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A Mark–Recapture Experiment to Estimate the Escapement of Coho Salmon in the Situk River, 2005, 2006

by

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and

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November 2007

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

FISHERY DATA SERIES NO. 07-70

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ABSTRACT

Reported here are the results of the second and third 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 2005 and 2006 was estimated using a two-event mark–recapture experiment. Fish were captured during Event 1 in the lower Situk River using a beach seine in September. Each fish was marked by operculum punch and given a secondary batch mark in the form of a Floy anchor tag. Fish were captured during Event 2 using beach seine upriver from Event 1 site and carcass surveys. In 2005, a total of 355 coho salmon were captured, marked, and released during Event 1. In 2005 Event 2 sampling, a total of 1,218 coho salmon were sampled and of these, 10 had been previously marked in Event 1. Using Chapman's modification of the Petersen estimator, abundance of coho salmon in the Situk River in 2005 was estimated to total 35,080 fish (SE ≈ 12,310). The peak survey of coho salmon in the Situk River in 2005 was 2,514 with the expansion factor estimated at 13.95 (SE ≈ 4.90). In 2006, a total of 780 coho salmon were captured, marked, and released during Event 1. In 2006 Event 2 sampling, a total of 516 coho salmon were sampled and of these, 11 had been previously marked in Event 1. Using Chapman's modification of the Petersen estimator, abundance of coho salmon in the Situk River in 2006 was estimated to total 24,805 fish (SE ≈ 8,582). The peak survey of coho salmon in the Situk River in 2005 was 7,951 with the expansion factor estimated at 3.12 (SE ≈ 1.08).

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 gillnet 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 gillnet 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 gillnet 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 inseason 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.

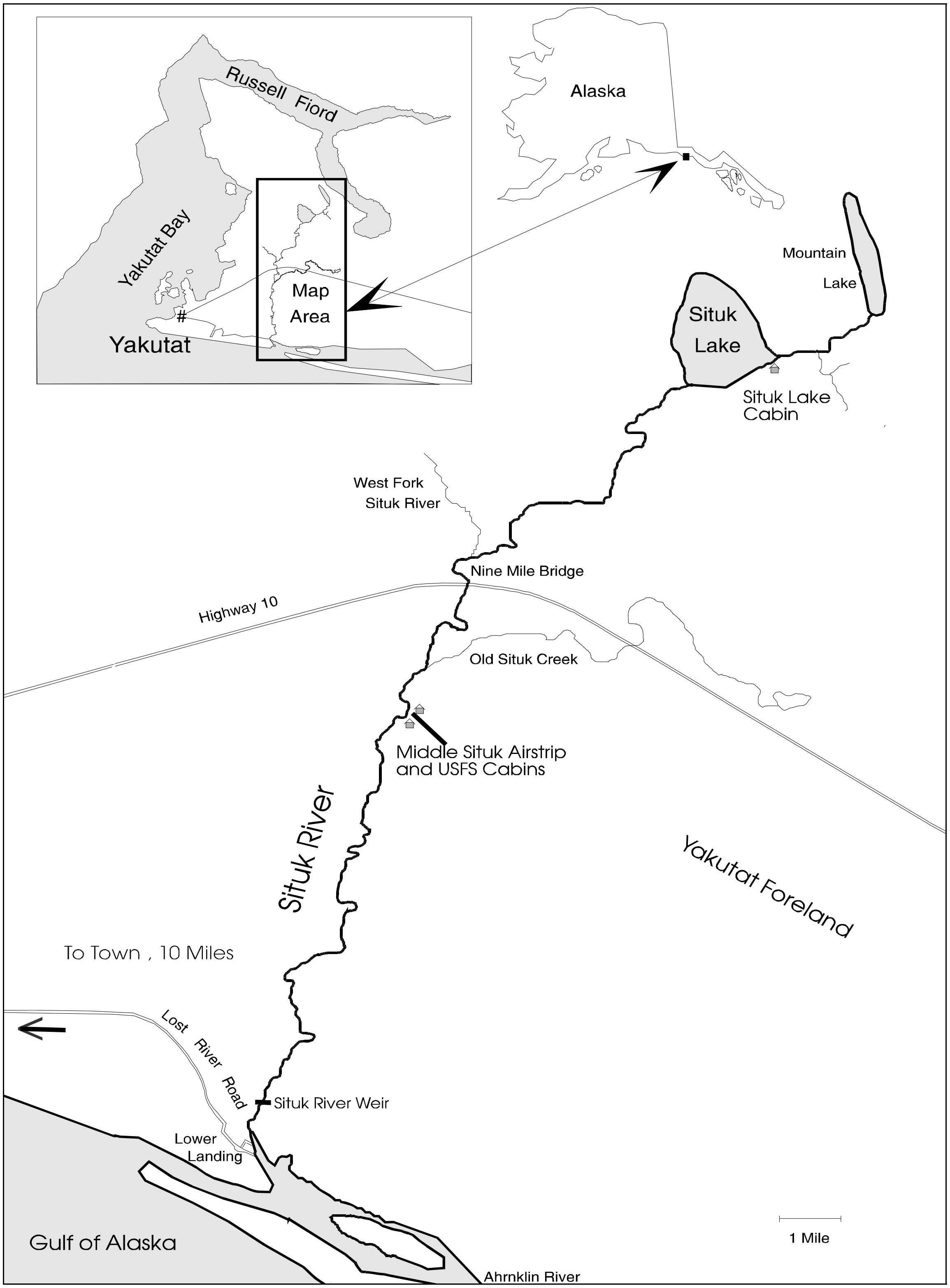

Figure 1.–Map of Situk River drainage near Yakutat, Alaska.

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.

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 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; Waltemeyer et al. 2005).

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 30×4 m (mesh 2.2 cm) beach seine was used to capture fish during Event 1. 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 to the nearest 5 mm, sexed by visual examination, and doubly marked, and released. The primary mark was an operculum punch. 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. 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 would not 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 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 and carcasses were examined from Old Situk Creek.

The numbers of marked and unmarked fish examined during Event 2 sampling were recorded and noted as to location. Sampling crews of five or six 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 for approximately 30 days during the roughly two-month period of the coho salmon entry period. Meeting the second condition depended primarily upon survey coverage. It was envisioned that Second event sampling take place over a two-month period that covered the roughly two-month spawning period. Meeting the third condition depended primarily upon behavior of fish marked during Event 1.

Conditions 1–3 could be violated if length 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 (Conover 1980). 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) would be necessary to estimate abundance.

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).

We used Chapman's modification of Petersen's 2-event, closed population estimator to estimate spawning abundance of coho salmon in the Situk River system. However, we did not expect all marked fish to fully recruit to the spawning grounds and thus planned this study to make use of results from the radio tagging effort to address this technical concern. Thus, the abundance estimator included an additional feature:

$$\hat{N} = \frac{(\hat{M}+1)(C+1)}{R+1} - 1 \qquad (1)$$

where $\hat{N}$ is the abundance estimate, C is the number of fish examined in the second event, R is the number of recaptured fish in the second event, and $\hat{M}$ is the estimated number of marked coho salmon in the experiment available to be recaptured during the second event.

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:

$$\hat{M} = T \cdot \hat{p} \qquad (2)$$

where T was the total number of salmon marked during the marking event and $\hat{p}$ was the estimated proportion of marked fish that remained in the study area and were available for sampling during Event 2. This proportion was estimated using radio-tagged salmon:

$$\hat{p} = v / r \qquad (3)$$

where r was the number of radio-tagged fish marked during Event 1 and v were those members of r that remained in the study area.

Variance for $\hat{N}$ was estimated using a bootstrap procedure (Efron and Tibshirani 1993) with slight modifications from what was described by Buckland and Garthwaite (1991). A stochastic model was used to estimate the actual number of tags in the experiment. A bootstrap sample was drawn with replacement from a sample of size $\hat{N}$ using the empirical distribution defined by capture histories (Fish seen during Event 1 only, during Event 2 only, seen during both events, and not seen during either event). The simulated frequencies were used to calculate surrogate statistics M', C', and R'. Simulated values for $\hat{M}'$ were obtained by drawing values for $\hat{p}'$, from a binomial distribution with parameters *v/r* and *r* each bootstrap sample. Simulated statistics were substituted for observed values in equations (1) and (2) to produce a simulated estimate $\hat{N}'$. One million such bootstrap samples were drawn, creating the empirical distribution $\hat{F}(\hat{N}')$, which is an estimate of $\hat{F}(\hat{N})$. The standard error of of the estimate $\hat{N}$ was estimated as the standard deviation of the distribution $\hat{F}(\hat{N}')$.

EXPANSION FACTOR

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

$$\hat{\pi}_y = \hat{N} / I_y \qquad (4)$$

$$var(\hat{\pi}_y) = var(\hat{N}) I_y^{-2} \qquad (5)$$

where π_y was the expansion factor and I_y the peak count of several surveys conducted. The variance in equation 4 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

2005 TAGGING, RECOVERY AND ABUNDANCE

A total of 355 coho were captured, sampled and released with primary and secondary marks between 10 September and 27 September 2005 (Figure 2; Table 1). Detailed information, including the numbers of fish radio tagged by day is available in Appendices A2 and A3. From 23 September through 26 October of 2005, we inspected a total of 1,218 fish from the Situk River and Old Situk Creek during Event 2 (Table 1; Appendix A4). Of these, a total of 10 fish were observed with marks. All marked fish recovered possessed their primary operculum punch mark, and no fish had shed their secondary anchor tag.

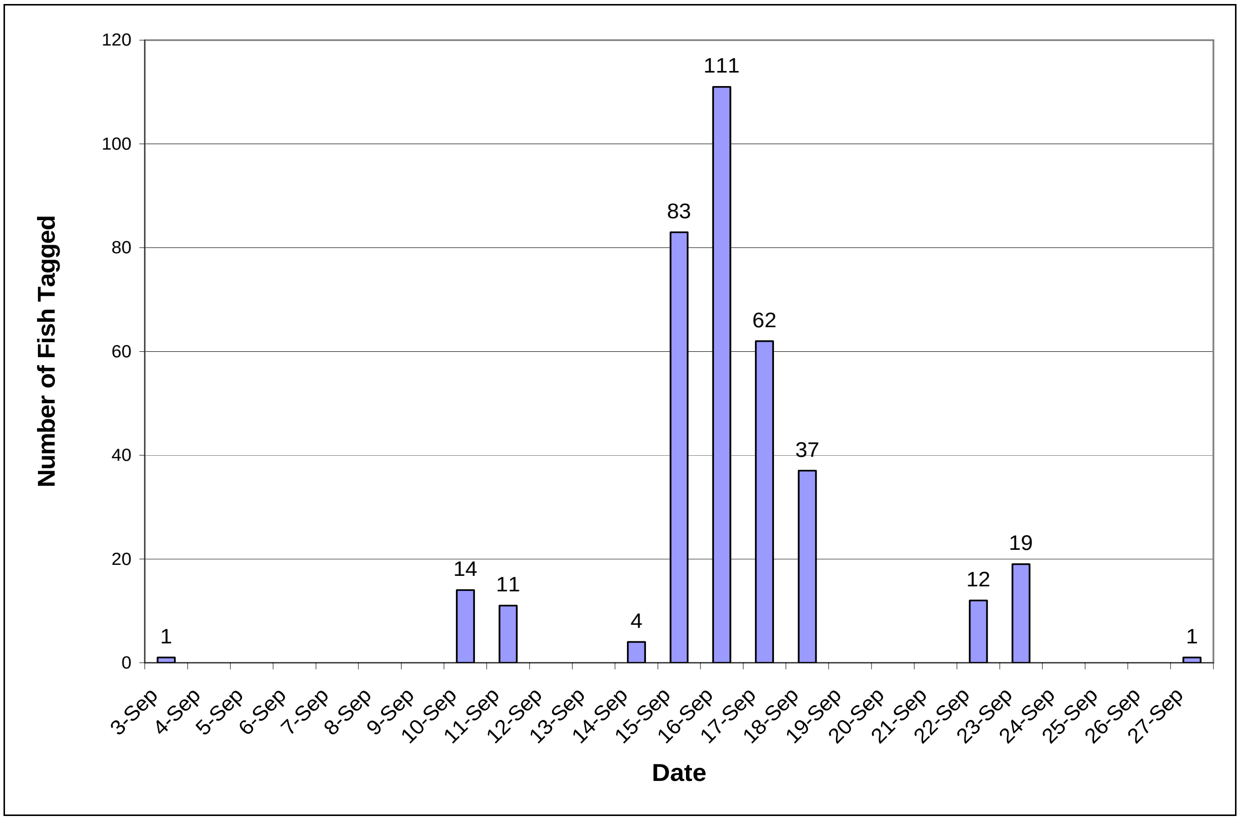

Figure 2.–Number of coho salmon captured and marked during Event 1, Situk River, 2005.

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, 2005.

	No. of Fish
Event 1:	
Released with marks (M)	355
Event 2:	
Captured (C)	
Situk River	1,004
Old Situk Creek	214
Total	1,218
Recaptured (R)	
Situk River	8
Old Situk Creek	2
Total	10

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 = 0.201, p = 0.793; 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 = 0.232, p = 0.636). 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 = 0.181, p<0.001) indicating potential for size bias sampling during either Event 1 or Event 2. While the direct tests between captures (C) and recaptures (R) and between marks (M) and recaptures indicated no strong evidence of size bias sampling during Event 1 or Event 2, respectively, we conservatively concluded that we likely had either a Case II or Case III experiment (see Appendix A1). Both Case II and Case III prescribe that one unstratified abundance estimate should be calculated.

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 differ statistically (K-S = 0.112, p = 0.025; Figure 3).

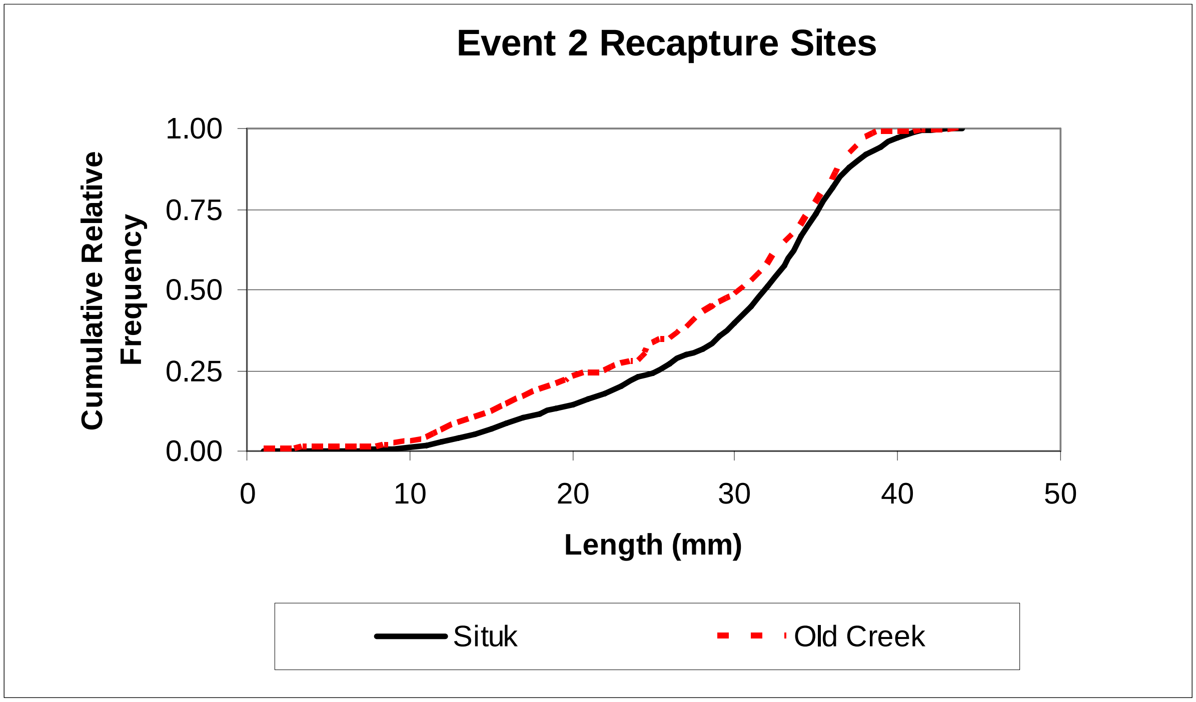

Figure 3.–Cumulative relative frequency distributions of Situk River and Old Situk Creek coho salmon captured on the spawning grounds in Event 2, 2005.

However, no direct evidence of size bias sampling during Event 2 was detected, suggesting that sampling efforts were fairly proportional between these two capture sites.

A summary of the number of coho salmon inspected and the number with marks observed during Event 2 is shown in Appendix A4. Three consistency tests described by Seber (1982) were performed (Appendix A6). The first condition (null hypothesis that the probability that a marked fish was recovered during Event 2 was independent of the time of marking) was not rejected (χ^2 = 1.761, p = 0.62). The second condition (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 not rejected (χ^2 = 1.613, p = 0.204), indicating probability of capture during Event 1 was consistent over time. The third condition (null hypothesis that marked fish mixed completely with unmarked fish between events) was not rejected (χ^2 = 3.573, p = 0.73). Therefore the failure to rejection of the null hypothesis for all three tests was sufficient to conclude that conditions 1–3 were satisfied and the Chapman's modification to the Petersen method was sufficient for population estimation.

Tagging totals per stratum were further adjusted based on radio tagging results. Based on the radio tags, we had eight out of nine radio tagged fish remain in the Situk River (Appendix A3). Applying the fraction of radio-tagged fish that remained in the Situk to the total number marked fish (355) results in an estimated 316 valid tagged fish ($\hat{M}$) remaining in the study read during Event 2 sampling.

Using the estimator described in equation (1), we estimated the escapement coho salmon in the Situk River in 2005 to be 35,079 with a standard error of 12,310.

2005 Expansion Factor

During 2005, there were six boat surveys of the Situk River and Old Situk Creek wherein coho salmon were counted (Table 2).

The peak survey occurred on 23 September and the count was 2,514 coho salmon. The survey expansion factor (the ratio of the total abundance estimate of coho salmon to the peak survey count) for 2005 was estimated to be 13.95 with an estimated SE of 4.90

Table 2.–Survey counts of coho salmon escapement in the Situk River, 2005.

Date	Situk	Old Situk
8/12	190[a]	
9/03	879[a]	
9/14	975[a]	
9/23	2,514[a]	
10/01		525[b]
10/31	921[c]	

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

2006 Tagging, Recovery and Abundance

A total of 780 coho were captured, sampled and released with primary and secondary marks between 31 August and 26 September 2006 (Figure 4, Table 3). Detailed information, including the numbers of fish radio tagged by day is available in Appendices B1 and B2. From 18 September through 24 October of 2006, we inspected a total of 516 fish from the Situk River above 9 mile Creek and Old Situk Creek during Event 2 (Table 3, Appendix B3). Of these, a total of 11 fish were observed with marks. All marked fish recovered possessed their primary operculum punch mark, and no fish had shed their secondary anchor tag.

A summary of the number of coho salmon inspected and the number with marks observed during Event 2 is shown in Appendix B3. Three consistency tests were performed (Appendix B5). The first condition (null hypothesis that the probability that a marked fish was recovered during Event 2 was independent of the time of marking) was not rejected (χ^2 = 2.079, p = 0.56). The second condition (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 not rejected (χ^2 = 1.871, p = 0.171), indicating probability of capture during Event 1 was consistent over time. The third condition (null hypothesis that marked fish mixed completely with unmarked fish

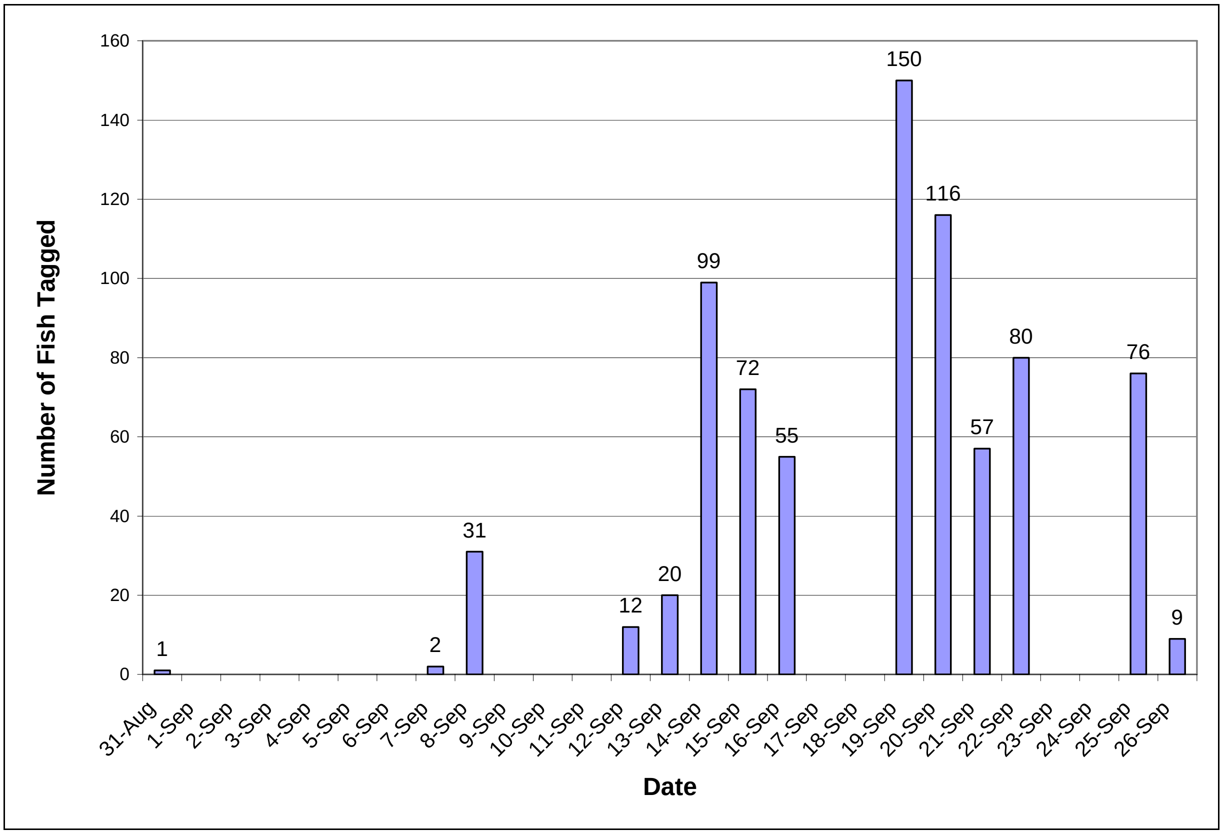

Figure 4.–Number of coho salmon captured marked during Event 1, Situk River, 2006.

between events) was not rejected (χ^2 = 5.3, p = 0.51). Therefore the failure to reject the null hypothesis for all three tests was sufficient to conclude that conditions 1–3 were satisfied and the Chapman's modification to the Petersen method was sufficient for population estimation.

Table 3.–Number of coho salmon marked in Event 1 and inspected for marks on the spawning grounds by location in Event 2, Situk River, 2006.

	No. of Fish
Event 1:	
Released with marks (M)	780
Event 2:	
Captured (C)	
Situk River above 9 mile Cr.	157
Old Situk Creek	359
Total	516
Recaptured (R)	
Situk River	1
Old Situk Creek	10
Total	11

Tagging totals per stratum were further adjusted based on radio tagging results. Based on the radio tags, we had 14 out of 19 radio tagged fish remain in the Situk River. Applying the fraction of radio-tagged fish that remained in the Situk to the total of fish number marked (780) results in an estimated 575 valid tagged fish ($\hat{M}$) remaining in the study area during Event 2 sampling.

Using the estimator described in equation (1), we estimated the escapement of coho salmon in the Situk River in 2006 to be 24,804 with a standard error of 8,582.

2006 EXPANSION FACTOR

During 2006, there were six boat surveys of the Situk River and Old Situk Creek wherein coho salmon were counted (Table 4).

Table 4.–Survey counts of coho salmon escapement in the Situk River, 2006.

Date	Situk	Old Situk
9/11	1,799[a]	
9/15	2,756[a]	
9/25	7,951[b]	
9/26	703	
10/24		1,137
11/1	173[c]	

[a] Nine Mile to landing.
[b] Situk Lake to landing.
[c] Situk Lake to Nine Mile.

The peak survey occurred on 25 September and the count was 7,951 coho salmon. The survey expansion factor (the ratio of the total abundance estimate of coho salmon to the peak survey count) for 2006 was estimated to be 3.12 with an estimated SE of 1.08.

SUMMARY OF EXPANSION FACTORS

One of the primary objectives of the mark recapture experiments for Situk coho salmon was to develop expansion factors to convert historical survey counts to total escapement. The results for the three year study (2004 from Waltermeyer et al 2005, and for 2005 and 2006 reported here) are provided in Table 5.

Table 5.–Coho salmon escapement, peak survey count, expansion factor and standard error expansion factor estimated from 2004 to 2006 mark–recapture experiments**.**

Year	Coho Salmon Escapement	Peak Survey Count	Expansion Factor	SE Expansion Factor
2004	54,014	10,284	5.25	1.65
2005	35,079	2,514	13.95	4.9
2006	24,804	7,951	3.12	1.08

The mean of the expansion factor (ratio of escapement to survey count) is 7.4 with standard error of 3.3. There is substantial between year variation in the expansion factor.

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 in 2005 size selective sampling did not occur at detectable levels during either Event 2, but it was likely that size selective sampling occurred during Event 1. This resulted in a Case II or Case III scenario. In 2005, we used an unstratified abundance estimator based on Chapman's modification of the Petersen Estimate. In 2006, based on the diagnostic tests for size selectivity we concluded that no size selective sampling occurred in Event 1 or Event 2. In 2006, we used an unstratified abundance estimator based on Chapman's modification of the Petersen estimator.

Tests for equal probability of sampling over time for Event 1 and Event 2 and for complete mixing indicated no temporal or spatial variation in probability of capture between sampling event. Consequently it was not necessary to temporally stratify the estimates.

We believe that condition 4 (no recruitment) was generally satisfied in 2005 and 2006. 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. In both 2005 and 2006 we attempted to implement Event 1 sampling across a relatively long time period (53 days in 2005 and 55 days in 2006) 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. In both years seine catches started out low (late August and early September) and fluctuated throughout an intermittent schedule of 31 days for 2005 and 27 days for 2006. Catches dropped off in both years by the end of September. In both years, sampling had to be suspended because of torrential rains, and limited the sampling to 11 days in 2005, and 14 days in 2006. Marking goals were not achieved, particularly in 2005. 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 did not change.

During 2005, Event 2 sampling began on 23 September and continued intermittently until 26 October. The persistent flooding seemed to have a flushing effect on carcasses, and limited the number of days of Event 2 sampling. We had difficulty finding an abundance of carcasses. During 2006, Event 2 sampling began on 18 September and continued intermittently until 24 October. As in 2005 there was persistent flooding during the period of Event 2 sampling which greatly limited the number of fish inspected for marks.

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. A limited number of radio transmitters (9 in 2005 and 19 in 2006) were applied 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. In 2005, the observed value of 89% of radio-tagged fish being documented to have reached the Situk River spawning grounds and in 2006, 74% of radio tags reached the spawning grounds. These observations were consistent with assumptions made during experimental planning.

We believe that the 2005 abundance estimate of 35,079 (12,310 SE) and 2006 abundance estimate of 24,804 (8,582 SE) coho salmon derived from the mark–recapture experiments in 2005 and 2006 were imprecise and relatively unbiased estimates of the actual abundance of coho salmon that returned to the Situk River in 2005 and 2006. We note that in both years the diagnostic tests used to evaluate assumptions and potential bias implicit in the estimates were based on a low number of tag recoveries. Because of low sample sizes, these tests would have relatively low statistical power (i.e., the ability to detect deviation from assumptions given they actually occur).

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 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.

Expansion factors as the ratio of escapement to survey counts were estimated for years 2004–2006. The estimated coho salmon escapements averaged 7.4 times the survey counts. This indicates that survey counts were extremely conservative, with substantial between variability in availability of fish to surveys occurring. There is substantially uncertainty in historical Situk River coho salmon escapement estimated by expansion of survey counts.

ACKNOWLEDGMENTS

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APPENDIX A: DETAILS OF THE 2005 MARK/RECAPTURE EXPERIMENT

Appendix A1.–Detection of size or sex selective sampling during a 2-sample mark recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R), using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test, comparing M and C, is conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi-square test) is generally used to detect significant evidence that sex selective sampling occurred during the first or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C as described above, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared between samples using a two sample test (e.g. Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during either sampling event.

Case II:		
Reject H_o	Fail to reject H_o	Reject H_o

There is no size/sex selectivity detected during the first event but there is during the second event sampling.

Case III:		
Fail to reject H_o	Reject H_o	Reject H_o

There is no size/sex selectivity detected during the second event but there is during the first event sampling.

Case IV:		
Reject H_o	Reject H_o	Reject H_o

There is size/sex selectivity detected during both the first and second sampling events.

Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

-continued-

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, an overall composition parameters (p_k) is estimating by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{, and} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right) \tag{2}$$

where:

j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size k among fish in stratum i;

$\hat{N}_i$ = the estimated abundance in stratum i;

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

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, 2005.

Date	Start Time	Number Marked	Daily Total	Cumulative Marked	Number of Radio Tags	Cumulative Total of Radio Tags	Number of CWT Recovered	High Tide(s)
9/3	10:00	1	1	1				14:11, 9.0 ft.
9/10	10:38	14	14	15	1	1		6:02, 7.0 ft.
9/11	10:29	11	11	26		1		7:23, 6.4 ft.
9/14	12:42	1		27		1		11:31, 7.7 ft.
9/14	14:01	3		30		1	1	
			4	30		1		
9/15	10:10	28		58	1	2	2	12:14, 8.7 ft.
9/15	13:20	3		61		2		
9/15	14:00	26		87		2		
9/15	15:11	26		113	1	3		
			83	113		3		
9/16	10:14	39		152	1	4	1	12:52, 9.6 ft.
9/16	11:20	20		172	1	5	1	
9/16	14:51	26		198		5	1	
9/16	15:43	26		224	1	6		
			111	224		6		
9/17	13:00	20		244		6	1	13:28, 10.4 ft.
9/17	13:57	42		286	2	8		
			62	286		8		
9/18	9:50	14		300		8	1	14:03, 11.1 ft.
9/18	10:35	23		323		8		
			23	323		8		
9/22	10:00	8		331	1	9		16:24, 10.7 ft.
9/22	10:35	4		335		9	1	
			4	332		9		
9/23	16:08	19		354		9	1	17:04, 9.9 ft.
9/27	14:00	1		355		9		11:03, 7.1 ft.

Note: Sample period 25 days, sample days 9.

Appendix A3.–Number of radio transmitters deployed, date of deployment, and location of final aerial detection in the Situk River coho study during 2005.

									Mainstem			
No.	transmitter	Deployed	Recovered	Redeployed	9/26 aerial detection	Removed	West Fork	Old Situk	Lower	Middle	Upper	Total
1	151.263-24	9-Sep			Live - mid					1		
2	151.301-24	15-Sep			Live - mid					1		
3	151.343-24	15-Sep			Live - mid					1		
5	151.430-24	16-Sep			Live - Down From Weir				1			
6	151.623-24	16-Sep			Live - mid					1		
7	151.683-24	16-Sep			Not Detected							
8	151.803-24	17-Sep			Live - mid					1		
7	151.823-24	17-Sep			Live - mid					1		
9	151.883-24	22-Sep			Live - mid					1		

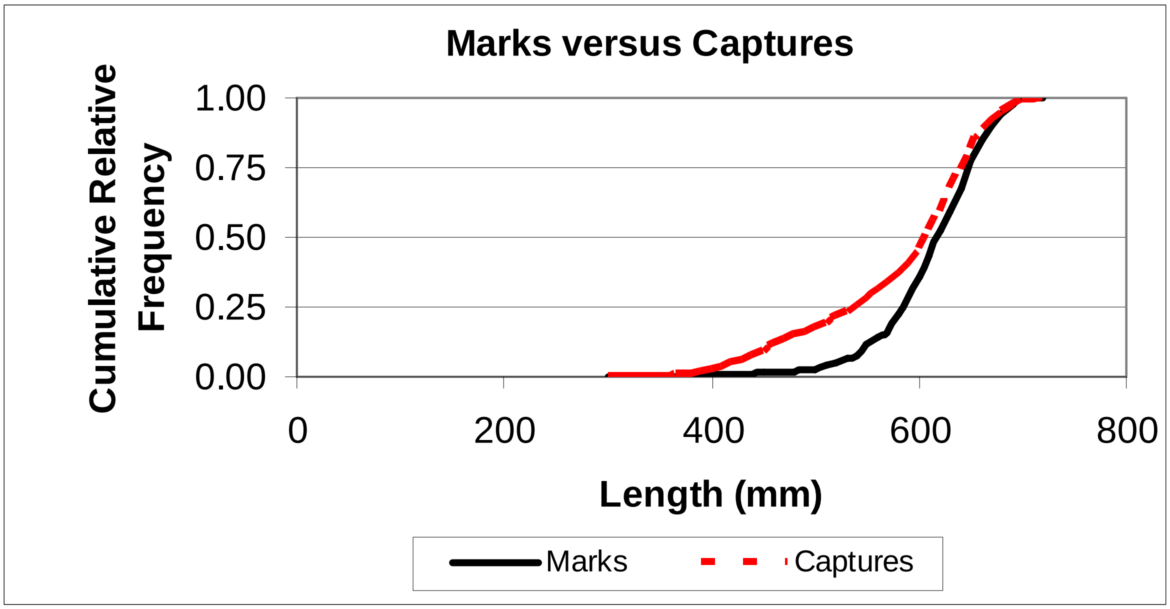
Appendix A4.–Summary of number of coho salmon inspected and number with marks observed in Event 2 by date and location, Situk River, 2005.

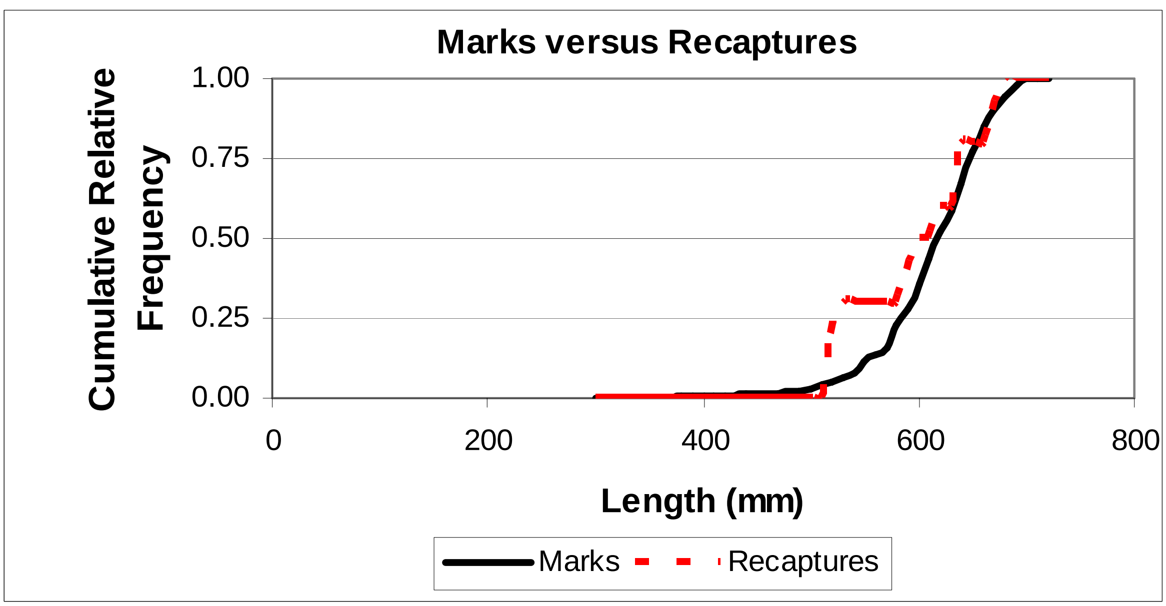
	Number Inspected			Number Inspected with Marks		
Date	Mainstem	Old Situk	Total	Mainstem	Old Situk	Total
9/23	177					
9/24						
9/25						
9/26						
9/27	73			1		
9/28						
9/29		9				
9/30						
10/01						
10/02						
10/03						
10/04	155			2		
10/05	229			4		
10/06						
10/07		99			2	
10/08						
10/09						
10/10	192					
10/11						
10/12						
10/13						
10/14						
10/15						
10/16						
10/17						
10/18						
10/19						
10/20						
1021		106				
10/22						
10/23						
10/24						
10/25						
10/26	63			1		

Appendix A5.–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, 2005.

	M/C	R/C	R/M
Test Statistic 'D'	0.181	0.232	0.201
P-value	0.000	0.636	0.793

Sample size	
Minimum Length	285
Maximum Length	730
Mark (M)	355
Capture (C)	1218
Recapture (R)	10





Appendix A6.–Results of "consistency tests" for the Situk River coho salmon experiment, 2005.

Condition 1

Probability	0		0.034		0.023		0.043		
Event 1	9/3–11		9/12–15		9/16–17		9/18–27		
Situk & Old Situk									
Event 2	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Total
Released, recaptured	0	1	3	3	4	3	3	2	10
Released, recaptured	26	25	84	84	169	168	66	67	345
Total	26		87		173		69		355
Probability			0.046207		0.005929		0.005929		
	Cont. to X^2		Cont. to X^2		Cont. to X^2		Cont. to X^2		
Released, recaptured	1.000		0.000		0.200		0.500		
Released, not Recaptured	0.040		0.000		0.006		0.015		

Note: H_o probability of finding a marked fish during second event is independent of time of initial tagging or equal probability of capture during second event (Chi-square = 1.761, *P*-value = 0.62, non-significant chi-square, fail to reject H_o).

Condition 2

Time Period	9/23–10/05	10/07–26
Marked	7	3
Unmarked	640	578
Total	647	581
Probability	0.011	0.005

Note: H_o marked to unmarked ratio was independent of sampling stratum during second event or equal probability of sampling during the first event (Chi-square = 1.613, *P*-value = 0.204, df = 1).

Condition 3

Marking	Recaptured 9/23–10/05		Recaptured 10/17–26		Not Recaptured	
Period	Observed	Expected	Observed	Expected	Observed	Expected
9/3–11	0	1	0	0	26	25
9/12–15	3	2	0	1	84	85
9/15–17	3	3	1	1	169	168
>9/18	1	1	2	1	66	67
Probability	0.02		0.01		0.97	

Note: H_o marked fish mixed completely with unmarked fish between events (Chi-square = 3.573, *P*-value = 0.73, df = 6).

APPENDIX B: DETAILS OF THE 2006 MARK/RECAPTURE EXPERIMENT

Appendix B1.–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, 2006.

Date	Location	Number Marked	Daily Total	Cumulative Marked	Number of Radio Tags	Cumulative Total of Radio Tags	Number of CWT Recovered
8/31	Situk Weir	1	1	1			
9/07	Situk Estuary	1		2			
9/07	Situk Estuary	1		3			
			2	3			
9/08	Situk Mouth	31		34	1	1	1
9/12	Confluence	12		46		1	
			43	46			
9/13	Confluence	20	20	66	1	2	
9/14	Confluence	67		133		2	
9/14	Below Confluence	10		143		2	
9/14	Below Confluence	22		165	2	4	3
			99	165			
9/15	Confluence	41		206	2	6	
9/15	Middle Cabins	31		237		6	
			72	237			
9/16	Situk Weir	55	55	292	2	8	1
9/19	Confluence	60		352		8	3
9/19	Below Confluence	90		442	2	10	3
			150	442			
9/20	Situk Weir	29		471	1	11	
9/20	Situk Weir	87		558	2	13	1
			116	558			
9/21	Situk Weir	57	57	615	2	15	
9/22	Situk Weir	9		624		15	
9/22	Confluence	71		695		15	4
			80	695			
9/25	Situk Weir	16		711	1	16	
9/25	Confluence	60		771	2	18	1
			76	771			
9/26	Situk Weir	9	9	780	1	19	

Note: Sample period 26 days, sample days 13.

Appendix B2.–Number of radio transmitters deployed, date of deployment, and location of final aerial detection in the Situk River coho study during 2006.

Number	transmitter	Deployed	Length (mm)	Sex	Floy Tag No.	Aerial Surveys 10/14 & 10/27
1	151.512-24	9/08	520	M	2982	Sport caught 9/10
2	151.943-24	9/13	650	F	2761	Not Detected
3	151.902-24	9/14	650	F	2862	Not Detected
4	151.923-24	9/14	605	F	2847	10/14 “live” middle Situk
5	151.962-24	9/15	610	F	2904	10/14 “mort” mid-river
6	151.982-24	9/15	700	M	2892	10/14 “mort” upper Situk
7	153.302-23	9/16	645	F	2028	10/14 “live” mid-river
8	153.332-23	9/16	630	M	2950	Not Detected
9	153.423-23	9/19	660	F	2122	10/14 “live” upper river
10	153.452-23	9/19	635	F	2139	Not Detected
11	153.003-24	9/20	610	F	2203	10/14 “live” lower river
12	153.362-23	9/20	590	M	2289	Not Detected
13	153.392-23	9/20	680	M	2270	10/27 “live” Colorado Road ditch
14	152.223-24	9/21	600	M	2327	10/14 “live” mid-river
15	152.972-23	9/21	650	F	2320	captured Old Situk 9/28
16	152.075-24	9/25	605	F	2452	10/27 “live” Colorado Road ditch
17	152.191-24	9/25	680	M	2481	netted Old Situk 9/28
18	152.041-24	9/25	540	F	2521	10/14 “live” Old Situk
19	152.643-24	9/26	685	M	2529	10/14 “mort” lower river

Appendix B3.–Summary of number of coho salmon inspected and number with marks observed in Event 2 by date and location, Situk River, 2006.

	Number Inspected			Number Inspected with Marks		
Date	Situk Above 9 mile	Old Situk	Total	Situk Above 9 mile	Old Situk	Total
e	56					56
19-Sep						
20-Sep						
21-Sep	98			1		99
22-Sep	3					3
23-Sep						
24-Sep						
25-Sep						
26-Sep						
27-Sep						
28-Sep		206		9		215
29-Sep						
30-Sep						
01-Oct						
02-Oct						
03-Oct						
04-Oct						
05-Oct		95		1		96
06-Oct						
07-Oct						
08-Oct						
09-Oct						
10-Oct						
11-Oct						
12-Oct						
13-Oct						
14-Oct						
15-Oct						
16-Oct						
17-Oct						
18-Oct						
19-Oct						
20-Oct						
21-Oct						
22-Oct						
23-Oct						
24-Oct		58				58

Appendix B4.–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, 2006.

	M/C	R/C	R/M
Test Statistic 'D'	0.062	0.214	0.172
P-value	0.183	0.673	0.884

Sample Size	
Minimum Length	300
Maximum Length	775
Mark (M)	780
Capture (C)	518
Recapture (R)	11

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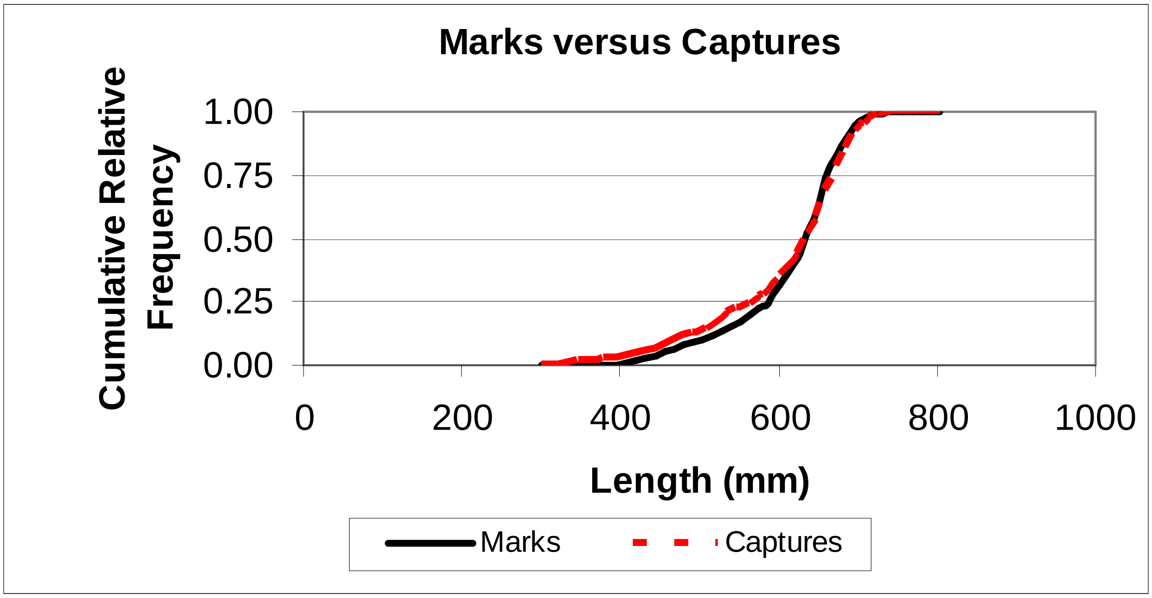

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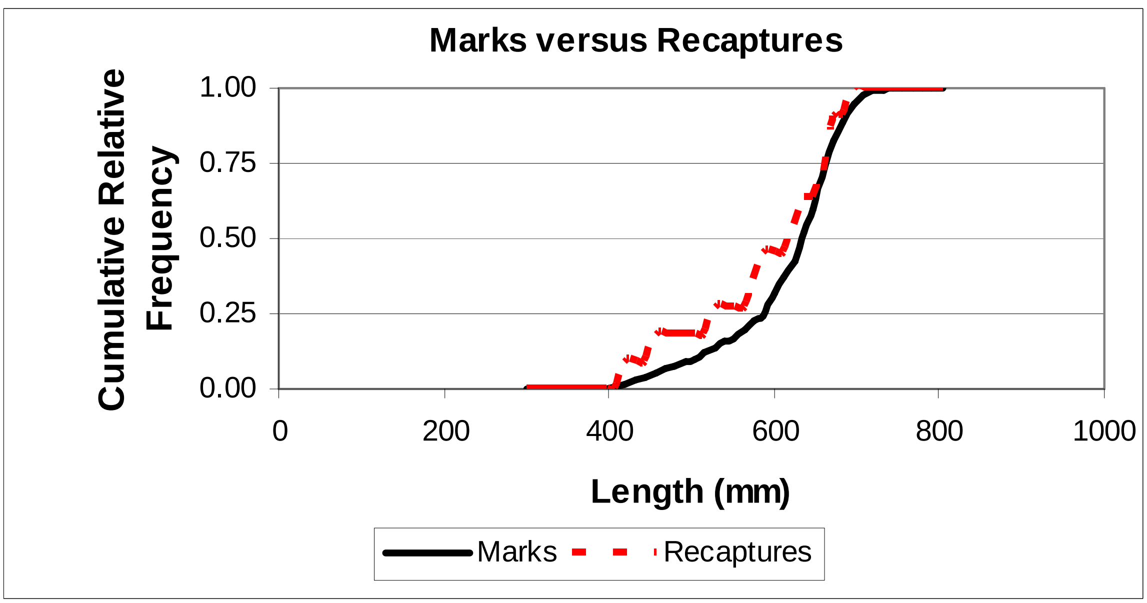

Appendix B5.–Results of "consistency tests" for the Situk River coho salmon experiment, 2006.

Condition 1				
Probability	0	0.020	0.009	0.018
Event 1	8/31–9/12	9/13–16	9/19–21	>9/22

Situk & Old Situk

Event 2	Observed	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Total
Released, recaptured	0	1	5	3	3	5	3	2	11
Released, not Recaptured	46	45	242	243	323	318	162	163	769
Total	46		246		323		165		780
Probability			0.04621		0.0059		0.0059		

	Cont. to X^2	Cont. to X^2	Cont. to X^2	Cont. to X^2
Released, recaptured	0.649	0.675	0.531	0.195
Released, not recaptured	0.009	0.010	0.008	0.003

Note: H_o probability of finding a marked fish during second event is independent of time of initial tagging or equal probability of capture during second event (Chi-square = 2.079, *P*-value = 0.56, non-significant Chi^2, fail to reject H_o).

Condition 2

Time Period	9/18–9/28	10/5–10/24
Marked	10	1
Unmarked	353	152
Total	363	153
Probability	0.028	0.007

Note: H_o marked to unmarked ratio was independent of sampling stratum during second event or equal probability of sampling during the first event (Chi-square = 1.871, *P*-value = 0.171, df = 1).

Condition 3

Marking Period	Recaptured 9/18–28		Recaptured 10/5–24		Not Recaptured	
	Observed	Expected	Observed	Expected	Observed	Expected
8/31–9/12	0	1	0	0	46	45
9/13–16	5	3	0	0	242	243
9/19–21	2	4	1	0	320	318
>9/22	1	1	2	1	162	163
Probability	0.01		0.00		0.99	

Note: H_o marked fish mixed completely with unmarked fish between events (Chi Square = 5..3,P-value = 0.51, df = 6).