Fishery Data Series No. 05-31

A Mark–Recapture Experiment to Estimate the Escapement of Coho Salmon in the Situk River, 2004

by

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June 2005

Alaska Department of Fish and Game — Divisions of Sport Fish and Commercial Fisheries

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Department of Fish and Game	ADF&G
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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June 2005

Development and publication of this manuscript were partially financed by the Southeast Sustainable Salmon Fisheries Fund under Project 45215.

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This document should be cited as:
Waltemyer, D. L., D. Reed, M. Tracy, and J. H. Clark. 2005. A Mark–Recapture Experiment to Estimate the Spawning Escapement of Coho Salmon in the Situk River, 2004. Alaska Department of Fish and Game, Fishery Data Series No.05-31, Anchorage.

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ABSTRACT

This was the first year of a planned multi-year study to estimate the abundance of coho salmon *Oncorhynchus kisutch* returning to spawn in the Situk River located near Yakutat, Alaska. The abundance of coho salmon in 2004 was estimated using a two-event mark–recapture experiment. Biological data were collected during both sampling events. Fish were captured during Event 1 in the lower Situk River using a beach seine from 23 August through 20 September. Each fish was marked by removal of the adipose fin and given a secondary batch mark in the form of a Floy anchor tag. A total of 2,687 coho salmon were captured, marked, and released during Event 1. In Event 2, fish were caught using a beach seine at the confluence of the Situk River and Old Situk Creek from 29 August through 17 September. Due to torrential rains and subsequent flooding that lasted several weeks, the sampling strategy for Event 2 had to be altered to collecting and examining carcasses for marks on the spawning grounds in the headwaters of the Situk River and Old Situk Creek. Once water levels receded to workable levels, Event 2 sampling was again initiated on 26 October and continued through 15 November. In Event 2, 1,012 coho salmon were sampled and of these, 85 had been previously marked in Event 1. After stratification of sample data into time strata and using the partially stratified Petersen or Darroch estimator, abundance of coho salmon in the Situk River in 2004 was estimated to total 54,014 fish (SE ≈17,000). The peak survey of coho salmon in the Situk River in 2004 was 10,284 fish on 9 September. The expansion factor calculated from dividing the estimated escapement by the peak aerial survey count was 5.2 (SE ≈ 1.65).

Key words: coho salmon, *Oncorhynchus kisutch*, spawning abundance, Situk River, mark–recapture, peak survey count, expansion factor, Yakutat, Alaska

INTRODUCTION

The Situk River is a small river located about 10 miles southeast of the city of Yakutat, Alaska (Figure 1). The river is approximately 20 km in length. Situk Lake forms the headwaters of the drainage. The Situk River flows into the Situk-Ahrnklin lagoon before entering the Gulf of Alaska. Since the winter of 1999–2000, the Lost River which is located just to the northwest of the Situk River has also flowed into the Situk-Ahrnklin lagoon. The Ahrnklin River also drains into the lagoon and all three of these rivers produce substantial numbers of coho salmon (*Oncorhynchus kisutch)*.

Major terminal commercial and subsistence set gill net fisheries occur in the Situk-Ahrnklin lagoon where large numbers of coho salmon are harvested. Commercial harvests of coho salmon from the Situk River set gill net fishery (Statistical Area 182-70) during the period 1960–2003 have ranged from 10,026 fish in 1973 to 189,828 fish in 2002. Coho salmon harvests in the Lost River commercial set gill fishery averaged about 6,000 fish per year from 1972–1999 (years prior to the Lost River channel change). These terminal harvests in the set gill net fishery are directed at coho salmon that are returning to spawn in the Situk, Ahrnklin, and Lost Rivers, with the Situk stock believed to be the largest. Offshore troll fisheries are mixed stock commercial fisheries which likely harvest as many as 50,000 coho salmon that would otherwise return to the Situk, Ahrnklin, and Lost Rivers (Clark and Clark 1994). After returning to freshwater, these three stocks of coho salmon also support important local subsistence and sport fisheries that are road accessible in the Yakutat area. Recent average harvests (2000–2003) are about 3,000 coho per year in the terminal subsistence fishery, about 10,000 coho caught and 3,000 coho retained in the terminal sport fishery.

Set gill net and sport fisheries in the Situk area are managed to achieve escapement objectives on an in-season basis. The Situk weir is pulled prior to the coho salmon run. Current escapement objectives are based on peak annual aerial or boat survey counts of 3,300 to 9,800 coho spawners in the Situk River and 2,200 to 6,500 coho spawners in the Lost River (Clark and Clark 1994). Escapement counts of coho salmon in the Ahrnklin River are limited to five years (1982, 1986–1988, and 1992) with the highest count being 2,200 fish in 1992. The Antlen River which is a tributary of the Ahrnklin River has been surveyed between 1986 and 1989 with the highest count being 3,500 fish in 1989.

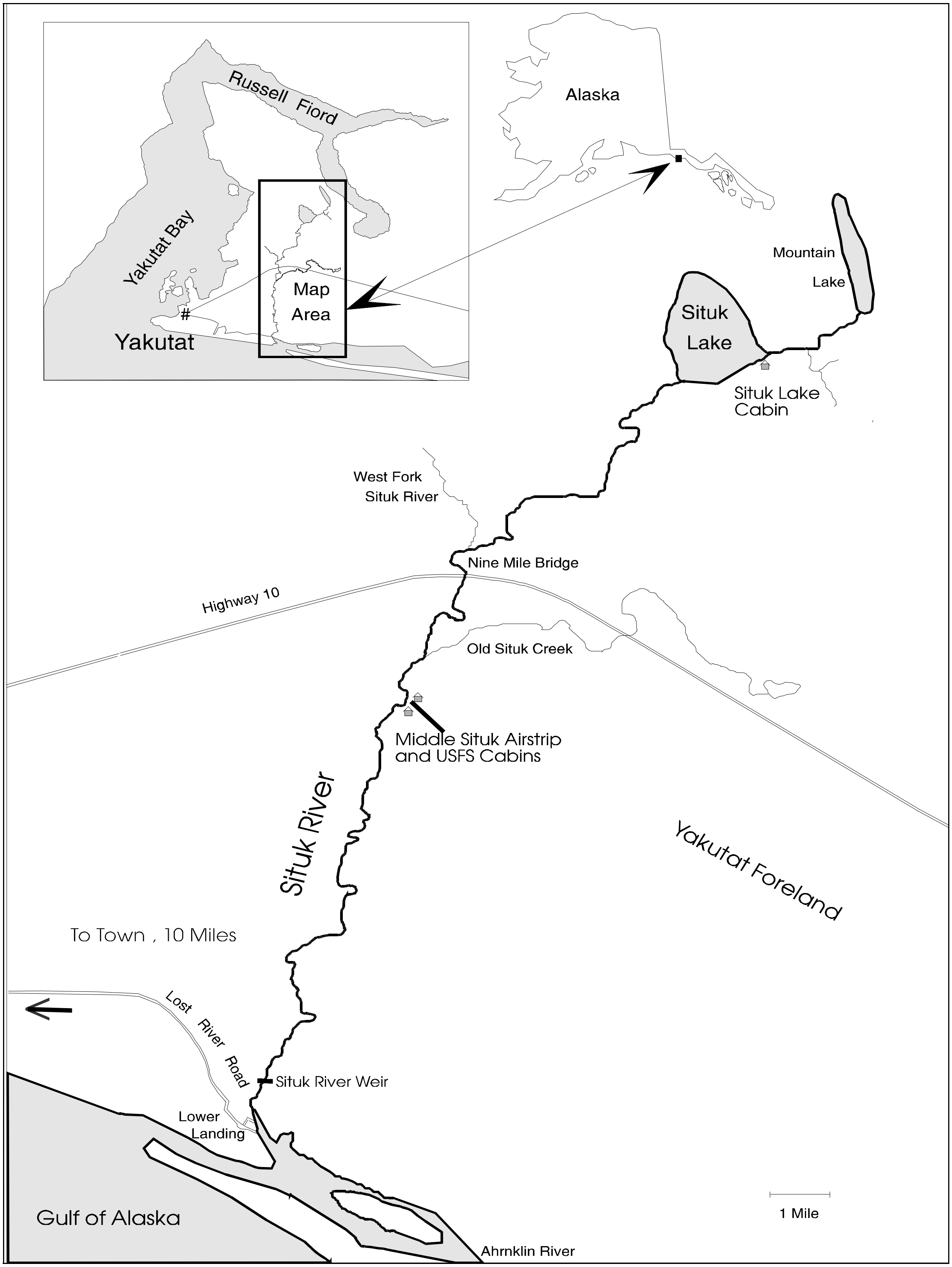

Figure 1.–Map of Situk River drainage near Yakutat, Alaska.

Visibility in these river systems limits the effectiveness of aerial and boat surveys (Clark and Clark 1994). While the management intent is appropriate, the existing stock assessment program is rudimentary and the escapement goals currently in use were based upon a wide array of untested assumptions. Total escapements of coho salmon in these rivers has been unknown, instead spawning strength has historically been gauged based upon aerial and boat survey counts of coho salmon. Distribution of the harvest among offshore troll and inshore fisheries is largely unknown. The existing database for distribution of these offshore versus inshore harvests is limited to coded wire tag results obtained for the Lost River stock in 1986 and the Situk stock in 1985 and 1993 (Shaul et al. 1991). Stock composition of the large annual Situk-Ahrnklin Lagoon set net harvests is unknown. Development of appropriate escapement goals and improvement of harvest contribution estimates of these coho salmon stocks to both offshore and inshore fisheries is needed.

Improvements in the annual stock assessments for Situk River coho salmon have been recommended in several past technical reports. Upon these recommendations, a program to estimate coho escapements to the three major systems (Situk, Lost and Ahrnklin rivers) and a companion coded-wire-tag study to provide estimates of off-shore harvest contribution and total return has been funded. This specific stock assessment study is primarily intended to provide direct estimates of total escapement of coho salmon in the Situk River. Intent is to continue this effort so that the annual average and inter-annual variance for the relationship between peak survey counts and total escapements can be scientifically determined for coho salmon spawning in the Situk River system.

In the fall of 2002, funding was obtained from the Southeast Sustainable Salmon Fisheries Fund to augment stock assessment information available for management of coho salmon fisheries in the Yakutat area. In 2004, the Alaska Department of Fish and Game (ADF&G) implemented a mark–recapture experiment for coho salmon, in an effort to (1) estimate the total spawning abundance of coho salmon in the Situk River system to within 35% of the true value 95% of the time, (2) estimate the expansion factor (escapement estimate divided by the peak survey count); and (3) estimate the age and sex composition of the escapement of coho salmon in the Situk River.

METHODS

A two-event mark–recapture experiment for a closed population (Seber 1982) was conducted to estimate abundance of coho salmon in the Situk River in 2004.

Capture and Marking (Event 1)

Immigrating coho salmon were caught in the vicinity of the lower river weir site (river kilometer 3.2) above the upper boundary of the Situk-Ahrnklin lagoon commercial set gillnet fishing district. A 30 m x 4 m (mesh 2.2 cm) beach seine was used to capture fish during Event 1 from 23 August to 20 September. The time of day, tidal stage, and catch for each beach seine set were recorded on field data forms.

Upon retrieval of the beach seine, coho salmon were carefully removed from the net for sampling. Coho salmon captured and in good condition were measured from mid-eye to fork of tail (MEF) to the nearest 5 mm, sexed by visual examination, and doubly marked, and released. The primary mark was an adipose fin clip. The secondary mark was a sequentially numbered, anchor floy tag attached interstitially of the distal pterygiophori beneath the posterior insertion of the dorsal fin.

The secondary marks were used to ensure that when a fish was examined on the spawning grounds, anywhere from two weeks to three months later, the time period when the fish was marked and released could be determined. Further, this ensured that we could conduct appropriate tests of these data when calculating the mark–recapture estimate. The condition of each fish was assessed, noted, and recorded. Fish with deep wounds, damaged gills or fish in a lethargic condition were released without being marked or sampled.

A subset of fish captured over the course of Event 1 were fitted with radio transmitter tags and then released. The radio transmitters used were manufactured by Advanced Telemetry Systems

(ATS). The tags were 51 mm long and necked from a diameter of 19 to 15 mm. The tag was positioned in the mouth and manually inserted through the esophagus into the stomach with a tag plunger. Prior to deploying each radio transmitter tag, the frequency was checked and verified and the frequency noted on the field data form. Once the radio transmitter was in place and measures taken to insure that the tag wouldn't be regurgitated, the fish was released. The radio transmitter tags were used to examine conditions necessary for unbiased estimation with the mark–recapture experiment and to to verify that marked fish moved into the Event 2 sampling area rather than dying or moving elsewhere. This information enabled us to later adjust the number of marks used in the abundance estimation process. Tracking of the radio transmitter tagged fish occurred weekly through ground surveys and/or aerial surveys using fixed wing airplane.

Recovery on Spawning Grounds (Event 2)

Event 2 sampling was initially conducted by seining and inspecting coho salmon for marks at the confluence of the Situk River and Old Situk Creek beginning 30 August and intermittently through 17 September. Thereafter, this sampling strategy became impractical due to torrential rain and high water conditions in the Situk River. There was a one-month interval before water levels had receded to safe, workable levels at the confluence of the Situk River and Old Situk Creek. As a result, the sampling strategy was modified to collecting and examining carcasses from the headwaters of the Situk river and Old Situk Creek.

Carcass sampling was conducted from September 24 through November 15. The numbers of marked and unmarked fish examined during Event 2 sampling were recorded and noted as to location. Sampling crews, consisting of 5 to 6 persons, worked these sections of the Situk River gathering and sampling carcasses. Once a fish was examined, a slash mark was made on the left side of the fish to ensure that these fish were not sampled again (without replacement).

Abundance Estimation

This experiment was designed to estimate coho salmon abundance using a two-sample mark-recapture experiment. Under ideal conditions, Chapman's modification of the Petersen Method (Seber 1982) would be used to estimate the coho salmon escapement. The conditions for appropriate use of this methodology are:

1. all coho salmon have an equal probability of being marked; or
2. all coho salmon have an equal probability of being inspected for marks; or
3. marked fish mixed completely with unmarked fish between events; and
4. there is no recruitment to the population between events; and
5. there is no mark-induced mortality; and
6. fish do not lose their marks and all marks are recognizable.

This experiment was designed so that these conditions could either be ensured by field procedures or the conditions could be evaluated with diagnostics testing, and the appropriate model for estimating abundance could be selected.

Meeting the first condition depended upon entry pattern, how long these fish remained in the area where netting occurred, and the fishing effort that took place during Event 1. Residence time at the first event sampling site is unknown and only limited inference can be gleaned concerning entry pattern based on catch per effort statistics. Event 1 sampling effort represented from 0 to 3 beach seine sets per day over 29 days of sampling of a planned 54-day schedule. Meeting the second condition depended primarily upon survey coverage. Second event sampling took place over a 68-day period, but actual sampling of fish occurred on only 11 days. Meeting the third condition depended primarily upon behavior of fish marked during Event 1.

Conditions 1–3 could be violated if length or sex selective sampling occurred. Meeting these conditions was tested through a series of hypothesis tests (Appendix A1). Determination of whether the coho salmon sampled in Event 1 had similar length distributions to fish sampled in Event 2 was based upon the Kolmogorov-Smirnov (K-S) test. The test hypothesis was that fish of different lengths were captured with equal probability using the test criterion level of $\alpha = 0.1$.

Three consistency tests described by Seber (1982) were used to test for temporal and/or spatial violations of conditions 1–3. Contingency table analyses were used to test three null hypotheses: (1) the probability that a marked fish was recovered during Event 2 was independent of when it was marked; (2) the probability that a fish that was inspected during Event 2 was marked was independent of when/where it was caught during the second event; and 3) for all marked fish recovered during Event 2, time of marking was independent of when/where recovery occurred. Failure to reject at least one of these three hypotheses is sufficient to conclude that at least one of conditions 1–3 was satisfied.

If none of conditions 1-3 were satisfied, the partially stratified estimator described by Darroch (1961) was utilized to estimate abundance. The software package Stratified Population Analysis System (SPAS) (Arnason et al. 1996) was employed to calculate a Darroch – type estimate and variance.

The basis for meeting condition 4 (no recruitment) is based on the timing of the tagging event, observations of salmon abundance at the tagging site throughout Event 1, and aerial and ground surveys. The timing of the tagging event coincided with the commercial fishery however, after 29 days of a defined 54-day sampling regime activities were suspended due to torrential rain storms which caused high water conditions for a month. Since tagging operations were suspended during a time when coho salmon were still being caught in the commercial fishery, there is reason to believe that recruitment was occurring and condition 4 was likely violated. In the presence of recruitment between sampling events, an unbiased estimate of abundance can still be calculated so long as either no mortality or effective emigration occurs between events, or loss of marks can be estimated and adjusted for prior to estimating abundance. The estimate of abundance under these conditions will be germane to the timing/location of second event sampling.

Any time salmon are caught and handled, there is potential for mark-induced mortality (condition 5). Periodic visual examinations of the area where Event 1 sampling occurred failed to document marked coho salmon that had died. This information provides only limited evidence for the lack of mark-induced mortality, however further testing of condition 5 was possible through analysis of the tracking information of radio-tagged coho salmon. Adjustments to the number of marked fish were made based on findings from aerial and ground surveys of radio tag fish distribution.

Each marked fish received a primary mark and a secondary mark to insure that marks were recognizable during second-event sampling. Thus it is highly unlikely that any marked fish inspected during the second event were not accurately identified as marked (condition 6).

The number of valid marked salmon in the experiment was estimated by correcting the total number of salmon marked during Event 1 using the estimated proportion of radio-tagged salmon that remained in the study area from each of three marking periods:

$$\hat{M} = \sum_{t=1}^{3} \hat{M}_t = T_t \hat{p}_t \qquad (1)$$

where $\hat{M}_t$ is the estimated number of salmon marked during period t (t = 1 to 3) that remained in the study area, T_t was the total number of salmon marked during marking period t and p_t was the proportion of fish marked during period t that remained in the study area and were available for sampling during Event 2. These proportions were estimated using radio-tagged salmon:

$$\hat{p}_t = v_t / r_t \qquad (2)$$

where r_t was the number of radio-tagged fish marked during period t and v_t were those members of r_t that remained in the study area.

Expansion Factor

The expansion factor for the peak count of coho salmon from the survey in 2004 and its variance was estimated as follows:

$$\hat{\pi}_{2004} = \hat{N} / I_{2004} \quad (5)$$

$$var(\hat{\pi}_{2004}) = var(\hat{N}) I_{2004}^{-2} \quad (6)$$

where π was the expansion factor for 2004 and *I* the peak count of several surveys conducted in 2004. The variance in equation 6 represents sampling-induced variation from the mark–recapture experiment, and accordingly represents the same precision attained with the estimate of abundance from that experiment.

RESULTS

Tagging, Recovery and Abundance

A total of 2,687 coho salmon were captured, sampled and released with primary and secondary marks between 23 August and 20 September 2004 (Figure 2, Table 1). Detailed information, including the numbers of fish radio tagged by day is available in Appendices A2 and A3. From 9 September through 15 November of 2004, we inspected a total of 1,812 fish from the Situk River and Old Situk Creek during Event 2 (Table 1, Appendix A4). Of these, a total of 93 fish were observed with marks. However, eight of the marked fish captured in the Situk River were originally tagged in the Lost River as part of the mark-recapture program being conducted on that system. The eight fish originally marked in the Lost River were considered part of the Event 2 catch, but not considered as recaptures from Event 1. Consequently, only 85 fish were used to represent the total number of recaptured marked fish in Event 2 for the Situk River. The eight fish that were noted as being tagged in the Lost River were treated as part of the overall capture number of fish in Event 2, but were not treated as recaptures because of having not been marked in Event 1. All marked fish recovered possessed their primary adipose fin clip mark, although 7 fish had shed their secondary anchor tag.

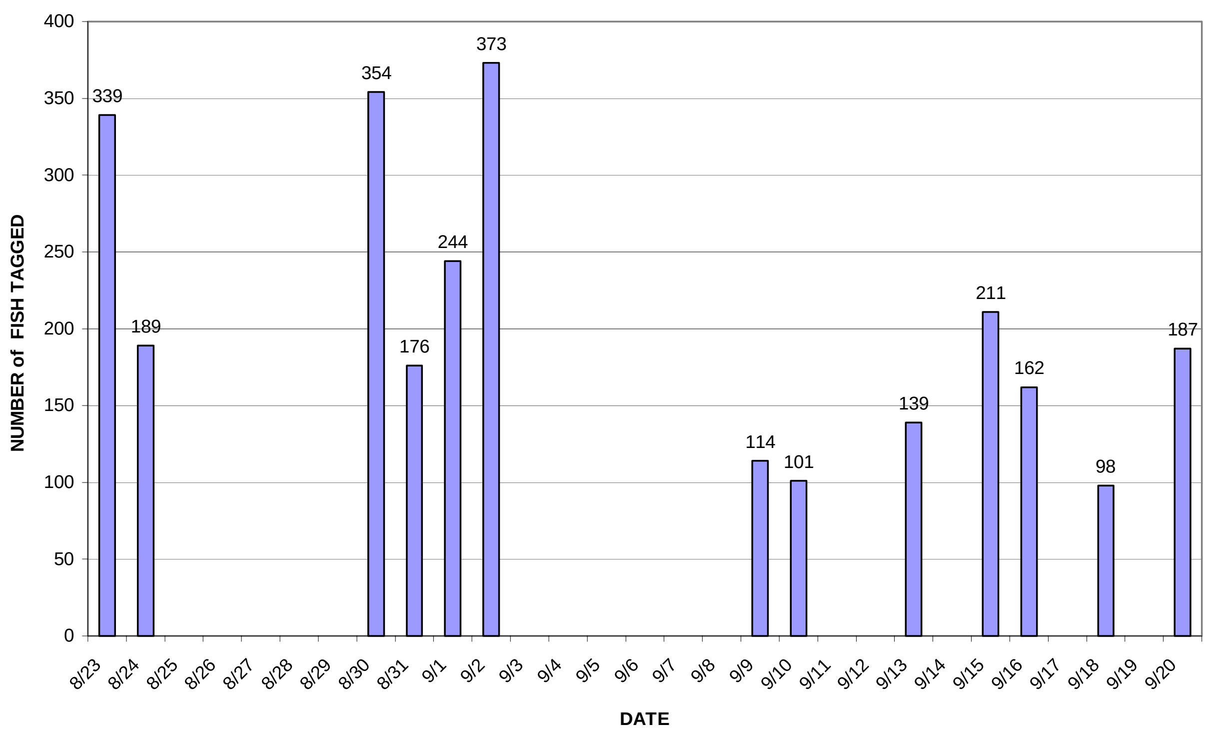

Figure 2.–Number of coho salmon captured and marked during Event 1, Situk River, 2004.

Table 1.–Number of coho salmon marked in Event 1 and inspected for marks on the spawning grounds by location in Event 2, Situk River, 2004.

	No. of Fish
Event 1:	
Released with marks (M)	2,687
Event 2:	
Captured (C)	
Situk River	1,654
Old Situk Creek	158
Total	1,812
Recaptured (R)	
Situk River [a]	80
Old Situk Creek	5
Total	85

[a] The total number of mark recoveries from the Situk River project was 88, but this number was reduced to 80 for further analysis because 8 of the marked fish had been tagged on the Lost River.

Diagnostic testing for size bias sampling was conducted according to methods described in Appendix A1. The length frequency distribution of all fish marked (M) during Event 1 did not differ significantly from that of those marked fish recaptured (R) during Event 2 (K-S = 0.070, p= 0.803; Appendix A5) indicating no evidence of size bias sampling during Event 2. The direct test for first event length bias between captures (C) and recaptures (R) indicated no statistical difference (K-S = 0.123, p = 0.163). However, there was a statistical difference between length frequencies for all fish marked (M) during Event 1 and captures (C) in Event 2 (K-S = 0.099, $p < 0.001$) indicating potential for size bias sampling during Event 1. While the direct test between captures (C) and recaptures (R) indicated no strong evidence of size bias sampling during Event 1 (K-S = 0.123, p = 0.163) we conservatively concluded that we had a Case II experiment (see Appendix A1). Case II prescribes that one unstratified abundance estimate should be calculated, however lengths, sexes, and ages from the second sampling event are used to estimate proportions in the composition.

While the above tests provided no evidence of size bias sampling during Event 2, we conducted one additional test for potential bias. Because fish were sampled at two sites which could possibly be comprised of different stocks and we could not directly evaluate our ability to sample proportional to abundance at the two sites we compared length frequency distributions of fish inspected at the two sampling sites. Length frequencies between the Situk River and Old Situk Creek capture sites were plotted and found to not differ statistically between fish captured on the spawning grounds in Event 2 (K-S = 0.095, p=0.143; Figure 3).

We did not conduct tests for gender bias because we found evidence that gender was not consistently classified correctly during one or both sampling events. Assuming the Event 2 sex classifications were correct, an analysis indicates that 7 of 46 fish classified as males during Event 1 ended up being classified as females during Event 2. And 6 of 32 fish classified as females during Event 1 ended up being classified as males in the Event 2 sampling. While these error rates don't indicate a clear bias one way or the other (females were misclassified about as often as males), it does not provide a true means of testing gender bias in a contingency table analysis with hypothesis testing. Due to complexities in aging coho salmon scales and insufficient staff time, age composition analysis was not completed at the time this analysis was finalized and therefore is not included in this report.

A summary of the number of coho salmon inspected and the number with marks observed during Event 2 is shown in Appendix A3. The null hypothesis that the probability that an Event 2 fish was marked was independent of the time interval during Event 2 when the fish was sampled was rejected ($\chi^2 = 3.524$, p = 0.060), indicating probability of capture during Event 1 was not consistent over time. Also, the null hypothesis that marked fish mixed completely with unmarked fish between events was rejected ($\chi^2 = 40.661$, $p < 0.001$). Therefore, rejection of the null hypothesis for all three tests was sufficient to conclude that conditions 1–3 weren't satisfied and a partially stratified model for abundance estimation was needed.

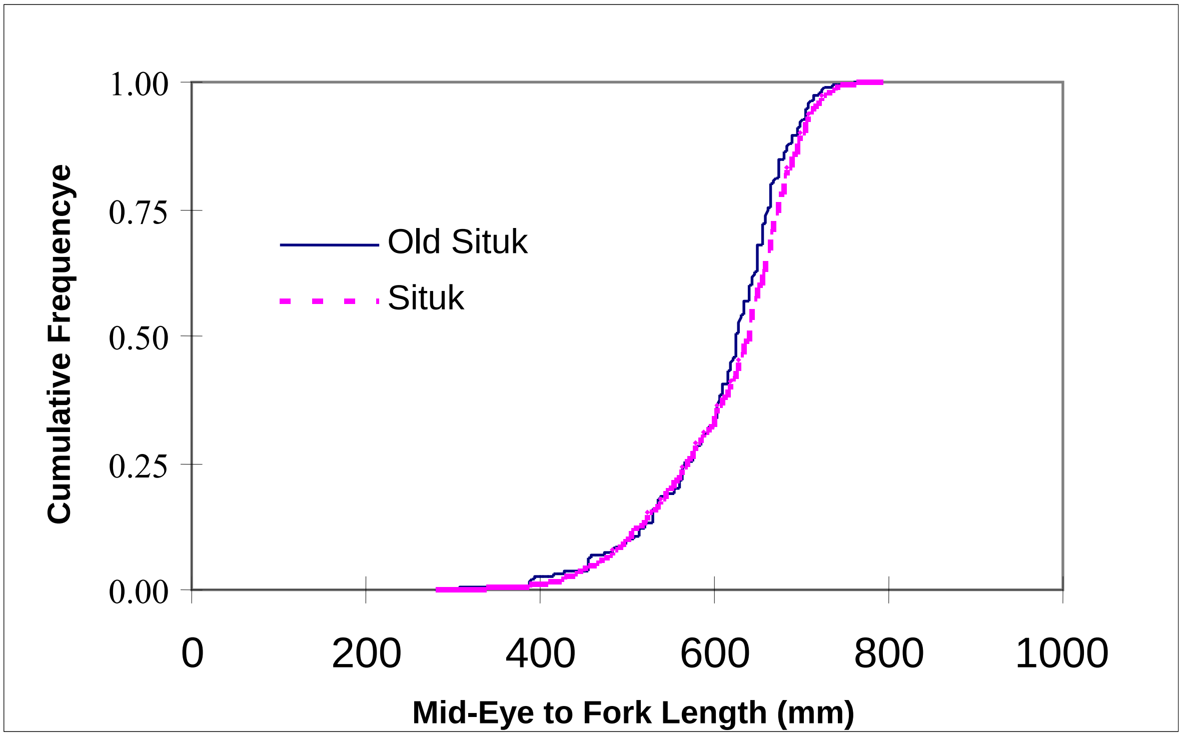

Figure 3.–Cumulative relative frequency distributions of Situk River and Old Situk Creek coho salmon captured on the spawning grounds in Event 2, 2004.

Data used for estimating abundance were separated into temporal strata. For Event 1 strata were based on examination of probability of recapture over time. For Event 2 strata were based on marked to unmarked ratios over time. Because the proportions of fish released and recaptured to the total number of marked fish released for the first two marking periods (23–24 August versus 30 August–2 September) were fairly homogeneous (0.035, 0.046), while the third marking period (9–20 September) was different (0.0059), Event 1 tagging totals were divided into two temporal strata. The Event 2 data were stratified into two temporal periods, 9-17 September and 24 September-15 November, because of significantly different marked:unmarked ratios during these periods (0.0519 vs 0.0296).

Tagging totals per statum were further adjusted based on radio tagging results by marking period. Based on the radio tags, we had 10 out of 11 radio tagged fish from 528 total tags during the first marking period, 10 out of 14 radio-tagged fish from 1,147 total marked fish during the second period, and 7 out of 11 radio-tagged fish from 1,012 total marked fish during the third marking period. Applying the fraction of radio-tagged fish that remained in the Situk to the total number marked during each period results in an estimated 1,299 valid tagged fish ($\hat{M}_t$) during the first two tagging periods (1st marking temporal stratum) and an estimated 644 valid tagged fish ($\hat{M}_t$) during the third marking period (2nd marking temporal stratum).

There were 7 recaptured fish that lost their floy tag identifier (4 recaptures during the 1st capture temporal stratum and 3 recaptures during the 2nd capture temporal stratum). Consequently, it was necessary to estimate the number of recaptures for each of the two capture event temporal strata (9–17 September versus 24 September–15 November). This was accomplished by dividing the 4 recaptures according to these observed ratios (68/69, 1/69) and assigned 3.942 fish to the 1st marking stratum and 0.058 fish to the 2nd marking stratum. For the 2nd capture stratum, the corresponding ratios (4/9, 5/9) were used and assigned 1.333 fish to the 1st marking stratum and the remaining 1.667 fish to the 2nd marking stratum. The temporally stratified Maximum

Likelihood (ML) Darroch estimator was used to estimate the coho escapement in the Situk River and resulted in an estimate of 54,014 fish. The ML estimate of standard error (SE) of the abundance estimate is 11,862, but this estimate of precision is biased low because not all sources of variation are accounted for. Specifically, uncertainty due to corrections for marked fish that left the system and for marked fish recovered during the second event without tags indicating marking strata is not accounted for in the ML estimate of SE. Ideally, bootstrap procedures adapted from those described by Buckland and Garthwaite (1991) can be used to model all sources of variation to provide an unbiased estimate of SE. In this instance, that effort was not productive due to the nature of the Darroch-type estimator and characteristics of this data set. Based on unpublished simulation studies conducted by the authors when planning this and similar studies, we expect the ML estimate of SE to be approximately 25% smaller than the true value when estimating the true number of marked fish from a sample of 50 radio-tagged fish. Extrapolating to this data set, The ML estimate of SE of 11,862 is likely to be approximately 30% smaller than the true value, providing an approximation of SE of about 17,000. Even though estimating SE is problematic for this data set, all diagnostic tests indicated that the abundance estimate of 54,014 is minimally biased.

Expansion Factor

During 2004, there were five boat surveys of the Situk River and Old Situk Creek wherein coho salmon were counted (Table 2).

Table 2.–Survey counts of coho salmon escapement in the Situk River, 2004.

Date	Situk	Old Situk
8/17	1,222[a]	
8/30	8,392[b]	
9/09	10,284[b]	
10/24		1,126[c]
10/26	3,325[d]	

[a] Old Situk confluence to landing
[b] Nine Mile to landing
[c] Road (bridge) to confluence
[d] Situk Lake to Nine Mile.

The peak survey occurred on 9 September and the count was 10,284 coho salmon. The survey expansion factor (the ratio of the total abundance estimate of coho salmon to the peak survey count) for 2004 was 5.25 with an approximate SE (based on extrapolation described in the previous section) of 1.65.

DISCUSSION

We designed this experiment so that if all necessary conditions were met, Chapman's modification of the Petersen method would be used to estimate escapement. We collected data such that we could directly evaluate if the three "or" conditions were violated due to size selectivity of sampling gear or inconsistent effort over time. Based on the results of the diagnostic tests for size selectivity, we concluded that size selective sampling did not occur at detectable levels during Event 2, but it was likely that size selective sampling occurred during Event 1. This resulted in a Case II scenario of calculating one unstratified abundance estimate, and only using lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

We were unable to test for equal probability of capture by gender because we detected errors in gender classification that we attributed primarily to difficulties in classification during Event 1. An analysis comparing the gender classification of fish marked in Event 1 and recaptured in Event 2 provided error rates that didn't indicate a clear bias in classification one way or the other.

Tests for equal probability of sampling over time for Event 1 and Event 2 and for complete mixing indicated that none of the first three conditions were satisfied due to temporal variation in sampling. As a result, the partially stratified estimator of Darroch (1961) was necessary to compute an abundance estimate with minimal bias. This necessitated breaking the sampling in Events 1 and 2 into time strata where probability of capture was fairly homogeneous within strata but significantly different between strata. We were careful in ensuring we addressed condition 6 (recognizable marks). Seven of the 1,812 coho salmon examined during the second event had adipose clips, but not secondary marks. Review of the data collection during Event 1 sampling identified that several adipose clipped fish squirmed loose before secondary marks were applied by the sampling crew and hence confirmed that these fish with missing adipose fins were in fact, valid recaptures but whose time of marking was indiscernible. These four fish were incorporated into the estimation process. Protocols for fin clipping in future years may need to be changed to prevent this problem. One suggestion would be to reverse the order of application of marks: apply the floy anchor tag first and follow with the adipose fin clip.

We believe that condition 4 (no recruitment) may be in question. Recruitment through growth was not possible. Recruitment was only a possibility if fish entered the system before or after Event 1 sampling took place and subsequently died and disappeared before Event 2 or alternatively, died after Event 2. We attempted to implement Event 1 sampling across a relatively long time period (54 days) that coincided with the time period in previous years when coho salmon were caught in the commercial fishery located just downstream from our sampling site. Seine catches started out high and fluctuated through out an intermittent schedule of only sampling 29 days with no drop off in catches observed. Sampling had to be suspended because of torrential rains which commenced on 21 September and didn't abate for a month. Fish condition was not changing over the course of the sampling regime. At the start most of the fish were bright. As we progressed in the sampling schedule, the fish condition didn't change. The major comments as to fish condition were noticeable gillnet marks and some fish with fungus. On the other hand, in Event 2, seining began on 30 August and there were no fish at the confluence the first week of sampling. Coho only started to arrive by 14 September and then the rains came. The persistent flooding seemed to have a flushing effect on carcasses, so despite what was perceived to be a sizable escapement, we had difficulty finding an abundance of carcasses. Marked fish may have had a greater mortality rate than unmarked fish (condition 5) because catching, handling and marking coho salmon may induce mortality or delay their upstream migration. By tagging fish with radio transmitters to ascertain capture and handling-induced mortality and distribution information, we were able to evaluate the degree to which condition 5 may have been violated, and make adjustments in estimation methods to minimize bias. The observed value of 75% of radio-tagged fish being documented to have reached the Situk River spawning grounds is consistent with assumptions made during experimental planning. We note that only one radio-tagged fish was recovered (6 days after it was tagged) in the commercial fishery located a short distance below the tagging site, despite the large catch of 178,804 coho salmon in the fishery.

We believe that the abundance estimate of 54,014 coho salmon derived from the mark–recapture experiment in 2004 is a relatively unbiased estimate of the actual abundance of coho salmon that returned to the Situk River in 2004. While recruitment likely occurred between sampling events, we were able to adjust for losses of fish between sampling events resulting in an abundance estimate that is germane to the timing of Event 2, which is appropriate for estimating escapement. The maximum likelihood estimate of standard error of the abundance estimate is biased low because not all sources of uncertainty in the estimation procedure are modeled adequately. Efforts to construct alternative standard error estimates using a bootstrap algorithm didn't provide sensible results for the Darroch model. We suggest the true standard error of the abundance estimate is on the order of 17,000, approximately 1.43 (1.0/0.7) times the maximum likelihood estimate of 11,862 fish.

The project objective of estimating the total coho escapement in the Situk River to within 35% of the true value 95% of the time was not achieved. The failure is primarily due to imprecision resulting from the prescribed model for estimating abundance, which was due to our inability to maintain fairly consistent sampling probability over time during both Events 1 and 2. This was primarily due to the adverse water conditions which created intermittent sampling during both sampling events. The foresight in the detailed experimental design provided for the best possible outcome under the circumstances that were beyond the scope of this experiment. The raw numbers of fish sampled would have been sufficient to achieve our precision criteria for abundance estimation had we achieved equal probability of sampling across either Event 1 or Event 2.

Scale samples were collected during Event 2 for the purpose of documenting age composition information. However, aging coho scales throughout the Southeast Region has come into question. There appears to be a considerable uncertainty in accurately determining the freshwater age of coho salmon. There is work being conducted presently to validate this question (C. Farrington, Fishery Biologist, ADF&G, Juneau; personal communication). Therefore, at this time, the estimate of abundance has not been broken down by age.

CONCLUSIONS AND RECOMMENDATIONS

Estimating total escapement is important information for assessment and management of the Situk coho salmon stock. Use of a two-event mark–recapture abundance estimator provided a relatively accurate estimate of about 54,014 fish as the estimated abundance for the 2004 escapement of coho salmon in the Situk River. The peak aerial survey of 10,284 on 9 September 2004 represented about 19% of the actual abundance of coho salmon in the Situk River.

Multiple years are critical to determining annual variation and an appropriate average for application of expansion factors to historic peak aerial surveys for run reconstruction efforts. Three years of useable abundance estimates and companion expansion factors should be collected at a minimum. This should provide the data needed to improve historic run reconstructions and improve information relative to better understand productivity and estimation of an appropriate escapement goal for this stock of salmon.

ACKNOWLEDGMENTS

We thank Alyssa Caracciolo, Matt Caterson, Ann Crane, Mike Freeman, Nicole Miller, and Greg Vaughn for conducting the field work and data collection. We thank Gordie Woods for providing support and logistics associated with the field work. Gordie Woods and Mike Freeman conducted aerial surveys for this study. We thank Andy McGregor for reviewing this report and providing helpful suggestions. We thank Amy Carroll for help in formatting and finalization of this report.

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APPENDIX A

Appendix A1.–Detection of size-selectivity in sampling and its effects on estimation of size composition.

Results of Hypothesis Tests (K-S and χ^2) on lengths of fish MARKED during the First Event and RECAPTURED during the Second Event	Results of Hypothesis Tests (K-S and χ^2) on lengths of fish CAPTURED during the First Event and CAPTURED during the Second Event
Case I: "Accept" H_o There is no size-selectivity during either sampling event.	"Accept" H_o
Case II: "Accept" H_o There is no size-selectivity during the second sampling event but there is during the first.	Reject H_o
Case III: Reject H_o There is size-selectivity during both sampling events.	"Accept" H_o
Case IV: Reject H_o There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	Reject H_o

Case I: Calculate one unstratified abundance estimate, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of composition.

Case II: Calculate one unstratified abundance estimate, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data (p. 17).

Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Use lengths, ages, and sexes from only the second sampling event to estimate proportions in compositions, and apply formulae to correct for size bias to the data from the second event.

Whenever the results of the hypothesis tests indicate that there has been size-selective sampling (Case III or IV), there is still a chance that the bias in estimates of abundance from this phenomenon is negligible. Produce a second estimate of abundance by not stratifying the data as recommended above. If the two estimates (stratified and unbiased vs. biased and unstratified) are dissimilar, the bias is meaningful, the stratified estimate should be used, and data on compositions should be analyzed as described above for Cases III or IV. However, if the two estimates of abundance are similar, the bias is negligible in the UNSTRATIFIED estimate, and analysis can proceed as if there were no size-selective sampling during the second event (Cases I or II).

Appendix A2.–Summary of beach seine sets made, number of coho salmon caught and marked with numbered floy tags and radio transmitter tags by date and location, Situk River, 2004.

Date	Start Time	Number Marked	Daily Total	Cumulative Total	Number Radio Tagged	Cumulative Total	High Tide (Time and Height)
8/23	11:45	198			3		7:14, 6.7’
8/23	14:45	141			2		18:53, 9.4’
			339	339		5	
8/24	12:00	124		339	1	5	8:49, 6.4’
8/24	15:15	65		339	1	5	
			189	528		7	
8/30	11:15	7		528	1	7	14:25, 10.1’
8/30	11:50	186		528	2	7	
8/30	15:30	161		528	1	7	
			354	882		11	
8/31	9:30	176		882	3	11	14:59, 10.3’
			176	1,058		14	
9/1	9:45	126		1,058	1	14	15:32, 10.4’
9/1	10:40	118		1,058	2	14	
			244	1,302		17	
9/2	9:15	256		1,302	1	17	16:05, 10.2’
9/2	10:55	117		1,302		17	
			373	1,675		18	
9/9	14:45	114		1,675	2	18	11:41, 6.8’
			114	1,789		20	
9/10	14:15	101		1,789	2	20	12:17, 7.4’
			101	1,890		22	
9/13	9:57	139		1,890	3	22	13:38, 9.2’
			139	2,029		25	
9/15	10:30	92		2,029	1	25	14:30, 10.2’
9/15[1]	11:45	119		2,029	2	25	
			211	2,240		28	
9/16	9:50	162		2,240	3	28	14:57, 10.5’
			162	2,402		31	
9/18	10:25	39		2,402	1	31	16:00, 10.6’
9/18	11:15	59		2,402	1	31	
			98	2,500		33	
9/20	10:00	138		2,500	3	33	17:24, 9.9’
9/20	11:20	49		2,500		33	
			187	2,687		36	
Sample Period				29 days			
Sample Days				13			

Appendix A3.–Number of radio transmitters deployed, date of deployment, and location of final aerial detection in the Situk River coho study during 2004.

									Mainstem			
No.	transmitter	Deployed	Recovered	Redeployed	10/7 aerial detection	Removed	West Fork	Old Situk	Lower	Middle	Upper	Total
1	151.000-23	23-Aug			W. Fork & Redfield		1					
2	151.022-23	23-Aug	11/15 dn WFk br		W. Fork & Redfield		1					
3	151.043-23	23-Aug			W. Fork & Redfield (m)		1					
5	151.084-23	23-Aug			Situk slough (m)					1		
6	151.102-23[a]	23-Aug	8/24 sport	24-Aug	redeployed	1						
8	151.122-23	23-Aug		24-Aug	Situk slough (m)					1		
7	151.102-23[a]	24-Aug			W. Fork (m)		1					
9	151.142-23	30-Aug			W. Fork ch.		1					
10	151.163-23	30-Aug			above Situk slough (m), cabins					1		
11	151.182-23	30-Aug			Situk & S. Lk./F. Creek (m)						1	
12	151.203-23	30-Aug			Old Situk			1				
13	151.222-23	31-Aug			CH (m)				1			
14	151.243-23	31-Aug			W. Fork & Redfield		1					
15	151.272-23	31-Aug			10/12 Old Situk live fish			1				
4	151.063-23	1-Sep			Situk & S. Lk./blowdown (m)						1	
16	151.292-23	1-Sep			Situk mid-river (m)					1		
17	151.312-23	1-Sep				1						
18	151.332-23	2-Sep			Situk cabins (m)					1		
19	151.352-23	9-Sep				1						
20	151.374-23	9-Sep			Situk confl. (m)					1		
21	151.392-23	10-Sep				1						
22	151.412-23	10-Sep			W. Fork & Redfield		1					
23	151.433-23	13-Sep			Situk confl.					1		
24	151.451-23	13-Sep			W. Fork & Redfield		1					
25	151.473-23	13-Sep			Situk flats	1						
26	151.492-23	15-Sep			W. Fork & Redfield		1					
27	151.512-23[b]	15-Sep	9/21 Situk est.			1						
28	151.532-23	15-Sep			Situk, mid-river (m)					1		
29	151.552-23	16-Sep			Situk, 9 mile					1		
30	151.571-23	16-Sep			Situk, mid-river (m); slough					1		

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No.	transmitter	Deployed	Recovered	Redeployed	10/7 aerial detection	Removed	West Fork	Old Situk	Mainstem Lower	Mainstem Middle	Mainstem Upper	Total
31	151.592-23	16-Sep			Situk, mile below lake						1	
32	151.612-23	18-Sep			Situk, flats	1						
33	151.633-23	18-Sep			Situk, flats	1						
34	151.653-23	20-Sep				1						
35	151.672-23	20-Sep			Situk, below oxbow				1			
36	151.692-23	20-Sep			Old Situk			1				
						9	9	3	2	10	3	36
					number of fish moved to spawning grounds		75%					27

[a] 151.102-23 was released on 8/23, caught by a sport fisherman the following day and immediately redeployed, it was later found during the aerial tracking of 10/7 residing in the West Fork of the Situk.
[b] 151.512-23 was released on 9/15 and harvested by a commercial gillnet in the Situk estuary on 9/21, it was not redeployed.

Appendix A1.–Summary of number of coho salmon inspected and number with marks observed in Event 2 by date and location, Situk River, 2004.

	Number Inspected			Number Inspected with Marks		
Date	Mainstem	Old Situk	Total	Mainstem	Old Situk	Total
9/9	28		28	2		2
9/10						
9/11						
9/12						
9/13						
9/14	497		497	22		22
9/15						
9/16						
9/17	881		881	54		54
9/18						
9/19						
9/20						
9/21						
9/22						
9/23						
9/24		61	61		0	
9/25						
9/26						
9/27		4	4		0	
9/28						
9/29						
9/30						
10/1						
10/2						
10/3						
10/4						
10/5						
10/6						
10/7						
10/8		44	44		2	2
10/9						
10/10						
10/11						
10/12						
10/13						
10/14						
10/15		5	5		1	1
10/16						
10/17						
10/18						
10/19						
10/20						
10/21						
10/22						

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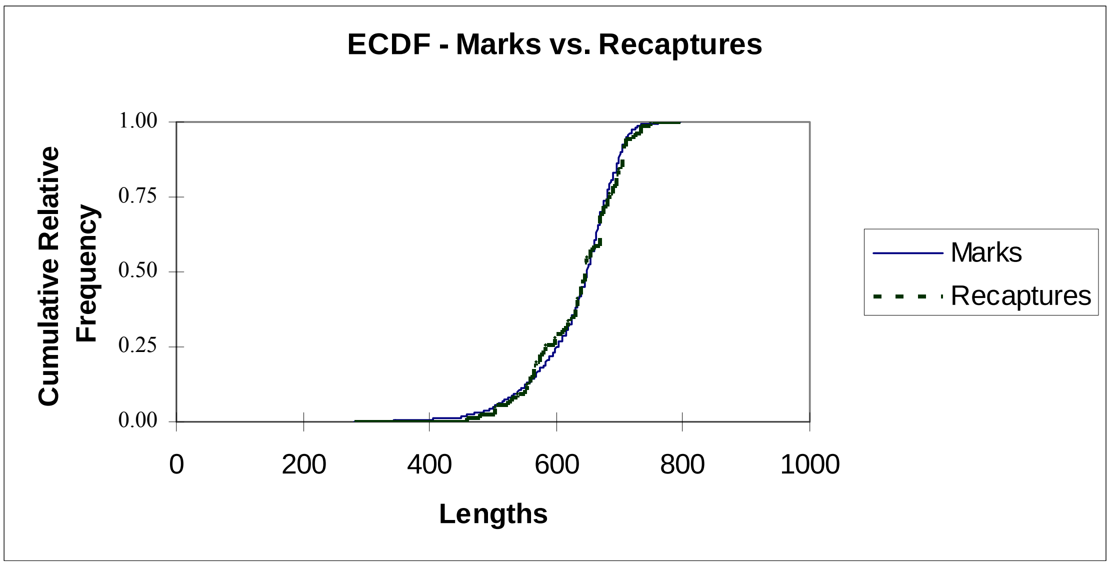
	Number Inspected			Number Inspected with Marks		
Date	Mainstem	Old Situk	Total	Mainstem	Old Situk	Total
10/23						
10/24						
10/25						
10/26	171		171	5		5
10/27	54	31	85	4	1	5
10/28						
10/29						
10/30						
10/31						
11/1						
11/2						
11/3						
11/4						
11/5		13	13		1	1
11/6						
11/7						
11/8						
11/9						
11/10						
11/11						
11/12						
11/13						
11/14						
11/15	23		23	1		1
Total[a]	1,654	158	1,812	88	5	93
Sample Period	68 days					
Sample Days	11					

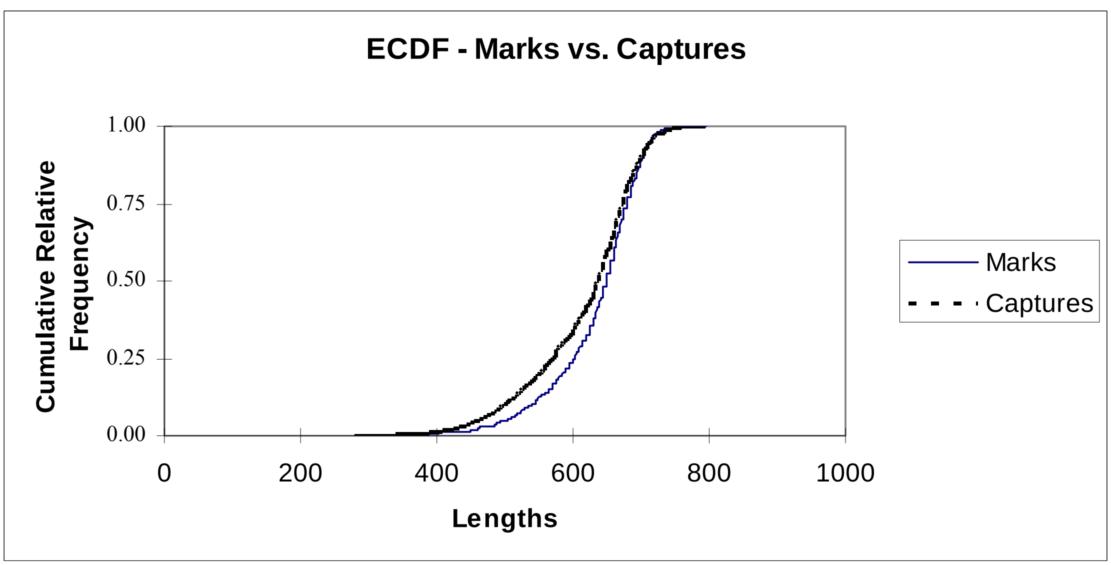
[a] The total number of marked fish recaptured in the mainstem Situk River was 88, of which 8 fish were originally tagged in the Lost River. The total number of recaptures considered in the abundance analysis totaled 85 fish, including the 80 from mainstem Situk and 5 from the Old Situk.

Appendix A2.–Summary statistics and graphs for the K-S tests comparing marks (M) to recaptures (R) and marks (M) to captures (C) of coho salmon in the Situk River, 2004.

	M/C	R/C	R/M
Test Statistic 'D'	0.099	0.123	0.070
P-value	0.000	0.163	0.803

	Sample Size
Minimum Length	280
Maximum Length	795
Mark (M)	2687
Capture (C)	1790
Recapture (R)	85





Appendix A3.–Results of "consistency tests" for the Situk River coho salmon experiment, 2004.

Condition 1:

	p =	0.035985		0.046207		0.005929	
First Event		8/2–24		8/30–9/2		9/9/–20	Totals
Situk + OldSituk 2nd event		Observed	Expected	Observed	Expected	Observed	Expected	
Released & Recaptured		19	14	53	31	6	27	78
Released & Not Recaptured		509	513	1094	1114	1006	983	2609
		528		1147		1012		
Totals		528		1147		1012		2687
		0.035985		0.046207		0.005929		
		Cont. to X^2		Cont. to X^2		Cont. to X^2		
Released & Recaptured		1.5108		15.3048		16.8032		
Released & Not Recaptured		0.0263		0.3486		0.5561		

Ho: Probability of finding a marked fish during second event is independent of time of initial tagging.

Or equal probability of capture during second event

Statistic 34.550 P-Value 0.0000 Significant Chi^2, reject Ho

reject Ho at α 0.10

Condition 2:

Time Period	9/9–17	9/24–11/15
Marked	73	12
Unmarked	1333	394
Total	1406	406
P=	0.05192	0.02955

df = 1

Chi2 = 3.524076

P value = 0.060484

Ho: marked to unmarked ratio was independent of sampling stratum during second event.

Or equal probability of sampling during the first event.

Condition 3:

Marking Period	Recaptured 9/9–17	Recaptured 9/24–11/15	Unseen
8/23–9/2	68	4	1603
9/9–20	1	5	1006

Chi2	40.66115
df	2
P value	1.48E-09

Ho: marked fish mixed completely with unmarked fish between events