Duncan Dam Project Water Use Plan

Lower Duncan River Kokanee Spawning Monitoring

Implementation Year: 8

Reference: DDMMON-4

Study Period: September – October 2015

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EXECUTIVE SUMMARY

The Duncan Dam (DDM) Water Use Planning (WUP) process was initiated to address flow management issues related to local resources such as Lower Duncan River (LDR) Kokanee populations. Monitoring of the abundance of Kokanee spawning in this area was initiated by BC Hydro in 2008 as part of its Water License Requirements (WLR) DDMMON#4 program. Year 2015 represented the eighth year of this ten year monitoring program and as in the previous seven years, Kokanee aerial spawner counts were carried out from a helicopter. In addition to aerial counts, features of the preferred spawning habitats and observer efficiency verification were carried out on the ground during stream walks. Year 8 represents the continuation of the work carried out by ONA and LGL in 2013 and 2014 (Zimmer et al. 2015, 2016) and previous to that by AMEC from 2008–2012 (AMEC 2009, AMEC 2010, AMEC 2011, AMEC 2012, AMEC 2013). Methods have been standardized for the duration of this monitoring program to ensure comparability between years. None of the changes made in 2015 affected the comparability of 2015 results with results obtained in previous years.

Based on an Area Under the Curve (AUC) calculation, the 2015 Kokanee spawning population in the Lower Duncan River was estimated to be 8620 fish, with a lower 95% Confidence Interval (CI) of 560 fish and an upper 95% CI of 55990 fish. In comparison to previous years, the 2015 estimate is the lowest on record at about half the previously lowest estimate of 14750 in 2013 (Lower CI = 1680; Upper CI = 53920) and about 12% of the highest estimate of 69950 in 2012 (Lower CI = 37630; Upper CI = 126350). Similarly, the lowest peak count on record for Meadow Creek spawning channel of 7653 fish was counted in 2015.

Specific management questions defined in the DDMMON#4 Terms of Reference (TOR) and the progress made in addressing them in 2015 is summarized in Table 1.

Table 1 Management questions and the status of the answers to them based on field work and data analysis carried out as part of the BC Hydro project DDMMON-4 from 2008-2015.

Management Question	Status
What is the spawn run timing, fry emergence timing, and relative intensity of Kokanee spawning in the Lower Duncan River? What potential operational/environmental cues affect this variable?	Spawn Run Timing: Based on AMEC (2013) and ONA and LGL (2015), between 2008 and 2013 Kokanee spawned in the LDR from late August to late October and peak spawning occurred from September 20 –October 10. In 2015, the peak of Kokanee spawning activity was estimated for September 27, 2015 within the range of peaks observed from 2008–2014. In the 8 years of study, changes in LDR flow and decreasing seasonal trend in water temperature have not been shown to trigger changes in spawning migration or the distribution pattern of Kokanee spawners in the LDR. Kokanee entered the LDR in increasing and decreasing water temperatures in 2015. Fry Emergence Timing: In general, fry emergence timing is dependent on the Accumulated Thermal Units or ATUs of fish eggs during incubation and early development. Kokanee typically accumulate 900–950 thermal units from spawning to emergence from the gravel (Quinn 2005) and therefore emergence occurs in late when eggs are incubated at an average temperature of 7 °C (based on the LDR Environment Canada

	Hydrometric Station) as typically found in the LDR over the incubation period. Fry emergence in the Lower Duncan River was previously estimated to occur between late December-late January (AMEC and Poisson 2012) Based on observations in AMEC (2013) and ONA and LGL (2015 and 2016), the DDM low level outlets (LLOs) discharge water may be warmer than surface waters in the winter, resulting in emergence timing that is earlier for LDR Kokanee than seen in adjacent systems such as Meadow Creek and Lardeau River. In general, higher winter DDM discharges reservoir elevations result in higher temperatures over incubation. <u>Relative Intensity of Spawning in the LDR in Comparison to Lardeau River and Meadow Creek:</u> For the first time since this project was initiated in 2008, the 2015 values for the percentage of Kokanee counted in Meadow Creek (29%), Lardeau River (39%) and LDR (32%) were all within 10% based on the very low counts in all three segments of the Duncan system. In previous years, Kokanee escapement to Meadow Creek and Lardeau River had always represented >85 (2014) and typically >94% (2008-2013) of the total Duncan system Kokanee run.
What are the timing/cues of Kokanee spawners in Meadow Creek and Lardeau River systems?	<u>Spawn Timing Cues:</u> Kokanee spawning in Meadow Creek occurs from mid-August to late October with peak spawning during the last week of September as in 2015 and in 2011 or the first week of October as in the other six years of the study (AMEC 2013; Zimmer et al. 2015, 2016). In this context, water temperature does not appear to either influence the arrival of Kokanee in the LDR or their spawn timing. In 2015, water release through DDM was kept constant throughout most of the spawning period (October 1 – 21) and therefore neither water temperature nor discharge, fluctuated enough to act as a possible cue for spawn timing or river entry. It is known that Kokanee spawning in the Lardeau River occurs from early September to mid-October but it is unknown which environmental cues trigger river entry or spawning in the Lardeau River (AMEC 2013).
What are the relative distribution of Kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River? What potential operation/ environmental/ physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable?	<u>Kokanee Spawner Distribution in the LDR:</u> As in previous years, Kokanee were observed to spawn in the upper nine kilometers of the study area with main concentrations of redds observed between Kilometers 0.8 and 6.6 (See Appendix A). No redds were observed upstream of Kilometer 0.8 (Duncan Dam discharge channel, upstream end of the study reach), or from Kootenay Lake to Km 8.9 (downstream end of the study reach). Most notable concentrations of spawning Kokanee in 2015 were found around river km 2 and river km 3 within the upper third of the study reach (Reach 3.1 as referenced in the DDM WUP). Side channel use for spawning in 2015 was observed in SC 4.1 and 4.4 during the peak count on October 5 (post flow reduction) and in S.C. 4.4 on October 15 (also post flow reduction) (See Appendix A).

	<u>Kokanee Spawner Distribution Meadow Creek:</u> As specified in the study terms of reference, no additional work with regards to Kokanee spawner distribution in Meadow Creek was carried out past year 4 of the monitoring program. Based on previous studies (AMEC 2013), the majority of spawning occurs in the 3 km of Meadow Creek Spawning Channel (located approximately 4 km upstream of the confluence with the Lower Duncan River) with idealized conditions for Kokanee egg incubation. Areas outside of the spawning channel are mainly used when the spawning channel itself is filled to capacity with Kokanee spawners (AMEC 2013). The bottom substrate of the lower section of Meadow Creek has a high percentage of silt and fewer spawning gravels and is therefore limited in suitability for Kokanee spawning (Quamme 2008). <u>Kokanee Spawner Distribution Lardeau River:</u> As specified in the study terms of reference, no additional work with regards to Kokanee spawner distribution in Lardeau River was carried out past year 4 of the monitoring program. Based on previous studies (AMEC 2013), Kokanee spawning in the Lardeau River has been observed along its whole length with the highest densities found in the upriver side channels. Based on its natural hydrograph, the Lardeau River experiences typical spring flush flows that aid in removing fines (AMEC 2013). As a general comment, genetic analysis of Kokanee spawning in the LDR, Lardeau River and Meadow Creek revealed that Kokanee spawners from the three locations are not genetically different. They are therefore considered to belong to the same Kokanee stock (AMEC 2012, Lemay and Russello 2011).
What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended Kokanee spawning operations?	A primary goal of this study is to evaluate the effectiveness and impacts of the Water Use Plan's kokanee protection flow regime. Several factors are limiting the ability to manipulate flows during the late September – early October period, including operations agreements (Columbia River Treaty and International Joint Commission). In addition, very limited feasibility of physical works to minimize access to side channels affected by the spawning flows (AMEC 2012) has been determined. It is recommended that the DDM Works 4 program *("Action Plan to Minimize Risk of Stranding Spawning Kokanee")* utilize the information gathered in this monitoring program to evaluate alternatives that minimize impacts to the early kokanee spawning run, in consideration of operating agreements (Columbia River Treaty, International Joint Commission) and other Water Use Plan objectives (flood control and recreation). The outcome of this analysis would be used inform future Water Use Plan review processes on opportunities that minimize stranding while accommodating other important water use objectives.

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Okanagan Nation Alliance

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LGL Limited

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TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

APPENDICES

IMPORTANT NOTICE

1.0 INTRODUCTION

The Duncan Dam (DDM) was constructed from 1965 to 1967 for water storage under the Columbia River Treaty (CRT). Since 1967, the Lower Duncan River has been managed as a regulated river and is operated by BC Hydro for flood control purposes. The dam, which is situated 12.4 kilometers upstream of the north end of Kootenay Lake, regulates water levels in the Lower Duncan River (LDR) through daily, seasonal and annual operations (Figure 1) (AMEC 2013). The complexity of up and downstream ecological function, and social and economic interests of the many users of the LDR and Kootenay Lake, poses many challenges for the operation of DDM. Therefore a Water Use Planning, or WUP, consultation process was initiated in 2001 and completed in 2004 to address flow management issues with respect to impacts on competing resources in the area (BC Hydro 2004; AMEC 2013). The DDM WUP Consultative Committee (CC) identified Kokanee (*Oncorhynchus nerka*) spawning success in the LDR as a valuable ecosystem component that could be impacted by DDM operations (BC Hydro 2007).

Therefore, Kokanee escapement into the LDR has been monitored since 2008 as part of the DDMON-4 project. For the initial 5 years form 2008-2012 the Kokanee escapement was assessed by AMEC (AMEC 2009, AMEC 2010, AMEC 2011, AMEC 2012, AMEC 2013) and assessment was continued by ONA in 2013 and 2014 (Zimmer et al. 2015 and Zimmer et al. 2016).

1.1 Objectives

DDMMON-4 is a 10 year project with the following specific objectives. Bolded objectives were addressed in Year 8 (2015) of this study and remaining objectives were addressed from 2008–2014 (AMEC 2009-2013; Zimmer et al. 2015 and Zimmer et al. 2016):

1. **Document the annual Kokanee escapement to the Lower Duncan River**, Lardeau River, Meadow Creek, and Meadow Creek Spawning Channel;
2. **Document Kokanee spawning in the Lower Duncan River within and outside of operational constraints**; and;
3. Define Kokanee spawning habitat preferences, timing and Kokanee morphology between spawning runs in the Lower Duncan River, Lardeau River and Meadow Creek for consideration of future decisions.

DDMMON-4 responds to the following management questions based on the terms of reference (BC Hydro 2008) and scope of services (BC Hydro 2013). Bolded management questions were addressed in Year 8 (2015) or this study and remaining management questions were addressed from 2008–2012 (AMEC 2009-2013; Zimmer et al. 2015 and Zimmer et al. 2016):

1. **What is the spawn run timing**, fry emergence timing, and relative intensity of **Kokanee spawning in the Lower Duncan River**? What potential operational/environmental cues affect this variable?
2. What are the timing/cues of Kokanee spawners in Meadow Creek and Lardeau River systems?
3. **What are the relative distribution of Kokanee spawners in the Lower Duncan River**, Meadow Creek and Lardeau River? What potential operation/environmental/physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable?; and
4. What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended Kokanee spawning operations?

1.2 Purpose

Seven years of monitoring have been completed (AMEC 2009-2013; Zimmer et al. 2015, 2016) prior to 2015, with 2years remaining in the 10 year DDMMON-4 monitoring program. The purpose of this monitoring program is to evaluate the effectiveness and impacts of operational constraints defined in the DDM WUP. This report fulfills the ONA and LGL commitment to provide BC Hydro with a data report for the 2015 (Year 8) monitoring of Kokanee spawning in the LDR.

2.0 METHODS

2.1 Study Area

The LDR is fed by DDM at its upstream end and flows over a distance of approximately 12.4 km into the northern end of Kootenay Lake, which is located north of Nelson in southeastern British Columbia. The Duncan River watershed above DDM receives input from the Selkirk and Purcell mountains. The 2015 study covered the entire 12.4 km of LDR from DDM (River Km 0.0) to Kootenay Lake (Km 12.4) and its side channels (Figure 1).

2.2 Environmental Parameters

Since discharge was a factor that needed to be related to Kokanee spawning onset, abundance, distribution and potential desiccation of eggs, hourly discharge through DDM and water temperature records for LDR were obtained from the Water Survey of Canada (WSC) gauge (No: 08NH118) (https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08NH118)

2.3 Sample Timing

A summary of Kokanee spawning monitoring dates and methods for 2015 is summarized in Table 2. Sampling methods included visual Kokanee counts from a helicopter and simultaneous aerial redd mapping. During two of the aerial overflights, stream walks were carried out on selected side-channels to assess observer efficiency for the helicopter counts. The selected side-channels had low and clear water and were un-shaded and thus offered optimum fish viewing conditions from the ground and air. During the stream walks, counters also verified their counts through independent surveys of each section. Corrected stream counts were used to determine helicopter observer efficiency.

During aerial counts, the helicopter flew at a low altitude of 20–40 m above the river (AMEC 2012) at a low speed. Therefore all aerial surveys conformed with low level, low speed flight planning requirements of BC Hydro. Data collection methods for each type of survey are provided below.

Table 2 Sample timing, survey conditions and survey type for DDMMON-4 Lower Duncan River Kokanee spawner monitoring, 2015.

Survey Date and Crew	Survey Conditions	Water Clarity	Survey Type	Helicopter Type
September 15	Sunny-cloudy	High (> 1 m)	Aerial	Twin Engine, BO105LS
September 28	Sunny-clear	High (> 1 m)	Aerial and Stream Walk	Twin Engine, BO105LS
October 5	Sunny-clear	High (> 1 m)	Aerial and Stream Walk	Twin Engine, BO105LS
October 15	Sunny-clear	High (> 1 m)	Aerial	Twin Engine, BO105LS

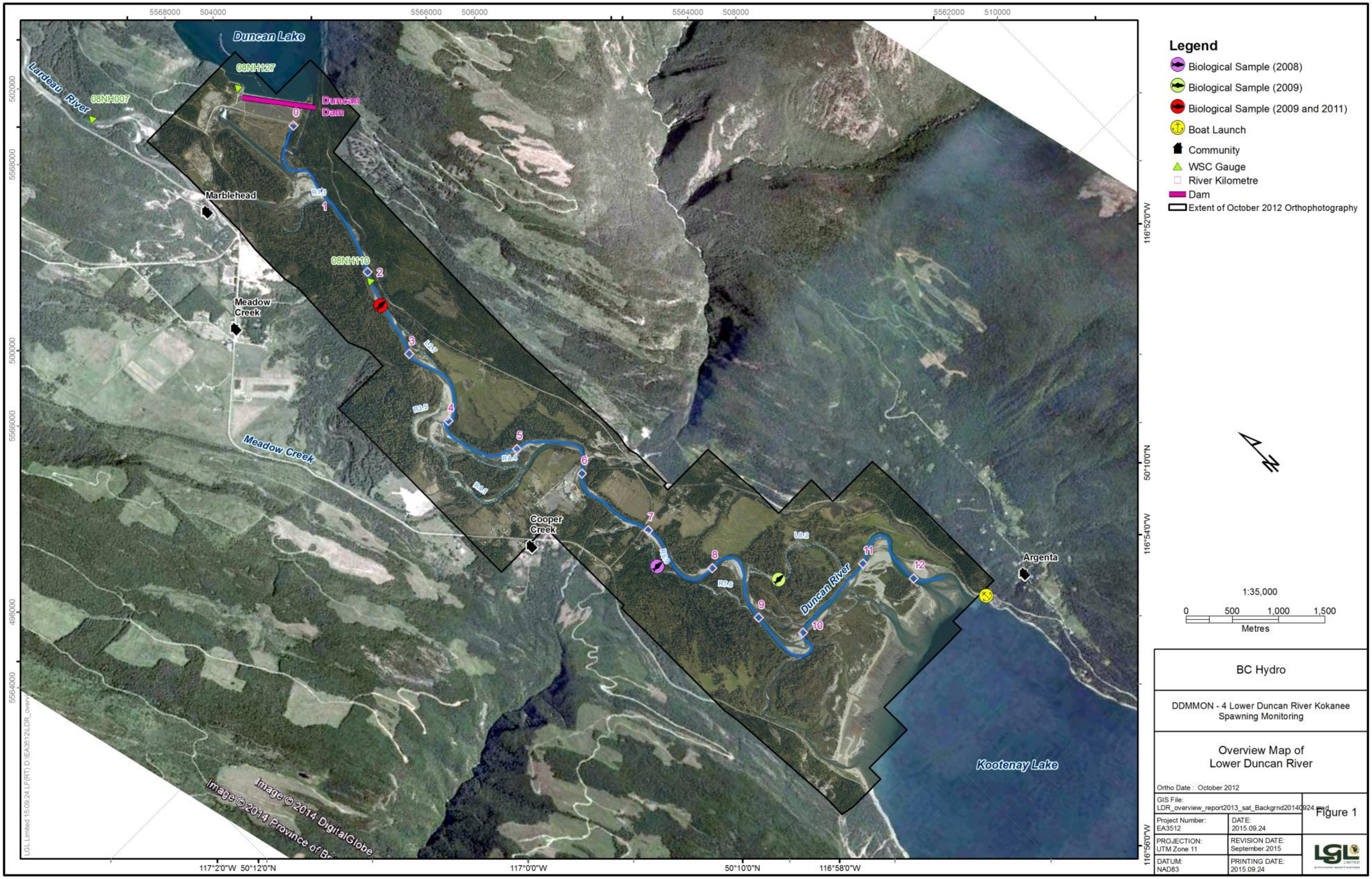

Figure 1 Lower Duncan River (LDR) study area for DDMMON 4 Kokanee enumeration and redd surveys (adapted from AMEC 2013).

2.4 Helicopter Enumeration Surveys

All helicopter aerial surveys covered the entire length of the LDR from the delta in Kootenay Lake flying upstream to approximately 600 m below DDM and also covered all LDR side channels following the protocol that was used from 2008–2014 (AMEC 2009-2013; Zimmer et al. 2015 and Zimmer et al. 2016). In 2015, all surveys were carried out using a BO105LS twin engine helicopter operated by Dam Helicopters (Castlegar, BC) and piloted by Duncan Wassick, who had operated the helicopter in previous surveys for DDMMON-4.

During the surveys, fish were visually counted and their numbers were recorded with tally counters by the lead fish counter in the front of the helicopter. The lead counter had an approximately 180^{o} view of the river because the helicopter was flying upstream at a 45^{o} angle to the direction of the current. The position, number and the extent of the area that Kokanee were using to hold or spawn was then manually drawn on a detailed 1:2,000 orthophoto and later geo-referenced as a polygon layer on a map. The crew member in the back seat of the helicopter also tallied Kokanee observed using the same visual methods and recording materials. On the orthophotos of the main stem and the side-channels, 100 m orientation markings helped to describe the exact location of Kokanee over all four surveys. Each side channel and main stem reach was named and the naming conventions conformed to the conventions established in the 2008-2014 studies (AMEC 2009–2013; Zimmer et al. 2015, 2016). In addition to the number of fish and extent of the area the main counter categorized Kokanee behaviour as follows:

- **Holding** – Kokanee observed in a school that were holding stationary often in calmer eddies and did not appear to be spawning;
- **Migrating** – Kokanee observed in a school that were moving in a line in an upstream direction and did not appear to be spawning;
- **Spawning** – Kokanee observed stationary, paired up and distributed evenly throughout an area (sometimes redd digging was observed); and
- **Dead** – Kokanee observed drifting at the surface belly up without any volitional movement.

As described above, all flights were conducted at approximately 20–40 m above the ground at a speed of 10–18 km/hr upstream. Depending on the terrain, safety hazards, and weather conditions, the helicopter had to increase elevation or speed at times. During each survey, the main stem of the LDR was surveyed first followed by individual side channels to ensure the surveys could be carried out in a systematic and consistent manner (AMEC 2013; Zimmer et al. 2015 and Zimmer et al. 2016). For the first survey (15-Sep), Gerry Nellestijn was the lead counter in the front of the helicopter while Elmar Plate was the lead counter for the remaining three surveys when Gerry Nellestijn was the second counter. Gerry Nellestijn was also one of the counters in 2014 and thus transferred methods over from previous years to maintain consistency in counting. The methods used in 2014 followed the standards set for salmonid aerial counts throughout the Pacific Northwest (Jones et al. 2007).

2.5 Data Analyses

2.5.1 Area Under the Curve (AUC) Abundance Estimates

All statistical analysis were carried out by Poisson Consulting Limited (Nelson, BC). Repeated spawner counts can be converted into abundance estimates by dividing the area under the spawner curve (AUC) by the observer efficiency and residence time (English et al. 1992) where the residence time is the number of days fish spent on the spawning grounds. With the inclusion of an arrival time model, the method provides a basis for statistically describing uncertainty (Hilborn et al. 1999) and estimating spawn timing. When data is sparse hierarchical methods allow “borrowing strength” from years with informative data to improve estimates for years with uninformative data (Su et al. 2001). Here we used hierarchical Bayesian AUC methods with a normal arrival time model to estimate spawn timing and spawner abundance with credible intervals.

Hierarchical Bayesian models were fitted to the LDR Kokanee enumeration data using R version 3.0.2 (Team 2013) and JAGS 3.3.0 (Plummer, 2012) which interfaced with each other via Jaggernaut 1.6 (Thorley 2014). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kéry and Schaub (2011, pp. 41-44).

Unless specified, the models assumed vague (low information) prior distributions (Kéry and Schaub, 2011, p. 36). The posterior distributions were estimated from a minimum of 1,000 Markov Chain Monte Carlo (MCMC) samples thinned from the second halves of three chains (Kéry and Schaub 2011, pp. 38-40). Model convergence was confirmed by ensuring that Rhat (Kéry and Schaub 2011, p. 40) was less than 1.1 for each of the parameters in the model (Kéry and Schaub, 2011 p. 61). Model adequacy was confirmed by examination of residual plots.

The posterior distributions of the *fixed* (Kéry and Schaub 2011, p. 75) parameters are summarized in terms of a *point* estimate (mean), *lower* and *upper* 95% Confidence Intervals (CIs) (2.5th and 97.5th percentiles), the standard deviation (*SD*), percent relative *error* (half the 95% CI as a percent of the point estimate) and *significance* (Kéry and Schaub 2011, p. 37,42).

The results are displayed graphically by plotting the modeled relationships between particular variables and the response with 95% CIs with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values, respectively while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kéry and Schaub 2011, pp. 77-82). Where informative, the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% CIs (Bradford et al. 2005). Plots were produced using the ggplot2 R package (Wickham 2009).

2.5.2 Observer Efficiency

Observer efficiency was based on a comparison between fish counts provided by ground counters with fish counts provided by aerial counters over the exact same sections. Surveys were completed on September 25 and October 5 at known side channel locations (i.e., SC 3.5, SC 6.9 and SC 8.2) in the LDR. The ground surveys were conducted on the same day as the aerial surveys, immediately prior or past the fly-over, coordinated via radio communication. In all other years, ratios of ground counts to aerial counts were calculated by Poisson and compared to observer efficiency calculated from 2008-2014.

2.5.3 Relative Intensity of Spawning

Kokanee enumeration counts for the four surveys conducted in 2015 were used by Poisson Consulting Ltd. to generate an estimate of the relative intensity of spawning run timing in the LDR as part of the AUC analysis. Spawning run abundance estimates for Meadow Creek and the upper Lardeau River were provided by Ministry of Forest Lands and Natural Resource Operations (MFLNRO) (M. Neufeld, unpublished data 2016).

2.5.4 Potential Egg Deposition and Losses

Potential egg deposition (PED) and loss calculations followed methods and assumptions on dewatering effects, spawn timing/superposition/predation, multiple-redd construction, and sex ratios employed by AMEC (2012, 2013), where peak counts were used to estimate female numbers, and where egg deposition for LDR Kokanee = average fecundity (225) – average egg retention (4) for a total of average of 221 eggs per female spawned. Redd mapping exercises were conducted on September 25 (prior to significant flow reduction) and October 5 (post flow reduction). Egg losses were calculated separately for side channel and mainstem redds that were observed to be dewatered throughout the duration of the study period (September 15 to October 15, 2015).

The 1:2000 orthophotos with redd locations were scanned and digitized by GIS and areas of redds measured. Comparisons were then made between observed redd locations (area, square metres) in side channels and mainstem to before and after flow reductions (September 28-October 2) to calculate PED.

3.0 RESULTS

Environmental Parameters

3.1 Lower Duncan River Discharge and Temperature

Based on data collected from Lower Duncan River Water Survey Canada (WSC) hydrometric station 08NH118 (Figure 2), the Kokanee spawning period in September and October 2015 was characterized by a regulated decrease from summer period flows through a step-wise decrease during the spawning period in late-September to early October as part of Columbia River Treaty flow release commitments (A. Leake, BC Hydro, pers comm.). Summer flows were stepped down from 255 m^3/s on September 21, 2015 in three steps: to 185 m^3/s on September 24; down to 130 m^3/s on September 27, 2015; and finally reduced to 75 m^3/s on October 1, 2015, where they stayed until October 23, 2015 (Figure 3).
The third and final flow reduction between September 29 to October 1 lowered the water level in the LDR from 1.95 m to 1.65 m (Figure 4), which was similar to 2014 and 2013 and slightly higher than the previous surveys from 2008 to 2012.

Daily average water temperature data was summarized from the WSC station (Figure 3) to determine any correlations to timing of spawning and to predict incubation and emergence timing. Temperatures during spawning and through the duration of the field investigations followed seasonal trends, from 11.7 °C to 12.2 C (September 15-26), decreasing to the lowest temperature of 10.2 °C on October 16. From there the temperature increased slightly to 11.2 °C on October 21 and trended lower from there on.

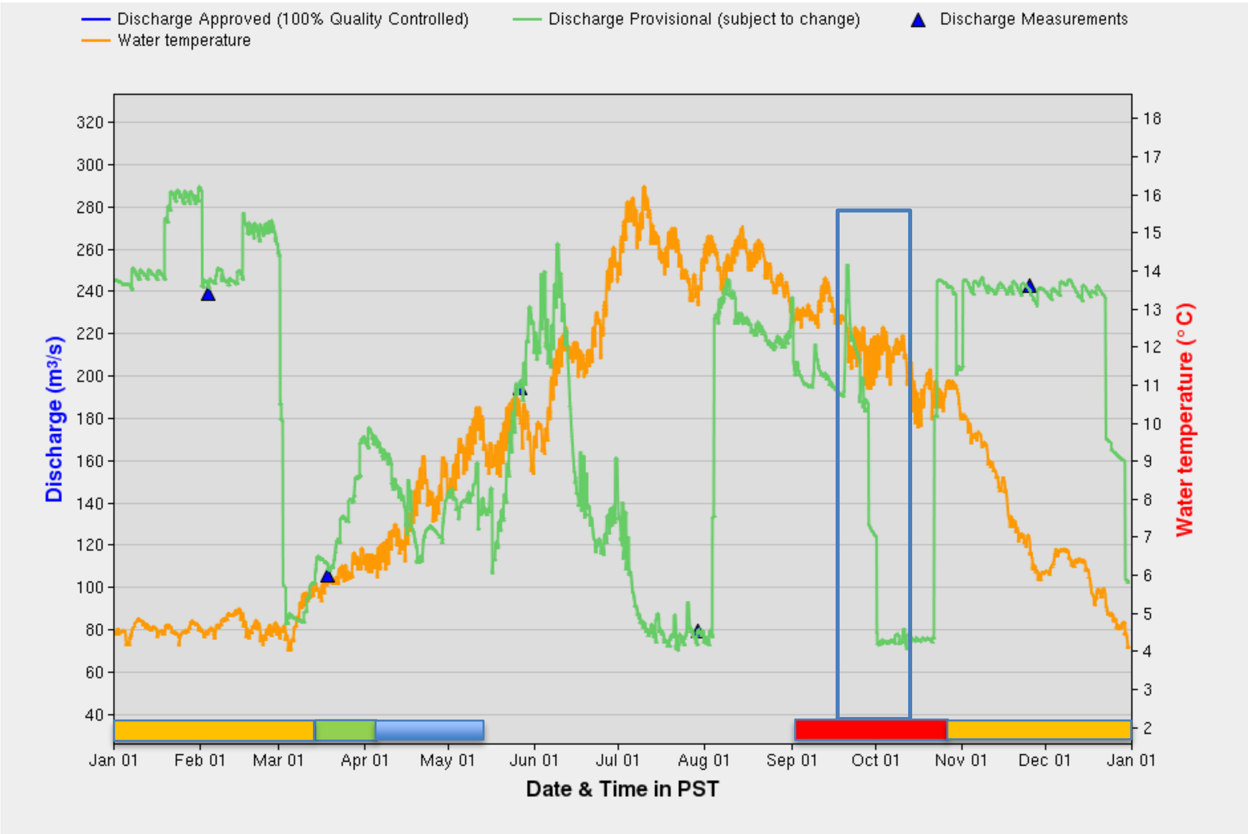

Figure 2. Discharge (m^3/s) and temperature (°C) for Duncan River at Lardeau River confluence for 2015. Blue line box indicates Kokanee enumeration study period for DDMMON 4 (Source: Water Survey of Canada Stn. 08NH118). Solid colour boxes indicate Kokanee life history in the Lower Duncan River: Red – Spawning (migration, holding, redd construction); Orange – Incubation; Green – Emergence; Blue – Ponding and out-migration (to Kootenay Lake) (Source: AMEC 2010).

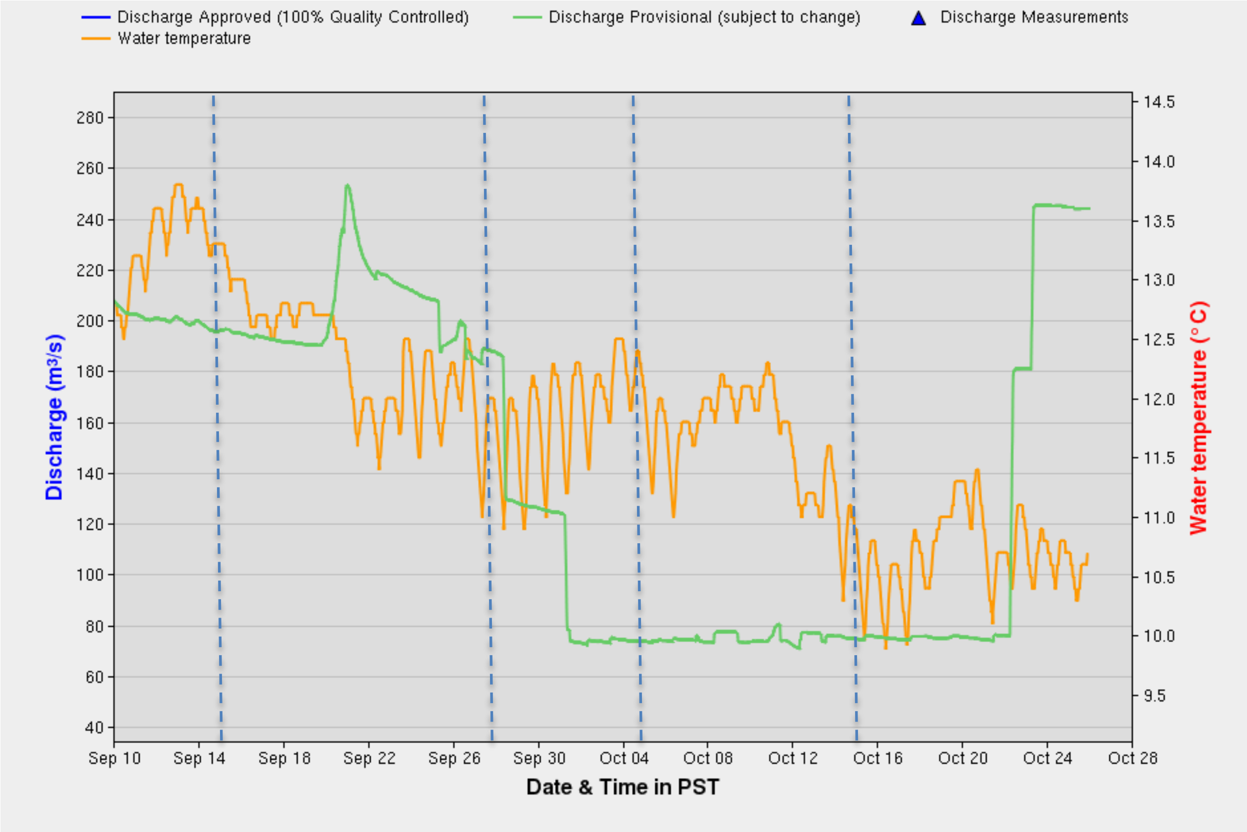

Figure 3. Duncan River (Stn 08NH118) discharge (m^3/s) and temperature (°C), September 10 - October 26, 2015. (Source: Water Survey of Canada). Dashed lines indicate survey dates.

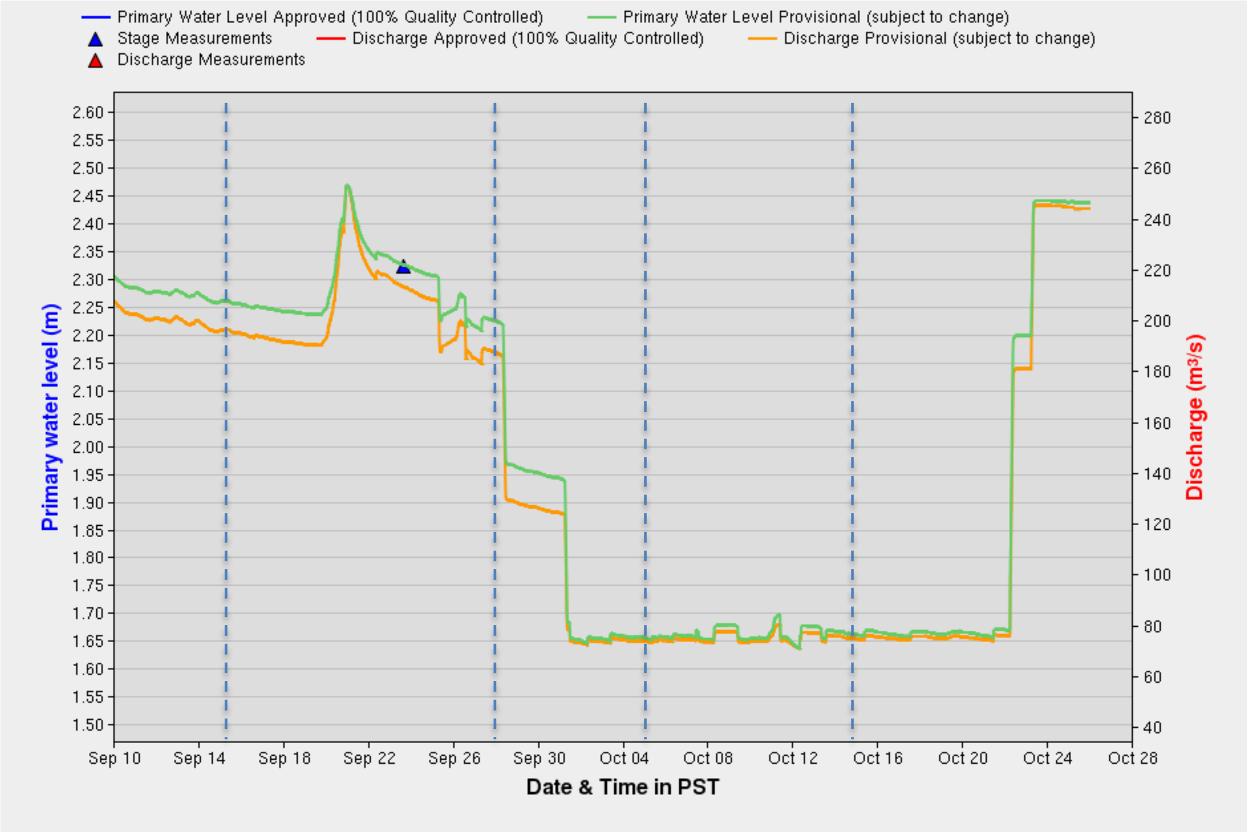

Figure 4. Duncan River (Stn 08NH118) water level elevation (m) and discharge (m^3/s), September 10- October 26, 2015. (source: Water Survey of Canada; direct discharge measurement data not provided here). Dashed lines indicate survey dates.

3.2 Kokanee Peak Count Timing

The estimated peak spawn timing for Kokanee in 2015 and throughout the rest of the DDMMON-4 project period from 2008–2014 is shown in Figure 5 and a tabular summary for the peak spawn timing from 2008–2015 is shown in Table 3. Peak spawning was predicted for September 27 in 2015 (Figure 6). The 2015 peak fell within the range of peaks from September 26–October 7 observed in previous years. The peak timing estimate for 2015 was more certain than in 2013 as the counts showed a distinct decline in the latter part of the survey period. The very wide 95% confidence intervals (Table 3) were based on the smaller than previously observed changes from one count to the next based on the very small 2015 run.

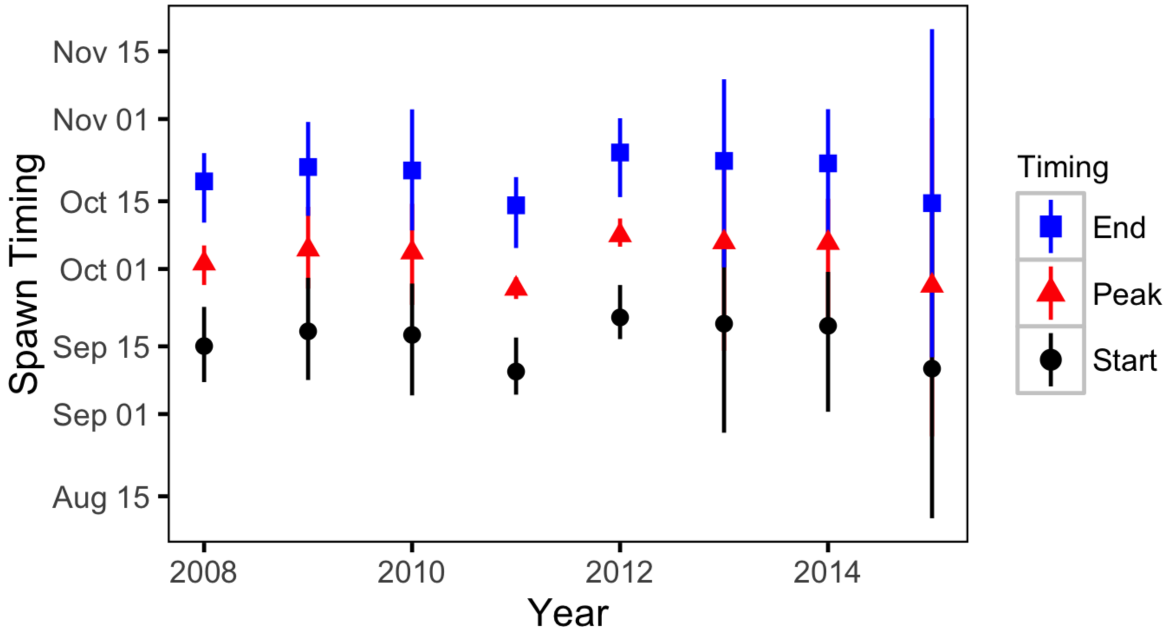

Figure 5. Predicted Kokanee peak spawn timing by year with 95% CIs.

Table 3. Annual peak counts of Kokanee spawners in the LDR study area, 2008-2015

Year	Date of Peak Spawning	Lower 95% CI	Upper 95% CI
2008	Oct 1	Sep 25	Oct 5
2009	Oct 3	Sep 21	Oct 13
2010	Oct 2	Sep 20	Oct 14
2011	Sep 26	Sep 24	Sep 28
2012	Oct 7	Oct 4	Oct 10
2013	Oct 4	Sep 8	Oct 21
2014	Oct 5	Sept 25	Oct 13
2015	Sep 27	Aug 27	Nov 11

3.3 Area Under the Curve Estimates

Figure 6, shows the Area Under the Curve (AUC) estimate of abundance for 2015 (bottom center panel) based on four aerial counts (dots) in comparison to the last seven years from 2008–2014. The plot also shows the daily spawner abundance estimates calculated by the hierarchical Bayesian AUC model. In Figure 7, the total 2015 spawner abundance estimate is shown in comparison to the seven previous years. The 2015 Kokanee AUC estimate of abundance (8,620 fish) represented the lowest estimate within the last eight years.

AUC estimates, their 95% confidence intervals, their Standard Deviation (SD) and the number of surveys undertaken are summarized in Table 4. The large 95% confidence intervals in 2015 were based on the small differences between individual counts and the small overall run size that was outside of the previously estimated range of estimates.

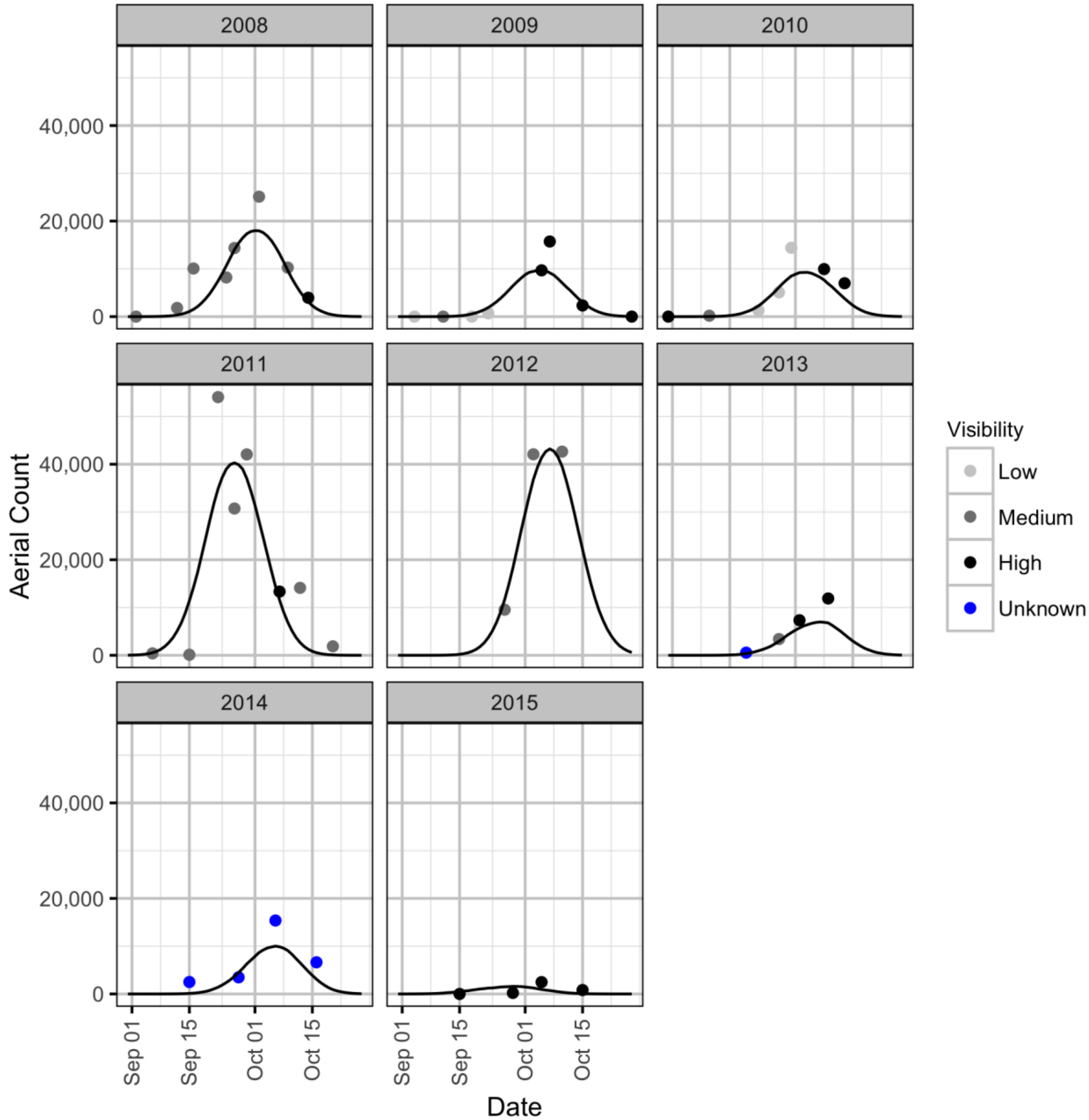

Figure 6. Kokanee spawner aerial counts with predicted aerial counts by date and year (red dots indicate water clarity not documented).

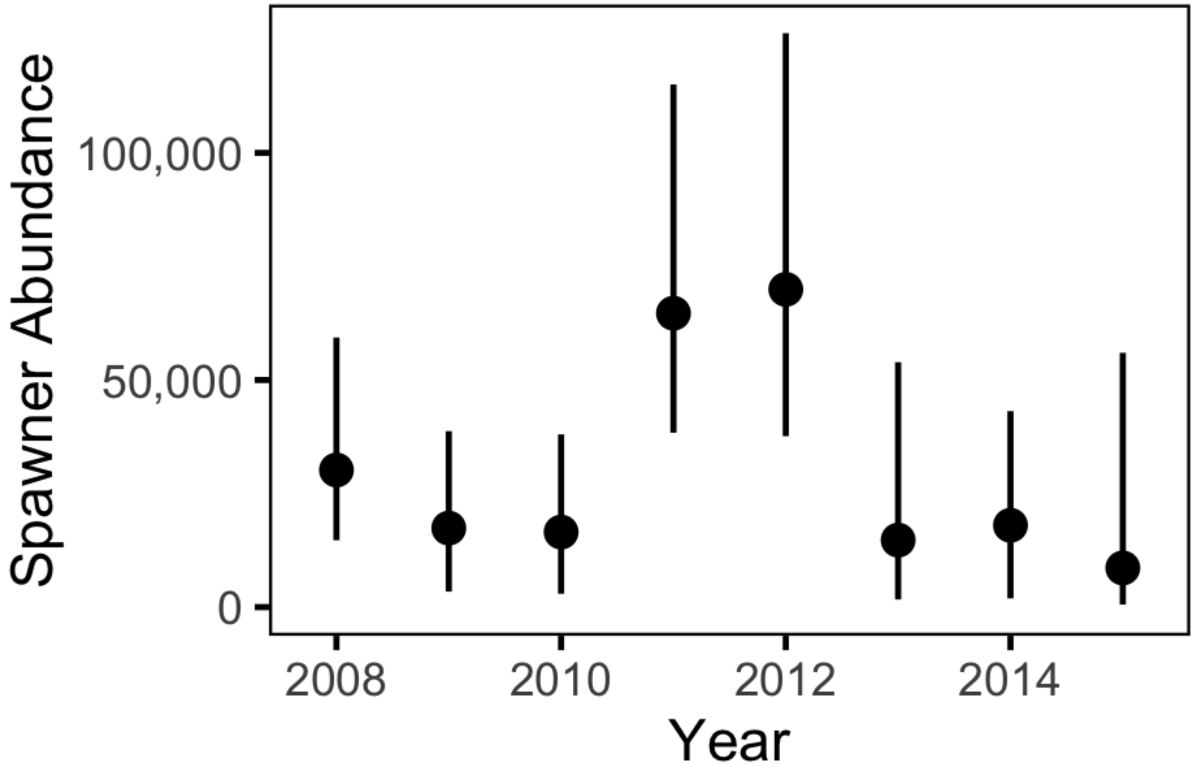

Figure 7 Predicted total Kokanee spawner abundance by year with 95% CIs.

Table 4 Kokanee spawner abundance estimates in the LDR from 2008–2014.

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI	SD	# of Counts
2008	32,300	13,300	58,300	11,770	8
2009	19,600	2,400	42,500	10,745	8
2010	19,000	2,100	42,300	12,305	7
2011	70,700	37,700	117,300	21,141	8
2012	75,600	40,100	128,200	23,784	3
2013	20,300	900	62,000	25,617	4
2014	22,080	7,280	45,000	9,710	4
2015	8,620	560	55990	*	4

* Based on the low number of surveys, the not-normally distributed individual counts and the low number of fish observed in 2015, the SD is artificially inflated and does not have any descriptive power and was therefore not reported for 2015.

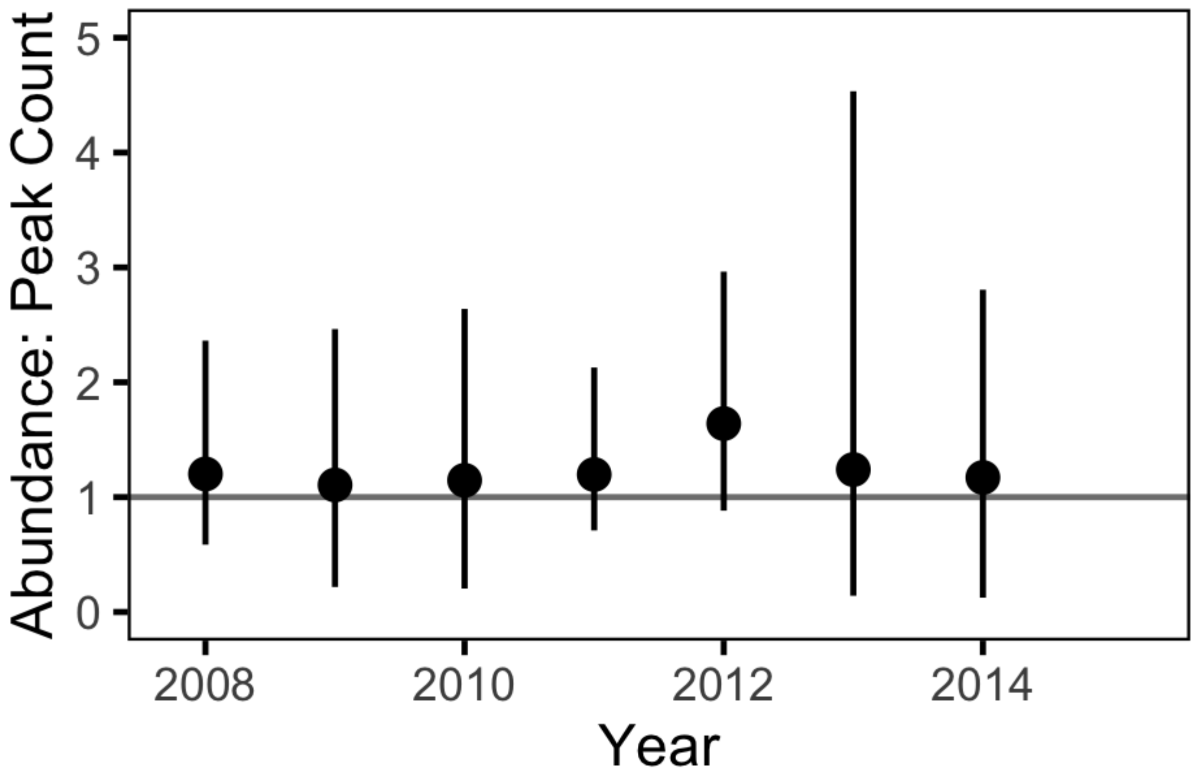

Figure 8 Ratio of estimated annual spawner abundance to peak counts by year for Kokanee in the LDR. The value for the 2015 ratio was not included since the actual value and its confidence interval (upper 95% CI = 15.4) was much higher than previously observed and thus would have not allowed for the small differences in previous years to be seen.

As another measure to estimate total spawner abundance, the ratio of peak count to total spawner abundance was calculated and the results are shown in Figure 8. The ratio was 3.1 for 2015 and therefore outside of the previously observed range from 1.3–1.8 observed between 2008–2014 (Table 5). The value for the 2015 ratio was not included into Figure 8 since the actual value and especially its upper confidence interval (upper 95% CI = 15.4) was much higher than previously observed and thus would have not allowed for the small differences in previous years to be seen.

Table 5 Summary of ratios between spawner estimate and peak count for LDR Kokanee 2008–2015.

Year	Estimate	Peak Count	Ratio Estimate to Peak Count
2008	32,300	25,100	1.3
2009	19,600	15,700	1.3
2010	19,000	14,400	1.3
2011	70,700	54,000	1.3
2012	75,600	42,600	1.8
2013	20,300	11,900	1.7
2014	22,080	15,379	1.4
2015	8,620	2,769	3.1

3.4 Relative Intensity of Kokanee Spawning in the Duncan River System

For the first time since this project was initiated in 2008, the values for the percentage of Kokanee counted in Meadow Creek (29%), Lardeau River (39%) and LDR (32%) were all within 10% based on the very low counts in all three segments of the Duncan system (Figure 9 and Table 6). In previous years, Kokanee escapement to Meadow Creek and Lardeau River had always represented >85 (2014) and typically >94% (2008-2013) of the total Duncan system Kokanee run.

The combined escapement estimate for all three segments of the Duncan system in 2015 (26,576 Kokanee) was the lowest on record and approximately 68 times smaller than the largest escapement estimate of 1,804,044 Kokanee in 2011.

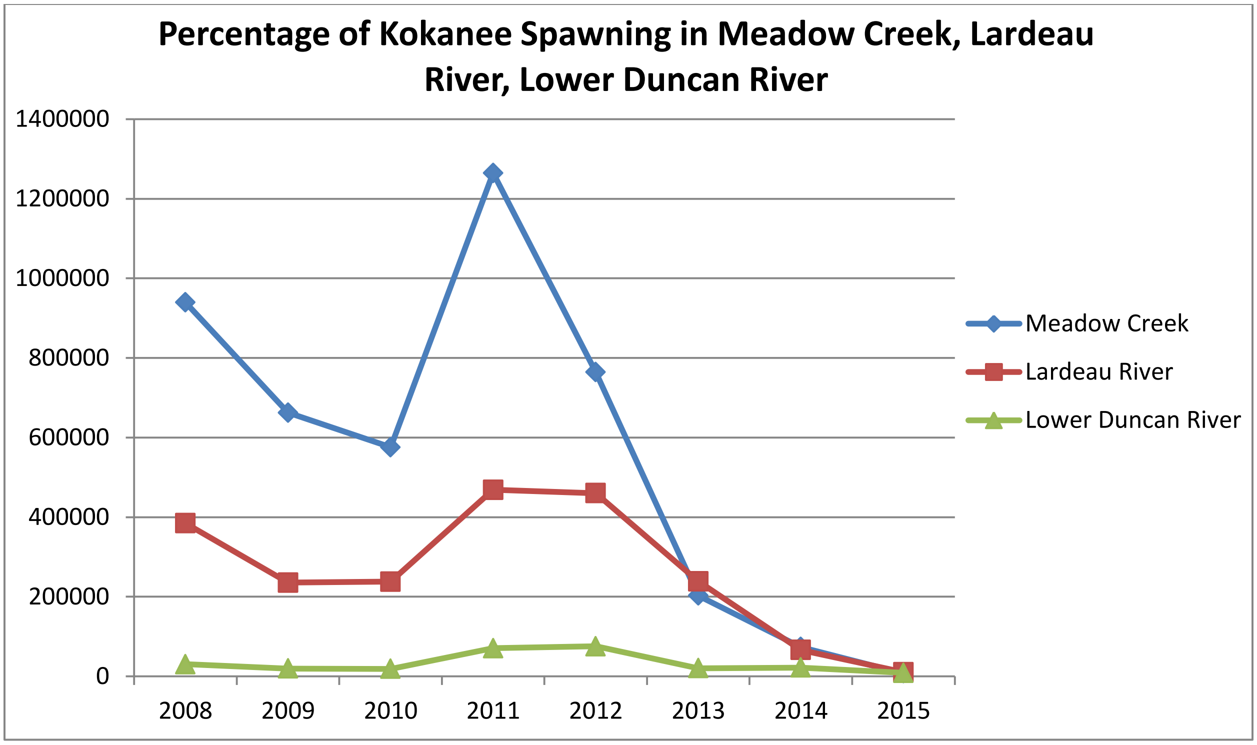

Figure 9 Estimated abundance of Kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008-2015. (source: Meadow Creek and Lardeau River MFLNRO (M. Neufeld pers comm/unpublished data); Lower Duncan River AMEC (2013); ONA and LGL 2015)

Table 6 Relative intensity of Kokanee spawning in the whole Duncan River system 2008-2015.

Year	Meadow Creek (%)	Lardeau River (%)	Lower Duncan River (%)	Total Estimate
2008	69%	28%	2%	1354517
2009	72%	26%	2%	917235
2010	69%	29%	2%	832760
2011	70%	26%	4%	1804044
2012	59%	35%	6%	1299944
2013	44%	52%	4%	461687
2014	45%	41%	14%	161856
2015	29%	39%	32%	26576

3.5 Migration, Holding and Spawning Behaviour

The initial survey conducted on September 15 showed low numbers of Kokanee in the LDR, which were all holding close to the confluence of the Lardeau River and the LDR (Figure 10), no spawning was observed. As the season progressed, a higher proportion of spawning behaviour was observed until October 5 when 315, 5 and 2476, Kokanee were observed migrating, holding and spawning, respectively . During the last survey on October 15, 816 spawning and no migrating or holding Kokanee were observed. It therefore appears as if the 2015 Kokanee spawning period for this very small run was covered from very few fish to covering the peak spawning period and the tail end of the run when the number of spawning fish was decreasing.

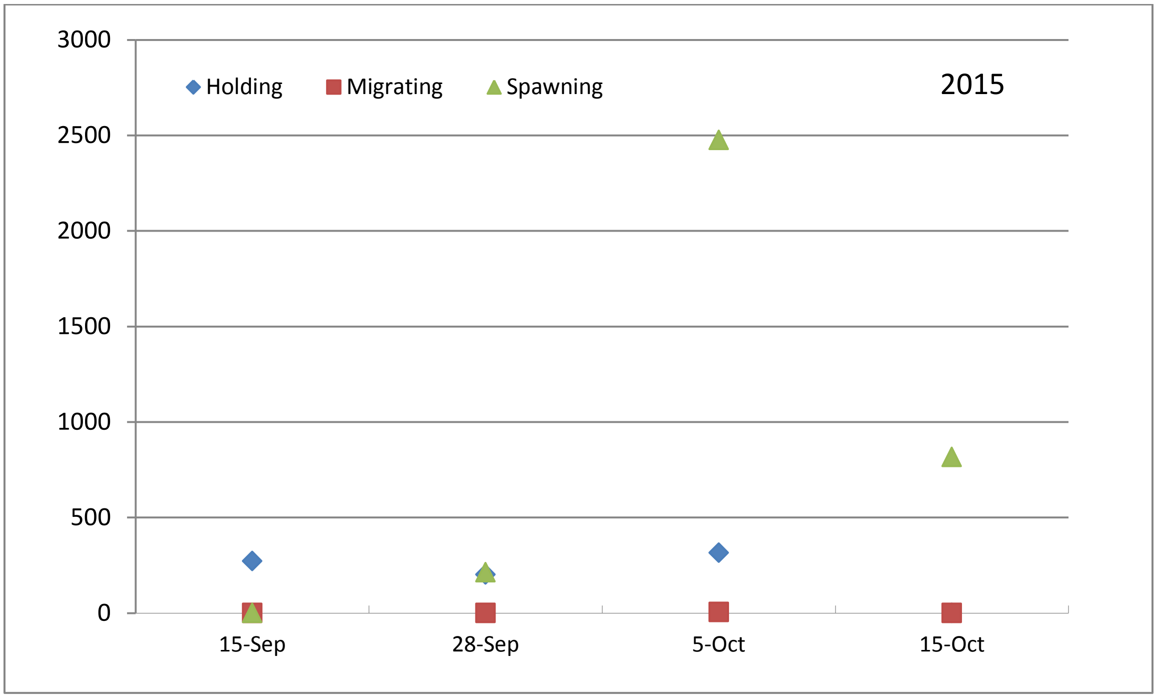

Figure 10 Number of migrating, holding and spawning Kokanee enumerated in the Lower Duncan River for 2015 (September 15 holding Kokanee were observed at the confluence with the Lardeau River).

3.6 Spawner Distribution and Habitat Use in the LDR

As in previous years, Kokanee were observed to spawn in the upper nine kilometers of the study area with main concentrations of redds observed between Kilometers 0.8 and 6.6 (See Appendix A). No redds were observed upstream of Kilometer 0.8 (Duncan Dam discharge channel, upstream end of the study reach), or from Kootenay Lake to Km 8.9 (downstream end of the study reach). Most notable concentrations of spawning Kokanee were found around km 2 and km 3 within the upper third of the study reach. Side channel use for spawning was observed in SC 4.1 and 4.4 during the peak count on October 5 (post flow reduction) and in S.C. 4.4 on October 15 (also post flow reduction) (See Appendix A).

Table 7 Number of spawning Kokanee distributed in the LDR main stem and side channels for 2015.

Date	Main Stem (MS) or Side Channel (SC)	Holding (N)	Migrating (N)	Spawning (N)
15-Sep-15	MS	272	0	0
	SC	0	0	0
28-Sep-15	MS	201	0	213
	SC	0	0	0
5-Oct-15	MS	110	5	2286
	SC	205	0	190
15-Oct-15	MS	0	0	786
	SC	0	0	30

3.7 Kokanee Potential Egg Deposition, Egg Losses and Effectiveness of Flow Reductions

The 2015 Kokanee spawning locations in the LDR were mapped on a series of six maps attached as Appendix A. Redd mapping was based on redd surveys conducted on September 28 and October 5, 2015. Potential egg deposition and egg losses were calculated from area calculations based on the comparative redd distributions between side channel and main stem habitats before and after flow reductions, starting from 185 m^3/s on September 24; down to 130 m^3/s on September 27; and finally to 75m^3/s on October 1, 2015.

The total area used by spawning Kokanee in the LDR side channels and main stem in 2015 was approximately 15,975 m^2, containing an estimated 273,450 eggs that were deposited (Table 8). No redd dewatering was observed as a result of the final (regulated) flow reduction September 27 to October 1. Subsequent egg losses were also calculated as zero (0). Total area of redd dewatering was estimated at 11 m^2 between the October 5 and October 15 enumerations and therefore independent from flow reductions (Table 9). Based on the 11 m^2 of non-flow reduction based dewatering approximately 200 eggs (based on 17 eggs/m^2) were lost.

Table 8. Total spawning area, area dewatered (difference), Potential Egg Deposition (PED), number of eggs dewatered and spawning success for side channel (SC) and mainstem areas (MS) within the LDR study area before (Pre) and after (Post) Kokanee Protection Flows, 2009 to 2015 (adapted from AMEC 2013; ONA and LGL 2015, 2016).

Year	Pre- or Post Flow Reduction	Total Spawning Area (m^2)		Potential Egg Deposition (N)	
		Side Channel	Main Stem	Side Channel	Main Stem
2015	Pre	1,118	14,857	19,148	254,450
	Post	1,118	14,857	19,148	254,450
	Difference	0	0	0	0
2014	Pre	2,795	12,847	297,332	1,366,664
	Post	2,755	12,825	293,077	1,364,324
	Difference	40	22	4,255	2,340
2013	Pre[a]	1,078	1,739	168,623	1,025,771
	Post	936	1,739	146,449	1,025,771
	Difference	142	0	22,173	0
2012	Pre[b]	4,734	N/A	473,172	2,713,272
	Post[c]	3,973	20,922	397,156	2,713,272
	Difference	760	0	76,016	0
2011	Pre	6,902	88,172	3,253,621	2,372,672
	Post	5,902	88,172	2,781,955	2,372,672
	Difference	1,000	0	471,666	0
2010	Pre	4,041	8,055	830,540	642,948
	Post	3,784	8,632	777,601	640,852
	Difference	258	-577	52,939	2,096
2009	Pre	399	0	48,732	-
	Post[d]	267	4219	32,667	-
	Difference	132	-	16,065	-

[a] Based on backcalculating areas based on observed watered and dewatered sidechannel and mainstem redds on one survey – October 2, 2013

[b] Mainstem mapping was not conducted prior to the flow reduction. However, no dewatered redds were observed in the mainstem during post-reduction mapping.

[c] Additional spawning areas were observed post-reduction (3556 m^2) because Kokanee moved into side channels but the information presented reflects the original spawning area dewatered and changes to PED.

[d] Larger area was observed post-reduction because Kokanee moved into side channels to spawn. Only 132 m^2 of area was dewatered from the original pre-reduction mapping, which is reflected in PED.

- Spawning was not observed pre-reduction. It was assumed that post-reduction spawning areas were not dewatered.

Table 9 Spawning area, number of spawners, spawners/m^2 and spawning area dewatered by date in 2015. The totals do not add up to the shown total spawning area shown for the whole study period in Table 8 since the spawning areas observed during the four aerial surveys overlapped. These overlapping areas were subtracted from the total area calculated for the whole study and therefore the spawning area for the total study was smaller than the sum of the individual areas observed during each flight.

Date	Spawning Area by Date (m^2)	Spawners by Date (N)	Spawners/m^2 by Date (N)	Spawning Area Dewatered by Date (m^2)
15-Sep	0	0	0.0	0
28-Sep	689	203	0.3	0
5-Oct	8741	2502	0.3	0
15-Oct	8633	816	0.1	11*

*Dewatering not based on Duncan Dam flow reduction

3.8 Calibration of Observer Efficiency

The observer efficiency for 2015 was 100% based on the fact that no fish could be observed in either the aerial or the ground counts in side channels R 3.5, R 6.9 and L 8.2 used in 2014 and 2015. While the 2015 comparison between aerial and ground count is a valid result, it is preferred to undertake the calibration count in stretches where fish are spawning . Therefore, 2015 results are not included into the results shown in Table 10, Figure 11 and Figure 12.

Table 10 Ratios of aerial and ground Kokanee calibration counts for standardized locations in the LDR from 2008-2014.

Year	Average of Aerial Counts for Calibration Locations	Average of Ground Count for Calibration Locations	Average Ratio of Aerial to Ground Count for Calibration Sections (# of surveys with data)
2008	1580	1410	1.12 (1)
2009	51	51	1.00 (5)
2010	300	284	1.06 (1)
2011	2665	1461	1.82 (2)
2012*	-	-	- (0)
2013	100	116	0.86 (1)
2014	220	292	0.75 (4)**
2015	0	0	1.00 (6)***

*Not reported (AMEC 2013); **October 16, 2014 surveys in SCs 3.5 and 8.2 (Ground and air) both yielded counts of zero Kokanee; ***SCs 3.5, 6.9 and 8.2 surveys yielded zero counts on both September 28 and October 5, 2015

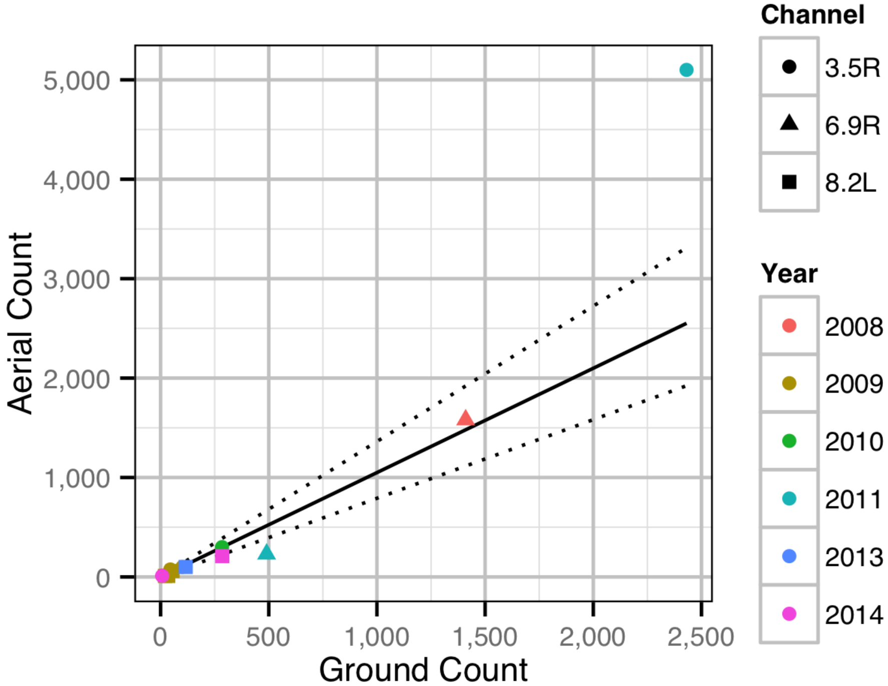

Figure 11 Aerial versus ground Kokanee spawner counts and predicted ground count (with 95% CRIs) by year and channel from 2008-2014.

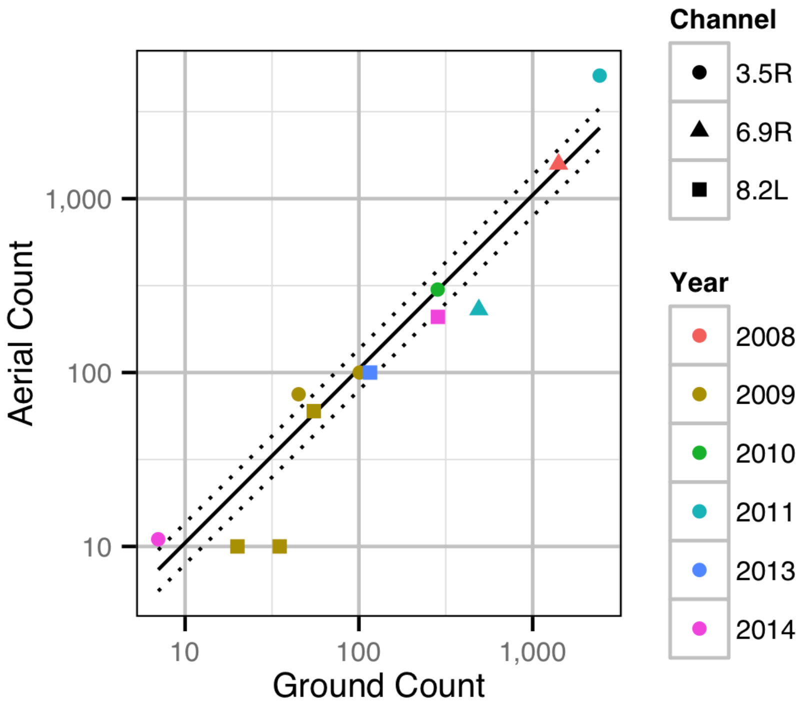

Figure 12 Aerial versus ground Kokanee spawner counts (on log10 scales) and predicted ground count (with 95% CRIs) by year and channel from 2008 to 2014.

4.0 DISCUSSION

The following discussion is structured along the management questions that were applicable to Year 8 of DDMMON-4.

4.1 Lower Duncan River Environmental Parameters: Temperature and Discharge

Temperatures during spawning and throughout the duration of the field investigations in 2015 followed seasonal trends, from 11.7 °C to 12.2 C (September 15-26), decreasing to the lowest temperature of 10.2 °C on October 16. From there the temperature increased slightly to 11.2 °C on October 21 and trended lower from there on. This pattern was very similar to the pattern observed in 2014, when, following a small (+1 °C) increase in water temperature from September 15-25, water temperature decreased steadily throughout the spawning period in the LDR. Similar trends of decreasing water temperatures throughout the main spawning period were observed since 2009, and ranged from 16 °C to 8 °C (AMEC 2012, 2013, no data recorded in 2008). Temperature reductions are primarily due to reductions in DDM discharge, which draws flows from a warmer reservoir when compared to the colder and natural flow contribution of the Lardeau River during this period. This may also explain the slight increase in temperature at the onset, coincident with higher DDM discharge. It is believed that reducing the proportion of DDM discharge to the Lower Duncan River therefore reduces the temperature (AMEC and Poisson 2012) in the fall. Further monitoring of Duncan Reservoir temperatures, contrasting surface with Low Level Outlet depth temperatures would be required to understand the effects of dam releases on incubation and emergence timing of Kokanee.

Lower Duncan River discharge is regulated through DDM in consideration of Lardeau River flows in September and October 2015 to manage for protection of Kokanee spawning in the LDR. 2015 discharge in the LDR underwent a series of flow reductions from summer highs (255 m^3/s) down to around 75 m^3/s for the period September 21 to October 1. This was very similar to the 2014 flow reduction pattern. Previous to 2014, from 2008-2013, discharge varied from highs of approximately 202 m^3/s to lows of 69.8 m^3/s, with intermittent spikes within this range in some years.

4.2 Spawn Run Timing

The initial spawning survey took place on September 15, 2015 with 272 Kokanee observed holding at the confluence with the Lardeau River. Although in 2015 a much smaller number of Kokanee was observed when compared with 2014 (18,000) at this location, it appears to be typical for mid-September surveys to find the majority of fish holding at the LDR and Lardeau River confluence bound for the Lardeau River. The September 15 survey was also concurrent with higher Duncan Dam discharges preceding the initiation of annual discharge reductions for Kokanee spawning protection. The highest visual peak count of 2,476 Kokanee was observed on the third enumeration flight on October 5, 2015, which was similar to count timing in 2014 (Peak of 15,379 on October 6) and 2013 (Peak of 11,900 on October 9; Zimmer et al. 2015), but at the later range of previous years' peak counts which have ranged from September 19 to October 7 from 2002 to 2011 (AMEC 2013).

4.3 Relative Intensity of 2015 Kokanee Spawning in the LDR

Continued surveys indicated a successive increase in the numbers of Kokanee in the LDR from September 15 (first survey), culminating in the peak count, on the third survey (October 5), with a significant decrease on the final survey on October 15. This trend is consistent with observations from annual Kokanee enumerations conducted by MFLNRO throughout the Kootenay and Arrow Lakes regions. Observing the visual peak during the third enumeration supports the adaptation of extending the survey period to 30 days (minimum), from the 20 day period used in 2013 (Sept 19-Oct 9) which failed to capture the descending limb of spawner abundance.

4.4 Area Under the Curve Estimates

Based on an Area Under the Curve (AUC) estimate, the 2015 Kokanee spawning population in the Lower Duncan River was estimated to be 8620 fish, with a lower 95% CI of 560 fish and an upper 95% CI of 55990 fish. In comparison to previous years, the 2015 estimate is the lowest on record at about half the previously lowest estimate of 14750 in 2013 (Lower CI = 1680; Upper CI = 53920) and about 12% of the highest estimate of 69950 in 2012 (Lower CI = 37630; Upper CI = 126350). Similarly, in 2015 the lowest combined escapement estimate of 26,576 Kokanee for all three segments of the Duncan system (Meadow Creek: 7653; Lardeau River: 10303; LDR: 8620) was recorded. The 2015 combined estimate was approximately 68 times smaller than the largest combined escapement estimate of 1,804,044 Kokanee in 2011.

The lower 95% CI (560 fish) and the upper 95% CI (55990) for the abundance estimate of 8620 fish were very large in 2015. The large CIs were based on numbers of fish that were lower than the numbers in previous years and therefore outside of the values had been used in the AUC model before. In addition, the low number of four surveys or counts will always create large CIs around the estimated abundance. Similarly, and also based on unprecedented low numbers of fish, the ratio of peak count to total abundance of 3.1 and was much large than in previous years (1.3-1.8).

In addition to the model used for the calculation of population estimates in DDMMON-4 up to 2015, we applied the trapezoidal AUC model (AUCmonteMASTER 2.04 LGL) to the 2015 data and are representing the results in Figure 13 and Table 11 below. The AUCmonte simulation approach connects a probability value between 0 and 100 % with a calculated total escapement. While the AUCmonte Model is well suited to give a good population estimate for few and low counts it lacks rigorous statistical methods to calculate CIs (Hilborn et al. 1999, Su et al. 2001a).

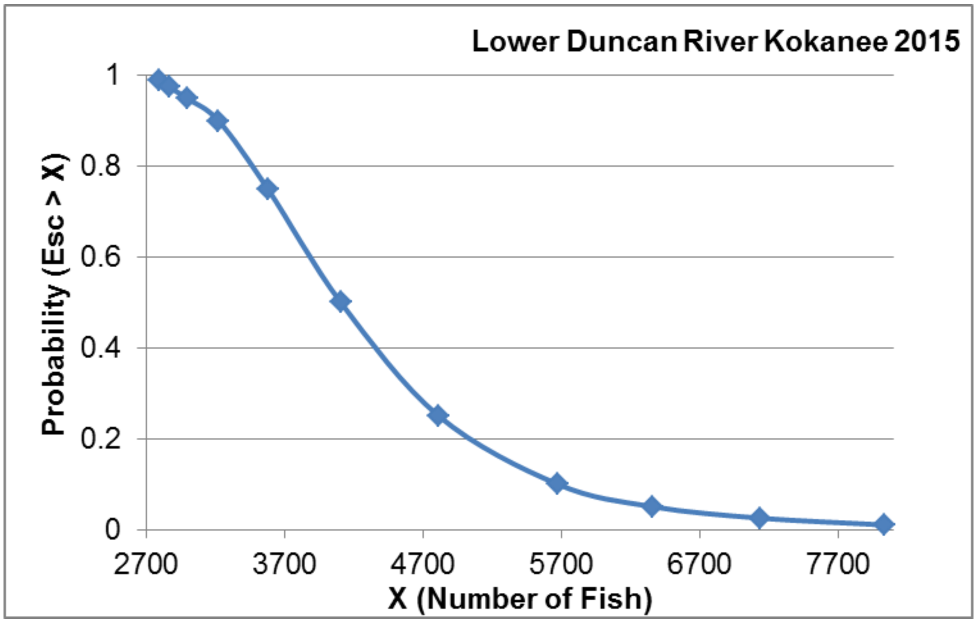

Figure 13 Graphical representation of Monte Carlo simulation based AUC estimates and their probabilities resulting from the LGL based model.

Table 11 Tabular results of the Monte Carlo simulation based AUC estimates and their probabilities resulting from the LGL based model.

Monte Carlo Result Summary:	%offset
There is a 99% chance that escapement was at least 2796 fish.	-32%
There is a 97.5% chance that escapement was at least 2864 fish.	-30%
There is a 95% chance that escapement was at least 2993 fish.	-27%
There is a 90% chance that escapement was at least 3222 fish.	-21%
There is a 75% chance that escapement was at least 3577 fish.	-13%
There is a 50% chance that escapement was at least 4105 fish.	0%
There is a 25% chance that escapement was at least 4811 fish.	17%
There is a 10% chance that escapement was at least 5670 fish.	38%
There is a 5% chance that escapement was at least 6359 fish.	55%
There is a 2.5% chance that escapement was at least 7137 fish.	74%
There is a 1% chance that escapement was at least 8035 fish.	96%

Based on the LGL model the population had a 50% probability for an estimate of 4,105 Kokanee with a low 95% CI of 2,864 fish and a high 95% CI of 7,137 fish. The ratio of estimate to peak count using the LGL model was 1.48 for 2015 and in line with previous ratios ranging from 1.3–1.8. Although this model lacks robust CI estimation, its trapezoidal approach will be considered when re-designing the Bayesian approach in the future.

4.5 Relative distribution of Kokanee spawners in the Lower Duncan River

As in previous years, Kokanee were observed to spawn in the upper nine kilometers of the study area with main concentrations of redds observed between Kilometers 0.8 and 6.6 (See Appendix A). No redds were observed upstream of Kilometer 0.8 (Duncan Dam discharge channel, upstream end of the study reach), or from Kootenay Lake to Kilometer 8.9 (downstream end of the study reach). Most notable concentrations of spawning Kokanee were found around Kilometer 2 and Kilometer 3 within the upper third of the study reach. The use of side-channels, just like the overall number fish observed, was reduced when compared with previous years and limited to small sections of SCs 4.1 and 4.4 during the peak count on October 5 (post flow reduction) and in S.C. 4.4 on October 15 (also post flow reduction) (See Appendix A).

4.6 Kokanee Spawn Mapping, PED and Egg Losses

The total area used by spawning Kokanee in the LDR SCs and main stem in 2015 was approximately 15,975 m^2, containing an estimated 273,450 eggs that were deposited. Total area of redd dewatering was estimated at 11 m^2 between the October 5 and October 15 enumerations and therefore independent from flow reductions that were realized between September 24 to October 1. Based on the 11 m^2 of non-flow reduction based dewatering approximately 200 eggs were lost.

Historically, side channel usage is highest at the start of the run prior to the kokanee protection flows being implemented, as kokanee seek low velocities. Once flows are reduced, mainstem habitats are more abundant and preferred (AMEC 2013). Main stem of the LDR was the preferred spawning habitat in 2015 during the smallest Kokanee run observed, as only 220 (6%) spawners out of the total run of 3,285 Kokanee were observed spawning in the side channels.

4.7 Calibration of Observer Efficiency

The observer efficiency for 2015 could not be calibrated as in previous years, using the comparison of aerial and ground counts in side channels R 3.5, R 6.9 and L 8.2 when fish are present. Nevertheless, the results of the aerial and ground counts were identical and no fish were counted. For future years, it is recommended that alternative side channels or main stem stretches with features that allow for high accuracy ground counts will be identified and used.

5.0 RECOMMENDATIONS

1. Efficiency of Spawner Protection Flows: Annual Kokanee spawner protection flows implemented in the DDM WUP provide a benefit to kokanee spawning October 1-21st each year but there is a measurable impact to that portion of the run that spawns in higher flows prior to implementing the protection flow regime. It is recommended that the DDM Works 4 program *("Action Plan to Minimize Risk of Stranding Spawning Kokanee")* utilize the information gathered in this monitoring program to evaluate alternatives that minimize impacts to the early kokanee spawning run, in consideration of operating agreements (Columbia River Treaty, International Joint Commission) and other Water Use Plan objectives (flood control and recreation). The outcome of this analysis would be used inform future Water Use Plan review processes on opportunities that minimize stranding while accommodating other important water use objectives.

2. Confidence Intervals (CIs) of Population and Run Timing Estimates: The CIs of the 2015 population and run timing estimate were too large to allow BC Hydro to draw conclusions that can be used to contemplate operational changes for Duncan Dam. We therefore suggest a much improved analysis approach for 2016. The currently used Bayesian approach will be complimented with timing data from Meadow Creek spawning channel, the form of the model will be changed to better fit low counts and an additional aerial count is planned. These changes will also be reflected in a re-allocation of funding to the data analysis portion of this project.

3. Survey Period: By expanding the survey period by 10 days in 2014 and 2015 compared to 2013, the onset, peak and decrease in numbers of Kokanee spawners in the LDR was covered by aerial counts. Further sampling plans should also include a minimum of 30 days centered on the spawning peak from last week of September to first week of October, over a minimum of four enumeration events and designed to capture the annual DDM flow reduction period of September 25 – October 1.

4. Spawner Enumeration Methods: Current methods for spawner enumeration and redd surveys should be continued, including low elevation flights (>20 m). Furthermore, future enumerations will aim to be completed by the same study team, replicating to the furthest degree possible, the most experienced core of the teams used in 2014 and 2015 surveys.

5. Ground Counts to Calibrate Aerial Counts: The calibration counts comparing the aerial counts with stream walk counts in a side-channel that provides ideal conditions for a ground based count should include a location either in the main stem or new side-channel locations. The new calibration count locations should be chosen based on observations made in 2015 that were used by Kokanee for spawning during the 2015 low run year, to minimize the risk of zero counts. Sections of SCs 4.1 or 4.4 appear to be fitting this description.

6. Communications: Throughout the study period discussions with BC Hydro Fisheries and Science staff should be ongoing to develop suitable approaches to emerging questions or problems. In addition, discussions with operations staff should be ongoing during enumeration planning and implementation stages.

7. Orthophoto Updates: Updated orthophoto maps (2012) provided by contractors for DDMMON 3 continue to be very useful for enumeration and redd survey data collection. Since the Lower Duncan River is an active, alluvial channel, we recommend using regularly updated orthophotos as base-maps for enumeration and redd surveys when available.

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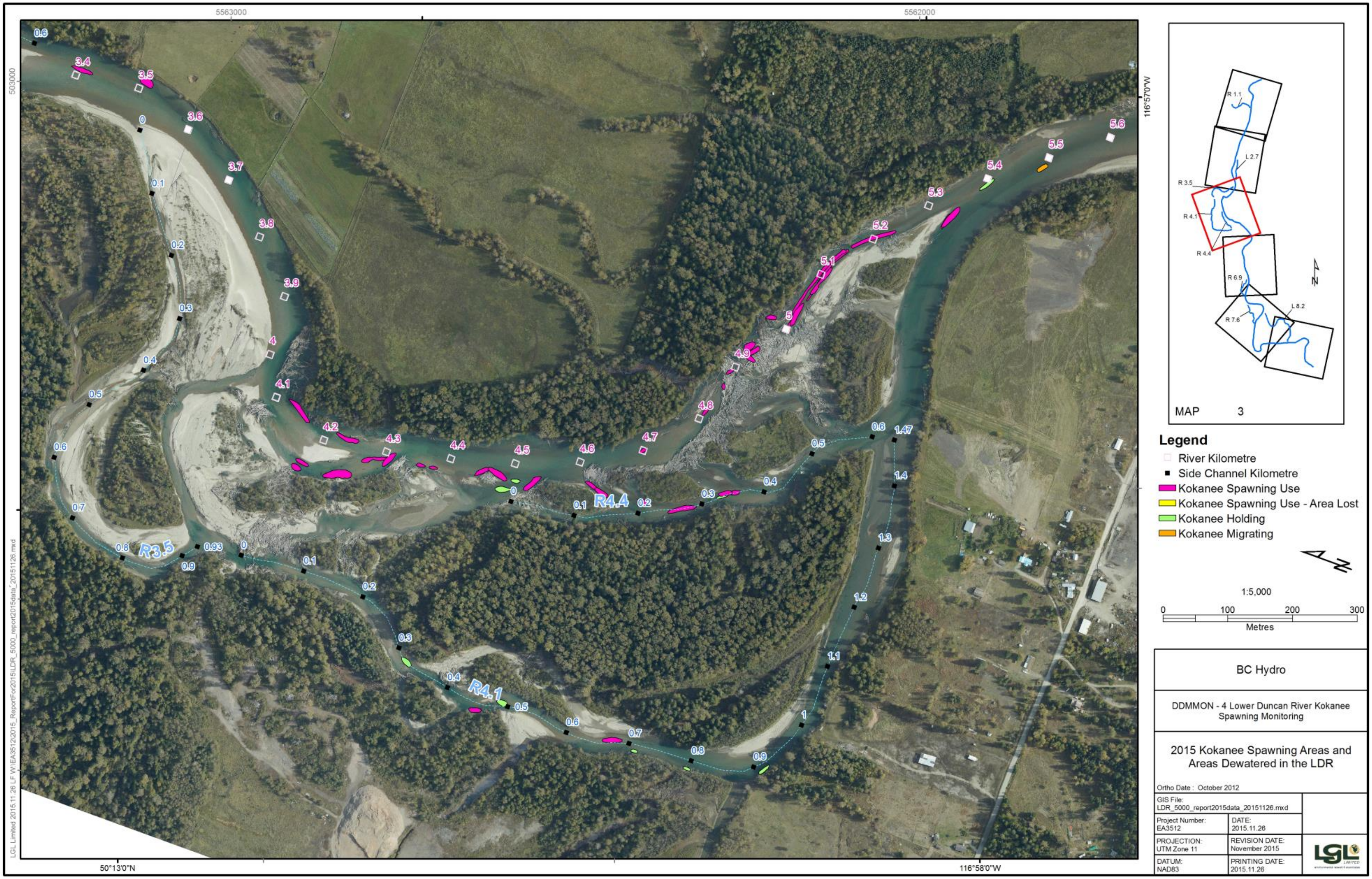
Appendix A – Kokanee Spawner Mapping for the Lower Duncan River 2015 (6 maps)


MAP 1
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151126.mxd
Project Number: EA3512
DATE: 2015.11.26
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.26
R1.1


5564000
5563000
L2.7
R3.5
MAP 2
R 1.1
L 2.7
R 3.5
R 4.1
R 4.4
R 6.9
R 7.6
L 8.2
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151126.mxd
Project Number: EA3512
DATE: 2015.11.26
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.26
50°14'0"N
116°58'0"W



Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
MAP 3
1:5,000
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151126.mxd
Project Number: EA3512
DATE: 2015.11.26
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.26

MAP 4
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151126.mxd
Project Number: EA3512
DATE: 2015.11.26
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.26
5.7
5.8
5.9
6
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7
7.1
7.2
7.3
7.4
7.5
R6.9


MAP 5
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
1:5,000
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151130.mxd
Project Number: EA3512
DATE: 2015.11.30
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.30
50°11'0"N
116°57'0"W

5559000
505000
116°56'0"W
L8.2
0.5
0.6
0.7
1.1
1.2
1.3
1.4
1.5
1.6
1.68
10.3
10.4
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2
11.3
11.4
11.5
11.6
11.7
11.8
11.9
12
12.1
12.2
12.3
R 1.1
L 2.7
R 3.5
R 4.1
R 4.4
R 6.9
L 8.2
R 7.6
MAP 6
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Spawning Use - Area Lost
Kokanee Holding
Kokanee Migrating
N
1:5,000
0
100
200
300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2015 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2015data_20151126.mxd
Project Number: EA3512
DATE: 2015.11.26
PROJECTION: UTM Zone 11
REVISION DATE: November 2015
DATUM: NAD83
PRINTING DATE: 2015.11.26