Fishery Data Series No. 06-11

Abundance of Coho Salmon in the Lost River System, Yakutat, Alaska, 2003

by

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and

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March 2006

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 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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ABSTRACT

This was the first year of a planned multi-year study to estimate the abundance of coho salmon *Oncorhynchus kisutch* in the Lost River located near Yakutat, Alaska, and calculate an expansion factor for peak spawner counts. The abundance of coho salmon in 2003 was estimated using a two-event mark–recapture experiment. Biological data were collected during both sampling events. Fish were captured during Event 1 at the mouth of the Lost River where it empties into the Situk-Ahrnklin Lagoon using a beach seine from August 29 through October 6. Each fish was marked by removal of the adipose fin and given a secondary batch mark; either a left or right axillary process was removed or a hole placed in the left or right operculum with a paper punch. A total of 798 coho salmon were captured, marked, and released during Event 1. In Event 2, live fish were caught using a beach seine. Carcasses were also collected and sampled. Event 2 sampling took place in Tawah Creek, Ophir Creek and other portions of the Lost River system from October 2 through November 7. In Event 2, 667 coho salmon were sampled and of these, 18 had been previously marked in Event 1. After gender stratification of sample data, abundance was estimated using a modification of the Petersen estimator. The estimated abundance of female coho salmon in the Lost River in 2003 was 14,675 fish (SE=7,255). The estimated abundance of male coho salmon in the Lost River in 2003 was 9,010 fish (SE = 2,565). The total abundance of coho salmon in the Lost River in 2003 was estimated to have been 23,685 fish (SE = 7,835; CV = 33%). The peak survey count of coho salmon in the Lost River in 2003 was 6,396 fish on October 1. The expansion factor calculated from dividing the estimated abundance by the peak aerial survey count was 3.7 (SE =1.2).

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

INTRODUCTION

The Lost River is a small stream located on the Yakutat Forelands near Yakutat, Alaska (Figure 1) and coho salmon *Oncorhynchus kisutch* return each year to this stream and spawn. Portions of the drainage include Ophir Creek, Tawah Creek, and Coast Guard Lake. Alaska Department of Fish and Game (ADF&G) staff annually count spawning and/or migrating coho salmon in the Lost River system during foot and boat based escapement surveys. The annual peak survey counts are used as indices of the annual escapement strength for this stock of salmon.

The Lost River system drained into its own lagoon before entering the Gulf of Alaska prior to the winter of 1999–2000. In that winter, the Lost River changed channels and migrated into the Situk-Ahrnklin lagoon. A commercial set gill net fishery took place in the Lost River lagoon prior to the year 2000. Prior to 2000, it is believed that virtually all of the salmon harvest that took place in the Lost River lagoon were fish of Lost River origin. The Situk-Ahrnklin stock of coho salmon is more abundant than the Lost River stock of coho salmon. The Situk-Ahrnklin lagoon fishery primarily targets fish from the Situk and Ahrnklin rivers. Although there is no catch allocation methodology in place for that fishery, it is assumed that some coho salmon from the Lost River have been harvested in the Situk-Ahrnklin lagoon fishery since the channel change.

Coho salmon harvests in the Lost River commercial set gill fishery averaged about 6,000 fish per year from 1972–1999. Coho salmon from the Lost River are also harvested in the commercial troll fishery. Clark and Clark (1994) estimated the harvest of Lost River origin coho salmon by the commercial troll fishery at about 6,000 fish per year. The Lost River harvest of coho salmon by sport fishermen has averaged about 1,000 fish per year over the past 15 years and a few coho salmon are also harvested in a subsistence fishery. Peak counts of spawning coho salmon in the Lost River since 1972 have averaged about 4,500 fish. In 1994, ADF&G adopted an escapement goal range of 2,200 to 6,500 coho salmon counted during peak surveys of the Lost River based upon the technical recommendations of Clark and Clark (1994).

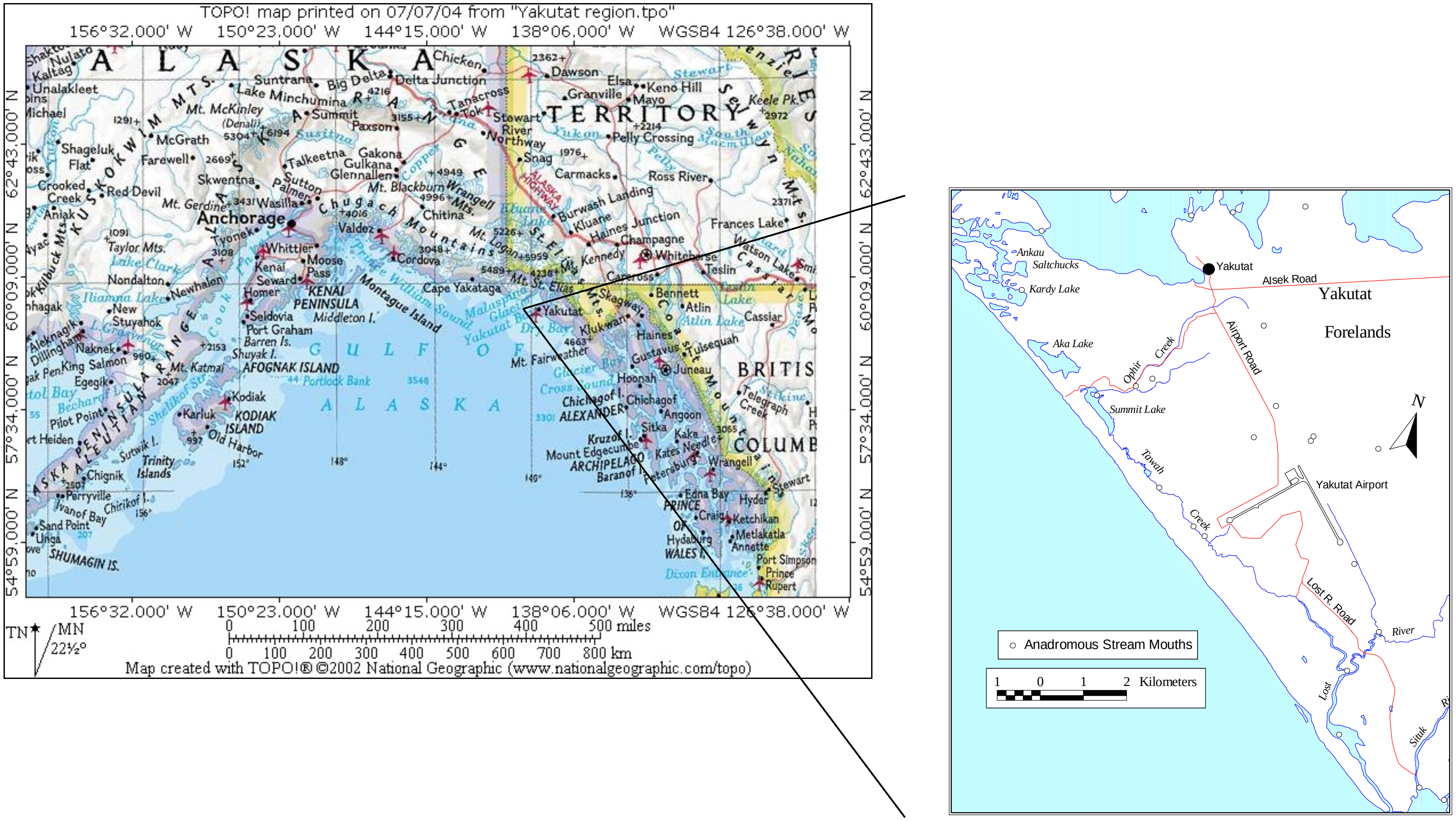

Figure 1.–Map depicting Alaska and showing location of the Lost River southeast of Yakutat, Alaska.

Concerning coho salmon stock assessments, Clark and Clark (1994) assert:

"One of the major limitations in this analysis is the lack of any total escapement estimates for coho salmon in the Yakutat Area. Because of high water conditions typically present during the fall coho salmon migration period, the likelihood of maintaining a weir in a fish tight manner is low. However, we believe that fairly good estimates of total escapement could be obtained through mark–recapture experiments at a relatively low cost."

Thus, improvements in the annual stock assessments for Lost River coho salmon have been recommended in past technical reports and are needed to ensure conservation and sustained yield management. In this study, we conducted a stock assessment to provide a direct estimate of total abundance of coho salmon in the Lost River in 2003. Intent is to continue these efforts so that the annual average and inter-annual variance for the relationship between peak survey counts and total escapements can be scientifically determined. The stock assessment objectives for this study in 2003 were as follows:

1. To estimate the total abundance of coho salmon in the Lost River in 2003 such that the estimate is within ± 30% of the true value 95% of the time.
2. To estimate the expansion factor, the coho salmon abundance estimate divided by the peak survey count, in 2003 in the Lost River such that the estimate is within ± 30% of the true value 95% of the time.

METHODS

A two-event mark–recapture experiment for a closed population (Seber 1982) was conducted to estimate abundance of coho salmon in the Lost River in 2003. A survey expansion factor was calculated using the abundance estimate and peak survey count.

CAPTURE AND MARKING

Immigrating coho salmon were caught in the Lost River immediately upstream of its confluence with the Situk-Ahrnklin Lagoon. A 30 m × 4 m (mesh 2.2 cm) beach seine was used to capture fish during Event 1 from August 29 to October 6. 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. The condition of each fish was assessed, noted, and recorded. 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, doubly marked, and released. The primary mark was an adipose fin clip. The secondary mark was one of four mutilations: 1) clipping of the right axillary process, 2) clipping of the left axillary process, 3) a paper punch in the right upper opercle, or 4) a paper punch in the left upper opercle. The secondary marks were used to ensure that when a fish was examined on the spawning grounds, anywhere from a few days to two 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.

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. After the depth of the tag and firmness of seating were checked to ensure that the radio transmitter was in place and 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 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 aircraft.

RECOVERY ON SPAWNING GROUNDS

Event 2 sampling was conducted by crews of two to four persons seining live fish and collecting carcasses. Sampling occurred in Tawah Creek and in Ophir Creek at locations accessible along the Yakutat area road system during the period of October 2 through November 7. Once coho salmon were captured, either by seine or through collection of carcasses, they were measured from mid-eye to fork of tail (MEF) to the nearest 5 mm, sexed by visual examination, and examined for the presence of a first event mark (missing adipose fin and secondary mutilation mark). Once a carcass 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). Live fish were marked by removing a portion of the dorsal fin prior to release to prevent sampling of the same fish at a later date.

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 diagnostic 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. Meeting the second condition depended primarily upon sampling coverage. Meeting the third condition depended primarily upon behavior of fish marked during Event 1.

Three consistency tests described by Seber (1982) were used to test for temporal and/or spatial violations of conditions 1–3 (Appendix A1). 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, time of marking was independent of if and when/where recovery occurred during Event 2.

Failure to reject at least one of these three hypotheses is sufficient to conclude that at least one of conditions 1–3 was satisfied.

Conditions 1–3 could also be violated if length selective sampling occurred. Determination of whether all length categories of the sockeye salmon run were subject to similar probabilities of capture during sampling in Events 1 and 2 was based upon the Kolmogorov-Smirnov (K-S) test (Conover 1980). Procedures are described in Appendix A2 as well as corrective measures (stratification) based on diagnostic test results to minimize bias in estimates of abundance. The diagnostic test hypotheses were evaluated using the test criterion of $\alpha = 0.10$.

Further, conditions 1–3 could be violated if sex selective sampling occurred. Determination of whether both sexes of the sockeye salmon run were subject to similar probabilities of capture during sampling in Events 1 and 2 was based upon contingency table analyses using the Chi-square test for independence (Conover 1980). For detection of possible size bias sampling, comparison of samples and corrective measures follow the pattern described in Appendix A2. Gender bias was detected through diagnostic testing and as a result, samples were completely stratified by gender and abundance of the female and male populations were estimated independently to eliminate bias.

The evaluation of condition 4 (no recruitment) is based solely on the timing of the tagging and recovery events and information concerning observations of peak survey abundance in the Lost River system. Coho salmon moving into the Lost River were captured from late August through early October and second event sampling occurred until November 7. Since 1964, peak counts of coho salmon in the Lost River occurred prior to October 10 in 30 of the 36 years (83%). Thus, although some coho salmon may have entered the Lost River after the marking event was complete, it is likely that the majority entered during Event 1 and that few coho salmon entered the river after the conclusion of Event 2. In the presence of some recruitment after Event 1 but not after Event 2, an unbiased estimate of abundance can still be calculated, but the estimate is germane to the timing of Event 2.

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 surveys of the distribution and fates of radio-tagged fish.

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 (1951) modification of Petersen's two-event, closed population estimator to estimate spawning abundance of coho salmon in the Lost 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 estimate the number of marked fish on the spawning grounds. Thus, the abundance estimator included an additional feature:

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

where $\hat{M}_e$ is the estimated number of marked coho salmon in the experiment available to be recaptured during the second event. Because a fraction of the coho salmon marked at the mouth of the Lost River are likely not available for sampling during the second event (i.e., they are considered mortalities from Event 1), the number of tagged fish in the experiment was estimated as:

$$\hat{M}_e = M\hat{y} \qquad (2)$$

where $\hat{y}$ was the proportion of marked fish that survived and moved upriver to the spawning grounds as estimated from the radio tagging results. Introduction of radio telemetry adds another condition for accuracy of the estimate: test subjects fitted with transmitters must be representative of other marked fish. Test subjects were selected systematically from among those salmon captured and marked. A fixed number of test subjects were selected during each of three temporal periods (Aug 29–Sep 9, Sep 12–22, Sep 28–Oct 6) during the first sampling event, so y for the run was estimated using a weighted procedure:

$$\hat{y} = \sum_{s=1}^{3} w_s \hat{y}_s \qquad (3)$$

where w_s was the weight ($= M_s / M$) for the statistic from a temporal period denoted by s, M_s the number of marked fish released during period s, and $\hat{y}_s$ the fraction of test subjects released during period s that subsequently migrated upstream.

Variance and bias for $\hat{N}$ was estimated using a bootstrap procedure similar to 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. The simulated frequencies were used to calculate surrogate statistics M'_s, C'_t, and R'_{st} where t denotes a stratum during the second event. Simulated values for $\hat{M}'_s$ were obtained by drawing values for $\hat{y}'_1$, $\hat{y}'_2$, and $\hat{y}'_3$ from $\text{binom}(19, \hat{y}_1)$, $\text{binom}(18, \hat{y}_2)$, and $\text{binom}(14, \hat{y}_3)$ for each bootstrap sample. Simulated statistics were substituted for observed values in estimators to produce a simulated estimate $\hat{N}'$.

One thousand such bootstrap samples were drawn, creating the empirical distribution $\hat{F}(\hat{N}')$, which is an estimate of $\hat{F}(\hat{N})$. The difference between the average of bootstrap estimates and $\hat{N}$ is an estimate of statistical bias (Efron and Tibshirani 1993). Variance was estimated as:

$$v\hat{a}r(\hat{N}) = (1000-1)^{-1}\sum_{b=1}^{1000}(\hat{N}'_b - \overline{\hat{N}'})^2 \qquad (4)$$

EXPANSION FACTOR

The expansion factor for the peak count of coho salmon from the survey in 2003 and its variance was estimated as follows:

$$\hat{\pi}_{2003} = \hat{N}/I_{2003} \qquad (5)$$

$$v\hat{a}r(\hat{\pi}_{2003}) = v\hat{a}r(\hat{N})I_{2003}^{-2} \qquad (6)$$

where π was the expansion factor for 2003 and *I* the peak count of several surveys conducted in 2003. 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

MARKING EVENT

A total of 798 coho salmon were captured, marked, and released at the mouth of the Lost River in 2003 from August 29 through October 6. In the 40-day period, fishing occurred on 24 of those days (60%) and from one to four seine sets were made on these sampling days (Figure 2). Of these fish, 370 were females and 428 were males. Four secondary marks were applied as the sampling effort progressed through time (Table 1). From August 29 through September 9, 157 coho salmon were given right axillary process clips as a secondary mark. From September 12 through September 28, 603 coho salmon were given left axillary process clips as a secondary mark. From September 29 through October 5, 27 coho salmon were given secondary marks consisting of a right opercula punch. On October 6, a left opercula punch was applied to 11 coho salmon. A total of 51 of these first event fish were also fitted with a radio tag; details concerning radio-tagging are provided in Appendix A3.

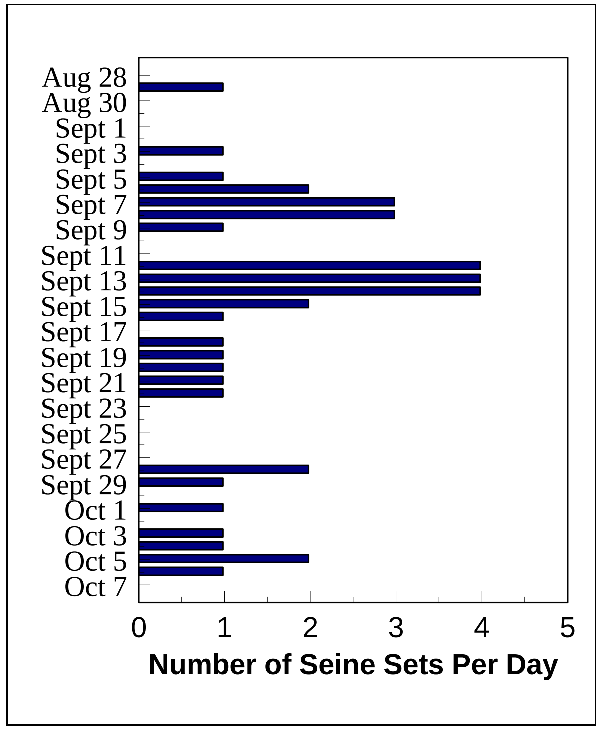

Figure 2.–Fishing effort expended during the first event of the 2003 mark–recapture experiment for coho salmon in the Lost River**.**

RECOVERY EVENT

A total of 667 coho salmon were captured and examined for the presence of marks during the second event of the 2003 Lost River mark–recapture experiment (Table 2). Of these 667 coho salmon, 257 were females and 410 were males. The second event took place during six sampling dates between October 2 and November 7 (Figure 3). A total of 18 coho salmon were recaptured during second event sampling, all of those fish had a missing left axillary process, indicating they were released sometime between September 12 and September 28. Of the 18 recaptures, 4 were females and 14 were males.

Table 1.–Summary of the number of coho salmon released with marks during the first event of the Lost River mark–recapture experiment in 2003. Mark abbreviations are as follows: RAUX = clipping of the right axillary process, LAUX = clipping of the left axillary process, RUOP = a paper punch in the right upper opercle, and LUOP = a paper punch in the left upper opercle.

Date	Number	Cumulative	Type of
29-Aug	6	6	RAUX
3-Sep	2	8	RAUX
5-Sep	38	46	RAUX
6-Sep	48	94	RAUX
7-Sep	19	113	RAUX
8-Sep	41	154	RAUX
9-Sep	3	157	RAUX
12-Sep	92	249	LAUX
13-Sep	69	318	LAUX
14-Sep	75	393	LAUX
15-Sep	167	560	LAUX
16-Sep	46	606	LAUX
20-Sep	11	617	LAUX
21-Sep	3	620	LAUX
22-Sep	7	627	LAUX
28-Sep	133	760	LAUX
29-Sep	4	764	RUOP
1-Oct	18	782	RUOP
4-Oct	1	783	RUOP
5-Oct	4	787	RUOP
6-Oct	11	798	LUOP

Table 2.–Summary of the number of coho salmon captured during the second event of the Lost River mark–recapture experiment in 2003 with the number of those captured fish that were marked during the first event. Mark abbreviation: LAUX = clipping of the left axillary process.

		LAUX-	Other
2-Oct	87	2	0
22-Oct[a]	81	3	0
22-Oct[a]	116	3	0
23-Oct	81	2	0
30-Oct	96	5	0
31-Oct	58	0	0
7-Nov	142	3	0
Total	667	18	0

[a] On October 22, 81 coho salmon were sampled in the Ophir Creek-Beaver Slough area and then later another 116 coho were sampled near the Ophir Creek Bridge.

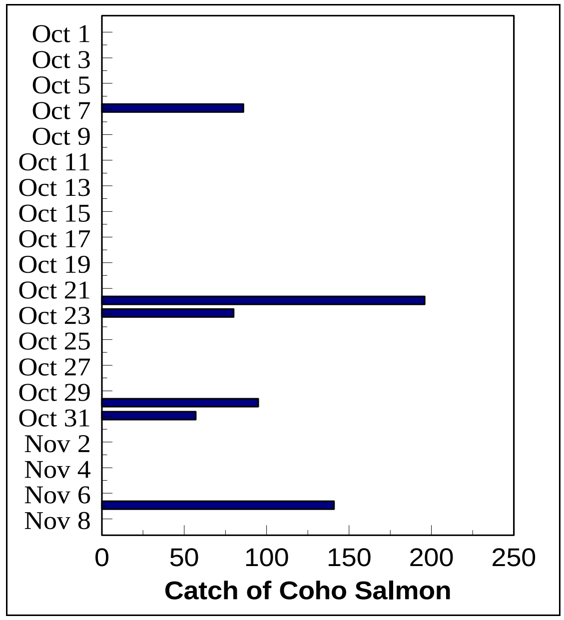

Figure 3.–Temporal pattern of sampling and daily catch of coho salmon during the second event of the 2003 mark–recapture experiment for coho salmon in the Lost River.

An additional five coho salmon carcasses were examined on October 21 from a ditch along the Cannon Beach Road, three of these fish had a missing right axillary process, indicating they were released sometime between August 29 and September 9. Those five fish were observed opportunistically that day while crew members were tracking a radio-tagged coho salmon. A thorough survey of the area did not take place, the sample size was small, and hence those fish were not considered as part of the second event sample.

Of the 51 coho salmon that were radio-tagged, 38 had remained in the Lost River system by the time they were last located (Table 3). Six of the

Table 3.–Distribution of last known locations of coho salmon caught at the mouth of the Lost River in 2003 and fitted with radio tags. See Appendix A3 for additional details.

Final Tracked Location	Number	Percent
Remained in Lost River	38	74
Never Relocated	6	12
Moved to Situk River	5	10
Caught in Commercial Fishery	2	4
Total Radio-Tagged Coho	51	100

radio tagged fish were never located after release, five migrated to the Situk River system and two were caught in the commercial set gill net fishery after being tagged and released at the mouth of the Lost River system.

DIAGNOSTIC TESTING OF MARK-RECAPTURE DATA

Several diagnostic tests of the mark–recapture data were directed at evaluation of the 3 "or" conditions associated with the experiment:

1. All coho salmon had an equal probability of being marked; or
2. All coho salmon had an equal probability of being inspected for marks; or
3. Marked fish mixed completely with unmarked fish in the population between events.

The first diagnostic test evaluated temporal violations of condition 2; we tested the null hypothesis that the probability of an Event 1 marked fish being inspected for marks during Event 2 was independent of the time during Event 1 when it was marked. Despite having no recoveries of coho salmon marked prior to September 12 nor after September 28, we failed to reject the null hypothesis (Table 4), the Chi-square test statistic was 5.96 with a *P*-value of 0.114. Because we failed to recover any coho salmon marked early in the run or late in the run, we elected to conduct a second test. The second test evaluated temporal violations of condition 1; the null hypothesis was that the probability that a fish inspected during Event 2 was marked was independent of the time/location during the Event 2 when the fish was caught and inspected. The Chi-square test statistic was 4.42 with a *P*-value of 0.619, hence we failed to reject the null hypothesis (Table 5). As we found no significant evidence that we failed to satisfy either condition 1 or 2 due to temporal or geographic bias, a Petersen-type estimator was used to estimate abundance, rather than the partially stratified estimator described by Darroch (1961). Notwithstanding model selection, other potential sources for bias based on temporal patterns in these data will be reviewed in the Discussion.

Table 4.–Contingency table for hypothesis test: H_O: probability of a coho salmon being inspected for marks was independent of the time during the run that it was marked. Chi-squared value = 5.96, 3 df, *P*-value = 0.114; failed to reject H_O.

Mark	Recaptured	Not Recaptured
RAUX	0	157
LAUX	18	585
RUOP	0	27
LUOP	0	11

Table 5.–Contingency table for hypothesis test: H_O: probability that a second event coho salmon was marked was independent of the time and location during the second event that it was caught. Chi-squared value = 4.42, 6 df, *P*-value = 0.619; failed to reject H_O.

Date	Marked	Unmarked
2-Oct	2	85
22-Oct	3	81
22-Oct	3	116
23-Oct	2	79
30-Oct	5	91
31-Oct	0	58
7-Nov	3	139

We also tested for potential size biased sampling. We used the Kolmogorov-Smirnov (KS) test to test the null hypothesis of no difference in size distributions of all coho salmon marked during the first event with those marked fish recaptured during the second event. The KS test statistic was 0.221 with a *P*-value of 0.346, hence we failed to reject the null hypothesis (Figure 4). We also used the KS test to compare the size distribution of all coho salmon marked during the first event with those captured during the second event (Figure 5). The KS statistic was 0.140 with a *P*-value of <0.001; so we rejected the null hypothesis and concluded that we had a Case II experiment (Appendix A2), indicating that size stratification was not needed to estimate abundance of coho salmon returning to the Lost River in 2003.

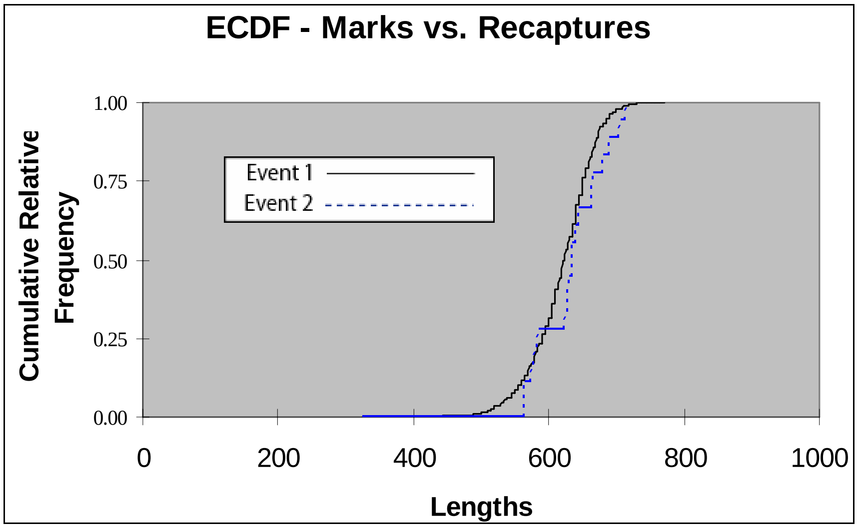

Figure 4.–Cumulative frequency distribution of lengths of coho salmon marked and released during Event 1 (solid line) versus those marked salmon recaptured during Event 2 (dotted line), Lost River mark–recapture experiment, 2003.

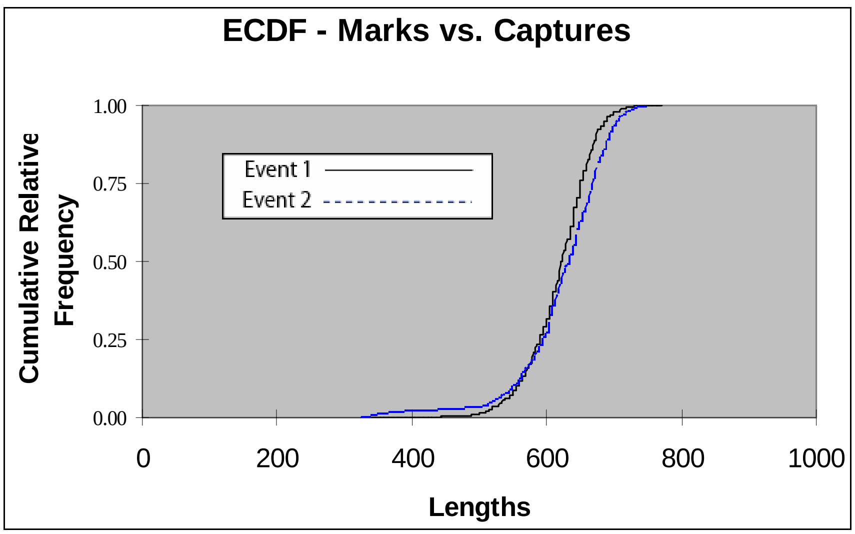

Figure 5.–Cumulative frequency distribution of lengths of coho salmon marked and released during Event 1 (black solid line) versus all salmon captured and inspected during Event 2 (blue line), Lost River mark–recapture experiment, 2003.

Potential gender bias sampling was also tested. We tested the null hypothesis that the probability that a marked fish was recovered during Event 2 sampling was independent of gender. The Chi-square test statistic was 4.32 with a *P*-value of 0.038, hence we rejected the null hypothesis (Table 6). We then tested the null hypothesis that male to female ratios were similar during both sampling events; the Chi-square test statistic was 9.11 with a *P*-value of 0.003, hence we rejected the null hypothesis (Table 7). As a result of these 2 statistical tests, we found evidence for gender bias in our sampling during both Events 1 and 2. In order to eliminate potential bias in estimates of abundance, it was necessary to completely stratify sampling data from both events by gender, and estimate abundance of males and females independently.

Table 6.–Contingency table for hypothesis test: H_O: probability of recovery during the second event was independent of gender. Chi-squared value = 4.32, 1 df, *P*-value = 0.038; rejected H_O.

Sex	Captured	Not Recaptured
Males	14	414
Females	4	366

Table 7.–Contingency table for hypothesis test: H_O: male to female ratios were similar during both sampling events. Chi-squared value = 9.11, 1 df, *P*-value = 0.003; rejected H_O.

Sex	Marked	Captured
Males	428	410
Females	370	257

After stratifying the data by gender, we repeated diagnostic tests for temporal/geographic violations of the "or" conditions and for evidence of size bias sampling by gender. In the gender specific temporal diagnostic, we tested the null hypothesis that the probability of an Event 1 marked female (or male) fish being inspected for marks during Event 2 was independent of the time during Event 1 when it was marked. For females, the Chi-square test statistic was 1.12 with a *P*-value of 0.773, so we failed to reject the null hypothesis (Table 8). For males, the Chi-square test statistic was 5.32 with a *P*-value of 0.150, so we failed to reject the null hypothesis (Table 9). We also tested the null hypothesis that the probability that a female (or male) fish inspected during Event 2 was marked was independent of the time/location during Event 2 when the fish was caught and inspected. For females, the Chi-square test statistic was 2.14 with a *P*-value of 0.543, so we failed to reject the null hypothesis (Table 10). For males, the Chi-square test statistic was 2.01 with a *P*-value of 0.571, so we failed to reject the null hypothesis (Table 11). As a result of these tests, we found no evidence that we failed to satisfy at least one of the "or" conditions due to temporal bias for either the female or male population, so a Petersen-type model was used to estimate abundance for both genders.

Table 8.–Contingency table for hypothesis test: H_O: the probability of a female coho salmon being inspected for marks was independent of the time during the run when it was marked. Chi-squared value = 1.12, 3 df, *P*-value = 0.773; failed to reject H_O.

Mark	Recaptured	Not Recaptured
RAUX	0	58
LAUX	4	286
RUOP	0	16
LUOP	0	6

Table 9.–Contingency table for hypothesis test: H_O: the probability of a male coho salmon being inspected for marks was independent of the time during the run when it was marked. Chi-squared value = 5.32, 3 df, *P*-value = 0.150; failed to reject H_O.

Mark	Recaptured	Not Recaptured
RAUX	0	99
lAUX	14	299
RUOP	0	11
LUOP	0	5

Table 10.–Contingency table for hypothesis test: H_O: the probability of a female coho salmon being marked was independent of the time during the second event when it was inspected. Chi-squared value = 2.14, 3 df, *P*-value = 0.543; failed to reject H_O.

Inspected	Marked	Unmarked
Oct. 2	1	34
Oct. 22-23	1	97
Oct. 30-31	0	53
Nov. 7	2	69

Table 11.–Contingency table for hypothesis test: H_O: the probability of a male coho salmon being marked was independent of the time during the second event when it was inspected. Chi-squared value = 2.01, 3 df, *P*-value = 0.571; failed to reject H_O.

Inspected	Marked	Unmarked
Oct. 2	1	51
Oct. 22-23	7	179
Oct. 30-31	5	96
Nov. 7	1	70

We used the KS test to test the null hypothesis of no difference in size distributions of female only (and male only) coho salmon marked during the first event with those marked fish that were recaptured during the second event. For females, the KS test statistic was 0.307 with a *P*-value of

0.850; hence, we failed to reject the null hypothesis (Figure 6). For males, the KS test statistic was 0.203 with a *P*-value of 0.621; hence, we failed to reject the null hypothesis (Figure 7). We also used the KS test to compare the size distribution of all female (and male) coho salmon marked during the first event with those captured during the second event. The KS statistic for females was 0.202 with a *P*-value of <0.001 (Figure 8); so we rejected the null hypothesis and concluded we had a Case II experiment (Appendix A2), indicating that size stratification was not needed to estimate abundance of female coho salmon returning to the Lost River in 2003. The KS statistic for males was 0.104 with a *P*-value of 0.019 (Figure 9); so we rejected the null hypothesis and again concluded we had a Case II experiment for the male coho salmon returning to the Lost River in 2003.

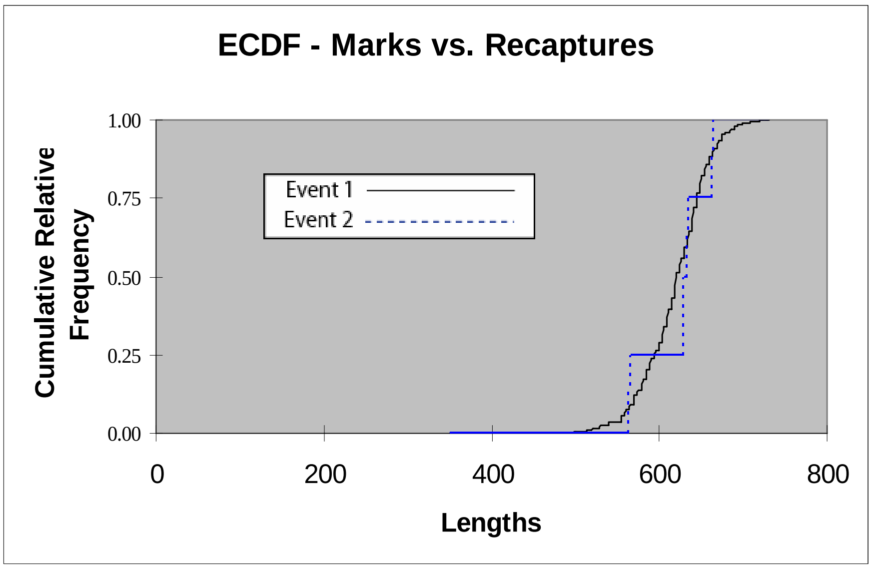

Figure 6.–Cumulative frequency distribution of lengths of female coho salmon marked and released during Event 1 (solid line) versus those marked female salmon recaptured during Event 2 (dotted line), Lost River mark–recapture experiment, 2003.

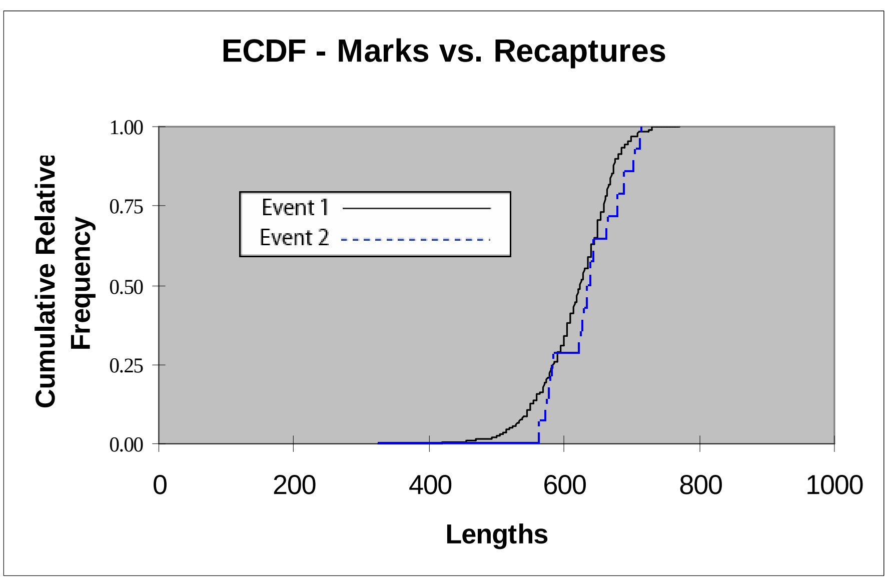

Figure 7.–Cumulative frequency distribution of lengths of male coho salmon marked and released during Event 1 (solid line) versus those marked male salmon recaptured during Event 2 (dotted line), Lost River mark–recapture experiment, 2003.

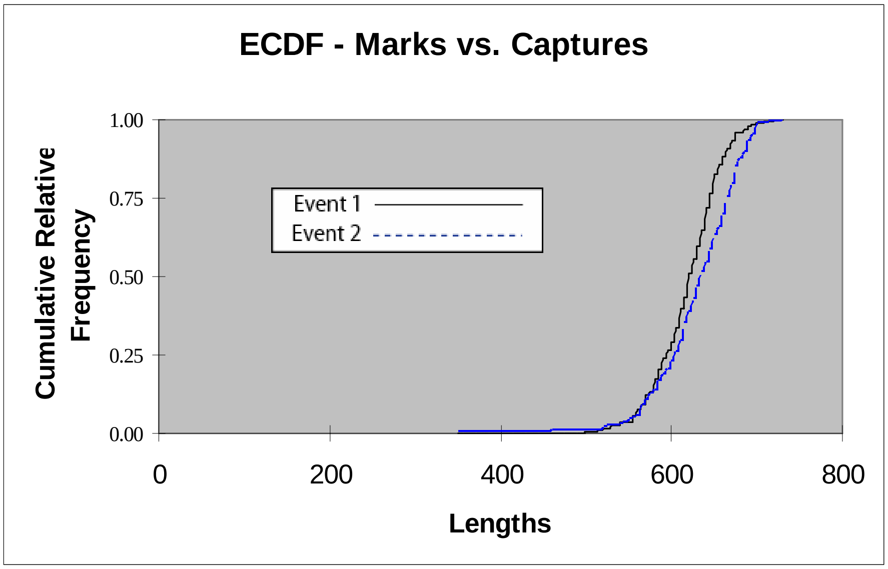

Figure 8.–Cumulative frequency distribution of lengths of female coho salmon marked and released during Event 1 (solid line) versus all females captured and inspected during Event 2 (dotted line), Lost River mark–recapture experiment, 2003.

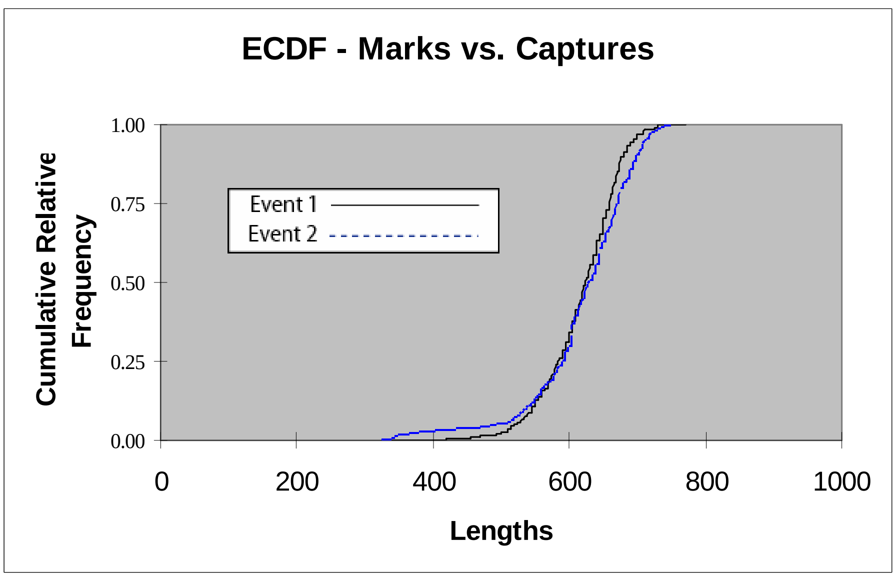

Figure 9.–Cumulative frequency distribution of lengths of male coho salmon marked and released during Event 1 (solid line) versus all males captured and inspected during Event 2 (dotted line), Lost River mark–recapture experiment, 2003.

ADJUSTMENT OF THE NUMBER OF MARKS FROM EVENT ONE

Because radio-tagged fish demonstrated that only a portion of the marked population remained in the Lost River and were thus susceptible to Event 2 sampling efforts (Table 3), it was necessary to adjust the number of fish released during Event 1 before abundance could be estimated. Based upon radio tag results, the estimated fraction of coho salmon that moved upstream into the Lost River from the first event sampling site was 0.766. The bootstrap standard error for this statistic was 0.0613 and the 95% confidence interval ranged from 0.629 to 0.874. The mean of the bootstraps was 0.766, indicating negligible bias in the estimate. Thus the adjusted number of marked coho salmon during Event 1 was estimated to have been 283 females and 328 males.

MARK–RECAPTURE ABUNDANCE ESTIMATES

Due to gender bias detected in both sampling events, it was necessary to completely stratify the sampling data by gender and estimate abundance independently for males and females. Total abundance was then calculated as the sum of the independent estimates for females and males.

The abundance estimate for female coho salmon in the Lost River system in 2003 was 14,675 fish with a bootstrapped standard error of 7,255 (CV=49%). The 95% confidence interval for the estimate ranged from 7,392 to 35,340. The mean of the bootstraps was 17,060 and the median was 15,570. Ignoring the variation associated with the portion of first event fish that moved upstream ($\hat{y}$), the potential computational (small sample size) bias of the point estimate using Chapman's formula (Seber 1982) was about 100 fish, a negligible amount. The abundance estimate for male coho salmon in the Lost River system in 2003 was 9,010 fish with a bootstrapped standard error of 2,565 (CV=28%). The 95% confidence interval for the estimate ranged from 5,711 to 15,670. The mean of the bootstraps was 9,558 with a median of 9,164. The potential computational bias of the point estimates for males was less than 1 fish.

Total abundance of coho salmon in the Lost River in 2003 was estimated to be 23,685 fish with a standard error of 7,835 (CV=33%). The 95% confidence interval was estimated to have ranged from 15,290 to 45,760 coho salmon. The mean of the bootstraps was 26,620 and the median was 25,270.

SURVEY EXPANSION FACTOR

Several surveys of the Lost River took place to count coho salmon in 2003 (Table 12). The first coho salmon count took place on September 4 and the last on October 28. The peak count occurred on October 1 when a total of 6,396 coho salmon were counted. The 2003 peak count represented 27% of the mark–recapture estimate. The 2003 expansion factor was estimated to be 3.7 with a standard error of 1.2 (CV = 33%).

Table 12.–Survey counts of coho salmon in the Lost River in 2003.

Date	Live Count	Dead Count	Total Count
9/4/2003	725	0	725
9/6/2003	1,332	0	1,332
9/15/2003	3,235	0	3,235
9/23/2003	3,500	0	3,500
10/1/2003	6,394	2	6,396
10/9/2003	5,907	0	5,907
10/29/2003	3,213	5	3,218
10/28/2003	2,128	97	2,225
10/28/2003	138	3	141

DISCUSSION

We designed this experiment so that if all necessary conditions were met, Chapman's modification of the Petersen method could be used to estimate escapement. We collected data such that we could directly evaluate if the three "or" conditions were violated due to size or gender selectivity of sampling gear or if probability of capture varied significantly over time or geographically. Based on the results of the diagnostic tests for size selectivity, we concluded that size selective sampling did not occur at detectable levels during both sampling events, and stratification by size was unnecessary to obtain an unbiased estimate of abundance. However, diagnostic tests revealed that gender selectivity did occur, resulting in a Case IV scenario for the entire data set and requiring complete stratification by gender before unbiased estimates of abundance could be calculated. Subsequent diagnostic tests for size selectivity within gender indicated that size stratification was not necessary prior to calculating gender specific abundance estimates,

Tests for equal probability of sampling over time for Event 1 and Event 2 did not provide significant evidence indicating temporal or geographic capture heterogeneity. Nonetheless, there were no recaptures of coho salmon marked early in the run and late in the run and the Event 1 test relied on available recaptures which may or may not be representative of fish that were marked early and late in the run. Further, the number of recaptured coho salmon in the experiment was low, only 4 females and only 14 males were recaptured. The experiment was designed to anticipate 50–60 recaptured marks and the realized 18 recaptures provided low power for detecting deviations from capture homogeneity conditions using our diagnostic tests. As can be seen in Figure 2, more sampling effort was expended during Event 1 in the middle portion of the sampling regime than was the case early and later. Further, our schedule for the use of the four batch marks over time was not temporally aligned with actual run timing past the tagging site. Had we been successful in deploying approximately similar numbers of marked fish with each mark, we would have more confidence in our tests to detect geographic or temporal capture heterogeneity even with the low number of recaptures. Sampling effort during the second sampling event was sporadic and only occurred on six days over a period of a month. A more rigorous second sampling event would have undoubtedly increased sample sizes, resulted in additional recaptured coho salmon from the first event and improved our estimation of abundance of coho salmon in the Lost River in 2003.

The ability of detecting movement of coho salmon into the Lost River through the use of radio tags was an important part of this experiment. The failure of coho salmon to continue to successfully migrate upstream when captured in the lower portions of streams can easily jeopardize the success of a mark–recapture experiment. In the case of this experiment, we were able to use results from radio-tagged fish to directly estimate the necessary adjustment for the number of marked fish released during the first sampling event, and incorporate the uncertainty in the estimate into our estimate of variance for our abundance estimate. As evidenced by the radio-tag results, some of the fish marked during the first event migrated back to the lagoon and were caught while others migrated into the Situk River system.

We suggest that the abundance estimate of about 24,000 coho salmon derived from the mark–recapture experiment in 2003 is a relatively unbiased estimate of the actual abundance that returned to the Lost River in 2003. However, diagnostic tests did not provide as robust of an evaluation of conditions of equal probability of capture as we desired, specifically with regard to potential temporal or geographic violations of these conditions. Inspection of radio-tracking data suggests that early fish marked with a RAUX remained in the study area throughout the Event 2 sampling effort (last date of tracking on the spawning grounds for these 12 fish was from October 20 to December 5), so it is unlikely that early run fish had a lower probability of being sampled during Event 2 due to early death and carcass washout. Further, a lower proportion of early run radio-tagged fish (12 of 19) were observed to have remained in the Lost River system for spawning than middle (14 of 18) or late (12 of 14) run radio-tagged fish. It may be possible that early or late run fish distributed themselves among Lost River spawning areas differently than those middle run fish marked with a LAUX, tending toward lower density or less used spawning grounds, making them less susceptible to Event 2 sampling efforts. Of the 12 early run radio-tagged fish marked with a RAUX, 4 (33%) moved into either Tawah or Ophir Creek while 8 (67%) moved upstream in the Lost River. On the other hand, of the 18 radio tagged fish with LAUX marks, 11 (61%) moved into either Tawah or Ophir Creek while 7 (39%) moved upstream in the Lost River.

The project objective of estimating the total coho salmon abundance in the Lost River in 2003 to within 30% of the true value 95% of the time was not achieved. While the sample sizes obtained would have been sufficient for a true population size of 8,000, which was used in experimental planning, the sample sizes were not sufficient to meet our precision criteria for the actual population size of about 24,000. In addition to planning for a population size that was 1/3 the size of that estimated, we employed less than anticipated sampling during the early and late portions of the first event and a less than anticipated level of sampling throughout the second event. These sampling problems occurred because the same sampling crew was assigned to conduct both first and second event sampling for three capture recapture experiments at the same time. Quite simply, the sampling crew did not have adequate time to sample coho in the Lost River in 2003 and less than desired precision of the estimate of abundance is the result of this difficulty.

CONCLUSIONS AND RECOMMENDATIONS

Estimating total abundance is important information for assessment and management of the Lost River coho salmon stock. Use of a 2-event mark–recapture abundance estimator provided an abundance estimate of about 24,000 coho salmon in 2003. The peak annual survey count of about 6,400 fish represented about 1 quarter of the total abundance of coho salmon in the Lost River in 2003. 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. We suggest obtaining 3 or more years of useable abundance estimates and companion expansion factors. Such a data set should provide the information needed to improve historic run reconstructions and improve the scientific information needed relative to better understand productivity and estimation of an appropriate escapement goal for this stock of salmon.

Recommendations to improve experimental design and implementation in future years are:

1. Design the experiment for a larger anticipated population size than occurred in this study, resulting in adequate first and second event sample size goals.
2. Provide an adjusted or more flexible schedule for the deployment of secondary batch marks to ensure a more uniform distribution of different marks throughout the marking effort.

Provide adequate staff resources to tagging crews to ensure that sampling is conducted more uniformly across and thoroughly throughout both sampling events.

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APPENDIX A

Appendix A1.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Tests of consistency for Petersen estimator

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I. Test For Complete Mixing[a]

Area/Time Where Marked	Time/Area Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
s					

II. Test For Equal Probability of capture during the first event[b]

	Area/Time Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked $(n_2\text{-}m_2)$				

III. Test for equal probability of capture during the second event[c]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

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[a] This tests the hypothesis that movement probabilities (θ) from time or area *i* (*i* = 1, 2, ...s) to section *j* (*j* = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where *k* = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum *j* at the time of sampling, and a_i = number of marked fish released in stratum *i*.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section *j* during the second event, and d is a constant.

Appendix A2.–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	"Accept" H_o
There is no size-selectivity during either sampling event.	
Case II:	
"Accept" H_o	Reject H_o
There is no size-selectivity during the second sampling event but there is during the first.	
Case III:	
Reject H_o	"Accept" H_o
There is size-selectivity during both sampling events.	
Case IV:	
Reject H_o	Reject H_o
There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

Case I: Calculate 1 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 1 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 2 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 2 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 A3.–Specifics concerning coho salmon that were captured at the mouth of the Lost River in 2003 and fitted with radio tags. Length is in mm measured as mid-eye to fork of tail (MEF); F indicates females and M indicates males; and secondary mark abbreviations are as follows: RAUX = clipping of the right axillary process, LAUX = clipping of the left axillary process, RUOP = a paper punch in the right upper opercle, and LUOP = a paper punch in the left upper opercle.

Date	Radio-TagNumber	Length (MEF)	Sex	Secondary Mark	Final Radio-Tracked Location	Comments
29-Aug	541-23	600	F	RAUX	Lost River System	
29-Aug	622-23	565	F	RAUX	Lost River System	
29-Aug	622-24	645	M	RAUX	Lost River System	
29-Aug	682-23	550	M	RAUX	Lost River System	
29-Aug	682-24	680	M	RAUX	Lost River System	
3-Sep	361-23	580	M	RAUX	Situk River	Coho moved out of system
3-Sep	501-23	610	F	RAUX	Lost River System	
5-Sep	343-23	635	M	RAUX	Situk River	Coho moved out of system
5-Sep	441-23	665	M	RAUX	Lost River System	
5-Sep	762-23	640	F	RAUX	Unknown	Never located
5-Sep	802-23	570	M	RAUX	Lost River System	
5-Sep	961-23	595	F	RAUX	Lost River System	
6-Sep	602-23	700	M	RAUX	Situk Fishery	Commercial fishery recovery
6-Sep	702-23	600	F	RAUX	Situk River	Coho moved out of system
7-Sep	722-23	610	F	RAUX	Unknown	Never located
7-Sep	742-23	700	M	RAUX	Lost River System	
8-Sep	781-23	570	M	RAUX	Lost River System	
8-Sep	822-24	645	M	RAUX	Situk Fishery	Commercial fishery recovery
9-Sep	862-23	675	F	RAUX	Lost River System	
12-Sep	842-23	610	F	LAUX	Unknown	Never located
12-Sep	882-23	640	F	LAUX	Situk River	Coho moved out of system
13-Sep	902-23	665	F	LAUX	Lost River System	
13-Sep	922-23	665	F	LAUX	Lost River System	
13-Sep	941-23	620	M	LAUX	Lost River System	
13-Sep	981-23	640	F	LAUX	Lost River System	
14-Sep	263-23	625	M	LAUX	Lost River System	
14-Sep	282-23	665	F	LAUX	Situk River	Coho moved out of system
14-Sep	301-23	655	M	LAUX	Lost River System	
15-Sep	322-23	620	F	LAUX	Unknown	Never located
15-Sep	381-23	730	M	LAUX	Lost River System	
15-Sep	402-23	660	M	LAUX	Lost River System	
16-Sep	381-24	695	M	LAUX	Lost River System	
16-Sep	402-24	625	F	LAUX	Lost River System	
20-Sep	562-23	635	M	LAUX	Lost River System	
20-Sep	941-23	655	F	LAUX	Lost River System	
21-Sep	481-23	645	M	LAUX	Lost River System	
22-Sep	662-23	650	F	LAUX	Lost River System	
28-Sep	522-23	640	F	LAUX	Lost River System	
28-Sep	583-23	675	M	LAUX	Lost River System	
28-Sep	602-23	575	M	LAUX	Lost River System	
28-Sep	642-23	675	F	LAUX	Lost River System	

-continued-

Appendix A3.–Page 2 of 2.

Date	Radio-TagNumber	Length (MEF)	Sex	SecondaryMark	Final Radio-Tracked Location	Comments
29-Sep	301-24	665	F	RUOP	Lost River System	
1-Oct	421-23	685	F	RUOP	Lost River System	
1-Oct	462-23	620	F	RUOP	Lost River System	
4-Oct	822-24	665	M	RUOP	Unknown	Never located
5-Oct	263-24	670	M	RUOP	Lost River System	
5-Oct	282-24	640	M	RUOP	Lost River System	
6-Oct	322-24	605	F	LUOP	Unknown	Never located
6-Oct	343-24	640	F	LUOP	Lost River System	
6-Oct	361-24	675	M	LUOP	Lost River System	
6-Oct	421-24	635	M	LUOP	Lost River System	