Creek). We initially considered those portions of the five streams above the weirs as five recovery strata with a single release stratum. The statistics were the total number of radio-tagged coho salmon located in all UCI streams including those caught in recreational fisheries ($n_1$), the number of coho salmon counted through each of the $j$ weirs ($n_{2j}$), and the number of radio-tagged coho salmon located above each of the $j$ weirs ($m_{2j}$). Radio tags not located in freshwater (i.e. captured in the commercial fishery, etc.) were excluded from this analysis, because we were estimating only the population size of coho salmon that entered freshwater. We next conducted a chi-square test of the null hypothesis of equal marked proportions among recovery strata. The pooled-Petersen method was then used to estimate the total population size of coho salmon entering all UCI streams ($N_{Radio}$) derived from radio tag recoveries. Since, the sample size was relatively small, an inverse cube root transform of the estimate was used to calculate the confidence interval (Arnason et al. 1991).

Our PIT tag estimate of the total population of coho salmon returning to UCI was then used to calculate the population size of coho salmon entering all UCI streams ($N_{PIT}$) by subtracting the commercial harvest from the total population. The PIT and radio tag estimates of the population of coho salmon entering all UCI streams were then compared. The z-test statistic was used to test whether the two estimates differed, i.e.

$$z = \frac{N_{PIT} - N_{Radio}}{\sqrt{\mathrm{Var}\left(N_{PIT} - N_{Radio}\right)}}, \tag{13}$$

where

$$\mathrm{Var}\left(N_{PIT} - N_{Radio}\right) = \mathrm{Var}\left(N_{PIT}\right) + \mathrm{Var}\left(N_{Radio}\right). \tag{14}$$

This test assumes that the two abundance estimates are independent and normally distributed.

The escapement of coho salmon into each of 33 major streams ($N_k$) was estimated from

$$N_k = p_k \cdot N_T, \tag{15}$$

where $p_k$ was the weighted proportion of the total number of recovered radio tags ($m_{ik}$) from tagging strata $i$ found in freshwater in each ($k$) stream, i.e.

$$p_k = \frac{\sum_i w_i m_{ik}}{\sum_k \sum_i w_i m_{ik}}. \tag{16}$$

To correct for apparent unequal tagging proportions among release strata, the number of radio tags ($m_i$) recovered in each stream was weighted ($w_i$) by the mean $CPUE_i$ in each ($i$) release stratum and the inverse of the proportion of tags used in release strata $_i$, i.e.

$$w_i = \frac{CPUE_i \Big/ \sum_i CPUE_i}{m_i \Big/ \sum_i m_i}. \tag{17}$$

The variance of the estimated escapement of coho salmon into each stream, $Var(N_k)$, was estimated from

$$Var(N_k) = N_T^2 Var(p_k) + p_k^2 Var(N_T) - Var(p_k) Var(N_T) \tag{18}$$

(Goodman 1960). An estimate of the variance of $p_k$ was derived from

$$\mathrm{Var}(m_{ik}) = M_i \left(\frac{m_{ik}}{M_i}\right)\left(1 - \frac{m_{ik}}{M_i}\right), \tag{19}$$

$$\mathrm{Var}(w_i m_{ik}) = w_i^2 M_i \left(\frac{m_{ik}}{M_i}\right)\left(1 - \frac{m_{ik}}{M_i}\right), \tag{20}$$

$$\mathrm{Var}\left(\sum_i w_i m_{ik}\right) = \sum_i w_i^2 M_i \left(\frac{m_{ik}}{M_i}\right)\left(1 - \frac{m_{ik}}{M_i}\right), \tag{21}$$

$$\mathrm{Var}\left(p_k\right) = \mathrm{Var}\left(\frac{\sum_i w_i m_{ik}}{\sum_k \sum_i w_i m_{ik}}\right), \tag{22}$$

$$\mathrm{Var}(p_k) = \frac{\sum_i w_i^2 M_i \left(\frac{m_{ik}}{M_i}\right)\left(1 - \frac{m_{ik}}{M_i}\right)}{\left(\sum_k \sum_i w_i m_{ik}\right)^2}, \tag{23}$$

where $M_i = \sum_k m_{ik}$ = number of radio tags from strata *i* recovered in freshwater.

The same method was used to estimate the escapement of coho salmon into 5 areas (Westside, Susitna, Knik Arm, Turnagin Arm, and Kenai Peninsula) around UCI by simply pooling the data from streams within each area. The area called 'Westside' included all streams flowing into UCI west of the Susitna River. Pooling tags recovered in these five areas increased the number of tag recoveries and narrowed the confidence intervals around the estimated population sizes.

We then examined the distribution of radio tag recoveries among the 33 streams flowing into the inlet by their date of release from the tagging vessels. The weighted proportion of the total number of recovered radio tags (in freshwater) found in each stream was plotted on a map of UCI using data for releases prior to and after July 20. This analysis was conducted using data from 2001 as well as 2002 for comparison of distributions between years, but proportions were not weighted in the 2001 analysis due to lack of *CPUE* data throughout the entire run. Next, we examined the timing of seven stocks of coho salmon migrating past the OTF transect by estimating the proportion of total radio tag recoveries in each area by their date of release from the tagging vessel. The seven stocks were defined by the five areas previously described except Susitna R., Yentna R., and Little Susitna R. were treated as separate stocks, because there were sufficient tag recoveries in these streams for the analysis. We conducted a chi-square test of the null hypothesis that the proportion of total tags recovered for each stock did not differ by their date of release. The first release stratum and the Kenai Peninsula stock were omitted from the chi-square analysis, because the small number of tag recoveries in these cells resulted in expected values less than five. We also examined the run timing of these seven stocks of coho salmon into freshwater using the date each radio tag was first detected in each stream. Radio tags returned by recreational fishermen were not included in this analysis, because the date of entry of these fish into freshwater could not be precisely determined. We conducted a chi-square test of the null hypothesis that the proportion of total tags recovered for each stock did not differ by their date of entry into freshwater. Six recovery strata were established for this analysis (July 14-20, July 21-27, July 28-Aug. 3, Aug. 4-10, Aug. 11-17, after Aug. 18). The first and last recovery strata and the Kenai Peninsula and Turnagin Arm stocks were omitted from this chi-square analysis, because the small number of tag recoveries in these cells resulted in expected values less than five. We further examined the migration patterns of coho salmon through UCI by estimating the proportion of total radio tags recovered by their date of release and their date of entry into freshwater. This analysis was conducted for all stocks pooled and for each of the seven stocks separately.

Residence times and migration rates of coho salmon were examined in relation to stock of origin and migration timing across the OTF transect. Residence time was estimated by the difference between the date each fish was first detected in freshwater and its date of release from the tagging vessel. The straight-line distance from the OTF transect to the mouth of each stream was used as a measure of the minimum distance each fish traveled in the inlet. Migration rate was estimated by the ratio of the minimum distance traveled and residence time in the inlet. Two ANOVAs were conducted to test the null hypotheses that mean residence time and mean migration rate did not differ by stock of origin or date of release. Each dependent variable was natural-logarithm transformed prior to the analysis and an interaction term was initially included in the model. Finally, we examined travel times for coho salmon between our fixed radio tag receivers at Sunshine Station and Yentna R. An ANOVA was conducted to test the null hypothesis that travel times (natural-logarithm transformed) did not differ by the date each fish was first detected by the receiver at Sunshine Station.

**RESULTS**

*Objective 1: Estimation of short-term tag mortality*

Survival ($S_t$) of tagged coho salmon declined from 88% to 56% as holding time increased from less than 83 mins to 251 mins (Table 4). Survival of tagged chum salmon was consistently high and not clearly related to holding time. Since our study on coho salmon was conducted in a shallow lagoon, tagged salmon may have been exposed to anoxic mud near the bottom of the net pen. It is not clear whether this affected our results, but this was not a factor in our study on chum salmon, because it was conducted in a deep bay.

*Objective 2: Application of PIT and radio tags*

The number of net sets made during five weekly time periods ranged from 34 to 75 (Table 5). The number of sets made each week was lowest during late July, because *CPUE* peaked at this time so fewer sets were required to catch the fish needed for tagging. Also, we restricted the number of PIT tags applied each day during this time to avoid exhausting our supply of tags. The *CPUE* for all 4 species of salmon peaked the third week of July, and it was highest for sockeye salmon (Table 5). The *CPUE* for sockeye and chum salmon declined at a greater rate in late July than it did for coho and pink salmon. PIT tags were applied to 4,925 coho salmon, 5,338 pink salmon, and 5,071 chum salmon (Table 6). Radio tags were applied to 729 coho salmon. The total catch of coho, pink, and chum salmon declined at a slower rate in late July than did the *CPUE*. The number of net sets made each day was increased during this period to maintain the number of tags released.

*Objective 3: Estimation of rate of PIT tag loss*

One hundred and sixty eight double-marked sockeye salmon were recovered to estimate PIT tag loss. Seventy nine percent of these fish were recovered at processors and the remainder in the escapement or recreational fishery. One hundred and fifty three ($c_L$=0.91, SE=0.02) of these fish retained a readable PIT tag. We did not find any PIT tags that could no longer be decoded by the electronic PIT tag reader, and we found no difference between the lengths of those fish that retained versus lost the PIT tag.

*Objective 4: Recovery of PIT tags at processors and estimation of PIT tag detection rates*

PIT tag readers were installed at seven plants that processed salmon harvested in UCI. The configuration of processing equipment at Ocean Beauty and Snug Harbor prevented an effective installation of PIT tag readers prior to July 27. Modifications were made to the equipment at these plants allowing readers to be installed and operated after that date. We scanned 73% of the commercial harvest of coho salmon, 42% of the pink salmon harvest, and 75% of the chum salmon harvest in UCI in 2002. The fraction of the pink salmon harvest that we scanned was relatively low, because several processors did not pass pink salmon through the heading machines.

The mean difference between detection rates estimated using dummy versus actual salmon heads ranged from 0 - 0.47 (Table 7). These mean differences were used to adjust detection rates estimated using dummy heads at the four plants listed in Table 7. The relatively large adjustment factor at Salamantof was only applied prior to July 23 when all tests were conducted with dummy heads. On that date, the configuration of the antenna array at Salamantof was modified, and all subsequent tests were conducted with actual salmon heads. No adjustments were necessary at Ocean Beauty and Snug Harbor, because all detection tests were conducted with actual salmon heads at these plants. An ANOVA indicated that mean detection rates differed significantly ($p$<0.001) among processors and recovery strata. At Icicle Seafoods and Ocean Beauty, detection rates also differed ($p$<0.05) among processing lines. Mean detection rates ($d_{kj}$) ranged from 0.37 on line 3 to 0.98 on line 2 both at Icicle Seafoods (Table 8). The low rate on line 3 was due to the configuration of the processing equipment. This line was only used to process pink salmon.

*Objective 5: Estimation of salmon population sizes and evaluation of sources of error*

Of the 4,925 PIT tags applied to coho salmon, we detected 167 at the 7 salmon processors included in our study (Appendix 1). When the total number of tags applied was adjusted for short-term tag mortality and tag loss, the effective number of tags released was reduced to 3,944 (Table 9). A short-term survival rate of 0.88 (SE=0.05) was used in this analysis, because this was the survival of coho salmon held less than 83 mins prior to tagging in our net pen study, and most of the coho salmon tagged in UCI were held for less time. When the number of tags recovered was adjusted for tag detection, the effective number of recovered tags was increased to 214. In every case, the peak number of recoveries from each release stratum occurred one week after release, and tags from each release stratum were recovered over a 3-4 week period after release. No tags were recovered from the first release stratum during the first week of July, and no tags were detected at processors during the first two recovery strata. These strata were dropped from the analysis. The remaining strata included 98% of the harvest that was scanned for tags. We attempted several different poolings. The final model, which produced the lowest standard error of the population estimate, involved pooling recovery strata for the weeks beginning July 14 and 21 (Table 10). This model resulted in 1 of 12 cells with $E[m_{ij}]<5$. The $G^2$ statistic for this model indicated no significant difference ($p$=0.08) between observed and fitted recoveries ($m_{ij}$). The estimated population size was 3.22 million with a 95% confidence interval from 2.76-3.68 million. The estimated population size was greatest during the middle of July. For comparison, the pooled Petersen population estimate was 3.19 million.

We also estimated the coho salmon population after adjusting the number of tags released for long-term tag mortality and tag loss. Long-term tag mortality was estimated from recoveries of radio-tagged coho salmon. We located 518 of 729 radio-tagged coho salmon released resulting in a long-term minimum survival of 0.71 (SE=0.02). The strata retained and the final pooling were the same as in the previous analysis. The $G^2$ statistic also indicated no significant difference ($p$=0.08) between observed and fitted recoveries (Table 11). The estimated population size was 2.52 million with a 95% confidence interval from 2.16-2.87 million. The estimated population size was greatest during the middle of July. For comparison, the pooled Petersen population estimate was 2.58 million.

Of the 5,333 PIT tags applied to pink salmon, we detected only 45 at processing plants (Appendix 1). When the total number of tags applied was adjusted for short-term tag mortality and tag loss, the effective number of tags released was reduced to 4,809 (Table 12). When the number of tags recovered was adjusted for tag detection, the effective number of recovered tags was increased to 85. This relatively large adjustment to the tag recoveries for pink salmon resulted in large part, because the greatest numbers of pink salmon were processed at Icicle Seafoods, and all of these fish were processed on line 3, which had a fairly low tag detection rate. The peak number of recoveries from most release strata occurred one week after release with one exception. The peak number of recoveries from the last release strata occurred during the same week the fish were released. Also, the period of time over which tags were recovered was less for pink than coho salmon. Tags from each release strata were recovered over a 1-3 week period after release. As with coho salmon, no tags were recovered from the first release stratum, and no tags were detected at processors during the first two recovery strata. These strata were dropped from the analysis. The remaining strata included 99% of the harvest that was scanned for tags. Several different poolings were attempted, the final model involved pooling recovery strata for the weeks beginning July 21 and 28 (Table 13). This model resulted in 6 of 12 cells with $E[m_{ij}]<5$. The $G^2$ statistic for this model indicated no significant difference ($p=0.61$) between observed and fitted recoveries ($m_{ij}$). The estimated population size was 21.28 million, but the precision was poor with a 95% confidence interval from 1.60-40.96 million. The estimated population size was greatest during the first week of August. For comparison, the pooled Petersen population estimate was 13.92 million.

Of the 5,071 PIT tags applied to chum salmon, we detected 154 at the 7 salmon processors included in our study (Appendix 1). When the total number of tags applied was adjusted for short-term tag mortality and tag loss, the effective number of tags released was reduced to 4,568 (Table 14). When the number of tags recovered was adjusted for tag detection, the effective number of recovered tags was increased to 197. Tags were recovered in all recovery strata. Similar to pink salmon, the peak number of recoveries from most release strata occurred one week after release with one exception. The peak number of recoveries from the last release strata occurred during the same week the fish were released. Recovery strata beginning July 1 and August 4 were dropped from the analysis, because of the relatively small number of chum salmon scanned for tags and small number of tags recovered in these strata. The remaining strata included 92% of the harvest that was scanned for tags. We attempted several different poolings. The final model involved pooling release strata for weeks beginning July 1 and 7, and July 21 and 28. Also, recovery strata were pooled for weeks beginning July 7 and 14, and July 21 and 28 (Table 15). This model resulted in no cells with $E[m_{ij}]<5$. The $G^2$ statistic for this model indicated no significant difference ($p=0.95$) between observed and fitted recoveries ($m_{ij}$). The estimated population size was 3.88 million with a 95% confidence interval from 3.30-4.47 million. The estimated population size was greatest during early July. For comparison, the pooled Petersen population estimate was 3.74 million.

The probability of recapturing PIT tagged coho, pink, and chum salmon was not significantly related to the latitude where the fish were captured. However, the probability of recapturing PIT tagged chum salmon was significantly greater ($p<0.01$) when the fish were captured during a flood or slack tide (Table 16). When the data from all species were pooled, recapture probabilities were still significantly related to stage of tide ($p<0.01$). For all 3 species of salmon, the probability of recapturing PIT tagged salmon increased with the time fish were held on the tagging vessel, but the differences were only significant for chum salmon ($p=0.02$) and when data from all species ($p=0.01$) were pooled (Table 17). Results from a chi-square test also indicated that the probability of recapturing PIT tagged salmon was significantly different ($p<0.01$) among six length classes of salmon (Table 18). Comparison of recovery probabilities and salmon length distributions indicated that the numbers of tags recovered from the smaller pink salmon were likely reduced due to the selective nature of gillnet harvests. The tagged-to-untagged ratio for coho salmon did not differ ($p>0.05$) among seven processors, but this ratio did differ ($p<0.05$) among processors for pink and chum salmon (Table 19). This result did not change when the number of tag recoveries was adjusted for tag detection rates measured at each processor. Tagged-to-untagged ratios were consistently higher at Icicle Seafoods and Ocean Beauty.

*Objective 6: Radio telemetry study on coho salmon*

In 2001, 67 coho salmon were radio tagged and 41 (68%) were later located in the UCI area. Nine percent of these fish were returned from commercial fishery and 54% were found in streams. In 2002, 729 coho salmon were radio tagged and 518 (71%) were later located in the UCI area. Seven percent of these fish were returned from the commercial fishery, 4% were returned from the recreational fishery, 69% were located in freshwater by either an aircraft or fixed receiver, 17% were located by aircraft in the intertidal zone but were not later located in freshwater, and 3% were either returned to ADF&G without any additional information or were imprecisely located by other means. The fates of the tagged salmon were somewhat related to their dates of release from the tagging vessel. Sixty-four percent of the tags returned by commercial fishermen were tagged after July 20, and 63% of the tags found only in the intertidal zone were tagged after July 20.

We first used our 2002 radio tag data to estimate the total coho salmon population entering all UCI streams. Chi-square analysis indicated that we could not reject the null hypothesis ($p$=0.21) of equal marked proportions of coho salmon returning to the five streams flowing into UCI (Table 20). There was also no apparent relationship between the run timing of coho salmon into each stream and their marked proportions. Thus, we used the pooled-Petersen method to estimate the total population size of coho salmon entering all UCI streams. The point estimate was 1.36 million with a 95% confidence interval of 0.98-1.96 million. When the 2002 commercial harvest of coho salmon in UCI (0.25 million) was subtracted from the total coho salmon population estimated using PIT tags (Table 11), the point estimate for the coho salmon population entering all UCI streams was 2.27 million with a 95% confidence interval of 1.91-2.62 million. Thus, our PIT tagging experiment estimated a population size for coho salmon entering UCI streams that was higher than the estimate obtained from radio tagging. Although, the 95% confidence intervals around the two estimates overlapped slightly, the z-test statistic indicated the two estimates were significantly ($p$=0.002) different.

We next partitioned our estimate of the total coho salmon escapement to 33 streams flowing into the inlet. The numbers of radio tags recovered in each stream were first weighted ($w_i$) by the mean $CPUE_i$ in each ($i$) release stratum: July 1, $w_i$ =0.25; July 7, $w_i$ =0.39; July 14, $w_i$ =1.78; July 21, $w_i$ =1.42; July 28, $w_i$ =0.58. Estimated numbers of coho salmon escaping into the 33 streams ranged from 2,051 in several small streams to 357,991 in the Susitna River (Table 21). Due to the small number of tag recoveries in individual streams, the 95% confidence intervals around these estimates overlapped zero in about 66% of the cases. But, when the data were pooled into 5 areas, the 95% confidence intervals around the estimates did not overlap zero.

Coho salmon migrating past the OTF transect before July 20 returned primarily to the Susitna drainage, while those migrating later in the season returned primarily to other streams around the inlet on both the west and east sides. Of the 67 coho salmon tagged before July 20, 2001, 41 were later found in 7 streams around the inlet and 68% of these were found in the Susitna River drainage (Figure 1). Of the 372 coho salmon tagged before July 20, 2002, 199 were later found in 21 streams around the inlet and 60% of these were found in the Susitna River drainage (Figure 2). Of the 358 coho salmon tagged after July 20, 2002, 178 were later found in 29 streams around the inlet and only 34% of these were found in the Susitna River drainage (Figure 3). Two hundred and seventy one tagged coho salmon were located during aerial surveys of the entire UCI drainage basin in October, 2002 (Figure 4). Tagged coho salmon were found throughout many parts of the Susitna, Little Susitna, and Beluga River watersheds. In the Little Susitna River, 9 tagged coho salmon were found above the weir located near the Parks Highway and 9 were found below the weir.

The timing of coho salmon migrating across the OTF transect was significantly ($p$<0.001) different among 7 stocks. Greater than 50% of the coho salmon returning to the Westside, Turnagin Arm and Kenai Peninsula migrated across the OTF transect after July 20 (Table 22). The migration of coho salmon returning to the Susitna drainage, Little Susitna River, and Knik Arm peaked during the week of July 14. The timing of entry into freshwater also differed significantly ($p$<0.001) among these 7 stocks of coho salmon. The migration of coho salmon entering freshwater along the Westside, Knik Arm and the Little Susitna River peaked the week of Aug. 4, while the peak of the migration into freshwater was earlier for salmon returning to the Susitna drainage, and later for salmon returning to Turnagin Arm and Kenai Peninsula (Table 23). Examination of the migration patterns of coho salmon through UCI (all stocks combined) indicated that their migration across the OTF transect peaked the week of July 14 while entry into freshwater peaked from July 28 through Aug. 10 (Table 24). A similar description of the individual migration patterns of these 7 coho salmon stocks is provided in Appendix 2.

An ANOVA indicated that the residence time of coho salmon differed significantly ($R^2$=0.260, df=10, $p$<0.001) among 7 stocks and 5 release strata. Similarly, ANOVA indicated that the migration rate of coho salmon also differed significantly ($R^2$=0.414, df=10, $p$<0.001) among 7 stocks and 5 release strata. The interaction terms were not significant in either of these models. Coho salmon returning to the Susitna drainage exhibited shorter residence times and higher migration rates through UCI than the other 5 stocks included in the analysis (Table 25). The migration rate of coho salmon through UCI increased from 6.7 km/day in early July to 14.9 km/day in late July (Table 26). Finally, the travel times for coho salmon between our fixed receivers at Susitna Station and Yentna River did not differ by their date of arrival at the Susitna Station receiver. The mean travel time between the 2 receivers was 3.5 days and the distance between the 2 sites was 20.5 km.

## DISCUSSION

The accuracy of mark-recapture estimates of population size is dependent on the degree to which the underlying model assumptions are satisfied. The pooled Peterson estimator is only valid if all individuals have equal probability of being tagged and recaptured. In our PIT tagging study, this assumption was not satisfied, because fish probably were not tagged in proportion to their relative abundance and recapture probabilities varied over time due to changing exploitation rates in the commercial fishery. Therefore, we used the stratified Darroch estimator to reduce bias resulting from variable initial capture and final recapture probabilities. In our analysis, we also applied correction factors for tagging-induced mortality, tag loss and tag detection. This was done to minimize bias in our population estimates that could otherwise result from violation of model assumptions.

Estimating tagging-induced mortality is problematic due to the difficulty of designing holding studies that simulate natural conditions. Our estimates of short-term mortality were likely a minimum estimate of actual tagging-induced mortality, because net pen studies of this kind cannot measure delayed mortality that may result from the stress of handling. Candy et al. (1996) estimated mortality of purse seine caught chinook salmon using ultrasonic telemetry. They documented a delayed mortality of 23% occurring 8-12 hrs after release and attributed it to stress-related physiological changes induced by hyperactivity during capture. Laboratory studies have shown that the stress of capture causes blood lactic acid levels to increase for up to 4 hrs after capture with mortality occurring if critical levels of lactate are reached (Parker and Black 1959; Parker et al. 1959; Farrell et al. 2000). Candy et al. (1996) found that delayed mortality of chinook salmon increased from zero to 50% for fish held <15 mins versus > 30 mins. To evaluate whether delayed mortality was related to holding time on the tagging vessel, we tested for a difference in the probability of recapture for groups of PIT tagged salmon held for different lengths of time. Holding time was not significantly related to probability of recapture for coho and pink salmon. But, we were surprised to find that the probability of recapture increased slightly with holding time for chum salmon (Table 17). Perhaps the stress of handling caused these fish to become more vulnerable to capture in the gillnet fishery without causing direct mortality. We also used recoveries of radio tags to estimate the maximum long-term mortality of coho salmon. Application of this estimate of tagging-induced mortality produced a minimum PIT tag population estimate for coho salmon (Table 11) since actual mortality was likely not higher. Although, we do not know whether mortality differs between fish that were radio tagged versus PIT tagged, the difference if any may be small since mortality of coho (Farrell et al. 2000) and chinook salmon (Candy et al. 1996) was not strongly related method of handling or obvious injuries.

We were also surprised to find 17% of our radio tagged coho salmon in the intertidal zone near the mouths of several rivers. These fish were never located in freshwater. The transmitters attached to many of these fish emitted a mortality code indicating that the fish were dead or had not moved recently. Some of these fish may have moved into freshwater undetected and later washed downstream after spawning, or they may have died, because they could not osmoregulate successfully in freshwater. If so, it is not clear whether this could have resulted from the stress of tagging, but it has been amply demonstrated that stress interferes with osmoregulation (Clarke and Hirano 1995).

We used PIT tags to estimate the population size of coho, pink, and chum salmon in part because this method eliminated the potential problem of under reporting of tags by fishermen. However, use of PIT tags required correcting for tag detection rates at salmon processing plants. Our approach involved estimating detection rates daily on each processing line at each plant. PIT tag detection rates were affected by the configuration of the processing equipment at each plant. The best detection rates were achieved at plants where the tag reader antennas were not in close proximity to the salmon header machines, because the vibration of these machines sometimes affected tag detection. During the early part of the season, we were unable to effectively scan for tags at three processing plants due to problems with the configuration of the processing lines (Table 8). This reduced the fraction of the total harvest that was scanned for tags. Differences in uncorrected marked proportions among processing plants can also be used to evaluate whether tag detection rates differed among plants. Our chi-square test indicated no difference in the marked proportions among processors for coho salmon but there was a significant difference for pink and chum salmon (Table 19). However, when corrections for measured detection rates at each processor were applied, the results did not change. This suggests that the different marked proportions among processors were due to something other than variable tag detection rates. The highest marked proportions occurred at Icicle Seafoods and Ocean Beauty. We examined whether marked proportions were related to numbers of fish processed from set versus drift gillnet harvests at each processor, but there was no apparent relationship. It may be that different marked proportions among processors were related to locations in the inlet where fish were harvested. But, we were unable to effectively evaluate this, because data on locations of harvests in the drift fishery are not very accurate.

Our PIT and radio tag estimates of the coho salmon population size likely bracket the actual population size. Both methods involved tagging fish using the same gear type in the same area, but the recovery methods were very different. Commercial fishing vessels recovered PIT tagged salmon in saltwater, while radio tagged salmon were located in freshwater by fixed receivers and aircraft. Bias in our pooled-Petersen estimate derived from radio tag recoveries may have been minimal, because any tagging-induced mortality likely occurred before the fish entered freshwater, and there was likely considerable mixing of tagged and untagged fish between their release from the tagging vessel and entry into freshwater. Mixing of coho salmon in the inlet was evident from their relatively long residence times (Tables 25 & 26) and the upper triangular structure in the recovery matrices (Schwarz and Taylor 1998) constructed from our PIT (Table 9) and radio tag data (Table 24). Our coho salmon population estimate could have been biased if the probability of locating radio tags above the weirs was different from the probability of locating all other radio tags found in freshwater. Our last survey to locate radio tags above weirs on streams east of the Susitna River was not conducted until late October due to poor weather earlier in the month. Loss of voltage in the transmitter batteries could have affected our probability of locating tags during this later survey. The battery manufacturer specified a 160-day life for the batteries used in our study, and Advanced Telemetry Systems warranties these batteries for 80 days of operation. About 105 days elapsed between the time these fish were tagged and the last survey. Previous experience with these transmitters has indicated the life of most of the batteries is about two times the warrantied life (pers. comm., Jay Carlon, ADF&G Sport Fish Division, Soldotna, Alaska). To further evaluate this question, we conducted a chi-square analysis to test whether marked proportions differed between

Deshka River, which was surveyed in early October, and those streams located east of the Susitna River, which were surveyed in late October. There was no difference ($p$>0.10).

Our PIT tag coho salmon population estimate could have been biased upward, because we dropped the July 1 release stratum to minimize the number of cells with E[$m_{ij}$]<5. When release strata are dropped, estimates of $\hat{a}_i$ (and stratum population estimates) can be biased upwards trying to account for the untagged recovered fish (Schwarz and Taylor 1998). Although our *CPUE* data indicated low relative abundances of coho salmon migrating across the OTF transect during the July 1 release stratum (Table 5), our radio tag data indicated that these fish migrated relatively slowly through the inlet and thus likely contributed to commercial harvests in later recovery strata (Table 25). The population estimate for the July 14+21 recovery stratum (Tables 10 & 11) may have been most affected by this bias, because fish from the first release stratum were most likely to have contributed to the commercial harvests during this time. Nevertheless, the bias resulting from dropping the first release stratum was likely small.

Our estimate of the population size of pink salmon was of questionable value. As with coho salmon, the estimate may have been biased upwards, because we dropped the July 1 release stratum to minimize the number of cells with E[$m_{ij}$]<5. Size-dependent tag loss may have also caused an upward bias in our pink salmon population estimate. Although, we did not find that tag loss was size dependent in our study using sockeye salmon, many pink salmon were much smaller than sockeye salmon. Although, we do not know whether these smaller fish lost tags at a higher rate, our observations on the tagging vessel suggest that this probably occurred. The precision of our pink salmon population estimate was also substantially reduced, because many processors did not pass pink salmon through their heading machines, and our tag detection rate was low on the one line at Icicle Seafoods where most of the pink salmon harvested in UCI were processed. Finally, we found the probability of recapturing PIT tagged salmon in the commercial gillnet fishery was strongly size dependent (Table 18). Although, gillnet selectivity caused lower recapture probabilities for small tagged pink salmon, it also resulted in lower capture probabilities for small untagged pink salmon. Our pink salmon population estimate was likely not biased significantly by gillnet selectivity, because we used a relatively non-selective gear type to obtain the initial tagging sample, and the sources of selectivity between the capture and recapture samples were independent (Seber 1982). We did not attempt to stratify our pink salmon population analysis by size because of the small number of tags recovered.

Our estimate of the population size of chum salmon may be biased upward, because we did not account for delayed mortality, and chum salmon captured on the ebb tide exhibited a lower tag recapture probability. Other factors do not appear to have biased the estimate. We did not drop any release or recovery strata, our estimate of tag loss from sockeye salmon was likely representative of this rate in chum salmon, and the $G^2$ statistic indicated a good model fit to the data (Table 15). However, in this analysis we used an estimate of short-term tag mortality obtained from net pen studies. Our studies with coho salmon and others with chinook salmon (Candy et al. 1996) indicate that delayed tag mortality probably occurs. If so, our chum salmon population estimate could be biased upward, but the magnitude of the bias, if any, likely does not exceed that found for coho salmon, i.e. about 28% (Tables 10 & 11). Finally, chum salmon captured on the ebb tide exhibited a lower tag recapture probability (Table 16) suggesting that fewer of these fish migrated into UCI. It is unclear whether this was a tagging effect, or if salmon migrating to areas outside UCI may have been captured at a higher rate on the ebb tide. Burbank (1977) described a cyclonic gyre south of our OTF transect and a northward flowing current along the east side of the inlet in spring and summer. Salmon migrating to areas south of UCI may orient to freshwater flowing into the inlet along the east side (Hasler and Scholz 1983). We attempted to scan catches of salmon harvested in lower Cook Inlet for PIT tags, but were unable to do so, because totes of fish from the entire inlet were mixed together when they were processed. Nevertheless, previous studies have indicated that the majority of chum salmon tagged west of Anchor Point migrated north into Cook Inlet, only 8% migrated to other areas outside of the inlet (Tyler and Noerenberg 1967).

Finally, we used our population estimates for coho, pink, and chum salmon to evaluate the probable ranges of exploitation rates on these species in the commercial fishery and their escapements in 2002 (Table 27). This was done as a first step toward determining escapement levels needed to achieve sustained yields. Our best PIT tag estimate of the total population size of coho salmon returning to UCI was 2.52 million (95% CI: 2.16-2.87 million). Given a commercial harvest of 0.25 million (Fox and Shields 2003), the total escapement of coho salmon into all UCI streams was 2.27 million (95% CI: 1.91-2.62 million), and the exploitation rate in the commercial fishery was 10% (95% CI: 9-11%). However, given the lower range of our radio tag escapement estimate for coho salmon (95% CI: 0.98 – 1.96 million), the exploitation rate could have ranged as high as 20%. This relatively low exploitation can be explained by a decrease in effort (no. of deliveries x hours fished) in the drift gillnet fishery over the past 20 years (Figure 5). Previous investigators estimated exploitation rates on hatchery-reared coho salmon using recoveries of coded-wired tagged fish in the commercial fishery (Hasbrouck and Hoffman 1994, Stratton et al. 1996, Cyr et al. 1997, 1998, 1999, 2001). Their estimates have ranged from 6-93% (Appendix 3). We conducted a regression analysis to test whether these coded-wire tag estimates of exploitation rate were related to effort in the drift gillnet fishery, which typically harvests over 70% of the coho salmon in the inlet. We omitted the estimate from Wasilla Creek in 1997, because the weir was removed due to high water before the end of the coho salmon run. Exploitation rate was significantly correlated ($R^2$=0.367, df=20, $p$=0.003) with effort in the drift gillnet fishery (Figure 6). Interestingly, effort in 1998 (28,932 boat-hours) was very similar to that in 2002 (30,504 boat-hours), and exploitation rates estimated using coded-wire tags in 1998 (0.15-0.21) were very similar to those estimated in our study.

Since our population estimate for pink salmon was of questionable value, we estimated a maximum exploitation rate on this species by simply summing escapements that were actually enumerated: Kenai River - 2,353,786, Deshka River – 946,255, Yentna River – 414,658 (Westerman and Willette 2003). We used side-scan sonar to roughly estimate the escapement of pink salmon into the Kenai River above river mile 19. The sonar was operated on the south bank of the river until August 29. Sonar counts of pink salmon migrating along the north bank were not considered reliable due to milling fish within the sonar beam, so we assumed the passage rate on the north bank was equal to that on the south bank. Catches of pink salmon in fish wheels operated by the ADF&G Sport Fish Division at river mile 26 through September 26 were used to estimate that the pink salmon run was 43% complete by August 29. We applied this fraction to our sonar count to estimate the pink salmon escapement above the sonar site. A large but unknown number of pink salmon spawned below our sonar site. Summing the escapements from these three rivers and given a commercial harvest of 0.45 million (Fox and Shields 2003), the maximum exploitation rate on pink salmon in the commercial fishery was about 12%. However, the actual exploitation rate must be much lower, since we did not account for pink salmon escapements into numerous other streams around the inlet. A relatively low exploitation rate on pink salmon may be expected since the probability of capture was substantially reduced for small pink salmon that comprised more than one half of the population (Table 17), and fishermen likely avoided this species due to its very low value.

Our PIT tag estimate of the total population size of chum salmon returning to UCI was 3.88 million (95% CI: 3.30-4.47 million). Given a commercial harvest of 0.24 million (Fox and Shields 2003), the total escapement of chum salmon into all UCI streams was 3.64 million (95% CI: 3.06-4.23 million), and the exploitation rate in the commercial fishery was 6% (95% CI: 5-7%). Tarbox (1988) tagged chum salmon in the middle of UCI in 1983 and 52% of these tags were captured in the commercial fishery. Since under reporting of tags by fishermen was likely, Tarbox (1988) estimated that the actual exploitation rate may have been as high as 75%, but this estimate was based on an assumption regarding chum escapements outside of the Susitna River. Typically, 87% of the commercial harvest of chum salmon has been taken in the drift gillnet fishery (Fox and Shields 2003). Since 1983, effort (no. of deliveries x hours fished) in this fishery has declined by nearly 5-fold (Figure 5). In 2002, effort was 28% of that in 1983. Assuming conditions in the fishery (other than the amount of effort) were similar in these 2 years, we calculated an expected exploitation rate on chum salmon in 2002 by applying this ratio (28%) to the fraction of recaptures and the exploitation rate Tarbox (1988) estimated for the 1983 season. The expected exploitation rate ranged from 14-21%. Although, this estimate is higher than the one obtained in our study, the difference is relatively small considering the uncertainty in both estimates. This analysis supports the notion that the difference in exploitation rates estimated in these 2 years was largely due to a 5-fold decline in effort in the fishery.

Relatively low exploitation rates on chum salmon may be expected since commercial gillnets in UCI extend only about 4 m deep in the water column. Ultrasonic tracking studies have shown that chum salmon spend a significant amount of time deeper in the water column during their inshore migration (Ishida et al. 1988). The offshore areas of the inlet are about 25-80 m deep, so chum salmon may be less vulnerable to capture in surface drift gillnets. Further studies are needed to determine the vertical distribution of chum salmon migrating though UCI and the distribution of chum salmon escapements around the inlet. We will be initiating studies in 2003 to begin investigating vertical and horizontal distributions of salmon migrating into the inlet and whether interannual changes in their vertical distribution affect catchability in drift gillnets.

Despite uncertainty in our salmon population estimates, it is reasonable to conclude that exploitation rates on coho, pink, and chum salmon in the UCI commercial fishery were substantially below optimal rates in 2002. Our population estimates for coho and chum salmon ranged between 1.23 and 4.23 million, and the commercial fishery harvested about 0.25 million of each species. Uncertainty regarding actual population sizes within this range resulted in little change in estimated exploitation rates (range 6-20%), because exploitation rate was an inverse function of estimated population size (Figure 7). Given that optimal exploitation rates typically range from 50-80% (Chapman 1986), a severe bias in our population estimates for coho and chum salmon would be necessary to approach the optimal range. Our assessment of uncertainties in these data indicates that this level of bias was unlikely. Finally, the exploitation rate on pink salmon in the commercial fishery was certainly far below the optimal rate in 2002, because in our calculation of the maximum rate, we only accounted for pink salmon actually enumerated in 3 streams, while this species was known to escape into numerous other streams around the inlet.

## LITERATURE CITED


Arnason, A.N. and K.H. Mills. 1981. Bias and loss of precision due to tag loss in Jolly-Seber estimates for mark-recapture experiments. Can. J. Fish. Aquat. Sci. 38: 1077-1095.

Arnason, A.N., C.J. Schwarz, and J.M. Gerrard. 1991. Estimating closed population size and number of marked animals from sighting data. J. Wildl. Mmgt. 55: 716-730.

Arnason, A.N., C.W. Kirby, C.J. Schwarz, and J.R. Irvine. 1996. Computer analysis of Marking data from stratified populations for estimation of salmonid escapements and the size of other populations. Can. Tech. Rep. Fish. Aquat. Sci. No. 2106.

Banneheka, S.G., R.D. Routledge, and C.J. Schwarz. 1997. Stratified two-sample tag recovery census of closed populations. Biometrics 53: 1212-1224.

Bevan, D.E. 1962. Estimation by tagging of the size of migrating salmon populations in coastal waters. *In* The research program of the Fisheries Research Institute in Bristol Bay, 1945-1958. W.F. Thompson (ed.), University of Washington, College of Fisheries, Contribution no. 105, pp 373-449.

Brannas, E. and five coauthors. 1994. Use of the passive integrated transponder (PIT) in a fish indentification and monitoring system for fish behavioral studies. Trans. Amer. Fish. Soc. 123: 395-401.

Burbank, D.C. 1977. Circulation studies in Kachemak Bay and lower Cook Inlet. *In* Environmental Studies of Kachemak Bay and Lower Cook Inlet, vol. III. L.L. Traskey et al. (eds.), Marine Coastal Habitat Management Report, Alaska Dept. Fish and Game, Anchorage, AK.

Candy, J.R., E.W. Carter, T. Quinn, and B.E. Riddell. 1996. Adult chinook salmon behavior and survival after catch and release from purse-seine vessels in Johnstone Strait, British Columbia. N. Amer. J. Fish .Mgmnt. 16: 521-529.

Chapman, D.W. 1986. Salmon and steelhead abundance in the Columbia River in the nineteenth century. Trans. Am. Fish. Soc. 115: 662-670.

Clarke, W.C., and T. Hirano. 1995. Osmoregulation. *In* Physiological Ecology of Pacific Salmon, C. Groot, L. Margolis, and W.C. Clarke (eds.). University of British Columbia Press, Vancouver, BC.

Conover, W.J. 1999. Practical nonparametric statistics. John Wiley & Sons, Inc. New York.

Cyr, P., B. Stratton, and J.J. Hasbrouck. 1997. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 97-3, Anchorage.

Cyr, P., B. Stratton, and J.J. Hasbrouck. 1998. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-5, Anchorage.

Cyr, P., B. Stratton, and J.J. Hasbrouck. 1999. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-7, Anchorage.

Cyr, P., B. Stratton, and J.J. Hasbrouck. 2001. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 01-6, Anchorage.

Eames, M., T. Quinn., K. Reidinger, and D. Haring. 1981. Northern Puget Sound 1976 adult coho and chum tagging studies. Wash. Dept. Fish. Tech. Rpt. 64, 217p.

Eames, M., T. Quinn., and M. Hino. 1983. Northern Puget Sound 1977 adult coho and chum tagging studies. Wash. Dept. Fish. Tech. Rpt. 75, 239p.

Farrell, A.P., P. Gallaugher, C. Clarke, N. DeLury, H. Kreiberg, W. Parkhouse, and R. Routledge. 2000. Physiological status of coho salmon (*Oncorhynchus kisutch*) captured in commercial nonretention fisheries. Can. J. Fish. Aquat. Sci. 57: 1668-1678.

Fox, J., and P. Shields. 2003. Upper Cook Inlet commercial fisheries annual management report, 2002. Alaska Department of Fish and Game, Regional Information Report no. 2A03-14.

Goodman, L.A. 1960. On the exact variance of products. J. Amer. Stat. Assoc. 55: 708-713.

Hasler, A.D., and A.T. Scholz. 1983. Olfactory imprinting and homing in salmon. Investigations into the homing and imprinting process. Springer-Verlag, New York..

Hiderbrand, R. H., and J.L. Kershner. 2000. Movement patterns of stream-resident cutthroat trout in Beaver Creek, Idaho–Utah. Trans. Ac. Fish. Soc. 129:1160–1170.

Hoffman, A.G. and J.J. Hasbrouck. 1994. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-45, Anchorage.

Ishida, K., S. Nagahora, Y. Inoue, and T. Watanabe. 1988. Behavior of adult chum salmon (*Oncorhynchus keta*) homing to the coast of Sanriku. Nippon Suisan Gakkaishi 54(8):1279-1287.

Parker, R.R., and E.C. Black. 1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). J. Fish. Res. Bd. Can. 16: 95-106.

Parker, R.R., E.C. Black, and P.A. Larkin. 1959. Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). J. Fish. Res. Bd. Can. 16: 429-448.

Pengilly D., and L.J. Watson 1994. Automated detection of red king crab at crab processing facilities. Fishery Research. 19: 293-300.

Plante, N. 1990. Estimation de la taille d’une population animale a l’ aide d’ un modele de capture-recapture avec stratification. M. Sc. thesis, Universite’ Laval, Quebec, Que.

Plante, N., and L.-P. Rivest. 1995. Stratified capture-recapture estimation of the size of a closed population. Tech. Rep. 95-03, Departement de mathematiques and de statistiques, Universite Laval, Quebec, Que.

Prentice, E.F. 1986. A new internal telemetry tag for fish and crustaceans. *In* Marine farming and enhancement: Proceedings of the 15$^{th}$ U.S.-Japan meeting on aquaculture, Kyoto Japan, NOAA Tech. Rep. NMFS 85: 1-9.

Prentice, E.F., 1990. A new internal telemetry tag for fish and crustaceans. *In* Marine farming and enhancement; proceedings of the fifteenth U. S.-Japan meeting on aquacuture, Kyoto, Japan, October 22-23. 1986. Sparks, A.K. editor. NOAA technical report NMFS 85, March 1990.

Prentice, E.P., C.W. Sims, and D.L. Park. 1985. A study to determine the biological feasibility of a new fish tagging system. Report to Bonneville Power Administration (Project 83-19), Portland, Oregon.

Prentice, E.F., T. A. Flagg, and C.S. McCutheon. 1990a. Feasibility of using passive intgegrated transponder (PIT) tags in salmonids. Am. Fish. Soc. Symp. 7: 317-322.;

Prentice, E.F., T. A. Flagg, and C.S. McCutheon. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Am. Fish. Soc. Symp. 7: 323-334.

Prentice, E.F., T. A. Flagg, C.S. McCutcheon, D.F. Brastow, and D.C. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT tagging. Am. Fish. Soc. Symp. 7: 335-340.

Price, A., and C. Powell. 2000. Clove oil as an anesthetic for invasive field procedures on adult rainbow trout. N. Amer. J. Fish. Mgmt. 20: 1029-1032.

Quinn, T.P., and N.P. Peterson. 1996. The influence of habitat complexity and fish size on overwinter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Can. J. Fish. Aquat. Sci. 53: 1555-1564.

Schwarz, C.J., and C.G. Taylor. 1998. Use of the stratified-Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Can. J. Fish. Aquat. Sci. 55: 281-296.

Seber, G.A.F. 1962. The multi-sample single recapture census. Biometrika 49(3-4): 339-350.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. Charles Griffin and Co. Ltd., London.

Shields, P.A. 2003. An estimate of the migratory timing and abundance of sockeye salmon into upper Cook Inlet, Alaska. Alaska Dept. of Fish and Game, Regional Information Report no. 2A03-01, 46p.

Skalski, J.R., S.G. Smith, R.N. Iwamoto, J. GT. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. Can. J. Fish. Aquat. Sci. 55: 1484-1493.

Stratton, B., J.J. Hasbrouck, and P. Cyr. 1996. Estimates of commercial harvest and escapement of coho salmon stocked in Northern Cook Inlet streams, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 96-4, Anchorage.

Tarbox, K.E. 1988. Migratory rate and behavior of salmon in Upper Cook Inlet, Alaska, 1983-1984. Fishery Research Bullentin 88-05, 56p.

Tarbox, K.E., and R.E. Thorne. 1996. Assessment of adult salmon in near-surface waters of Cook Inlet, Alaska. J. Mar. Sci. 53: 397-401

Thompson, S.H. 1930. Salmon tagging experiments in Alaska, 1929. U.S. Bureau of Fisheries Doc. 1084.

Tyler, R.W., and W.H. Noerenberg. 1967. Salmon tagging in Cook Inlet. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, Auke Bay, Alaska, Manuscript Report no. 37, 120p.

Westerman, D.L., and T.M. Willette. 2003. Upper Cook Inlet salmon escapement studies, 2002. Alaska Dept. of Fish and Game, Regional Information Report no. 2A02-17.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ.

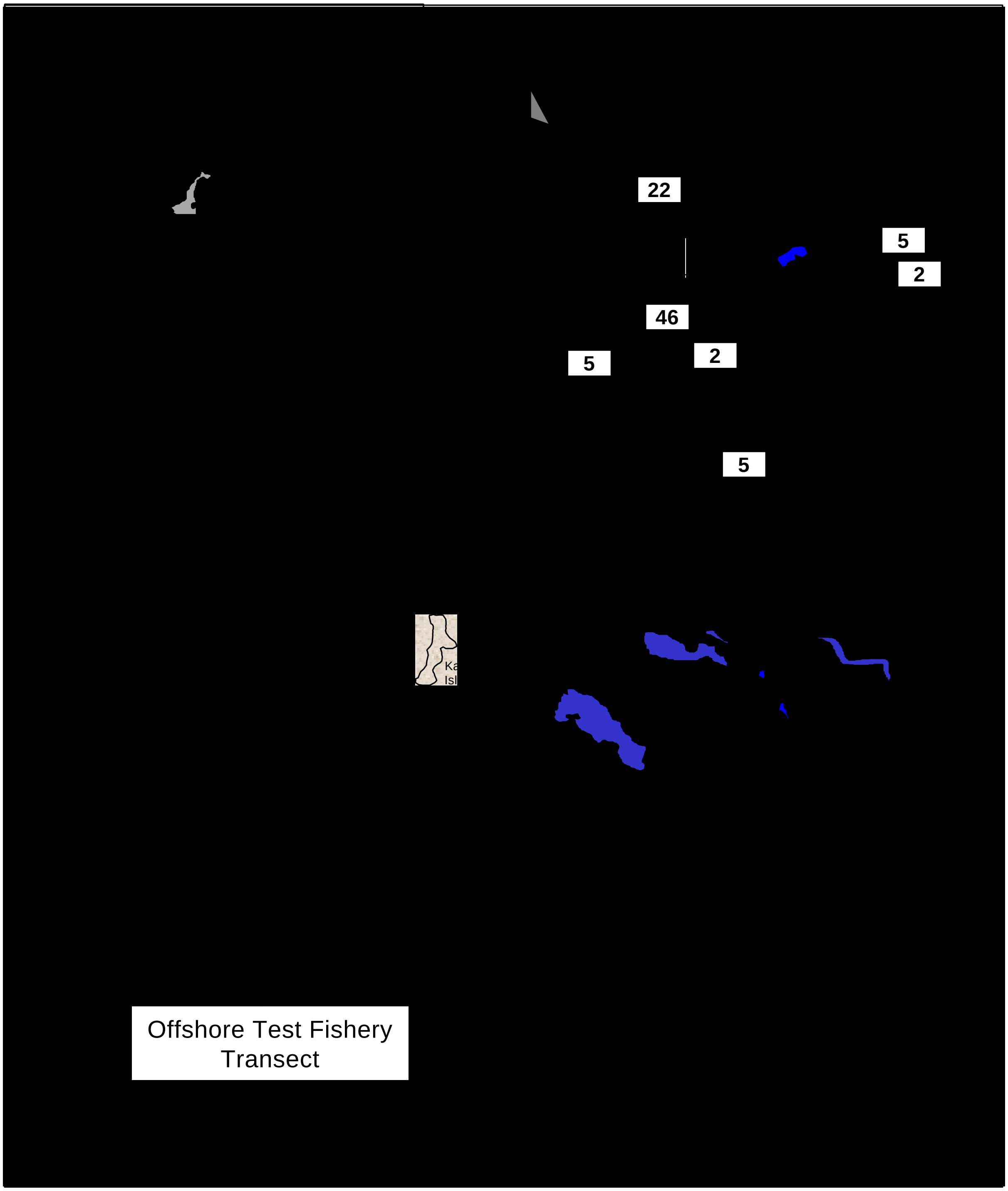


**Figure 1.** Locations of radio tagged coho salmon found during surveys of the lower portions of Upper Cook Inlet streams in 2001. These fish were tagged along the offshore test fishery transect west of Anchor Point before July 20, 2001. Numbers in boxes indicate percent of total recoveries (in freshwater) occurring in each stream. Numbers along test fishery transect indicate stations.

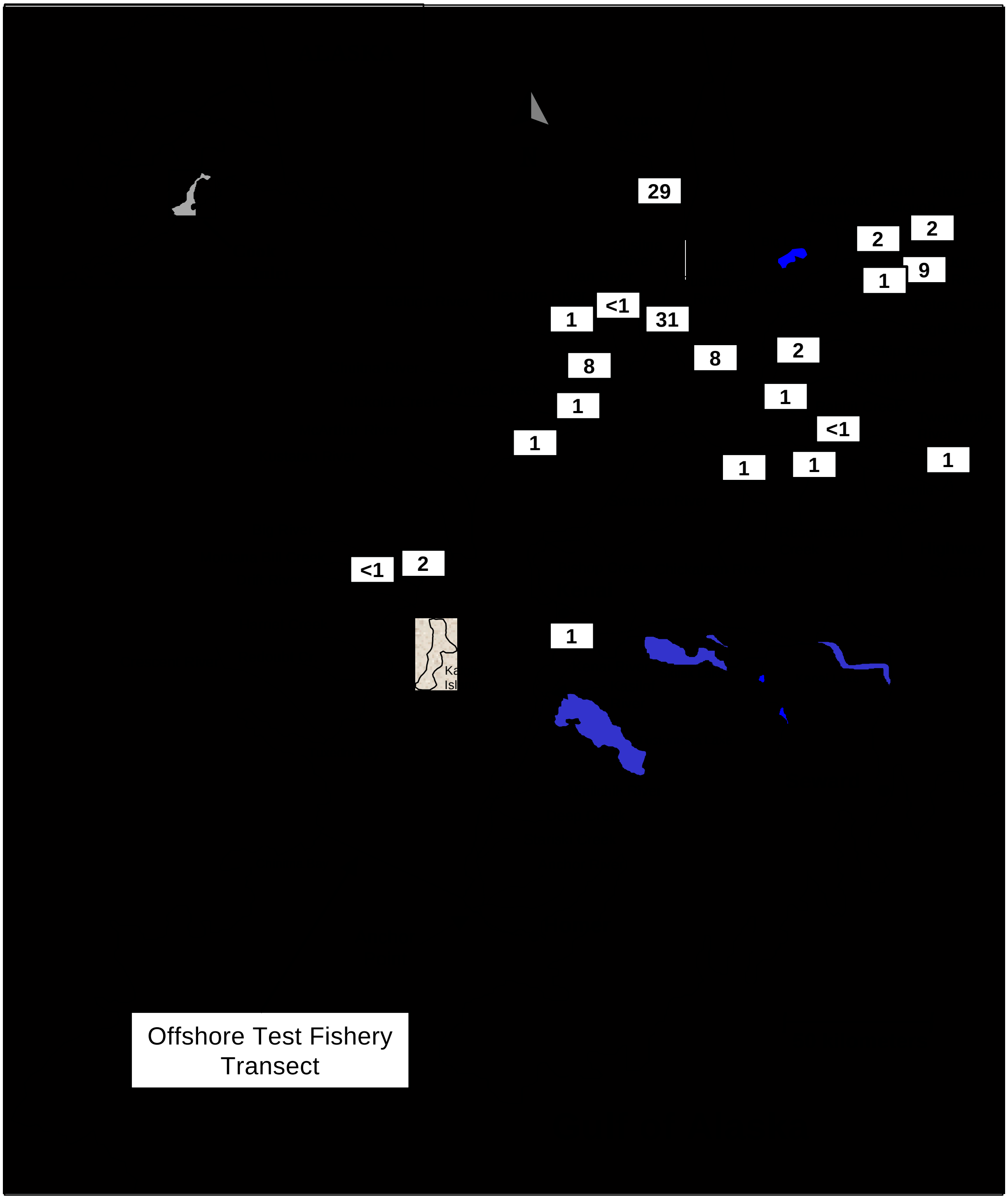


**Figure 2.** Locations of radio tagged coho salmon found during surveys of the lower portions of Upper Cook Inlet streams in 2002. These fish were tagged along the offshore test fishery transect west of Anchor Point before July 20, 2002. Numbers in boxes indicate percent of total recoveries (in freshwater) occurring in each stream.

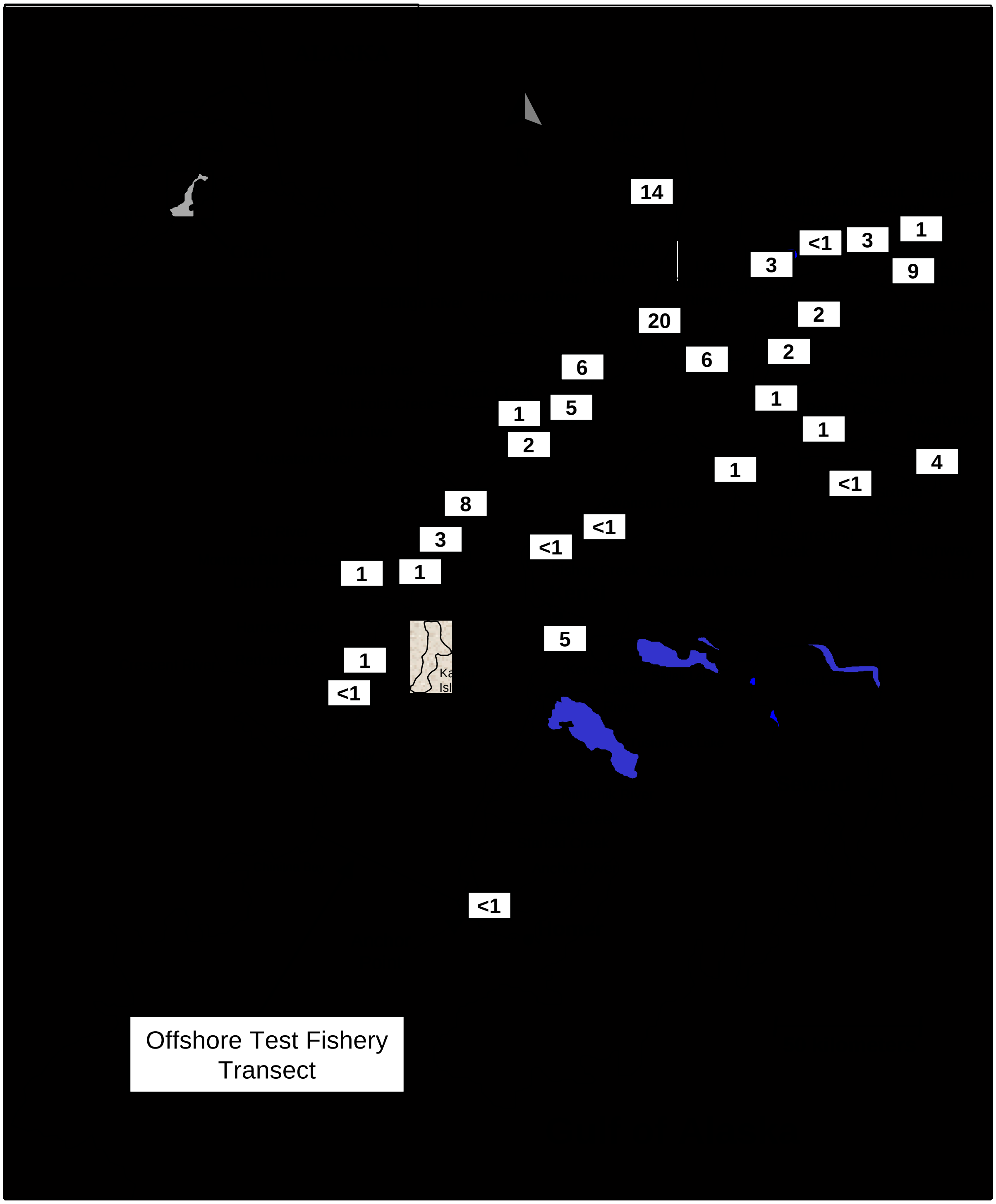


**Figure 3.** Locations of radio tagged coho salmon found during surveys of the lower portions of Upper Cook Inlet streams in 2002. These fish were tagged along the offshore test fishery transect west of Anchor Point after July 20, 2002. Numbers in boxes indicate percent of total recoveries (in freshwater) occurring in each stream.

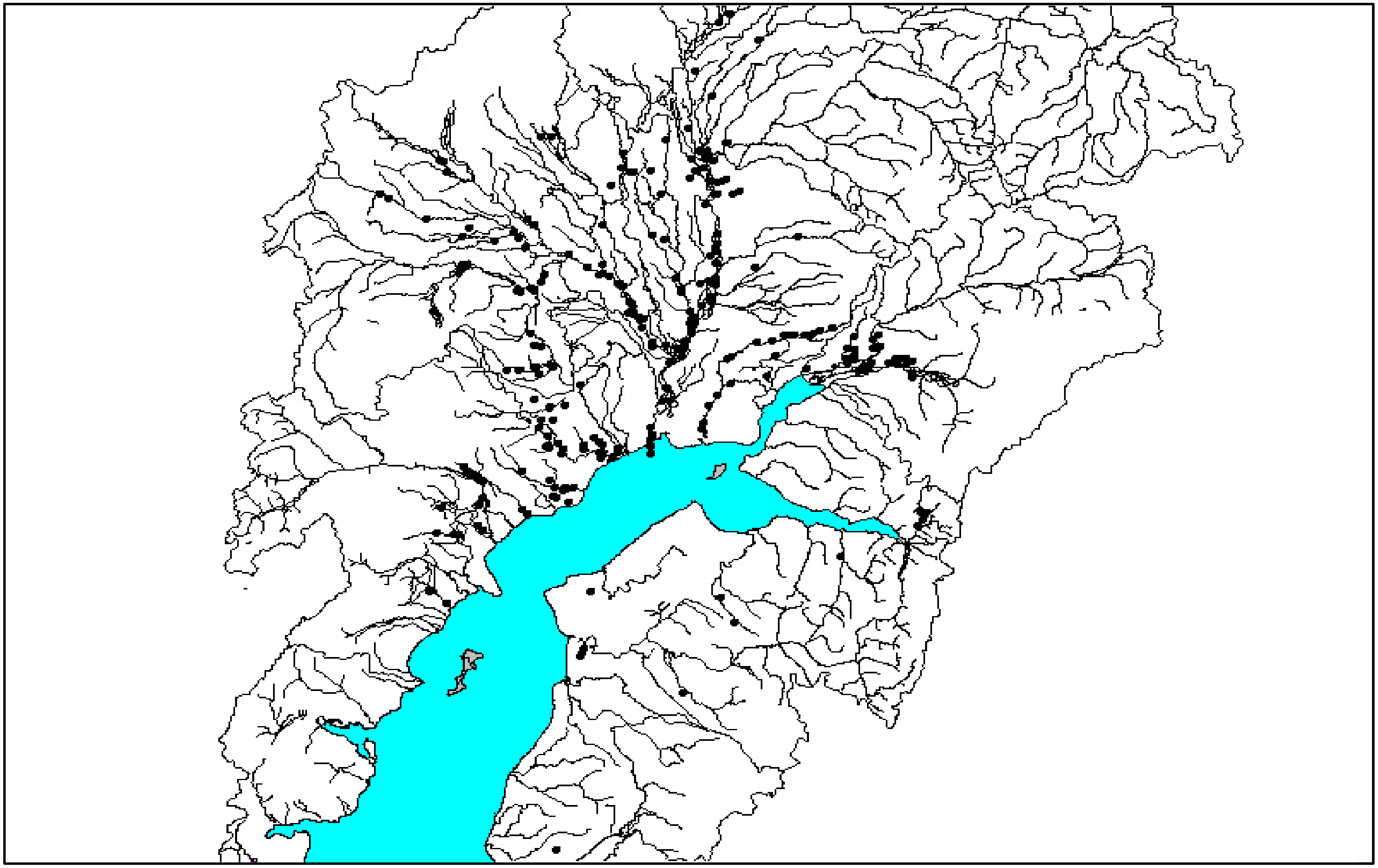

**Figure 4.** Locations of radio tagged coho salmon (solid circles) found during surveys of the Upper Cook Inlet drainage basin in October, 2002. Streams in the Anchorage area and those south of Big River on the west side of the inlet were not flown during these surveys. The fish were tagged along the offshore test fishery transect west of Anchor Point in 2002.

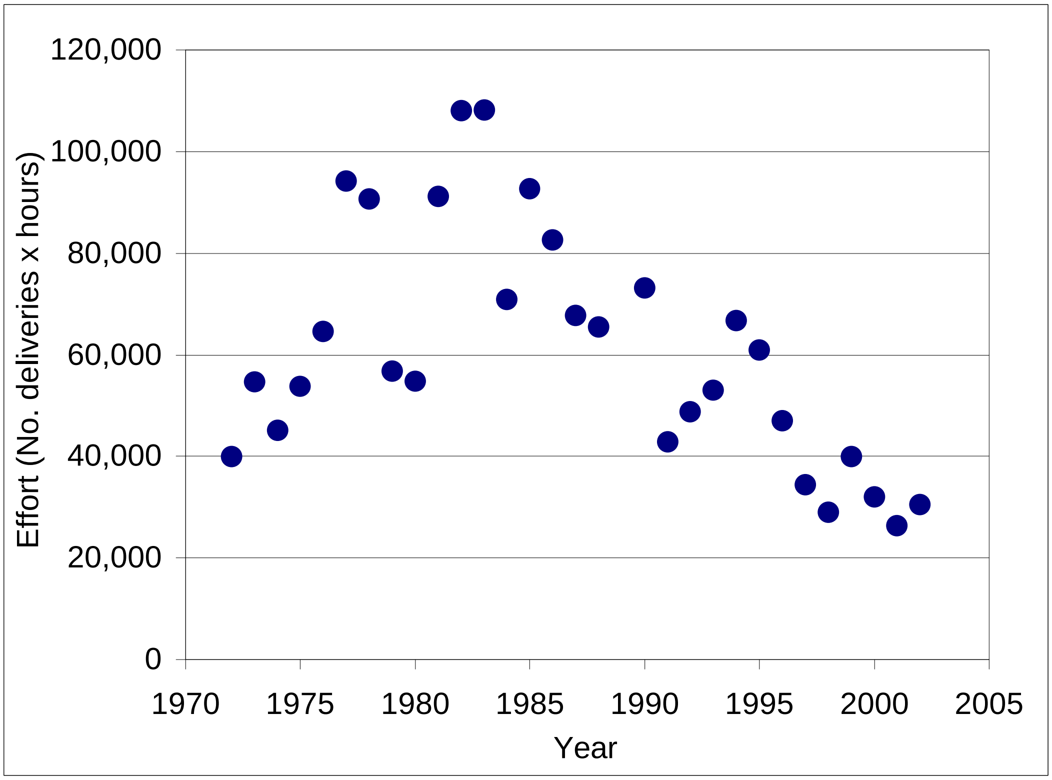


**Figure 5.** Historical effort (number of deliveries x hours fished) in the drift gillnet fishery (district wide openings only), 1972-2002.

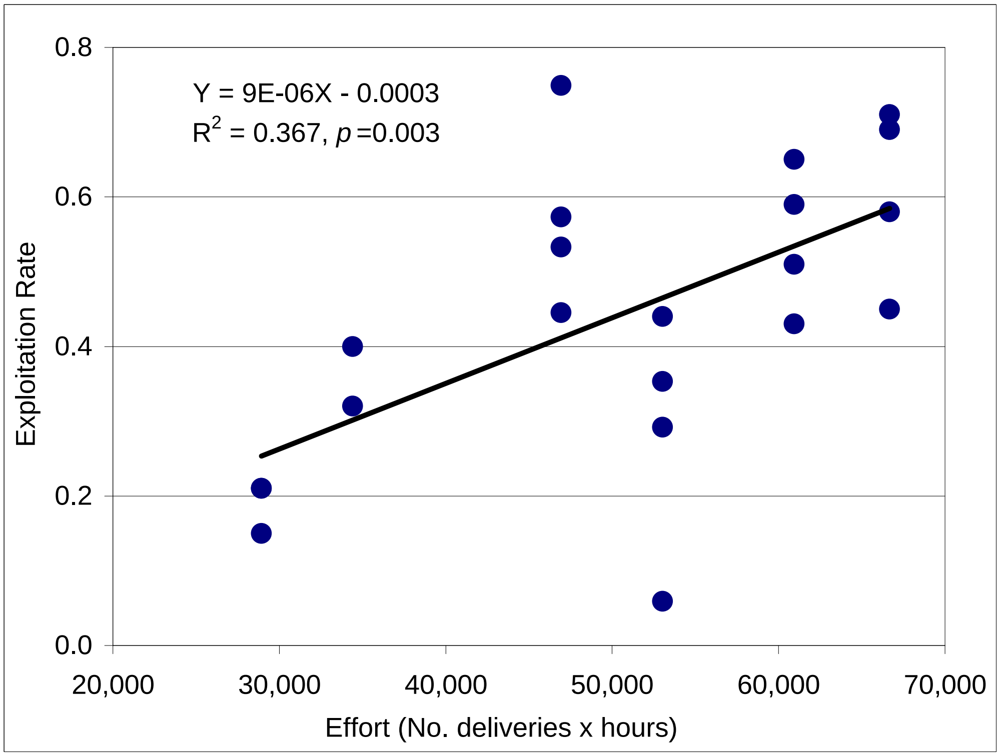


**Figure 6.** Relationship between commercial fisheries exploitation rate on coho salmon (estimated from coded wire tags) and effort (number of deliveries x hours fished) in the drift gillnet fishery (district wide openings only), 1993-1998.

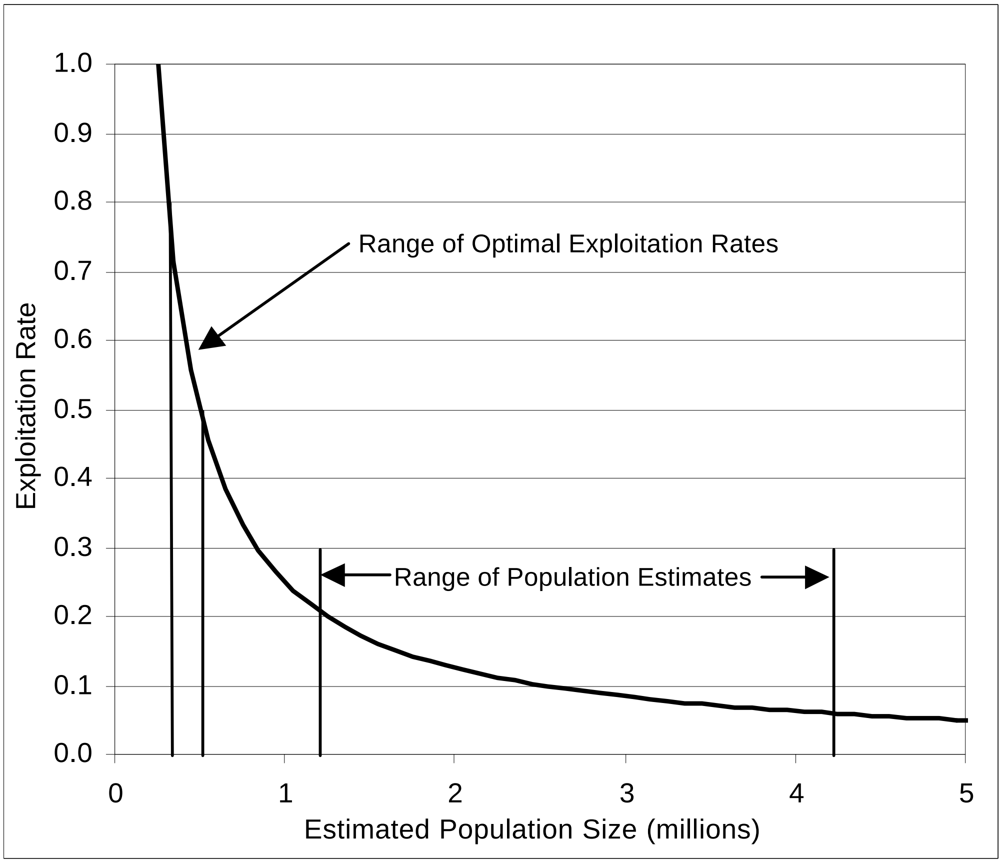


**Figure 7.** Relationship between exploitation rate and the uncertainty in estimated salmon population sizes assuming a harvest of 0.25 million (example for coho and chum salmon).

**Table 1.** Statistics collected from a stratified mark-recapture experiment (Schwarz and Taylor 1998).

| Tagging stratum | Fish tagged | Recovery stratum 1 | 2 | … | $t$ | Not recovered |
|---|---|---|---|---|---|---|
| 1 | $n_1^c$ | $m_{11}$ | $m_{12}$ | $\cdots$ | $m_{1t}$ | $n_1^c - m_{1.}$ |
| 2 | $n_2^c$ | $m_{21}$ | $m_{22}$ | $\cdots$ | $m_{2t}$ | $n_2^c - m_{2.}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $s$ | $n_s^c$ | $m_{s1}$ | $m_{s2}$ | $\cdots$ | $m_{st}$ | $n_s^c - m_{s.}$ |
| Total of untagged fish | | $u_1$ | $u_2$ | $\cdots$ | $u_t$ | |

**Table 2.** Population parameters from a stratified mark-recapture experiment (Schwarz and Taylor 1998).

| Tagging stratum | Total Fish | Recovery stratum 1 | 2 | … | $t$ | Died or did not move to recovery stratum |
|---|---|---|---|---|---|---|
| 1 | $N_1^c$ | $N_{11}$ | $N_{12}$ | $\cdots$ | $N_{1t}$ | $N_1^c - N_{1.}$ |
| 2 | $N_2^c$ | $N_{21}$ | $N_{22}$ | $\cdots$ | $N_{2t}$ | $N_2^c - N_{2.}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $s$ | $N_s^c$ | $N_{s1}$ | $N_{s2}$ | $\cdots$ | $N_{st}$ | $N_s^c - N_{s.}$ |
| Total | $N_.^c$ | $N_{.1} = N_1^r$ | $N_{.2} = N_2^r$ | $\cdots$ | $N_{.t} = N_t^r$ | |

**Table 3.** Expected value of statistics in Table 1 (Schwarz and Taylor 1998).

| Tagging Stratum | Fish tagged | Recovery statum 1 | 2 | … | $t$ | Not recovered |
|---|---|---|---|---|---|---|
| 1 | $N_1^c p_1^c$ | $N_1^c p_1^c q_{11} p_1^r$ | $N_1^c p_1^c q_{12} p_2^r$ | $\cdots$ | $N_1^c p_1^c q_{1t} p_t^r$ | $N_1^c p_1^c - \sum_{j=1}^{t} N_1^c p_1^c q_{1j} p_j^r$ |
| 2 | $N_2^c p_2^c$ | $N_2^c p_2^c q_{21} p_1^r$ | $N_2^c p_2^c q_{22} p_2^r$ | $\cdots$ | $N_2^c p_2^c q_{2t} p_t^r$ | $N_2^c p_2^c - \sum_{j=1}^{t} N_2^c p_2^c q_{2j} p_j^r$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $s$ | $N_s^c p_s^c$ | $N_s^c p_s^c q_{s1} p_1^r$ | $N_s^c p_s^c q_{s2} p_2^r$ | $\cdots$ | $N_s^c p_s^c q_{st} p_t^r$ | $N_s^c p_s^c - \sum_{j=1}^{t} N_s^c p_s^c q_{sj} p_j^r$ |
| Total untagged fish | | $\sum_{i=1}^{s} (1 - p_i^c) N_i^c q_{i1} p_1^r$ | $\sum_{i=1}^{s} (1 - p_i^c) N_i^c q_{i2} p_2^r$ | $\cdots$ | $\sum_{i=1}^{s} (1 - p_i^c) N_i^c q_{it} p_t^r$ | |

$$E\,[\text{fish not tagged or recovered}] = E\left[N_.^c - n_.^c - u_.\right] = \sum \sum N_i^c (1 - p_i^c) q_{ij} (1 - p_j^r)$$

**Table 4.** Short-term tag mortality of coho and chum salmon estimated from net pen studies.

| Species | Cum. Holding Time (mins) | Number Tagged | Number Survived | Survival | SE |
|---|---|---|---|---|---|
| Coho | 83 | 50 | 44 | 0.88 | 0.05 |
| | 136 | 50 | 33 | 0.66 | 0.07 |
| | 199 | 50 | 29 | 0.58 | 0.07 |
| | 251 | 50 | 28 | 0.56 | 0.07 |
| Chum | 83 | 50 | 50 | 1.00 | 0.00 |
| | 146 | 50 | 49 | 0.98 | 0.02 |
| | 208 | 50 | 50 | 1.00 | 0.00 |
| | 266 | 50 | 49 | 0.98 | 0.02 |

**Table 5.** Total number of net sets and geometric mean catch per net set for sockeye, coho, pink, and chum salmon during five weekly tag release strata, 2002. Numbers in parentheses indicate the standard error of the mean.

| Release | Number | Geometric mean catch per net set | | | |
|---|---|---|---|---|---|
| Strata | Net Sets | Sockeye | Coho | Pink | Chum |
| July 1 | 70 | 5.9 (0.2) | 0.3 (0.1) | 0.4 (0.2) | 1.8 (0.2) |
| July 7 | 75 | 74.0 (0.2) | 7.2 (0.1) | 6.6 (0.2) | 13.3 (0.2) |
| July 14 | 43 | 145.6 (0.3) | 32.1 (0.2) | 27.3 (0.2) | 24.5 (0.2) |
| July 21 | 34 | 37.0 (0.3) | 22.3 (0.2) | 18.5 (0.3) | 12.7 (0.2) |
| July 28 | 69 | 7.7 (0.2) | 11.8 (0.1) | 13.2 (0.2) | 7.4 (0.1) |
| Mean | | 54.0 | 14.7 | 13.2 | 12.0 |

**Table 6.** Total catch and number of coho, pink, and chum salmon tagged with PIT and radio tags during five weekly tag release strata, 2002.

| Release | Coho | | | Pink | | Chum | |
|---|---|---|---|---|---|---|---|
| Strata | Catch | No. PIT | No. Radio | Catch | No. PIT | Catch | No. PIT |
| July 1 | 52 | 27 | 12 | 49 | 46 | 428 | 399 |
| July 7 | 861 | 648 | 181 | 904 | 850 | 1,617 | 1,480 |
| July 14 | 1,997 | 1,606 | 179 | 4,201 | 997 | 3,010 | 995 |
| July 21 | 1,311 | 1,137 | 156 | 1,089 | 1,068 | 1,023 | 1,020 |
| July 28 | 1,714 | 1,507 | 202 | 2,381 | 2,377 | 1,178 | 1,177 |

**Table 7.** Mean difference between PIT tag detection rates estimated using dummy versus actual salmon heads by processor and line, 2002. Numbers in parentheses indicate the standard error of the mean.

| Processor | Line | Mean Difference | n | *p*-value |
|---|---|---|---|---|
| Deep Creek | 1 | 0.15 (0.00) | 1 | - |
| Icicle Seafoods | 1 | 0.11 (0.05) | 12 | 0.023 |
| Icicle Seafoods | 2 | 0.00 (0.03) | 11 | 0.787 |
| Icicle Seafoods | 3 | 0.16 (0.03) | 11 | 0.004 |
| Inlet Salmon | 1 | 0.10 (0.02) | 18 | 0.000 |
| Pacific Star | 1 | 0.02 (0.03) | 13 | 0.033 |
| Salamantof | 1 | 0.47 (0.11) | 2 | 0.500 |

**Table 8.** Mean PIT tag detection rate by processor and processing line during six weekly tag recovery strata, 2002. Numbers in parentheses indicate the standard error of the mean.

| | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Processor | Line | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| Deep Creek | 1 | 0.79 (0.09) | 0.66 (0.05) | 0.78 (0.05) | 0.83 (0.05) | 0.83 (0.05) | 0.82 (0.05) |
| Icicle Seafoods | 1 | 0.76 (0.07) | 0.68 (0.05) | 0.75 (0.05) | 0.64 (0.05) | 0.66 (0.05) | 0.72 (0.03) |
| Icicle Seafoods | 2 | 0.98 (0.07) | 0.88 (0.05) | 0.94 (0.05) | 0.95 (0.05) | 0.92 (0.05) | 0.91 (0.03) |
| Icicle Seafoods | 3 | - - | 0.64 (0.05) | 0.50 (0.05) | 0.38 (0.05) | 0.43 (0.05) | 0.37 (0.03) |
| Inlet Salmon | 1 | 0.79 (0.06) | 0.64 (0.05) | 0.78 (0.05) | 0.83 (0.05) | 0.86 (0.05) | 0.79 (0.04) |
| Ocean Beauty | 1 | - - | - - | - - | 0.86 (0.08) | 0.91 (0.03) | 0.89 (0.02) |
| Ocean Beauty | 2 | - - | - - | - - | 0.78 (0.08) | 0.88 (0.03) | 0.67 (0.02) |
| Pacific Star | 1 | 0.94 (0.06) | 0.93 (0.05) | 0.95 (0.05) | 0.91 (0.05) | 0.94 (0.05) | 0.92 (0.06) |
| Salamantof | 1 | 0.48 (0.06) | 0.50 (0.05) | 0.52 (0.05) | 0.66 (0.05) | 0.95 (0.05) | 0.94 (0.06) |
| Snug Harbor | 1 | - - | - - | - - | 0.94 (0.01) | 0.71 (0.05) | 0.86 (0.06) |

**Table 9.** Summary statistics for coho salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002. The number of tagged fish released ($n_i^c$) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 22 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 519 | 0.0 | 0.0 | 10.7 | 9.5 | 2.6 | 0.0 |
| July 14 | 1,286 | 0.0 | 0.0 | 19.5 | 40.4 | 20.5 | 3.8 |
| July 21 | 911 | 0.0 | 0.0 | 0.0 | 5.5 | 43.8 | 7.7 |
| July 28 | 1,207 | 0.0 | 0.0 | 0.0 | 0.0 | 19.7 | 30.8 |
| | | | | | | | |
| Total untagged | | 406 | 3,497 | 41,173 | 46,795 | 57,822 | 29,518 |
| Total recoveries | | 406 | 3,497 | 41,211 | 46,864 | 57,930 | 29,571 |

**Table 10.** Detailed results from a maximum likelihood Darroch estimate of the population size of coho salmon returning to Upper Cook Inlet, 2002 (final pooling) and test results for completing pooling. In this analysis, the number of tagged fish released ( $n_i^c$ ) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

(A) Detailed results from analyzing PIT tag data for coho salmon: final pooling.

| Release | | Observed recoveries ($m_{ij}$) with fitted values beneath | | | |
|---|---|---|---|---|---|
| Strata | Fish tagged | July 14+21 | July 28 | August 4 | Total |
| July 7 | 519 | 20.2 | 2.6 | 0.0 | |
| | | 26.7 | 3.1 | 0.0 | |
| July 14 | 1,286 | 59.9 | 20.5 | 3.8 | |
| | | 53.2 | 18.9 | 3.1 | |
| July 21 | 911 | 5.5 | 43.8 | 7.7 | |
| | | 5.7 | 44.8 | 8.2 | |
| July 28 | 1,207 | 0.0 | 19.7 | 30.8 | |
| | | 0.0 | 19.8 | 31.0 | |
| Population size | | 1,584,230 | 715,180 | 918,700 | 3,218,111 |
| SE (Population size) | | 209,021 | 201,280 | 202,445 | 233,466 |
| Probability (recapture) | | 0.0556 | 0.081 | 0.0322 | |
| SE (Prob. recapture) | | 0.0073 | 0.0228 | 0.0071 | |
| $G^2$ test for goodness of fit: | | $G^2$=3.16, df=1, *p*-value=0.08. | | | |

(B) Test results for completing pooling.

| | $\div^2$ | df | *p*-value |
|---|---|---|---|
| Test for complete mixing | 9.0 | 3 | 0.03 |
| Test for equal proportions | 9.1 | 2 | 0.01 |

**Table 11.** Detailed results from a maximum likelihood Darroch estimate of the population size of coho salmon returning to Upper Cook Inlet, 2002 (final pooling) and test results for completing pooling. In this analysis, the number of tagged fish released ( $n_i^c$ ) has been adjusted for long-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

(A) Detailed results from analyzing PIT tag data for coho salmon: final pooling.

| Release | | Observed recoveries ($m_{ij}$) with fitted values beneath | | | |
|---|---|---|---|---|---|
| Strata | Fish tagged | July 14+21 | July 28 | August 4 | Total |
| July 7 | 419 | 20.2 | 2.6 | 0.0 | |
| | | 26.7 | 3.2 | 0.0 | |
| July 14 | 1,038 | 59.9 | 20.5 | 3.8 | |
| | | 53.3 | 18.8 | 3.2 | |
| July 21 | 735 | 5.5 | 43.8 | 7.7 | |
| | | 5.7 | 44.8 | 8.1 | |
| July 28 | 974 | 0.0 | 19.7 | 30.8 | |
| | | 0.0 | 30.9 | 31.0 | |
| | | | | | |
| Population size | | 1,270,539 | 623,448 | 621,766 | 2,515,872 |
| SE (Population size) | | 165,823 | 165,063 | 168,732 | 181,164 |
| Probability (recapture) | | 0.0693 | 0.0929 | 0.0476 | |
| SE (Prob. recapture) | | 0.009 | 0.0246 | 0.0129 | |
| $G^2$ test for goodness of fit: | | $G^2$=3.14, df=1, $p$-value=0.08. | | | |

(B) Test results for completing pooling.

| | ÷$^2$ | df | $p$-value |
|---|---|---|---|
| Test for complete mixing | 4.7 | 3 | 0.20 |
| Test for equal proportions | 14.5 | 2 | 0.00 |

**Table 12.** Summary statistics for pink salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002. The number of tagged fish released ($n_i^c$) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 41 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 766 | 0.0 | 0.0 | 10.0 | 0.0 | 0.0 | 0.0 |
| July 14 | 898 | 0.0 | 0.0 | 14.0 | 2.6 | 0.0 | 0.0 |
| July 21 | 962 | 0.0 | 0.0 | 0.0 | 2.6 | 28.1 | 2.7 |
| July 28 | 2141 | 0.0 | 0.0 | 0.0 | 0.0 | 17.3 | 7.7 |
| | | | | | | | |
| Total untagged | | 142 | 3,016 | 31,593 | 38,883 | 107,960 | 72,476 |
| Total recoveries | | 142 | 3,016 | 31,620 | 38,889 | 108,010 | 72,487 |

**Table 13.** Detailed results from a maximum likelihood Darroch estimate of the population size of pink salmon returning to Upper Cook Inlet, 2002 (final pooling) and test results for completing pooling. In this analysis, the number of tagged fish released ( $n_i^c$ ) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

(A) Detailed results from analyzing PIT tag data for pink salmon: final pooling.

| Release | | Observed recoveries ($m_{ij}$) with fitted values beneath | | | |
|---|---|---|---|---|---|
| Strata | Fish tagged | July 14 | July 21+28 | August 4 | Total |
| July 7 | 766 | 10.0 | 0.0 | 0.0 | |
| | | 11.2 | 0.0 | 0.0 | |
| July 14 | 898 | 14.0 | 2.6 | 0.0 | |
| | | 12.8 | 2.6 | 0.0 | |
| July 21 | 962 | 0.0 | 30.7 | 2.7 | |
| | | 0.0 | 30.8 | 2.8 | |
| July 28 | 2141 | 0.0 | 34.6 | 7.7 | |
| | | 0.0 | 34.6 | 7.6 | |
| | | | | | |
| Population size | | 2,163,366 | 1,254,682 | 17,863,404 | 21,281,600 |
| SE (Population size) | | 447,972 | 3,947,598 | 13,416,101 | 10,039,425 |
| Probability (recapture) | | 0.0146 | 0.1171 | 0.0041 | |
| SE (Prob. recapture) | | 0.003 | 0.3684 | 0.003 | |

$G^2$ test for goodness of fit: $G^2$=0.25, df=1, *p*-value=0.61.

(B) Test results for completing pooling.

| | $\div^2$ | df | *p*-value |
|---|---|---|---|
| Test for complete mixing | 11.3 | 3 | 0.01 |
| Test for equal proportions | 23.1 | 2 | 0.00 |

**Table 14.** Summary statistics for chum salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002. The number of tagged fish released ($n_i^c$) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 359 | 1.0 | 6.4 | 3.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 1,333 | 0.0 | 1.5 | 45.0 | 2.2 | 1.5 | 0.0 |
| July 14 | 896 | 0.0 | 0.0 | 12.1 | 25.7 | 0.0 | 0.0 |
| July 21 | 919 | 0.0 | 0.0 | 0.0 | 8.2 | 41.9 | 0.0 |
| July 28 | 1,060 | 0.0 | 0.0 | 0.0 | 0.0 | 41.0 | 7.6 |
| | Untagged | 7,800 | 21,730 | 52,256 | 42,007 | 38,864 | 5,239 |
| | Total recoveries | 7,801 | 21,739 | 52,323 | 42,047 | 38,958 | 5,247 |

**Table 15.** Detailed results from a maximum likelihood Darroch estimate of the population size of chum salmon returning to Upper Cook Inlet, 2002 (final pooling) and test results for completing pooling. In this analysis, the number of tagged fish released ( $n_i^c$ ) has been adjusted for short-term tag mortality and tag loss. Number of tagged fish recovered ($m_{ij}$) has been adjusted for tag detection rate.

(A) Detailed results from analyzing PIT tag data for chum salmon: final pooling.

| Release | | Observed recoveries ($m_{ij}$) with fitted values beneath | | |
|---|---|---|---|---|
| Stratum | Fish tagged | July 7+14 | July 21+28 | Total |
| July 1+7 | 1,692 | 55.9 | 3.7 | |
| | | 56.0 | 3.7 | |
| July 14 | 896 | 12.1 | 25.7 | |
| | | 12.0 | 25.5 | |
| July 21+28 | 1,979 | 0.0 | 91.1 | |
| | | 0.0 | 91.3 | |
| | | | | |
| Population size | | 2,129,903 | 1,755,510 | 3,885,413 |
| SE (Population size) | | 274,161 | 168,816 | 300,451 |
| Probability (recapture) | | 0.0348 | 0.0461 | |
| SE (Prob. recapture) | | 0.0045 | 0.0044 | |
| $G^2$ test for goodness of fit: | $G^2$=0.00, df=1, *p*-value=0.95. | | | |

(B) Test results for completing pooling.

| | $\div^2$ | df | *p*-value |
|---|---|---|---|
| Test for complete mixing | 2.7 | 2 | 0.26 |
| Test for equal proportions | 10.3 | 1 | 0.00 |

**Table 16.** Results from a chi-square test of the null hypothesis that the probability of recapturing PIT tagged coho, pink, and chum salmon did not differ for fish that were captured during ebb, flood, or slack tides.

| | | Stage of Tide | | |
|---|---|---|---|---|
| Species | | Ebb | Flood | Slack |
| Coho salmon | | | | |
| | Number not recovered | 1355 | 2642 | 770 |
| | Number recovered | 34 | 105 | 28 |
| | Percent recovered | 2.45 | 3.82 | 3.51 |
| | Chi-square test: | $\div^2$=5.37, df=2, *p*-value=0.07 | | |
| Pink salmon | | | | |
| | Number not recovered | 1837 | 2789 | 677 |
| | Number recovered | 16 | 24 | 5 |
| | Percent recovered | 0.86 | 0.85 | 0.73 |
| | Chi-square test: | $\div^2$=0.11, df=2, *p*-value=0.95 | | |
| Chum salmon | | | | |
| | Number not recovered | 1638 | 2697 | 591 |
| | Number recovered | 38 | 84 | 32 |
| | Percent recovered | 2.27 | 3.02 | 5.14 |
| | Chi-square test: | $\div^2$=12.72, df=2, *p*-value<0.01 | | |
| Pooled | | | | |
| | Number not recovered | 4830 | 8128 | 2038 |
| | Number recovered | 88 | 213 | 65 |
| | Percent recovered | 1.79 | 2.55 | 3.09 |
| | Chi-square test: | $\div^2$=13.02, df=2, *p*-value<0.01 | | |

**Table 17.** Results from a chi-square test of the null hypothesis that the probability of recapturing PIT tagged coho, pink, and chum salmon did not differ among three groups that were held on the tagging vessels for <30 mins, 30-60 mins, and >60 mins.

| | | Holding time (mins.) | | |
|---|---|---|---|---|
| Species | | < 30 | 30-60 | >60 |
| Coho salmon | | | | |
| | Number not recovered | 3474 | 950 | 334 |
| | Number recovered | 118 | 35 | 14 |
| | Percent recovered | 3.29 | 3.55 | 4.02 |
| | Chi-square test: | $\chi^2$=0.63, df=2, *p*-value=0.73 | | |
| Pink salmon | | | | |
| | Number not recovered | 3777 | 1165 | 351 |
| | Number recovered | 26 | 14 | 5 |
| | Percent recovered | 0.68 | 1.19 | 1.40 |
| | Chi-square test: | $\chi^2$=4.17, df=2, *p*-value=0.12 | | |
| Chum salmon | | | | |
| | Number not recovered | 3319 | 1087 | 511 |
| | Number recovered | 91 | 37 | 26 |
| | Percent recovered | 2.67 | 3.29 | 4.84 |
| | Chi-square test: | $\chi^2$=7.76, df=2, *p*-value=0.02 | | |
| Pooled | | | | |
| | Number not recovered | 10570 | 3202 | 1196 |
| | Number recovered | 235 | 86 | 45 |
| | Percent recovered | 2.17 | 2.62 | 3.63 |
| | Chi-square test: | $\chi^2$=11.00, df=2, *p*-value<0.01 | | |

**Table 18.** Results from a chi-square test of the null hypothesis that the probability of recapturing PIT tagged coho, pink and chum salmon (pooled) did not differ among six length classes (<50 cm, 50-55 cm, 55-60 cm, 60-65 cm, 65-70 cm, >70 cm). The length distribution for each species tagged is also indicated for comparison.

| (A) Test of null hypothesis that probability of tag recovery was independent of length. | | | | | | |
|---|---|---|---|---|---|---|
| | Length class (cm) | | | | | |
| | 50 | 50-55 | 55-60 | 60-65 | 65-70 | >70 |
| Number not recovered | 2,080 | 2,409 | 2,718 | 4,620 | 2,829 | 312 |
| Number recovered | 10 | 39 | 77 | 167 | 66 | 7 |
| Percent recovered | 0.48 | 1.59 | 2.75 | 3.49 | 2.28 | 2.19 |
| Chi-square test: | $\div^2$=66.05, df=5, *p*-value<0.01 | | | | | |
| (B) Length distribution (percent of total sample) of tagged coho, pink, and chum salmon. | | | | | | |
| Coho salmon | 2.3 | 10.5 | 29.8 | 43.7 | 12.5 | 1.3 |
| Pink salmon | 36.9 | 35.8 | 20.8 | 6.3 | 0.3 | 0.0 |
| Chum salmon | 0.1 | 0.4 | 4.4 | 45.4 | 44.6 | 5.1 |

**Table 19.** Ratios of the number of tagged and untagged coho, pink and chum salmon recovered at seven plants processing salmon returning to Upper Cook Inlet, 2002. Tag ratios adjusted for tag detection rates at each processor are included for comparison.

| | Coho | | Pink | | Chum | |
|---|---|---|---|---|---|---|
| Processor | Ratio | Adj. Ratio | Ratio | Adj. Ratio | Ratio | Adj. Ratio |
| Deep Creek | 0.00088 | 0.00107 | - | - | 0.00097 | 0.00118 |
| Icicle Seafoods | 0.00100 | 0.00137 | 0.00035 | 0.00077 | 0.00137 | 0.00189 |
| Inlet Salmon | 0.00075 | 0.00090 | 0.00011 | 0.00013 | 0.00054 | 0.00065 |
| Ocean Beauty | 0.00128 | 0.00165 | 0.00022 | 0.00026 | 0.00224 | 0.00262 |
| Pacific Star | 0.00082 | 0.00088 | - | - | 0.00078 | 0.00083 |
| Salamantof | 0.00067 | 0.00090 | - | - | 0.00058 | 0.00092 |
| Snug Harbor | 0.00108 | 0.00144 | 0.00003 | 0.00004 | 0.00130 | 0.00181 |

**Table 20.** Results from a chi-square test of the null hypothesis that there was no difference in the ratio of the numbers of radio tagged to untagged coho salmon returning to five streams flowing into northern Cook Inlet for which salmon escapement estimates were available in 2002. The date at which 50% the total escapement passed the weir is included for comparison.

| Stream | Date for 50% of Total Escapement | Number Radio Tags | Total Escapement |
|---|---|---|---|
| Deshka River | August 8 | 10 | 24,612 |
| Little Susitna River | September 1 | 9 | 47,938 |
| Fish Creek | August 21 | 3 | 14,651 |
| Cottonwood Creek | August 21 | 0 | 3,957 |
| Wasilla Creek | August 23 | 6 | 13,195 |
| Sum | | 28 | 104,353 |
| Chi-square test: | $\div^2$=5.89, df=4, *p*-value=0.21 | | |

**Table 21**. Estimated total escapement (with 95% confidence intervals) of coho salmon into 33 streams and 5 areas around Upper Cook Inlet, 2002. The number of tags weighted by the catch per unit effort of coho salmon in each release stratum is also indicated, as well as, the weighted percent of total tags (recovered in freshwater) found in each stream or area.

| Area | Stream | Number Tags | Weighted No. Tags | Weighted Percent | Total Escapement | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|---|---|---|
| Westside | Beluga R. | 27 | 26.6 | 6.9 | 94,345 | 43,410 | 145,280 |
| Westside | Big R. | 3 | 5.0 | 1.3 | 17,617 | 0 | 38,084 |
| Westside | Chuitna R. | 10 | 10.0 | 2.6 | 35,328 | 8,716 | 61,941 |
| Westside | Harriet Cr. | 1 | 1.4 | 0.4 | 5,020 | 0 | 14,794 |
| Westside | Ivan R. | 2 | 0.8 | 0.2 | 2,794 | 0 | 6,685 |
| Westside | Kustatan R. | 6 | 5.1 | 1.3 | 18,247 | 1,450 | 35,045 |
| Westside | McArthur R. | 14 | 12.3 | 3.2 | 43,566 | 15,458 | 71,674 |
| Westside | Montana Bill Cr. | 3 | 1.6 | 0.4 | 5,501 | 0 | 11,944 |
| Westside | Nikolai Cr. | 5 | 4.9 | 1.3 | 17,473 | 0 | 35,378 |
| Westside | Redoubt Cr. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Westside | Theodore R. | 2 | 2.2 | 0.6 | 7,695 | 0 | 20,361 |
| Westside | Tyonek Cr. | 2 | 2.0 | 0.5 | 7,072 | 0 | 17,748 |
| Total | | 76 | 72.4 | 18.9 | 256,709 | 148,132 | 365,286 |
| | | | | | | | |
| Susitna | Yentna R. | 85 | 86.1 | 22.4 | 305,240 | 181,798 | 428,681 |
| Susitna | Susitna R. | 94 | 101.0 | 26.3 | 357,991 | 216,752 | 499,230 |
| Susitna | Little Susitna R. | 26 | 26.9 | 7.0 | 95,262 | 43,555 | 146,969 |
| Total | | 205 | 213.9 | 55.8 | 758,492 | 478,088 | 1,038,897 |
| | | | | | | | |
| Knik Arm | Cottonwood Cr. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Knik Arm | Eagle R. | 3 | 3.4 | 0.9 | 12,092 | 0 | 26,765 |
| Knik Arm | Fish Cr. | 6 | 4.3 | 1.1 | 15,278 | 1,321 | 29,235 |
| Knik Arm | Knik R. | 27 | 33.4 | 8.7 | 118,472 | 57,173 | 179,771 |
| Knik Arm | Matanuska R. | 5 | 5.8 | 1.5 | 20,411 | 0 | 41,522 |
| Knik Arm | Peters Cr. | 1 | 1.8 | 0.5 | 6,298 | 0 | 18,584 |
| Knik Arm | Rabbit Slough | 8 | 9.2 | 2.4 | 32,503 | 5,781 | 59,225 |
| Knik Arm | Ship Cr. | 7 | 7.9 | 2.1 | 28,137 | 3,568 | 52,706 |
| Total | | 58 | 66.3 | 17.3 | 235,242 | 131,985 | 338,500 |

**Table 21**. Continued.

| Area | Stream | Number Tags | Weighted No. Tags | Weighted Percent | Total Escapement | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|---|---|---|
| Turnagin Arm | Campbell Cr. | 3 | 2.9 | 0.8 | 10,401 | 0 | 24,178 |
| Turnagin Arm | Chickaloon R. | 3 | 3.6 | 0.9 | 12,715 | 0 | 28,997 |
| Turnagin Arm | Rabbit Cr. | 4 | 2.1 | 0.6 | 7,552 | 0 | 15,273 |
| Turnagin Arm | Resurrection Cr. | 1 | 1.8 | 0.5 | 6,298 | 0 | 18,584 |
| Turnagin Arm | Sixmile Cr. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Turnagin Arm | Twentymile R. | 10 | 7.8 | 2.0 | 27,730 | 6,621 | 48,840 |
| Total | | 22 | 18.8 | 4.9 | 66,748 | 27,774 | 105,722 |
| | | | | | | | |
| Kenai Peninsula | Anchor R. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Kenai Peninsula | Bishop Cr. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Kenai Peninsula | Kenai R. | 13 | 10.4 | 2.7 | 36,855 | 11,731 | 61,979 |
| Kenai Peninsula | Swanson R. | 1 | 0.6 | 0.2 | 2,051 | 0 | 6,054 |
| Total | | 16 | 12.1 | 3.2 | 43,008 | 15,881 | 70,135 |

**Table 22**. Percent of total radio tags recovered (in freshwater) for seven stocks of coho salmon in Upper Cook Inlet, 2002 by release strata.

| | Recovery Area (stock) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Release Strata | Westside | Susitna River | Yentna River | L. Susitna River | Knik Arm | Turnagin Arm | Kenai Peninsula | Total | Weighted No. Tags |
| July 1 | 0.0 | 0.0 | 0.6 | 0.0 | 0.4 | 0.0 | 0.0 | 0.2 | 0.7 |
| July 7 | 6.5 | 13.7 | 13.7 | 8.8 | 4.8 | 4.2 | 0.0 | 9.6 | 36.6 |
| July 14 | 31.9 | 54.5 | 59.8 | 52.9 | 45.5 | 37.7 | 14.6 | 47.7 | 183.0 |
| July 21 | 35.2 | 26.7 | 16.5 | 21.1 | 36.3 | 15.0 | 23.4 | 26.6 | 101.9 |
| July 28 | 26.4 | 5.2 | 9.4 | 17.2 | 13.1 | 43.0 | 62.0 | 16.0 | 61.3 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 383.6 |

**Table 23**. Percent of total radio tags recovered (in freshwater) for seven stocks of coho salmon in Upper Cook Inlet, 2002 by recovery strata.

| Recovery | Recovery Area (stock) | | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|---|
| Strata | Westside | Susitna River | Yentna River | L. Susitna River | Knik Arm | Turnagin Arm | Kenai Peninsula | Total | No. Tags |
| July 14 | 1.1 | 4.8 | 5.8 | 1.6 | 0.0 | 0.0 | 0.0 | 3.0 | 10.8 |
| July 21 | 15.3 | 36.53 | 25.7 | 0.0 | 0.7 | 14.7 | 0.0 | 19.9 | 71.8 |
| July 28 | 34.0 | 33.15 | 48.8 | 30.5 | 23.9 | 0.0 | 0.0 | 33.2 | 120.0 |
| Aug. 4 | 37.3 | 20.44 | 15.8 | 40.4 | 41.0 | 19.2 | 0.0 | 26.7 | 96.6 |
| Aug. 11 | 8.1 | 4.15 | 3.2 | 25.2 | 18.5 | 42.5 | 6.3 | 10.0 | 36.2 |
| Aug. 18 | 4.2 | 0.98 | 0.7 | 2.3 | 15.9 | 23.6 | 93.7 | 7.3 | 26.3 |
| Sum | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 361.7 |

**Table 24**. Percent of total radio tagged coho salmon recovered in streams flowing into Upper Cook Inlet, 2002 by release and recovery strata (all stocks combined).

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | 0.7 |
| July 7 | 1.5 | 4.5 | 2.5 | 0.5 | 0.3 | 0.3 | 9.7 | 35.1 |
| July 14 | 1.5 | 13.8 | 21.1 | 8.8 | 2.5 | 1.0 | 48.6 | 175.9 |
| July 21 | 0.0 | 1.6 | 9.0 | 12.1 | 2.0 | 2.0 | 26.6 | 96.3 |
| July 28 | 0.0 | 0.0 | 0.5 | 5.1 | 5.3 | 4.0 | 14.9 | 53.8 |
| Sum | 3.0 | 19.9 | 33.2 | 26.7 | 10.0 | 7.3 | 100.0 | 361.7 |

**Table 25**. Geometric mean residence time and migration rate for seven stocks of radio tagged coho salmon in Upper Cook Inlet.

| Area | Residence Time (days) | Migration Rate (km/day) |
|---|---|---|
| Westside | 13.5(1.1) | 10.5(1.1) |
| Susitna River | 12.0(1.1) | 17.8(1.1) |
| Yentna River | 11.9(1.1) | 19.9(1.1) |
| Little Susitna | 16.2(1.1) | 12.2(1.1) |
| Knik Arm | 19.7(1.0) | 13.0(1.1) |
| Turnagin Arm | 19.1(1.1) | 12.0(1.1) |
| Kenai Peninsula | 31.0(1.2) | 3.0(1.2) |

**Table 26**. Geometric mean residence time and migration rate for radio tagged coho salmon in Upper Cook Inlet by release strata.

| Release strata | Residence Time (days) | Migration Rate (km/day) |
|---|---|---|
| July 1 | 28.0(1.3) | 6.7(1.3) |
| July 7 | 19.1(1.1) | 9.9(1.0) |
| July 14 | 15.5(1.1) | 12.2(1.0) |
| July 21 | 12.9(1.1) | 14.1(1.1) |
| July 28 | 12.2(1.0) | 14.9(1.0) |

**Table 27.** Estimated population sizes (millions), escapements, and exploitation rates on coho, pink and chum salmon returning to Upper Cook Inlet in 2002 derived from mark-recapture studies.

| Species | Estimate (95% Conf. Int.) | Population Size | Comm. Fish. Harvest | Estimated Escapement | Estimated CF Exploitation Rate |
|---|---|---|---|---|---|
| Coho | Radio telemetry - lower | 1.23 | 0.25 | 0.98 | 0.20 |
| Coho | Radio telemetry - point | 1.61 | 0.25 | 1.36 | 0.15 |
| Coho | Radio telemetry - upper | 2.21 | 0.25 | 1.96 | 0.11 |
| Coho | PIT tag - lower | 2.16 | 0.25 | 1.91 | 0.11 |
| Coho | PIT tag - point | 2.52 | 0.25 | 2.27 | 0.10 |
| Coho | PIT tag - upper | 2.87 | 0.25 | 2.62 | 0.09 |
| | | | | | |
| Chum | PIT tag - lower | 3.30 | 0.24 | 3.06 | 0.07 |
| Chum | PIT tag - point | 3.88 | 0.24 | 3.64 | 0.06 |
| Chum | PIT tag - upper | 4.47 | 0.24 | 4.23 | 0.05 |
| | | | | | |
| Pink | PIT tag - lower | 3.72 | 0.45 | 3.27 | 0.12 |
| Pink | PIT tag - point | 21.28 | 0.45 | 20.83 | 0.02 |
| Pink | PIT tag - upper | 40.96 | 0.45 | 40.51 | 0.01 |

**Appendix 1:** Summary statistics for coho, pink, and chum salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002 without any adjustments for tag mortality, tag loss, or tag detection rate.

**Table 1.** Summary statistics for coho salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002 without any adjustments for tag mortality, tag loss, or tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| July 7 | 648 | 0 | 0 | 8 | 8 | 2 | 0 |
| July 14 | 1,606 | 0 | 0 | 16 | 30 | 15 | 3 |
| July 21 | 1,137 | 0 | 0 | 0 | 4 | 35 | 6 |
| July 28 | 1,507 | 0 | 0 | 0 | 0 | 17 | 23 |
| Total untagged | | 406 | 3,497 | 41,187 | 46,822 | 57,861 | 29,539 |
| Total recoveries | | 406 | 3,497 | 41,211 | 46,864 | 57,930 | 29,571 |

**Table 2.** Summary statistics for pink salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002 without any adjustments for tag mortality, tag loss, or tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 46 | 0 | 0 | 0 | 0 | 0 | 0 |
| July 7 | 850 | 0 | 0 | 5 | 0 | 0 | 0 |
| July 14 | 997 | 0 | 0 | 7 | 1 | 0 | 0 |
| July 21 | 1,068 | 0 | 0 | 0 | 1 | 16 | 1 |
| July 28 | 2,377 | 0 | 0 | 0 | 0 | 9 | 5 |
| Total untagged | | 142 | 3,016 | 31,608 | 38,887 | 107,985 | 72,481 |
| Total recoveries | | 142 | 3,016 | 31,620 | 38,889 | 108,010 | 72,487 |

**Table 3.** Summary statistics for chum salmon PIT tagged in Upper Cook Inlet and recovered in processors, 2002 without any adjustments for tag mortality, tag loss, or tag detection rate.

| Release | | Recovery strata (week beginning) | | | | | |
|---|---|---|---|---|---|---|---|
| Strata | Fish tagged | July 1 | July 7 | July 14 | July 21 | July 28 | August 4 |
| July 1 | 399 | 1 | 5 | 2 | 0 | 0 | 0 |
| July 7 | 1,480 | 0 | 1 | 35 | 2 | 1 | 0 |
| July 14 | 995 | 0 | 0 | 10 | 20 | 0 | 0 |
| July 21 | 1,020 | 0 | 0 | 0 | 7 | 33 | 0 |
| July 28 | 1,177 | 0 | 0 | 0 | 0 | 31 | 6 |
| | | | | | | | |
| Total untagged | | 7,800 | 21,733 | 52,276 | 42,018 | 38,893 | 5,241 |
| Total recoveries | | 7,801 | 21,739 | 52,323 | 42,047 | 38,958 | 5,247 |

**Appendix 2:** Percent of total radio tags recovered by release and recovery strata for seven stocks of coho salmon.

**Table 1**. Percent of total radio tags recovered by release and recovery strata for Kenai Peninsula coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 19.2 | 19.2 | 1.8 |
| July 21 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.7 | 30.7 | 2.8 |
| July 28 | 0.0 | 0.0 | 0.0 | 0.0 | 6.3 | 43.9 | 50.1 | 4.6 |
| Sum | 0.0 | 0.0 | 0.0 | 0.0 | 6.3 | 93.7 | 100.0 | 9.2 |

**Table 2**. Percent of total radio tags recovered by release and recovery strata for Knik Arm coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.4 | 0.2 |
| July 7 | 0.0 | 0.7 | 2.1 | 1.4 | 0.0 | 0.7 | 4.8 | 2.8 |
| July 14 | 0.0 | 0.0 | 21.8 | 21.8 | 0.0 | 3.1 | 46.8 | 26.6 |
| July 21 | 0.0 | 0.0 | 0.0 | 17.4 | 12.4 | 5.0 | 34.8 | 19.8 |
| July 28 | 0.0 | 0.0 | 0.0 | 0.0 | 6.1 | 7.1 | 13.2 | 7.5 |
| Sum | 0.0 | 0.7 | 23.9 | 41.0 | 18.5 | 15.9 | 100.0 | 57.0 |

**Table 3**. Percent of total radio tags recovered by release and recovery strata for Little Susitna River coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 1.6 | 0.0 | 3.2 | 1.6 | 1.6 | 0.0 | 8.0 | 2.0 |
| July 14 | 0.0 | 0.0 | 21.6 | 21.6 | 7.2 | 0.0 | 50.4 | 12.4 |
| July 21 | 0.0 | 0.0 | 5.7 | 17.2 | 0.0 | 0.0 | 22.9 | 5.7 |
| July 28 | 0.0 | 0.0 | 0.0 | 0.0 | 16.4 | 2.3 | 18.7 | 4.6 |
| Sum | 1.6 | 0.0 | 30.5 | 40.4 | 25.2 | 2.3 | 100.0 | 24.7 |

**Table 4**. Percent of total radio tags recovered by release and recovery strata for Susitna River coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 1.2 | 8.7 | 3.6 | 0.0 | 0.0 | 0.4 | 13.9 | 13.8 |
| July 14 | 3.6 | 25.0 | 19.6 | 3.6 | 3.6 | 0.0 | 55.3 | 55.1 |
| July 21 | 0.0 | 2.8 | 10.0 | 12.8 | 0.0 | 0.0 | 25.6 | 25.5 |
| July 28 | 0.0 | 0.0 | 0.0 | 4.1 | 0.6 | 0.6 | 5.2 | 5.2 |
| Sum | 4.8 | 36.5 | 33.2 | 20.4 | 4.2 | 1.0 | 100.0 | 99.5 |

**Table 5**. Percent of total radio tags recovered by release and recovery strata for Turnagin Arm coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 0.0 | 2.7 | 0.0 | 0.0 | 2.7 | 0.0 | 5.4 | 0.8 |
| July 14 | 0.0 | 12.1 | 0.0 | 0.0 | 24.1 | 0.0 | 36.2 | 5.3 |
| July 21 | 0.0 | 0.0 | 0.0 | 19.2 | 0.0 | 0.0 | 19.2 | 2.8 |
| July 28 | 0.0 | 0.0 | 0.0 | 0.0 | 15.7 | 23.6 | 39.3 | 5.8 |
| Sum | 0.0 | 14.7 | 0.0 | 19.2 | 42.5 | 23.6 | 100.0 | 14.7 |

**Table 6**. Percent of total radio tags recovered by release and recovery strata for Westside coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July 7 | 1.1 | 3.9 | 1.1 | 0.0 | 0.0 | 0.6 | 6.6 | 4.7 |
| July 14 | 0.0 | 7.5 | 15.0 | 10.0 | 0.0 | 0.0 | 32.4 | 23.1 |
| July 21 | 0.0 | 4.0 | 17.9 | 11.9 | 0.0 | 2.0 | 35.8 | 25.5 |
| July 28 | 0.0 | 0.0 | 0.0 | 15.4 | 8.1 | 1.6 | 25.2 | 17.9 |
| Sum | 1.1 | 15.3 | 34.0 | 37.3 | 8.1 | 4.2 | 100.0 | 71.2 |

**Table 7**. Percent of total radio tags recovered by release and recovery strata for Yentna River coho salmon.

| Release | Recovery Strata (week beginning) | | | | | | | Weighted |
|---|---|---|---|---|---|---|---|---|
| Strata | July 14 | July 21 | July 28 | Aug. 4 | Aug. 11 | Aug. 18 | Total | No. Tags |
| July 1 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 | 0.6 | 0.5 |
| July 7 | 3.7 | 4.6 | 3.2 | 0.9 | 0.5 | 0.0 | 12.9 | 11.0 |
| July 14 | 2.1 | 20.8 | 33.3 | 4.2 | 0.0 | 0.0 | 60.4 | 51.5 |
| July 21 | 0.0 | 0.0 | 10.0 | 6.6 | 0.0 | 0.0 | 16.6 | 14.2 |
| July 28 | 0.0 | 0.0 | 2.0 | 4.1 | 2.7 | 0.7 | 9.5 | 8.1 |
| Sum | 5.8 | 25.7 | 48.8 | 15.8 | 3.2 | 0.7 | 100.0 | 85.3 |

**Appendix 3.** Summary of historical coded-wire tag estimates of coho salmon exploitation rates in Upper Cook Inlet, 1993-1998.

**Table 1.** Historical coded-wire tag estimates of commercial fisheries exploitation rates on coho salmon in Upper Cook Inlet and effort (number of deliveries x hours fished) in the Central District drift gill net fishery (district wide openings only), 1993-1998.

| Year | Stream | Exploitation Rate | Effort | Reference |
|---|---|---|---|---|
| 1993 | Campbell Creek | 0.35 | 53,040 | Hoffman and Hasbrouck, 1994 |
| | Little Susitna River | 0.44 | | |
| | Bird Creek | 0.29 | | |
| | Ship Creek | 0.06 | | |
| 1994 | Campbell Creek | 0.71 | 66,680 | Stratton et al., 1996 |
| | Little Susitna River | 0.69 | | |
| | Bird Creek | 0.58 | | |
| | Ship Creek | 0.45 | | |
| 1995 | Campbell Creek | 0.65 | 60,948 | Cyr et al., 1997 |
| | Little Susitna River | 0.59 | | |
| | Bird Creek | 0.51 | | |
| | Ship Creek | 0.43 | | |
| 1996 | Campbell Creek | 0.75 | 46,932 | Cyr et al., 1998 |
| | Little Susitna River | 0.57 | | |
| | Bird Creek | 0.45 | | |
| | Ship Creek | 0.53 | | |
| 1997 | Bird Creek | 0.32 | 34,404 | Cyr et al., 1999 |
| | Anchorage Urban Streams | 0.40 | | |
| | Wasilla Creek | 0.93 | | |
| 1998 | Campbell Creek | 0.21 | 28,932 | Cyr et al., 2001 |
| | Bird Creek | 0.15 | | |
| | Ship Creek | 0.21 | | |