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Analyses for Effect of Survey Week and Reach in Mark-Recapture Studies of Metolius River Kokanee *Oncorhynchus nerka*

Peter F. Galbreath
and Saang-Yoon Hyun

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Columbia River Inter-Tribal Fish Commission
700 NE Multnomah, Suite 1200
Portland, OR 97232
503.238.0667
www.critfc.org

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Peter F. Galbreath

Columbia River Inter-Tribal Fish Commission

727 NE Oregon, Suite 200

Portland OR 97232

Saang-Yoon Hyun

School for Marine Science and Technology

University of Massachusetts at Dartmouth

200 Mill Road, Suite 325

Fairhaven MA, 02719

December 18, 2013

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Abstract. – Mark-recapture/resight procedures are used to estimate the annual spawning escapement of Kokanee *Oncorhynchus nerka* migrating from Lake Billy Chinook into the Metolius River, Jefferson County, Oregon. A sample of pre-spawning adults are marked with one or two plastic anchor tags, and several weeks later the fish are (re)sighted during three successive spawning ground surveys of the Metolius River, spaced two weeks apart. The spawning area is subdivided into multiple reaches, and a survey consists of a single pass through each. Data for the number of fish observed, and the number that possessed one or two tags, are summed across survey reaches and week. Initially the summary data were entered into standard Petersen estimators to derive population abundance. Recently, a likelihood model (MRmix; Hyun et al. 2012) has been used. Both analytical approaches assume that recapture/resighting is a single event, involving a random sampling of the population. Summing of the data across reaches and survey weeks assumes that neither time of the survey (week) nor location (reach) has a significant effect on the proportion of resighted tagged fish among the fish observed. To test the validity of this assumption, two-way ANOVAs were performed on the data for 2007 to 2012. A significant effect of reach was never observed. A significant effect of survey week was detected in two of the six years, and an effect was nearly significant ($p>0.05$ but <0.10) in two additional years. Average percent of marked fish in these four years tended to decline from the first to third week, inferring that loss of tags continued over the period of the spawning surveys. Nonetheless, a resulting bias in the point estimate of population abundance is likely small and within the confidence limits for the estimate based on the pooled data. In our judgment, it remains reasonable to continue to sum the data across survey weeks and reaches for the purposes of estimating abundance of Metolius River Kokanee.

Introduction

Lake Billy Chinook in Jefferson County, Oregon, is a reservoir lake created by the Round Butte dam. The lake contains an adfluvial population of Kokanee *Oncorhynchus nerka* which supports an important sport fishery (Figure 1). 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 over time is needed for informed management of this fishery.

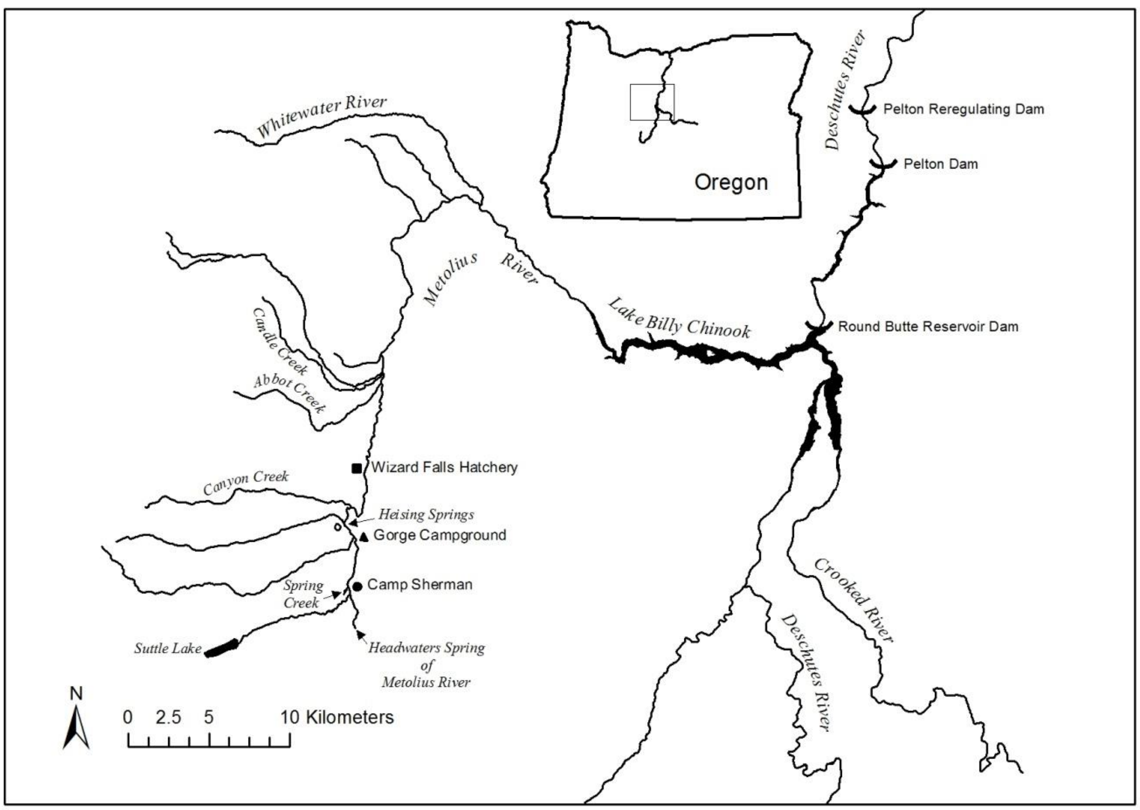

Figure 1. – Map of Lake Billy Chinook and the Metolius River, Jefferson County, Oregon.

From 1997 to 2000 and from 2006 to present, these agencies have collaborated on an annual mark-recapture study to estimate abundance of the spawning population, following the same

basic protocol. In August through early September each year, mature adult Kokanee migrate to the upper arm of the reservoir near its confluence with the Metolius River in anticipation of their spawning run (Figure 1). Beach seining at this time and location is performed to capture a sample of the Kokanee. One or two plastic anchor tags are inserted into each, and the fish are released back into the lake. Beginning in late September and extending through October, the Kokanee migrate up the Metolious River for spawning. The primary spawning areas are within the mainstem near the headwaters, and in adjacent tributary streams and springs. During this period, three separate spawning ground surveys are conducted, spaced two weeks apart. The spawning area is sub-divided into 5 to 7 different reaches, and each reach is surveyed once within a 3-4 day period per survey week. Each reach is walked (or floated in a kayak where the water is too deep for walking) in a downstream direction by 2 to 3 observers. The total number of Kokanee observed is noted, including the number that possessed a tag(s), and the tag color. (Lovtang et al. 2008; Gauvin et al. 2009, 2010 and 2012; Hogle et al. 2011 and 2013).

After the three surveys are completed, the data for the number of fish observed, and for the number of tagged fish, are summed across reaches and weeks. Between the times of tagging and resighting, some tags are shed by the fish. Initially, only single-tagging was performed and a presumed rate for tag loss of 25% (Smith et al. 1978) was used to readjust the value of the number of initially tagged fish prior to estimation of spawner abundance. Beginning in 2007, a portion of the tagged kokanee received two tags and the proportion of these fish observed during the surveys that retained both or only a single tag was used to obtain a direct estimate of tag loss. This observed estimate of tag loss was then used to readjust the number of initially tagged fish. The summary data were then entered into standard Petersen estimators (Seber 1973) to estimate population abundance ($\widehat{N}$):

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

and its variance (Var), which was used to calculate a 95% confidence interval (C.I.) for $\hat{N}$:

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

where M is the number of single-tagged fish (corrected for tag loss), C is the total number of fish observed in the spawning ground surveys, R is the number of resighted tagged fish.

More recently, the data have been entered into a likelihood model (MRmix) developed by Hyun et al. (2012), and now available online at: http://www.critfc.org/fish-and-watersheds/fishery-science/data-resources-for-scientists/mrmix-2/. Using data for both single and double tagged fish, the MRmix model estimates both tag loss rate and its variance, and simultaneously incorporates these values for estimation of $\hat{N}$ and Var($\hat{N}$). The advantages of MRmix are twofold. First, the model allows for the possibility of loss of both tags from a double-tagged individual; traditional methods (e.g., Gulland 1963, Seber and Felton 1981, Seber 1982) presumed loss of only one of the two tags. Second, the model accommodates data that includes a mixture of single-tagged and double-tagged individuals within a mark-recapture experiment. Abundance estimates provided by the MRmix model are therefore more robust than those obtained with the Petersen estimators (Hyun et al. 2012).

However, both procedures presume that recapture/resighting during the surveys is a single event involving a random sampling of the population, and that neither time of the survey (week) nor survey location (reach) has a significant effect on the proportion of resighted tagged fish among the fish observed. That is, that tag loss occurs relatively shortly after tagging (and prior to the surveys) such that the proportion of tagged fish remains constant across the three surveys, and that tagged and untagged fish are distributed randomly such that their ratio is similar across reaches. To test validity of these assumptions, two-way analyses of variance (ANOVAs) were performed on data for surveys conducted from 2007 to 2012 (Table 1).

Methods and Results

Data for the total number of fish observed and the number which possessed a tag (the sum of all single and double tagged fish), are provided in Table 1 for each survey week and reach, for the surveys conducted in 2007 through 2012, along with results of two-way ANOVAs to test for significant effects of week and reach ($p<0.05$) in each year.

Of note, two ANOVAs were conducted for the 2010 data, the first with data from all three survey weeks and the second for weeks #1 and #2 only. While data for weeks #1 and #2 were similar in pattern to that observed in other years, data for week #3 in 2010 appeared anomalous. In Reaches #1-#5, which comprise the principal spawning area located in the headwater region of the Metolius (above rkm 26; Figure 1), a total of only 58 fish were observed in week #3, inferring that spawning was already essentially complete. However in reach #6, which includes the lower portion of the Whitewater River, a tributary to the Metolius well downstream of the other reaches at rkm 10 (Figure 1), a large number of fish (n=1755, 18% of the total across the 3 surveys) were observed. A similar pattern for a high number of observations in the Whitewater relative to the upstream reaches was not observed in the third survey in other years. Therefore, a second ANOVA using data from weeks #1 and #2 only was conducted, whose results were the ones used in comparisons to those from the other years.

Across the six years of data, a significant effect of survey reach was never observed ($P>0.05$). In contrast, an effect of survey week was significant ($p<0.05$) in two years (2009 and 2012), and this effect was nearly significant ($P>0.05$ but <0.10) in two other years (2008 and 2011).

Discussion

The lack of an effect for survey reach was expected. There is no obvious reason that tagged fish would preferentially migrate to one spawning area versus another, relative to untagged fish. On the other hand, the (near) significant effects for survey week in four of the six years likely

indicate that tag loss is not necessarily complete prior to the initiation of the surveys. Indeed, resight rates show a numerical decline from the first to the third survey within these four years. However, as it is the middle (second) survey in which the largest number of fish are generally observed, a bias to the abundance estimate associated with an increase in tag loss over time is likely well within the confidence limits for abundance estimated for the data pooled across weeks. We conclude that summing data for reaches and weeks across the three surveys for the purpose of estimating tag loss and population abundance of Metolius River Kokanee remains reasonable.

Acknowledgments

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Table 1. Mark-Resight data for Metoloius River Kokanee for 2007 through 2012, with output from analyses of variance (ANOVAs) for testing effects of spawning survey week and reach on resight rate (R/C), where C represents that total number of fish observed, and R the number that possessed a tag(s).

2007

Week	Reach	C	R	%R
1	1	472	6	1.3%
1	2	510	14	2.7%
1	3	660	8	1.2%
1	4	1744	45	2.6%
1	5	356	13	3.7%
2	1	940	21	2.2%
2	2	453	5	1.1%
2	3	3344	89	2.7%
2	4	1497	40	2.7%
2	5	498	13	2.6%
3	1	123	1	0.8%
3	2	24	1	4.2%
3	3	561	14	2.5%
3	4	114	3	2.6%
3	5	148	4	2.7%
		11444	277	

Week	C	R	%R
1	3742	86	2.3%
2	6732	168	2.5%
3	970	23	2.4%

Reach	C	R	%R	
1	1535	28	1.8%	Headwaters to Camp Sherman/Spring Creek
2	987	20	2.0%	Camp Sherman Bridge to Gorge Campground
3	4565	111	2.4%	Gorge Campground to Canyon Creek
4	3355	88	2.6%	Canyon Creek to Candle Creek
5	1002	30	3.0%	Whitewater R

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Week	2	0.0000279	0.0000140	0.151	0.862
Reach	4	0.0004401	0.0001100	1.190	0.385
Residuals	8	0.0007399	0.0000925		

2008

Week	Reach	C	R	%R
1	1	2813	45	1.6%
1	2	674	23	3.4%
1	3	1665	42	2.5%
1	4	683	68	10.0%
1	5	891	21	2.4%
1	6	913	25	2.7%
2	1	4752	181	3.8%
2	2	945	13	1.4%
2	3	3120	26	0.8%
2	4	641	8	1.2%
2	5	554	18	3.2%
2	6	877	14	1.6%
3	1	525	3	0.6%
3	2	130	1	0.8%
3	3	3037	26	0.9%
3	4	478	7	1.5%
3	5	909	6	0.7%
3	6	1548	9	0.6%
		25155	536	

Week	C	R	%R
1	7639	224	2.9%
2	10889	260	2.4%
3	6627	52	0.8%

Reach	C	R	%R	
1	8090	229	2.8%	Headwaters to Camp Sherman/Spring Creek
2	1749	37	2.1%	Camp Sherman to Gorge Campground
3	7822	94	1.2%	Heising Springs to Canyon Creek
4	1802	83	4.6%	Wizard Falls Bridge to Candle Creek Campground
5	2354	45	1.9%	mainstem Metolius
6	3338	48	1.4%	Abbot/Candle/Jefferson Creeks

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Week	2	0.0026354	0.0013177	3.299	0.079
Reach	5	0.0015650	0.0003130	0.784	0.584
Residuals	10	0.0039946	0.0003995		

2009

Week	Reach	C	R	%R
1	1	177	3	1.7%
1	2	na	na	na
1	3	40	3	7.5%
1	4	na	na	na
1	5	64	1	1.6%
1	6	499	6	1.2%
2	1	4430	41	0.9%
2	2	913	11	1.2%
2	3	2465	25	1.0%
2	4	1051	7	0.7%
2	5	1152	18	1.6%
2	6	668	8	1.2%
3	1	4576	27	0.6%
3	2	1206	7	0.6%
3	3	2716	16	0.6%
3	4	495	3	0.6%
3	5	1622	9	0.6%
3	6	2088	10	0.5%
		24162	195	

Week	C	R	%R	
1	780	13	1.7%	2 reaches not surveyed
2	10679	110	1.0%	
3	12703	72	0.6%	

Reach	C	R	%R	
1	9183	71	0.8%	Headwaters to Camp Sherman/Spring Creek
2	2119	18	0.8%	* Camp Sherman to Gorge
3	5221	44	0.8%	Heising Springs - Canyon Creek
4	1546	10	0.6%	* (Float) Wizard Falls - Bridge 99
5	2838	28	1.0%	Abbot/Candle/Jefferson Creeks
6	3255	24	0.7%	Whitewater
				* not surveyed Week #1

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Week	1	0.0000838	0.0000838	15.451	0.011	*
Reach	5	0.0000200	0.0000040	0.737	0.627	
Residuals	5	0.0000271	0.0000054			

2010

Week	Reach	C	R	%R
1	1	1292	28	2.2%
1	2	771	11	1.4%
1	3	165	5	3.0%
1	4	583	14	2.4%
1	5	41	1	2.4%
1	6	551	17	3.1%
1	7	654	8	1.2%
2	1	765	8	1.0%
2	2	493	11	2.2%
2	3	305	5	1.6%
2	4	715	15	2.1%
2	5	52	1	1.9%
2	6	844	15	1.8%
2	7	505	7	1.4%
3	1	4	0	0.0%
3	2	2	0	0.0%
3	3	1	0	0.0%
3	4	7	0	0.0%
3	5	na	na	na
3	6	44	0	0.0%
3	7	1755	23	1.3%
		9549	169	

Week	C	R	%R
1	4057	84	2.1%
2	3679	62	1.7%
3	1813	23	1.3%

Reach	C	R	%R	
1	2061	36	1.7%	Headwaters to Camp Sherman
2	1266	22	1.7%	Spring Creek
3	471	10	2.1%	Camp Sherman to Gorge
4	1305	29	2.2%	(Float) Wizard Falls - Bridge 99
5	93	2	2.2%	* Heising Springs - Canyon Crk
6	1439	32	2.2%	Abbott Creek
7	2914	38	1.3%	Whitewater
				* not surveyed Week #3

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Week	2	0.0014160	0.0007080	16.289	0.000515	***
Reach	6	0.0000775	0.0000129	0.297	0.926	
Residuals	11	0.0004781	0.0000435			

(Weeks 1 and 2 only)

Reach	C	R	%R	
1	2057	36	1.8%	Headwaters to Camp Sherman
2	1264	22	1.7%	Spring Creek
3	470	10	2.1%	Camp Sherman to Gorge
4	1298	29	2.2%	(Float) Wizard Falls - Bridge 99
5	93	2	2.2%	Heising Springs - Canyon Crk
6	1395	32	2.3%	Abbott Creek
7	1159	15	1.3%	Whitewater

ANOVA (Weeks 1 and 2 only)

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Week	1	0.0000963	0.0000963	2.884	0.140
Reach	5	0.0002120	0.0000353	1.058	0.474
Residuals	5	0.0002004	0.0000334		

2011

Week	Reach	C	R	%R
1	1	1526	21	1.4%
1	2	506	9	1.8%
1	3	376	13	3.5%
1	4	465	12	2.6%
1	5	395	14	3.5%
1	6	720	43	6.0%
2	1	303	9	3.0%
2	2	171	6	3.5%
2	3	121	2	1.7%
2	4	1271	32	2.5%
2	5	451	17	3.8%
2	6	1704	44	2.6%
3	1	7	0	0.0%
3	2	44	0	0.0%
3	3	11	0	0.0%
3	4	205	6	2.9%
3	5	80	2	2.5%
3	6	107	3	2.8%
		8463	233	

Week	C	R	%R
1	3988	112	2.8%
2	4021	110	2.7%
3	454	11	2.4%

Reach	C	R	%R	
1	1836	30	1.6%	Headwaters to Camp Sherman
2	721	15	2.1%	Spring Creek
3	508	15	3.0%	Camp Sherman to Gorge
4	1941	50	2.6%	Heising Springs to Canyon Creek
5	926	33	3.6%	Abbott Creek
6	2531	90	3.6%	Whitewater

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Week	2	0.0010536	0.0005268	3.703	0.063
Reach	5	0.0013626	0.0002725	1.915	0.179
Residuals	10	0.0014228	0.0001423		

2012

Week	Reach	C	R	%R
1	1	860	25	2.9%
1	2	702	26	3.7%
1	3	1111	32	2.9%
1	4	843	22	2.6%
1	5	658	22	3.3%
1	6	1767	36	2.0%
2	1	2944	58	2.0%
2	2	1023	34	3.3%
2	3	1070	29	2.7%
2	4	2423	55	2.3%
2	5	802	25	3.1%
2	6	2150	35	1.6%
3	1	178	4	2.2%
3	2	193	1	0.5%
3	3	201	3	1.5%
3	4	616	7	1.1%
3	5	219	8	3.7%
3	6	207	1	0.5%
		17967	423	

Week	C	R	%R
1	5941	163	2.7%
2	10412	236	2.3%
3	1614	24	1.5%

Reach	C	R	%R	
1	3982	87	2.2%	Headwaters to Camp Sherman
2	1918	61	3.2%	Spring Creek
3	2382	64	2.7%	Camp Sherman to Gorge Campground
4	3882	84	2.2%	Heising Springs to Canyon Creek
5	1679	55	3.3%	Abbott Creek
6	4124	72	1.7%	Whitewater

ANOVA

Source of Variation	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Week	2	0.0005523	0.0002761	5.785	0.021	*
Reach	5	0.0006372	0.0001274	2.670	0.087	
Residuals	10	0.0004774	0.0000477			