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TECHNICAL REPORT 08-07

Procedures for Estimating Tag Loss Rate and Spawning Escapement in a Mark-Recapture Study of Metolius Kokanee *Oncorhynchus nerka*

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August 4, 2008

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Please cite as:

Galbreath, P. F. and S. Hyun. 2008. Procedures for estimating tag loss rate and spawning escapement in a mark-recapture study of Metolius River kokanee *Oncorhynchus nerka*. Columbia River Inter-Tribal Fish Commission Technical Report 08-06, Portland, Oregon. (http://www.critfc.org/tech/08-07report.html)

Abstract. – Mark-Recapture/Resight procedures were used to estimate the 2007 spawning escapement of kokanee *Oncorhynchus nerka* migrating from Lake Billy Chinook into the Metolius River, Jefferson County, Oregon. An initial analysis of data, which included an adjustment for a presumed 25% tag loss rate (without confidence limits), provided an escapement estimate of 101,854 ± 11,151 (± 10.9%; 95% confidence interval). Here we present an expanded analysis of the data to look for effects of the survey protocols, and we have re-estimated abundance, incorporating the additional uncertainty associated with estimation of tag loss rate based on recapture (resight) counts of double-tagged fish. The resight procedures in this project involved subdivision of the spawning area in the Metolius into five sections, each of which was surveyed once in each of three different weeks. A two-way analysis of variance of these data indicated no significant effect on the proportion of marked fish among observed spawners (overall average = 2.42%) for either survey section or survey week. Among the 3,298 fish tagged in 2007, 491 received a second tag. A total of 59 of these double-tagged fish were resighted - 35 with both tags and 24 with a single tag. A binomial likelihood analysis of these data indicated a tag loss rate of 25.6% ± 9.9%. Incorporation of the uncertainty associated with tag loss estimation into a hypergeometric likelihood procedure to calculate escapement yielded an estimate of 106,630 ± 16,393 (± 15.4%). Several scenarios based on the 2007 data were run using these likelihood procedures, to illustrate the effects on precision of the estimate from an increase or decrease in the total number of tagged fish, in the number of double-tagged fish, and in the total number of fish observed during the surveys, as well from an increase or decrease in observed tag loss rate. The most dramatic improvement in precision of the abundance estimate per unit change in 2007 tagging/survey effort could have been obtained from increasing the proportion of double-tagged fish - to increase certainty of the tag-loss estimate. We propose adoption of the binomial-hypergeometric likelihood estimator procedures to incorporate tag loss rate and its uncertainty into a Mark-Recapture/Resight analysis for estimation of abundance, and provide suggestions for modifications of the Metolius kokanee tagging and survey procedures for spawning escapement estimation in future years.

Introduction

Lake Billy Chinook in Jefferson County, Oregon, contains an adfluvial population of kokanee *Oncorhynchus nerka* which supports an important sport fishery. Management of kokanee in this system is the concern of the Oregon Department of Fish and Wildlife (ODFW) and the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) – co-managers of the fishery, and of Portland General Electric and the CTWSRO – co-licensees to the Pelton Round Butte Hydroelectric Project. Knowledge of trends in size of the kokanee population is needed for informed management of this fishery. The information will be of additional interest in light of current efforts to modify fish passage structures of the Pelton Round Butte Project, in order to re-establish an anadromous sockeye salmon population. During recent years these agencies have collaborated in efforts using various methodologies to quantify the spawning escapement of kokanee from the lake into the Metolius River, including a Mark-Recapture/Resight methodology. Note that we use the term Resight for these studies, as the fish were not physically recaptured, but instead were observed visually for presence of a tag as they swam freely in relatively shallow water within the spawning areas of the river.

Mark-Resight projects were conducted to estimate annual escapement of Metolius River kokanee from 1996 to 2000, and again from 2005 to 2007. In August and September in each of these years, during the period just prior to the spawning run, kokanee were captured by seining in the upper arm of the lake near the confluence with the Metolius River. Fish collected in this manner were generally greater than 250 mm, and all were considered to be pre-spawning adults. A random sample (number = M; “marked”, using notation of Everhart et al. 1975) were tagged with bright colored plastic anchor (Floy®) tags (Dell 1968) then released back into the lake. During late September through October, spawning ground surveys were conducted. The surveys involved walking (or floating in a section where the water depth and flow is too great) the spawning area in the upper portion of the river. During the surveys, the total number of fish observed (C; “captured”) was recorded, along with the number which possessed a tag (R;

"recaptured"). The data were then fit into Petersen Mark-Recapture formulae (Seber 1973) to provide a point estimate of population abundance (N):

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

and its variance (Var), which was used to calculate a 95% confidence interval (C.I.):

$$Var(N) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

It is obvious that for a given population, changing marking or survey effort to increase the value of M or C will produce an increase in R and in the precision of the abundance estimate. These increases, however, occur at a decreasing rate and are associated with increase in labor and material costs. Establishment of the appropriate level of effort for a Mark-Recapture/Resight project will involve a cost-benefit type of analysis which contrasts projections for increase or decrease in certainty of the abundance estimate, with those for increase or decrease in costs for the associated tagging or survey effort.

Assumptions to the Petersen Mark-Recapture model include the following (Seber 1973):

a) The population is closed so that N is constant.
b) All animals have the same probability of being caught in the first sample.
c) Marking does not affect the catchability of an animal.
d) The second sample is a simple random sample.
e) Animals do not lose their marks in the time between the two samples.
f) All marks are reported on recovery in the second sample.

These assumptions appear valid for the tagging and resight procedures used to estimate escapement of the Metolius River kokanee, with the notable exception of the assumption regarding loss of tags. If this assumption is violated – that is, if some portion of the tagged fish lose their marks prior to the time they are susceptible to being recaptured/resighted - then M needs to be adjusted downward prior to use in the Petersen calculation of abundance, otherwise the resulting estimate will be biased high. Additionally, estimation of tag loss is associated with an amount of uncertainty which must also be incorporated into the subsequent estimation of N, otherwise the the C.I. for N will be unrealistically small (Arnason and Mills 1981, Seber and Felton 1981, Rajwani and Schwarz 1997, McDonald et al. 2003).

Indeed, loss of Floy® tags in salmonid tagging studies is a well established phenomenon (Smith et al. 1978, Smith and McPherson 1981, Carline and Brynildson 1972, Ebener and Copes 1982, McAllister et al. 1992). The rate of tag loss is dependent on numerous factors, including expertise of the tagging crew, species, time and activity level of the fish between tagging and recapture, etc. (Rawstron 1973, Smith and McPherson 1981, McAllister et al. 1992, Muoneke 1992).

In the Metolius River kokanee studies, a tag loss rate of 25% reported by Smith et al. (1978) for spring Chinook in the Rogue River (Jackson County, Oregon) has been used each year to adjust the value of M (Theide et al. 2000, Lovtang et al. 2008). However, in 2007 the researchers decided to double-tag a portion of the fish in the Mark-Resight project, in order to estimate a tag loss rate specific to the Metolius River kokanee. The numbers of double-tagged fish which were resighted with both or only one of the two tags were to have been used to make this estimate of tag loss rate. A total of 491 of the fish were double-tagged (D; color = pink) in 2007, and 51 of these fish were resighted (D_R) – 30 with both tags (D_2), and 21 with only one tag (D_1) ($D_R = D_1 + D_2$). Another eight fish were observed with a pink tag(s), although the observers were unsure whether there were one or two tags present. Additionally, the observers indicated that they sometimes had difficulty distinguishing between the colors pink and orange of the tags in the live fish during the surveys (likewise, they had even greater difficulty distinguishing between yellow and green tags), and it was feared that the number (21) of pink single-tagged fish may have been inaccurate. Further, the tag loss rate using the 2007 double-tagging data was erroneously calculated to have been 42% (Lovtang et al. 2008), which was deemed to be unrealistically high. Therefore, the researchers reverted to use of the 25% rate presumed in previous years' studies (Theide et al. 2000).

However, two main problems exist regarding the presumption of a 25% tag loss rate. The first involves differences in methodology between the Smith et al. (1978) study and the Metolius River studies which could affect tag loss. Several of these differences are summarized in Table 1, along with information and tag loss rates observed in these and other salmonid studies. Tag loss varies between studies (sometimes substantially), and use of a tag loss rate calculated in one study can therefore not be presumed appropriate for use with a different population.

Table 1. – Comparative data on double-tagging study design and tag loss rate from various salmonid Mark-Recapture projects involving use of anchor tags.

	Metolius River studies	Smith et al. 1978	Smith and McPherson 1981	Smith and McPherson 1981	McAllister et al. 1992	Ebener and Copes 1982	Carline and Brynildson 1972
Species	kokanee	spring Chinook	spring Chinook	fall Chinook	rainbow trout	lake whitefish	brook trout
Size at tagging (cm)	35	70-80	70-80	70-80	(12-16 mo old)	33-79	17-19
Time tagging to recapture (mo)	2	5	5	3	9-12	12 & 24	8
Recapture location	river	river	river	river	hatchery	lake	lake
State - live vs. carcass	live (and carcass)	live and carcass	live and carcass	live and carcass	live	live	live
Tag loss rate		24%	21% (but approx. 30% for carcasses only)	39%	12% to 19%	11% (12 mo.), and 19% (24 mo.)	6% and 2%
Comment		(1975 data)	(avg. for 1975 and 1977 data)	(avg. for 1975 and 1977 data)			

The second problem with assuming a 25% tag loss rate in the Metolius kokanee studies is that this rate is not provided with an estimate of uncertainty. Unfortunately, there is not a straight forward procedure described in fisheries management texts for estimating the variance associated with tag loss based on recapture data of double-tagged fish. Further, even if the variance estimate were known, there is no defined procedure for incorporating this uncertainty into the Petersen estimator for abundance.

We describe here a two part re-analysis of the 2007 Metolius River kokanee Mark-Resight data. The first part involves an analysis of variance (ANOVA) to examine the effects of survey section and survey week on the estimate of abundance. The second part describes an analytical procedure to use data for double-tagged fish obtained as part of a Mark-Resight project, to provide an estimate of tag loss and its variance, which are then incorporated into the calculation for abundance. Several scenarios were then run, based on the 2007 kokanee data, to illustrate the relative effects of changing different study design variables on certainty of the abundance estimate: number of tagged fish, number of double-tagged fish, resight number, and tag loss rate.

Methods

Tagging of kokanee in 2007 was performed on three dates, each date using tags of alternative colors (Table 1; Lovtang et al. 2008):

Table 2. - Tagging data for the 2007 Mark-Resight study to estimate the kokanee spawning escapement in the Metolius River.

Date (2007)	# Tagged	Tag color	Single/Double
Aug. 4	491	pink	double
	822	green	single
	1,313		
Aug. 28	990	yellow	single
Sept. 5	995	orange	single
TOTAL	3,298		

In this case, the total number of marked fish (M = 3,298) is equal to the sum of single-tagged fish (S = 2,807) and double-tagged fish (D = 491). Beginning three weeks after the final tagging date, three sets of surveys were conducted of the spawning area in the mid and upper Metolius River, spaced approximately two weeks apart: Sept. 24-27, Oct. 11-12 and Oct. 24-25. This portion of the Metolius was subdivided into five primary survey sections as follows (indicated from an upstream to downstream direction):

Section 1 – Headwaters to Camp Sherman Bridge, including Spring Creek and Lake Creek

Section 2 – Camp Sherman Bridge to Gorge Campground

Section 3 – House on the Metolius Bridge to Canyon Creek, including Heising Springs, Jack Creek and Canyon Creek

Section 4 – Wizard Falls to Candle Creek, including Candle Creek and Abbot Creek

Section 5 – Mid-Metolius, in the vicinity of the Whitewater River

All, or the majority, of each section was surveyed once in each of the three weeks by a team of 2 to 3 observers. The surveys were conducted walking in a downstream direction, with the exception of the mainstem of the Metolius in Section 4 which was float-surveyed from inflatable kayaks.

Data on numbers of fish with and without tags, previously detailed in the appendices to Lovtang et al. (2008), are summarized by survey section and week in Table 3. A slight difference in the data is that the total number of observed fish (C) reported here is 11,444, while that reported by Lovtang et al. 2008 was 11,442. The observers encountered difficulties during the spawning ground surveys in distinguishing between green and yellow tags on the live marked fish, and to a lesser extent between pink and orange tags. With the exception of information for pink-tagged fish, the color-specific data were therefore considered unreliable, and the fish were classified simply as tagged or untagged. Despite some question as to the accuracy of the pink tag data, this information was retained, in order to illustrate the methodology by which a point estimate and variance can be calculated for tag loss using data on double-tagged fish. In 2007 data set, therefore, the total number of resighted tagged fish (R = 277) consisted of resighted single-tagged fish (S_R = 218) and resighted (pink) double-tagged fish (D_R = 59). The resighted double-tagged fish were comprised of 21 fish which retained only one tag (D_1), 30 fish with both tags (D_1 = 21), plus 8 fish for which the number of pink tags present (1 or 2) was unknown. For the purposes of estimating tag loss, these eight fish were presumed to have retained their tags in the same ratio as the known fish (therefore, single-tagged = 3 and double-tagged = 5), with the new values for D_1 and D_2 being 24 and 35, respectively.

Table 3. - Spawning ground survey data for the 2007 Mark-Recapture study used to estimate kokanee escapement to the Metolius River.

Survey Section		Sept. 24-27, 2007			Oct. 11-12, 2007			Oct. 24-25, 2007			Total per Section		
No.	Name	C	R	%R	C	R	%R	C	R	%R	C	R	%R
1	Headwaters to Camp Sherman Bridge	472	6	1.27%	940	21	2.23%	123	1	0.81%	1,535	28	1.82%
2	Camp Sherman Bridge to Gorge Campground	510	14	2.75%	453	5	1.10%	24	1	4.17%	987	20	2.03%
3	House on the Metolius bridge to Canyon Creek	660	8	1.21%	3,344	89	2.66%	561	14	2.50%	4,565	111	2.43%
4	Wizard Falls to Candle Creek	1,744	45	2.58%	1,497	40	2.67%	114	3	2.63%	3,355	88	2.62%
5	Mid-Metolius	356	13	3.65%	498	13	2.61%	148	4	2.70%	1,002	30	2.99%
	Totals / Average	3,742	86	2.30%	6,732	168	2.50%	970	23	2.37%	11,444	277	2.42%

Survey section and week effects

A two-way ANOVA was performed on the 2007 data to test for an effect attributable to survey section and to survey week, on the proportion of tagged fish among fish observed. The 2007 study was originally designed to also enable testing for an effect of tagging date, through use of tag colors specific to each of the three tagging dates. However, because of the difficulty in distinguishing between colors on the live fish, the resight data for tagged fish were summed across colors, and the analysis for an effect of tagging date could not be performed.

Binomial-hypergeometric likelihood methods for tag loss and abundance estimation

In this section, we describe a two step model to produce a population estimate based on Mark-Recapture data which incorporates the uncertainty associated with tag loss rate into the final abundance estimate. In the first step, the model calculates an estimate and variance for the rates of tag loss (q) and retention (p) between the time of tagging and the time of recapture/resighting. These values are used to calculate a corrected quantity for M (M^{actual}) representative of the total number of fish susceptible of being identified as tagged during the time of recapture/resighting. The rates of tag loss and retention are calculated using information for resighted double-tagged fish, which in 2007 consisted of the resighted pink double-tagged fish (D_1 = 24 and D_2 = 35). In the second step of the model, the value and variance for M^{actual} are used in the mark-recapture relationship to produce an estimate of population abundance – an estimate whose uncertainty is increased by inclusion of variance for tag loss.

In the first step, we built a likelihood model to infer tag loss rate using double-tagging data. Key assumptions to the model are that:

a) Tags are not distinguishable.
b) There is no fish that lost both tags.

(In the 2007 kokanee study, the pink tags were identical, and tag loss rate was estimated to have been sufficiently low for loss of both tags from a fish to have been rare.) With D_R = the number of double-tagged fish which were resighted, D_1 = the number resighted with only one tag, and D_2 = the number resighted with both tags, such that $D_R = D_1 + D_2$, we treat the value of D_1 (or D_2) as a binomial random variable [i.e., $D_1 \sim \text{Binomial}(D_R, \theta)$], where θ - the cell probability of D_1 is estimated as follows:

$$\begin{aligned} \theta &= \frac{pq + qp}{pq + qp + p^2} \\ &= \frac{2pq}{2pq + p^2} \end{aligned} \tag{1.1}$$

where *p* is the rate of tag retention [i.e., Pr(a fish retains a tag)] and *q* is the rate of tag loss [i.e., Pr(a fish loses a tag)]. As such, *p* + *q* = 1.

Thus, the likelihood function of q is as follows:

$$\begin{aligned} L(q) &= \binom{D_R}{D_1} \cdot \theta^{D_1} \cdot (1-\theta)^{D_R - D_1} \\ &= \binom{D_R}{D_1} \left(\frac{2pq}{2pq + p^2} \right)^{D_1} \left(1 - \frac{2pq}{2pq + p^2} \right)^{D_R - D_1} \\ &\propto \left(\frac{2pq}{2pq + p^2} \right)^{D_1} \left(\frac{p^2}{2pq + p^2} \right)^{D_2} \end{aligned} \tag{1.2}$$

The log-likelihood function of q is:

$$\ell(q) \propto D_1 \log(2p) + D_1 \log q - D_1 \log(2pq + p^2) + D_2 \log p^2 - D_2 \log(2pq + p^2) \tag{1.3}$$

Secondly, we built a likelihood model to estimate fish abundance using Mark-Recapture data. Letting M = the number of fish marked initially and released (which is comprised of S single-tagged fish and D double tagged fish); C = the total number of fish captured (sighted) in the spawning grounds surveys; and R = the number of recaptured (resighted) marked fish within C (which is comprised of S_R resighted fish from among the originally single-tagged fish, and D_R resighted fish from among the originally double tagged fish). Treating R as a hypergeometric random variable [i.e., R ~ Hypergeometric (N, M, C)], the mass function is as follows:

$$\Pr(R \mid N, M, C) = \frac{\binom{M}{R}\binom{N-M}{C-R}}{\binom{N}{C}} \tag{1.4}$$

Thus, the likelihood function of parameters is:

$$L(N, M, C \mid R)$$

$$= \frac{\{M!/[(M-R)! \cdot R!]\} \cdot \{(N-M)!/[(N-M-C+R)! \cdot (C-R)!]\}}{\{N!/[(N-C)! \cdot C!]\}} \tag{1.5}$$

$$\propto \frac{M! \cdot (N-M)! \cdot (N-C)! \cdot C!}{(M-R)! \cdot (N-M-C+R)! \cdot (C-R)! \cdot N!} \qquad \text{(ignoring } R\text{)}$$

The term for R is ignored because it is constant with respect to the three parameters of N, M and C.

The log-likelihood function is

$$\begin{aligned} \ell(N, M, C) \propto \log\Gamma(M+1) + \log\Gamma(N-M+1) + \log\Gamma(N-C+1) \\ + \log\Gamma(C+1) - \log\Gamma(M-R+1) \\ - \log\Gamma(N-M-C+R+1) \\ - \log\Gamma(C-R+1) - \log\Gamma(N+1) \end{aligned} \tag{1.6}$$

Because we are interested only in the parameters N and M, we can ignore constant terms with respect to these parameters. Also, values for C and R are obtained from the field data. Finally,

$$
\begin{aligned}
\ell(N,M) \propto \log\Gamma(M+1) + \log\Gamma(N-M+1) + \log\Gamma(N-C+1) \\
- \log\Gamma(M-R+1) - \log\Gamma(N-M-C+R+1) \\
- \log\Gamma(N+1)
\end{aligned}
\tag{1.7}
$$

Further, the two likelihood functions for tag loss (1.2) and abundance (1.5) are independent, because data for D_1 and R are independent. Thus, the joint likelihood function of parameters is:

$$L(q,\, N,\, M \mid D_1,\, R) = L(q \mid D_1) \cdot L(N,\, M \mid R) \tag{1.8}$$

Therefore, the logarithm of the total likelihood is simply the sum of equations 1.3 and 1.7.

$$\ell_{Tot} = \ell(q) + \ell(N,M) \tag{1.9}$$

Then, linking the inference for tag loss rate to that of abundance, we calculate a new value for the number of tagged fish (M) which has been adjusted for tag loss (M^{actual}). Recalling that M = S + D and that we presume that all double-tagged fish will retain at least one tag, M^{actual} requires a corrected value for number of single-tagged fish (S^{actual}) to account for those which lost their mark prior to the spawning ground surveys, as follows:

$$
\begin{aligned}
M^{actual} &= S^{actual} + D \\
&= S \cdot (1-q) + D
\end{aligned}
\tag{1.10}
$$

where q = tag loss rate. Recall that q is a parameter. Although M was theoretically considered a parameter in the above hypergeometric mass function, its value is available from empirical data. However, its value adjusted for tag loss (M^{actual}) is a parameter which must be estimated.

Thus, we replace M in the total likelihood function (1.9) with M^{actual}, and thus the logarithm of the total likelihood function is as follows:

$$\begin{aligned}\ell_{Tot} &= \ell(q) + \ell(N, M^{actual}) \\ &= D_1 \log(2p) + D_1 \log q - D_1 \log(2pq + p^2) + D_2 \log p^2 - D_2 \log(2pq + p^2) \\ &\quad + \log\Gamma(M^{actual} + 1) + \log\Gamma(N - M^{actual} + 1) + \log\Gamma(N - C + 1) \\ &\quad - \log\Gamma(M^{actual} - R + 1) - \log\Gamma(N - M^{actual} - C + R + 1) \\ &\quad - \log\Gamma(N + 1)\end{aligned} \tag{1.11}$$

By differentiating equation (1.11) with respect to a parameter of interest, we can calculate its maximum likelihood estimate (MLE). By differentiating equation (1.11) with respect to the parameter twice, we can calculate the variance estimate of the MLE. We took the negative total log-likelihood function (i.e., $-\ell_{Tot}$), and implemented the negative log-likelihood using Auto-Differentiation Model Builder (ADMB) optimization software (Fournier 2000).

We developed a simple program in ADMB, where users input data for D_1, D_2, S, D, C and R from a Mark-Recapture study, and the program produces MLEs and variance estimates for q and N. We have made the program available to the public by appending it as an executable file to the internet web link for this report (http://www.critfc.org/tech/08-07report.html).

Results

Effects of survey section and survey week

The overall proportion of tagged fish among fish observed in the spawning surveys was 2.42%. This proportion did not differ significantly between the five survey sections (P-value = 0.39) nor between the three survey weeks (P-value = 0.86)

Table 4. – Output of the two-factor ANOVA without replication for effects of survey section (#1 through #5) and Survey Week (a, b and c) for the 2007 Mark-Resight study to estimate kokanee spawning escapement in the Metolius River.

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
1	3	0.043182	0.014394	0.000053
2	3	0.080155	0.026718	0.000235
3	3	0.063691	0.021230	0.000063
4	3	0.078839	0.026280	0.000000
5	3	0.089648	0.029883	0.000033
a	5	0.114604	0.022921	0.000109
b	5	0.112817	0.022563	0.000045
c	5	0.128095	0.025619	0.000142

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Survey section	0.00044	4	0.000110	1.190	0.385	3.838
Survey week	0.00003	2	0.000014	0.151	0.862	4.459
Error	0.00074	8	0.000092			
TOTAL	0.00121	14				

Binomial-Hypergeometric likelihood methods for tag loss and abundance estimation

Analysis of resight data for pink double-tagged fish using the binomial likelihood model yielded an estimate for tag loss rate of 25.6% ± 9.9%. When this rate was applied to the hypergeometric likelihood procedure using the 2007 Mark-Resight data, the analysis produced an estimate for Metolius River kokanee escapement of 106,630 ± 16,393 (± 15.4%).

Effects of modifications to study design

In the Metolius kokanee Mark-Resight studies, the choice of tag type, of the number of fish tagged, of the number of marked fish which are double-tagged, and the choice and frequency of river sections surveyed are all aspects of the study design which can be manipulated. The 2007 data were used as a basis for a series of scenarios which illustrate the effects that modification of these study design variables have on the resultant estimate of abundance, and on the C.I. associated with this estimate. On the basis of these illustrations, we suggest modifications to the study design which may improve accuracy and/or precision, and at the same time economize labor involved in the tagging and surveying effort.

Change in tag loss rate

Loss of tags between the time of marking and the time of resighting reduces the original number of marked fish (M) susceptible of being resighted (M^{actual}), and it adds uncertainty to the estimated value of M^{actual}. Both conditions increase uncertainty in the resulting estimate of abundance. To illustrate this effect of tag loss, we ran the binomial-hypergeometric likelihood model with alternative values of D_1 and D_2, while maintaining $D_1 + D_2 = D_R = 59$, to obtain projected tag loss rates for each combination which ranged from 0% to 47%. Values for S^{actual} for each scenario were estimated based on the corresponding tag loss rate, then values for S_R and R were calculated assuming a resight rate for tagged fish of 10.7% (the overall average resight rate observed in 2007). The 2007 values for M = 3,298 and C = 11,444 were kept constant. The binomial-hypergeometric likelihood model was then run a second time. Results for each scenario yielded an estimate of N which was approximately constant (≈105,000) with confidence intervals for N ranging from approximately 9.6% to 16.9%, respectively (Table 5 and Figure 1).

Table 5. - Change in the confidence interval (C.I.) of the estimate for abundance (N) based on the 2007 Mark-Resight data for Metolius River kokanee, using alternative values of resighted double-tagged fish with one (D_1) or two (D_2) tags (D_1 + D_2 = 51). (Estimates based on 2007 data are in bold font.)

D_1	D_2	Tag Loss (%)	C.I. % of N≈105,000
0	59	0.0%	9.6%
2	57	1.7%	9.9%
4	55	3.5%	10.2%
8	51	7.3%	10.9%
12	47	11.3%	11.8%
16	43	15.7%	12.7%
20	39	20.4%	13.9%
24	**35**	**25.5%**	**15.3%**
28	31	31.1%	16.9%

Figure 1. - Change in the confidence interval (C.I.) of the estimate for abundance (N) based on the 2007 Mark-Resight data for Metolius River kokanee, using alternative values for resighted double-tagged fish with one (D_1) or two (D_2) tags (D_1 + D_2 = 59). (Estimate from 2007 data is circled.)

Number of tagged fish

The greater the number of fish which are tagged (M) during initiation of a Mark-Recapture study, the greater will be the number which are resighted. For a given amount of survey effort, this will result in an increasing number of marked and unmarked fish, and an estimate of N of increasing certainty; though again, this increase will occur at a diminishing rate. To illustrate the effect of an increase or decrease in M, we ran the binomial-hypergeometric likelihood program with values of S and S_R from the 2007 Metolius River kokanee data which varied in 25% intervals. The values for D=491, D_1 = 24, D_2 = 35, and C = 11,444 remained constant, and the resulting estimate of N remained approximately constant (≈ 107,000) (Table 7 and Figure 3).

Table 6. - Change in the confidence interval (C.I.) of the estimate of abundance (N) using the 2007 Mark-Resight data for Metolius River kokanee, with alternative values for the number of originally single-tagged fish (S) and the number which were resighted (S_R) which vary in increments of 25%; values for D=491, D_1 = 24, D_2 = 35, and C = 11,444 remained constant, and the resulting estimate of N remained approximately constant (≈ 107,000). (Estimates based on 2007 data are in bold font.)

% of S=2,807	M	C.I. (% of N≈107,000)
0%	491	23.9%
25%	1193	18.5%
50%	1895	16.8%
75%	2596	15.9%
100%	**3298**	**15.4%**
125%	4000	15.0%
150%	4702	14.8%
175%	5403	14.6%
200%	6105	14.4%

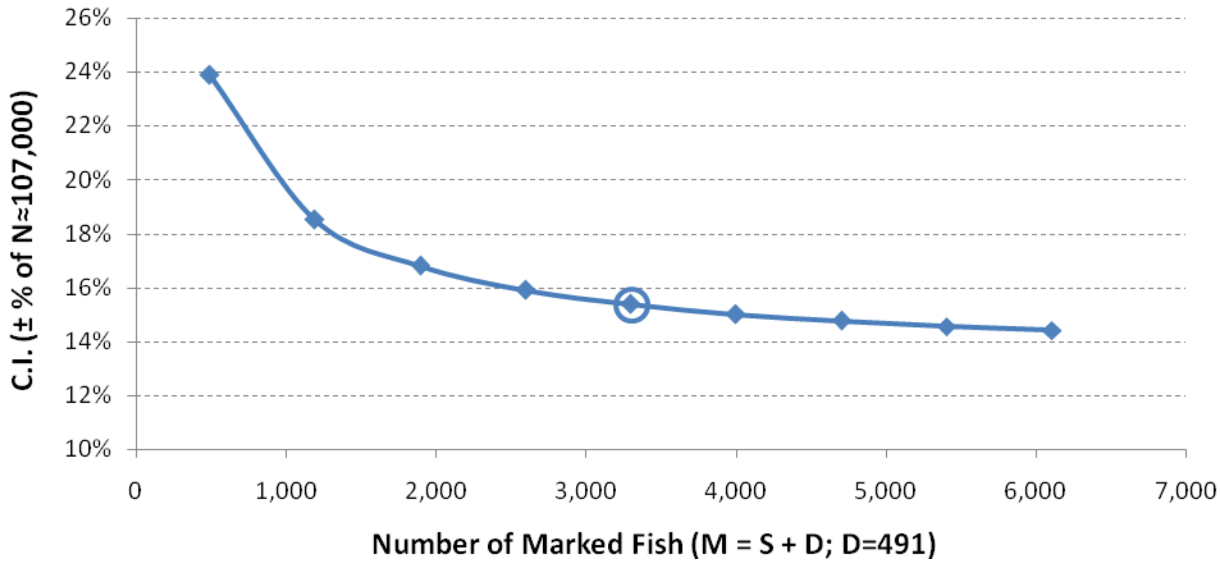

Figure 2. - Change in the confidence interval (C.I.) of the estimate of abundance (N) using the 2007 Mark-Resight data for Metolius River kokanee, with alternative values for the number of originally single-tagged fish (S) and the number which were resighted (S_R) which vary in increments of 25%; values for D=491, D_1 = 24, D_2 = 35, and C = 11,444 remained constant, and the resulting estimate of N remained approximately constant (≈ 107,000). (Estimate from 2007 data is circled.)

Number of double-tagged fish

To illustrate the effect that an increase or decrease in the proportion of double-tagged fish (D) in a Mark-Recapture study would have had, we ran the binomial-hypergeometric likelihood program with values of D which ranged from 0% to 100% of M, while maintaining the total number of marked fish (M = S + D) = 3,298. For each value of D, values for D_1 and D_2 were calculated to remain proportional to the values of 24 and 35 observed in 2007, to maintain the estimated tag loss rate at approximately 25.5%. Values for S_R were estimated using a presumed resight rate of 10.7% - the overall average resight rate for marked fish in 2007. The value for C = 11,444 remained constant, and the resulting estimate of N remained approximately constant (≈ 107,000). These scenarios demonstrate that increasing the proportion of marked fish with double-tags increased the certainty in the estimate of tag loss, resulting in turn in an increase in certainty of the abundance estimate (Table 8 and Figure 4).

Table 7.- Change in the confidence interval (C.I.) of the estimate of abundance (N) for increased proportion of double-tagged fish (D). Values for M = S + D = 3,298 and C = 11,444 remained constant, and values for D1, D2, SR and R were calaculated based on the values for tag loss = 25.5% and resight rate of tagged fish = 10.7% observed in 2007. (Estimates based on 2007 data are in bold font.)

% of D within M (M=3,298)	D	C.I. (% of N≈107,000)
5%	165	24.2%
10%	330	18.5%
15%	**491**	**15.4%**
20%	660	14.2%
30%	989	12.4%
40%	1319	11.5%
50%	1649	10.9%
60%	1979	10.5%
70%	2309	10.2%
80%	2638	10.0%
90%	2968	9.8%
100%	3298	9.7%

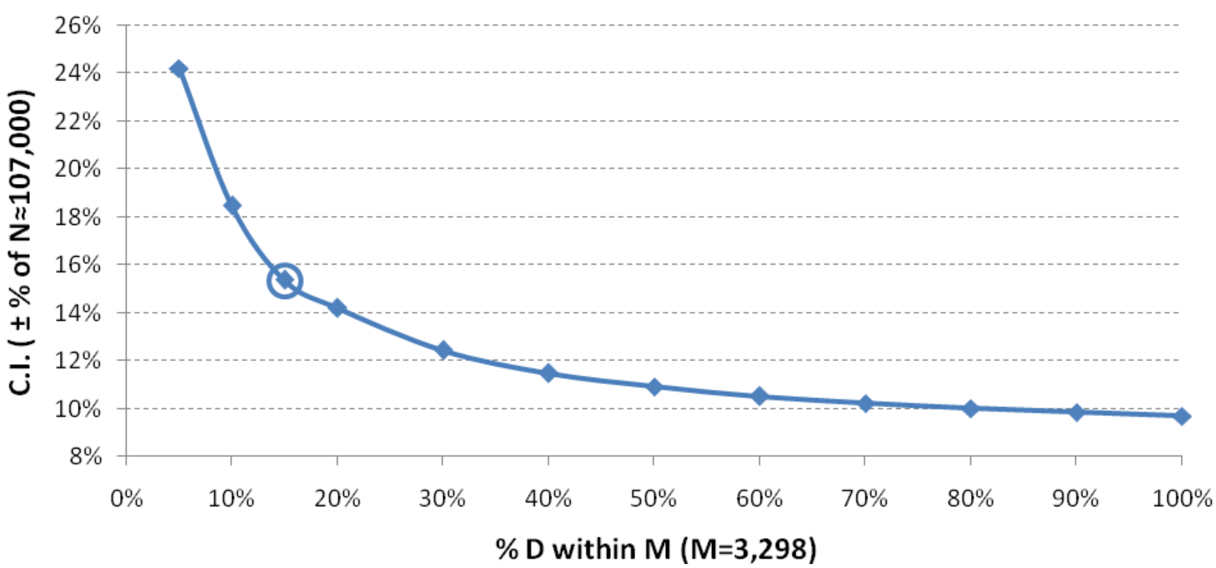

Figure 3.- Change in the confidence interval (C.I.) of the estimate of abundance (N) for increased proportion of double-tagged fish (D). Values for M = S + D = 3,298 and C = 11,444 remained constant, and values for D1, D2, SR and R were calaculated based on the values for tag loss = 25.5% and resight rate of tagged fish = 10.7% observed in 2007. (Estimate from 2007 data is circled.)

Change in survey effort

The greater the survey effort in a Mark-Recapture study, the larger will be the number of fish which are (re)sighted (C) and the more certain will be the estimate of N, though this increase in certainty occurs at a diminishing rate. To illustrate this effect of an increase or decrease in survey effort, we ran the binomial-hypergeometric likelihood program with values of D_1, D_2, R and C from the 2007 Metolius River kokanee data set, which vary in 25% intervals (Table 6 and Figure 2). The value for M = 3,298 remained constant, and the resulting estimate of N remained approximately constant (N ≈ 107,000).

Table 8.- Change in the confidence interval (C.I.) of the estimate of abundance (N) with change in the number of fish observed during the spawning surveys (C), based on the 2007 Mark-Resight data for Metolius River kokanee which varied in 25% intervals (M = 3,298, and N ≈ 107,000). (Estimates based on 2007 data are in bold font.)

% of C=11,444	C	C.I. (% of N≈107,000)
25%	2861	31.1%
50%	5722	21.8%
75%	8583	18.0%
100%	**11444**	**15.4%**
125%	14305	13.6%
150%	17166	12.3%
175%	20027	11.4%
200%	22888	10.5%
225%	25749	9.8%
250%	28610	9.2%

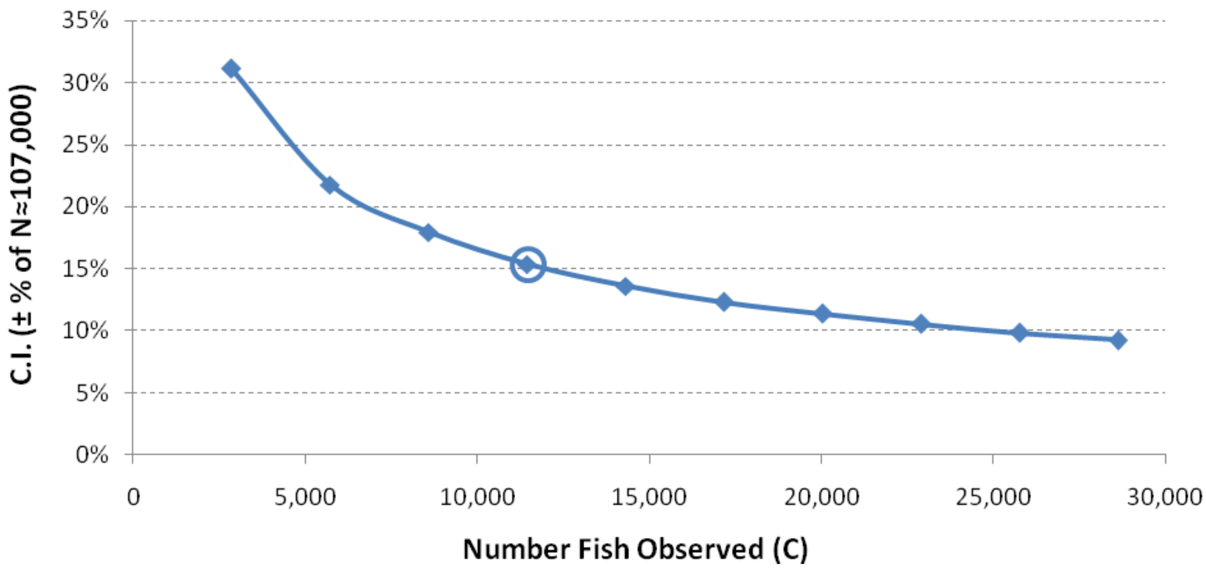

Figure 4.- Change in the confidence interval (C.I.) of the estimate of abundance (N) with change in the number of fish observed during the spawning surveys (C), based on the 2007 Mark-Resight data for Metolius River kokanee which varied in 25% intervals (M = 3,298, and N ≈ 107,000). (Estimate from 2007 data is circled.)

Discussion

Tag loss and abundance estimation

Use of the binomial-hypergeometric likelihood estimator to analyze the Mark-Resight data collected in 2007 on the Metolius River kokanee yielded an escapement estimate of 106,630 ± 16,393 (± 15.4%). The point estimate was close to that of 101,854 ± 11,151 (± 10.9%) reported by Lovtang et al. (2008), which was based on an assumed tag loss rate of 25% - a rate similar to that estimated from 2007 resight data for double-tagged kokanee - 25.6% ± 9.9%. However, the former estimate was derived from an unrelated study of migrating spring Chinook salmon adults in the Rogue River (a coastal river located in Jackson County, Oregon) and it was applied with no associated error. Incorporation of the uncertainty associated with tag loss rate (based on resight data for double-tagged fish in 2007) into the estimation for abundance, resulted in the confidence interval for this estimate increasing to 15.4% - a more realistic approximation of the uncertainty associated with the escapement estimate. The effect of inclusion of the additional uncertainty associated with tag loss, for a range of tag loss rates, is illustrated in Table 5 and Figure 1. The C.I. of the abundance estimate begins at approximately 10% for 0% tag loss - representing the uncertainty derived solely from the hypergeometric likelihood estimation of N - and increases steadily as tag loss increases.

Tag loss has been described as being of two types, I and II (Wetherall 1982). Type I tag loss is that which occurs immediately following tagging and release. The magnitude of this form of tag loss is largely associated with the tagging protocol and the skill level of the biologists/technicians to properly anchor the tag within the fish. A poorly applied tag will often quickly fall out and Type I tag loss will be high. Type II tag loss involves the progressive loss or removal of tags over time, and is largely associated with fish behaviors and other factors outside of management control – abrasion, aggressive behaviors (e.g., during spawning), water flow, flesh degradation (if tags are recovered from carcasses), etc.

In 2007, a test for Type I tag loss was conducted by holding 100 tagged fish in a floating net-pen for a period of 24 hours following tagging. Tag retention was 100% (Lovtang et al. 2008), indicating that the tagging protocols and skill level of the tagging personnel in 2007 were apparently good. The 25.6% tag loss rate observed in 2007 was therefore principally associated with Type II tag loss. While a tag loss rate of 25.6% is disappointingly high, this may simply be a rate which is inherent to the ability of kokanee to retain a Floy® anchor tag. Alternative tags with higher retention rates might be considered for future studies. However, the anchor tags have the advantage of being easily and rapidly applied, and in comparative studies with other tag types on live fish in a stream, anchor tags demonstrated the highest relative retention rates (Rawstron 1973, McAllister et al. 1992).

Study design effects and modifications to the study design

Various scenarios were run using the binomial-hypergeometric likelihood model, to project how modification of the tagging and/or survey effort in the Metolius kokanee Mark-Resight study would have affected certainty of the resulting abundance estimate. On the basis of these illustrations, we suggest modifications to the study design which may improve accuracy and/or precision, and at the same time economize labor involved in the tagging and surveying effort.

Tagging effort

The cost for tagging fish in a Mark-Recapture study primarily involves labor. In the 2007 Metolius kokanee study, tagging of approximately 1,000 fish was performed on 3 different days, each day involving approximately 7 persons (8 persons on day #1 when approximately half of the fish were double-tagged). As illustrated in Table 6 and Figure 2, increasing or decreasing the number of tagged fish results in an increase or decrease in the certainty of the abundance estimate. Had the total number of tagged fish been doubled, the confidence interval of the abundance estimate would have been reduced slightly, from 15.4% to 14.4 %, although this modest gain in certainty would have come at the cost of an additional 21 person-days of work. Halving the number of tagged fish would have reduced costs by 10.5 person-days, but increased the C.I. of the abundance estimate from 15.4% to 16.8%.

In contrast to the limited effects of a substantial change in the number of tagged fish, a change in the proportion of marked fish which were double-tagged would have had a relatively dramatic change in certainty of the abundance estimate. As illustrated in Table 7 and Figure 3, a doubling of the proportion of double-tagged fish from 15% n=491) to 30% (n=982), or a tripling to 45% (n=1473), would have reduced the C.I. of the abundance estimate from 15.4% to 12.4%, or to 11.3%, respectively. Importantly, this increase in certainty comes at a very modest increase in effort. The cost for marking fish lies primarily in the labor required to capture the fish and to apply a single tag to each, with the additional cost to apply a second tag being small. To double-tag approximately half of the 1,000 fish tagged per day, as was performed on tagging day #1 in 2007, the additional labor cost would be approximately one person-day. The beneficial reduction in the C.I. of the abundance estimate from a doubling or tripling the number of double-tagged fish could therefore have been achieved at the cost of only one or two additional person-days of work, respectively.

Survey effort

In addition to examining the effects of changing the numbers of single and double-tagged fish in the Mark-Resight study, we also studied the effects of changes in survey effort on the certainty of the abundance estimate. There were large differences in total number of fish observed among survey sections and among survey weeks in 2007. However, the ANOVA of the Mark-Resight data indicated that neither section nor week demonstrated a significant effect on the proportion of resighted tagged fish among the fish observed. This presents the possibility that one could prioritize the river sections and/or time periods to be surveyed where/when the number of observed fish is anticipated to be highest. This would maximize the number of observations per unit effort and minimize the uncertainty of the resulting abundance estimate for a given amount of survey effort (Table 8 and Figure 4).

As for tagging, the cost of performing the spawning ground surveys is principally associated with labor – approximately 2 person-days per survey in Sections #1, #2, #3 and #5. Section #4 is more extensive and two days of survey effort are required (total = 4 person-days). Therefore, a complete survey of all five sections requires a total of 12 person-days.

The numbers of fish observed in the complete surveys conducted in weeks #1, #2 and #3 in 2007 were 3,742, 6,732 and 970, respectively (Table 3). The third survey week yielded only 8% of the total number of fish observed– representing a relatively high cost for little additional information. As illustrated in Figure 4, if the third survey week had not been performed, (i.e., C = 3,742 + 6,732 = 10,474) uncertainty of the abundance estimate would have increased only slightly (a change in the C.I. of only 0.6% - from 15.4% to 16.1%), but would have provided a savings of 12 person-days in labor costs. Had the survey effort been restricted to a single complete survey, e.g., the survey conducted in Week #2 (C = 6,732), the C.I. for the abundance estimate would have increased to 20.1%, though for a savings of 24 person-days in labor costs.

Large differences were also observed in the number of fish counted among the survey sections, with Sections #3 and #4 having provided approximately 70% of the total count. Prioritizing surveys of these two sections would yield the greatest amount of data for the least cost. However, the researchers also expressed the desire that all sections be observed at least once - in order to obtain a quantified assessment of the relative spawning distribution within the river. As such, an option for future studies would be to perform a complete survey involving all five sections during the peak of the run in early October (e.g., Survey Week #2), and surveys of Sections #3 and #4 both one week prior and one week following the complete survey (e.g., Survey Weeks #1 and #3, respectively). Under this scenario, C would have been 9,811 in 2007, and the C.I. for the abundance estimate would have increased from 15.4% to 16.8%, but for a savings of 12 person-days in labor costs

Recommended changes to tagging and survey effort

Based on the above scenarios, and on the desire expressed by the researchers that surveying be conducted across all sections to assess spawning distribution, we examined the effect on uncertainty of the abundance estimate for a protocol which increased the proportion of double-tagged fish and reduced the survey effort. In this scenario, we presumed a similar number fish were marked (M = 3,298), but tripled the number of these fish which were double-tagged (D = 1,473; therefore S = 1,825), and we presumed that two complete surveys were conducted, yielding a total of 10,474 observations (the total observed during surveys #1 and #2). The value for S^{actual} was estimated based on a tag loss rate of 25.5% and new values for the numbers of resighted single (S_R) and double-tagged (D_R) fish were estimated assuming on a resight rate of 10.7%. Using these modifications, we ran the binomial-hypergeometric likelihood model, which produced an abundance estimate of N ≈ 107,000 with a confidence interval of 11.7%. This gain in certainty of the estimate under this Mark-Resight scenario came with a projected reduction in total labor for tagging and surveying of approximately 10 person-days (58 person-days in 2007 versus 48 person-days in the modified protocol).

Summary

We present here a binomial-hypergeometric likelihood model for estimating abundance and variance using data from a Mark-Recapture/Resight study. The model integrates recapture/resight data for double-tagged fish to provide estimates of both tag loss and its variance, which are then incorporated into the estimation procedure to calculate population abundance and its variance (http://www.critfc.org/tech/08-07report.html). The novel aspect of this model is that estimation and inclusion of the uncertainty associated with tag loss provides a more realistic assessment of the uncertainty in the abundance estimate. Using this program with the data obtained from the Mark-Resight study of Metolius River kokanee in 2007, we obtained estimates of 25.6% ± 9.9% for tag loss, and of 106,630 ± 16,393 (± 15.4% of N) for the spawning escapement.

After performing several scenarios based on the Metolius data, we propose that the protocol followed in future studies involve tagging a similar number of fish (M ≈ 3,298), that the proportion of tagged fish which are double-tagged fish be substantially increased (e.g., tripled), and that the number of complete surveys be reduced from three to two, conducted approximately a week apart near the peak of the run (e.g., survey week #1 and #2). Had this protocol been followed in 2007, the abundance estimate of N ≈ 107,000 would have had greater certainty – the confidence interval would have been reduced to ±11.7%, and total labor costs for tagging and surveying would have been reduced by approximately 17% (10 person-days).

ACKNOWLEDGEMENTS

We gratefully acknowledge the cooperation of Jens Lovtang with the Confederated Tribes of the Warm Springs Reservation of Oregon, Megan Hill with Portland General Electric, and Brett Hodgson and Richard Stocking with the Oregon Department of Fish and Wildlife, who provided us the opportunity to participate in the Mark-Resight project and who shared the data obtained in this project. We also acknowledge funding from PCSRF Project "Enumeration of Kokanee Salmon Escapement into the Metolius River", Project No. 2007-5-02, which supported our involvement in this study.

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