Duncan Dam Project Water Use Plan

2016 Lower Duncan River Kokanee Spawning Monitoring

Implementation Year 9

Reference: DDMMON-4

Lower Duncan River Kokanee Spawning Monitoring – Year 9

Study Period: September – October 2016

Michael Zimmer, MSc 1
Elmar Plate, PhD 3
Joe Thorley, PhD 2
Amy Duncan, MSc1

1 Okanagan Nation Alliance
 # 101, 3535 Old Okanagan Highway, Westbank, BC, V4T 3J6
2 Poisson Consulting Limited
4216 Shasheen Road, Nelson, BC, V1L 6X1
3 LGL Limited
9768 Second Street, Sidney, BC, V8L 3Y8

April 29, 2017

EXECUTIVE SUMMARY

The Duncan Dam (DDM) Water Use Planning (WUP) process was initiated to address flow management 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 2016 represented the ninth year of this ten year monitoring program. As in the previous eight years, Kokanee aerial spawner counts were carried out from a helicopter and ground counts were used to verify features of preferred spawning habitats and observer efficiency. Year 9 represents the continuation of the work carried out by ONA and LGL from 2013 to 2015 (Zimmer et al. 2015, Zimmer et al. 2016) and previously by AMEC from 2008–2012 (AMEC 2009, AMEC 2010, AMEC 2011, AMEC 2012, AMEC 2013). Field methods have been standardized for the duration of this monitoring program to ensure comparability between years. In 2016, the Area Under the Curve (AUC) model was modified so that the uncertainty varied with the annual spawner abundance. The refinement reduced the uncertainty around the abundance estimates for years with lower counts.

Based on an Area Under the Curve (AUC) calculation, the 2016 Kokanee spawning population in the Lower Duncan River was estimated to be 4,341 fish, with a lower 95% Confidence Interval (CI) of 1,874 fish and an upper 95% CI of 9,232 fish. In comparison to previous years, the 2016 estimate is the second lowest on record, next only to the 2015 estimate of 2,182 Kokanee (Lower CI = 540; Upper CI = 4,947) and about 13% of the highest estimate of 34,570 in 2011 (Lower CI = 18,460; Upper CI = 65,580). Similar to the results of previous years, both Meadow Creek and the Lardeau systems had a higher estimated number of spawners than the LDR (11,087 and 24,986, respectively), but again as in 2015 experienced comparatively low spawner escapement.

Similar to 2013, BC Hydro proposed and implemented elevated minimum flows of approximately 100 m^3/s discharge in LDR (as measured at WSC Station 08NH118) during the spawning period. In support of previous years' recommendations, these minimum flows were initiated early on September 24, 2016 to protect redds from dewatering during peak spawning.

Specific management questions defined in the DDMMON#4 Terms of Reference (TOR) and the progress made in addressing them in 2016 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 2008-2016.

Management Question	Status
What is the spawn run timing, fry emergence timing, and relative intensity of Kokanee spawning in the Lower Duncan River?	Spawn Run Timing: Based on AMEC (2013) and ONA and LGL (Zimmer et al. 2015, Zimmer et al. 2016), between 2008 and 2015 Kokanee spawned in the LDR from late August to late October and peak spawning occurred from September 28 to October 7. In 2016, the peak of Kokanee spawning activity was estimated for October 3, which falls within the range of peaks observed from 2008–2015.
What potential operational/environmental cues affect this variable?	In the nine years of study, changes in LDR flow and a 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 2016. <u>Fry Emergence Timing:</u> 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 early spring 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 early February to early April (AMEC and Poisson 2012). Based on observations in AMEC (2013) and ONA and LGL (Zimmer et al. 2015; Zimmer et al. 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> In 2016, the highest number of spawning Kokanee was observed in the Lardeau system, representing 62% of the total count for the three systems. Meadow Creek represented 27% of the count, and the Lower Duncan River represented 11% of the total count. In previous years, Kokanee escapement to Meadow Creek and Lardeau River 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 observed most commonly in 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; Zimmer et al. 2016). However, peak spawning occurred in the first week of September at Meadow Creek in 2016. In this context, water temperature does not appear to influence neither the arrival of Kokanee in the LDR nor their spawn timing. In 2016, water release through DDM was kept constant throughout most of the spawning period (September 25 - October 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 spawn in the Lardeau River 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	<u>Kokanee Spawner Distribution in the LDR:</u> As in previous years, Kokanee were observed to spawn between Kilometers 0.8 and 9.6 (See Appendix A). No redds were observed upstream of Kilometer 0.8 from Duncan Dam which is the upstream end of the study reach, or from Kootenay Lake

Creek and Lardeau River? What potential operation/ environmental/ physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable?	(downstream end of the study reach) to River km (Rkm) 9.6. Most notable concentrations of spawning Kokanee in 2016 were found between Rkm 1.8-3.1, 4.0-5.2, 5.7-7.0, and 8.7-9.6 within the study reach. Side channel (SC)use for spawning in 2016 was observed in SC 4.1R and 4.4R during the first two aerial counts (pre-flow reduction) and in SC 4.4R on October 11 and 19 (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 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 2012).
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 prevent Kokanee from accessing 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 to inform future Water Use Plan

	review processes on opportunities that minimize stranding while accommodating other important water use objectives. Notwithstanding the continued low escapement to the LDR, Meadow Creek and Lardeau River, DDM operations should continue to be sensitive to the known Kokanee spawning period in the LDR.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the following people for their contribution to this project:

BC Hydro

We gratefully acknowledge the input and guidance provided by Philip Bradshaw, Katy Jay, Jason Watson, Trish Joyce and Alf Leake of BC Hydro.

Ministry of Environment

Special thanks go to Matt Neufeld and Murray Pearson of the Ministry of Forests, Lands and Natural Resource Operations for input to field preparation and providing Meadow Creek and Lardeau River Kokanee spawner counts.

Okanagan Nation Alliance

We gratefully acknowledge the contributions of Gerry Nellestijn as the second counter in the helicopter and ONA Technician Autumn Solomon for counting during the ground surveys.

LGL Limited

Thanks to Lucia Ferreira of LGL Limited who prepared all maps for this study and estimated wetted widths and areas based on mapping data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

Appendix A – Kokanee Spawner Mapping for the Lower Duncan River 2016 (6 maps)

IMPORTANT NOTICE

This report was prepared exclusively for BC Hydro by the Okanagan Nation Alliance (ONA) in collaboration with LGL Limited and Poisson Consulting Limited. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in ONA, LGL and Poisson services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by BC Hydro only, subject to the terms and conditions of its contract with the ONA, LGL and Poisson. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

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. The dam, 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 (WUP) consultation process was initiated in 2001 to address flow management issues with respect to impacts on competing resources (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).

As a result of the CC's recommendations, Kokanee escapement in the LDR has been monitored under BC Hydro's DDMMON-4 since 2008. During the initial 5 years of the project (2008-2012),Kokanee escapement was assessed by AMEC (AMEC 2009-2013) and in 2013, ONA partnered with LGL to continue monitoring (Zimmer et al. 2015; 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 9 (2016) of this study and remaining objectives were addressed from 2008–2015 (AMEC 2009-2013; Zimmer et al. 2015; 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 is structured around the following Management Questions based on the associated Terms of Reference (BC Hydro 2008) and Scope of Services. Bolded Management Questions were addressed in Year 9 (2016) and remaining management questions were addressed from 2008–2015 (AMEC 2009-2013; Zimmer et al. 2015; 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

The purpose of this monitoring program is to evaluate the effectiveness and impacts of operational constraints defined in the DDM WUP. 2016 marked the ninth of a 10-year monitoring program for DDMMON-4. This report fulfills the ONA and LGL commitment to provide BC Hydro with a data report for the 2016 (Year 9) monitoring of Kokanee spawning in the LDR.

Similar to 2013, for 2016 BC Hydro proposed and implemented elevated minimum flows during the spawning period of around 100 m^3/s discharge in LDR (as measured at WSC Station 08NH118) and with an earlier initiation date (September 24), in support of previous years' recommendations to protect redds from dewatering during peak spawning. As part of DDMWORKS#4, this earlier (typically Sept 27) reduction to minimum flows, was proposed to test effects on reducing redd stranding and subsequent predicted egg desiccation and mortality.

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 north end of Kootenay Lake, which is located north of Nelson in southeastern British Columbia. The Duncan River watershed above DDM is fed by numerous tributaries flowing from the Selkirk and Purcell mountain ranges. The 2016 monitoring study covered the entire 12.4 km of LDR from DDM (River Rkm 0.0) to Kootenay Lake (Rkm 12.4) inclusive of side channels (Figure 1).

2.2 Environmental Parameters

Influence of hourly discharge through DDM and related water temperature records for the LDR (below the Lardeau River confluence) were obtained from the Water Survey of Canada (WSC) gauge 08NH118 (Water Survey of Canada 2016). These parameters were used to investigate relationships to Kokanee spawning onset, spawner abundance and distribution and potential desiccation of eggs.

2.3 Sample Timing

A summary of Kokanee spawning monitoring dates and methods for 2016 is summarized in Table 2. Sampling methods included five visual Kokanee counts from a helicopter and simultaneous aerial redd mapping. During the two aerial flights immediately pre and post flow reduction, stream walks were carried out on selected side-channels to assess observer efficiency for the helicopter counts. The selected side-channels were standardized locations from previous years. They typically had clear water and were un-shaded and thus offered optimum fish viewing conditions from the ground and air. An additional 700 m site along the main stem of Meadow Creek upstream of Highway 31 was included as a contingency if low or zero counts were documented in the LDR ground-count side channels. During the stream walks, ground counters verified their counts with one another through independent surveys of each section. The combined ground stream counts were used to determine helicopter observer efficiency.

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

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

Survey Date	Survey Conditions	Water Clarity	Survey Type	Helicopter Type
September 14	Sunny-cloudy	High (> 1 m)	Aerial	Twin Engine, BO105LS
September 23	Sunny-clear	High (> 1 m)	Aerial and Ground Count (pre-flow reduction to 100 m^3/s)	Twin Engine, BO105LS
September 29	Sunny-clear	High (> 1 m)	Aerial and Ground Count (post-flow reduction to 100 m^3/s)	Twin Engine, BO105LS
October 11	Sunny-clear	High (> 1 m)	Aerial	Twin Engine, BO105LS
October 19	Sunny-clear	High (> 1 m)	Aerial	Twin Engine, BO105LS

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 200 m below DDM. Aerial surveys also covered all LDR side channels following the protocol used from 2008–2014 (AMEC 2009-2013; Zimmer et al. 2015; Zimmer et al. 2016). In 2016, 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 counted visually and numbers recorded with tally counters by the lead fish counter in the front of the helicopter. To ensure the lead counter had an approximately 180^o view of the river, the pilot flew upstream at a 45^o angle to the direction of the current. The behaviour (holding, migrating, spawning or dead), number of spawners and the extent of the area that Kokanee were using was then manually drawn on a detailed 1:2,000 orthophoto and later geo-referenced digitally as a polygon layer. 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 pinpoint the exact location of Kokanee over each of the five surveys. Each side channel and main stem reach was named and the naming conventions conformed to the conventions established in the 2008-2015 studies (AMEC 2009–2013, Zimmer et al. 2015, Zimmer et al. 2016). The lead 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.

All flights were conducted at approximately 20–40 m above the ground at a speed of 10–18 km/hr upstream and conformed to BC Hydro's flight plan requirements. 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; Zimmer et al. 2016). Elmar Plate was the lead enumerator and Gerry Nellestijn the secondary enumerator for all five surveys conducted in 2016. Both enumerators have conducted surveys for this project in previous years and therefore replicated methods used previously.

2.5 Data Analyses

2.5.1 Area Under the Curve (AUC) Abundance Estimates

All statistical analyses were carried out by Poisson Consulting. 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 and fixed duration to estimate spawn timing and spawner abundance with credible intervals (CRIs). In 2016, the model was revised to allow the uncertainty in the spawner counts to vary with the annual abundance. The result was a substantial reduction in the uncertainty of estimates particularly for years with lower counts.

Hierarchical Bayesian models were fitted to the LDR Kokanee enumeration data using R version 3.3.2 (R-Team 2013) and JAGS 4.2.0 (Plummer 2012) which interfaced with each other via jaggernaut (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 R-hat (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. Plots were produced using the ggplot2 R package (Wickham 2009).

2.5.2 Observer Efficiency

Observer efficiency was based on a comparison of fish counts between ground counters and aerial counters over the exact same sections. Ground surveys were completed on September 23 and September 29 at known side channel locations (i.e., SC R3.5, SC R6.9 and SC L8.2) in the LDR and also included a 700 m section of Meadow Creek. 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 2016 all the available data were aggregated into a single database and the aerial and ground counts for all years were recalculated based on the raw data. A consequence of this consolidation was a change in the ground counts, which affected the estimates of observer efficiency. In addition, the observer efficiency model was modified so that all the error was in the aerial counts.

2.5.3 Relative Intensity of Spawning

Kokanee enumeration counts for the five surveys conducted in 2016 were used 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 AMEC's previous methods and assumptions on dewatering effects, spawn timing/superposition/predation, multiple-redd construction and sex ratios (AMEC 2012, AMEC 2013). Peak counts were used to estimate female numbers, and egg deposition for LDR Kokanee. To determine average fecundity per female, the average egg retention of 4 eggs was subtracted from the average fecundity of 225 eggs per female (AMEC 2012) for a total of 221 eggs spawned per female. Potential egg deposition was calculated as follows:

$$\text{Peak count prior to flow reduction} \times 0.5 = \text{Number of Females } (N_f)$$
$$\text{Potential eggs deposited per female } (PED_f) = \text{fecundity} - \text{egg retention}$$
$$\text{Potential total eggs deposited } (PED_t) = N_f \times PED_f$$

A second calculation of PED and loss was also included for 2016. Since Kokanee size (length, weight) in 2016 had notably increased since 2014 (based on enumerator observations), when fecundity data were collected by AMEC (2011), it was speculated that fecundity had also increased. Based on the Meadow Creek Spawning Channel biological assessment in 2016, it was confirmed that fecundity had more than tripled to an average 778 eggs with an average retention of 9 eggs for an average of 769 eggs spawned per female (M. Neufeld, pers. comm., MFLNRO, unpublished data). For comparison, calculations using historical and current average fecundity were included in this report.

Redd mapping exercises were conducted on September 23 (prior to pre-spawning flow reduction) and September 29 (post flow reduction). Potential egg losses (PEL) were calculated separately for side channel and main stem redds that were dewatered throughout the duration of the study period

(September 14 to October 19, 2016).The 1:2,000 orthophotos with hand drawn redd locations were geo-referenced using ArcGIS™ software to measure areas of redds. To calculate PED, comparisons of observed redd locations (area in m^2) in side channels and main stem before and after flow reductions were made (September 23 and September 29, respectively). Totals egg loss (PEL) from flow reduction was calculated using total eggs deposited, total area of spawning, compared to area of spawning dewatered as a result of DDM flow reduction, using the following equation:

$$\text{Potential total eggs deposited } (ED_t) \text{ / Pre-flow reduction Spawning Area } (SA_{pre}) = \text{Eggs/m}^2$$
$$\text{Total potential egg loss } (PEL_t) = \text{Spawning Area dewatered } (m^2) \text{ x Eggs/m}^2$$

Subsequently:

$$\text{Potential egg loss in Side channels } (PEL_{sc}) = \text{Spawning Area dewatered in Side Channels } (m^2) \text{ x Eggs/m}^2$$
$$\text{Potential egg loss in Mainstem } (PEL_{ms}) = \text{Spawning Area dewatered in Mainstem } (m^2) \text{ x Eggs/m}^2$$

Such that:

$$PEL_t = PEL_{sc} + PEL_{ms}$$

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, Figure 3), the Kokanee spawning period in September and October 2016 was characterized by a regulated decrease in primary water level and discharge 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 240 m^3/s on September 21, 2016 in two steps: to 180 m^3/s on September 24; down to 100 m^3/s on September 25; where they stayed until early November (Figure 3).The two flow reductions between September 23 and 25 lowered the primary water level in the LDR from 2.40 m to 1.80 m (Figure 4), which was similar to 2013-2015 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 13.2 °C to 14.7 °C (September 11-October 2), decreasing to the lowest temperature of 10.0 °C on October 13. From there the temperature increased slightly to ~11.0 °C on October 17 and trended lower from there on.

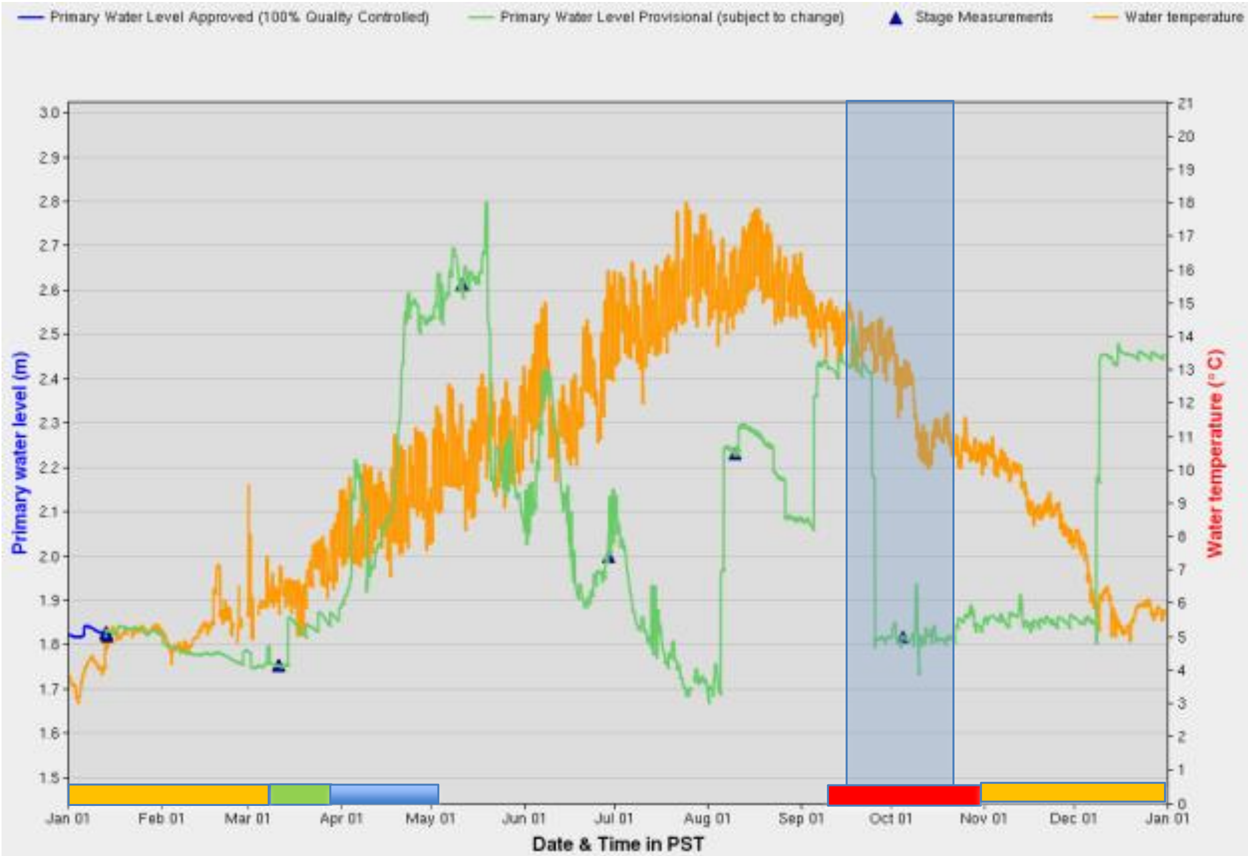

Figure 2: Primary water level (m) (green line) and temperature (°C) (orange line) for Lower Duncan River at Lardeau River confluence for 2016 (Source: Water Survey of Canada Stn. 08NH118). Transparent blue box indicates Kokanee enumeration study period for DDMMON 4 2016. Solid colour boxes along the bottom 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: Lower Duncan River (Stn 08NH118) discharge (m^3/s) (green line) and temperature (°C) (orange line) at the confluence of Lardeau River, September 11 - October 23, 2016 (Source: Water Survey of Canada). Survey dates are indicated by the dashed lines; blue lines indicate aerial surveys only, red lines indicate both aerial and ground survey dates.

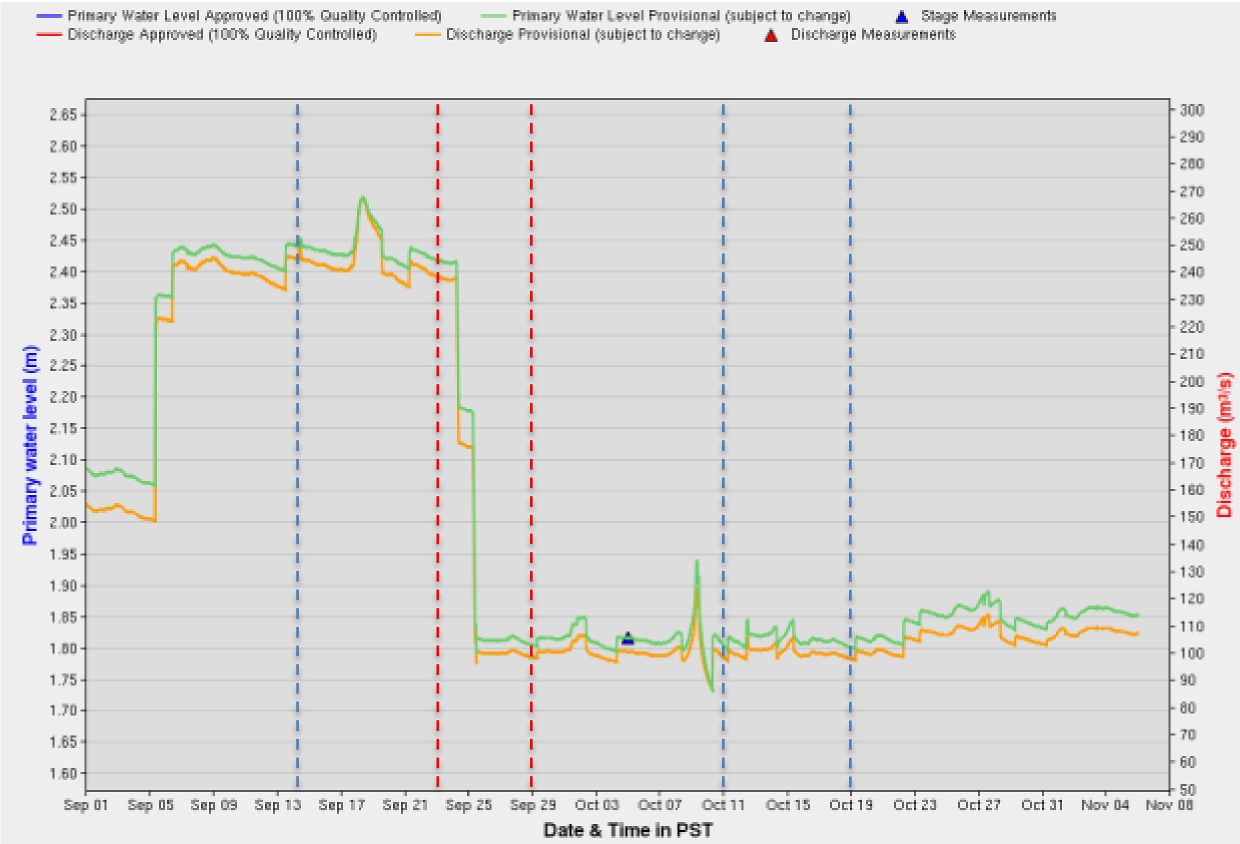

Figure 4: Primary water level (m) (green line) and discharge (m^3/s) (orange line) for Lower Duncan River at the confluence of the Lardeau River September 1 – November 5, 2016 retrieved from Water Survey of Canada Stn. 08NH118. Survey dates are indicated by the dashed lines; blue lines indicate aerial surveys only, red lines indicate both aerial and ground survey dates.

3.2 Kokanee Peak Count Timing

The estimated timing of peak spawning abundance for LDR Kokanee in 2016 and throughout the rest of the DDMMON-4 project period from 2008–2015 is shown in Figure 5. A tabular summary for the timing of the estimated annual peak counts from 2008–2016 is also shown in Table 3. Peak spawning abundance was estimated for October 3 in 2016 which fell within the time range of peak spawning abundance observed in previous years (Figure 6).

With the exception of 2015, the peak spawning estimates changed by at most two days from last year's analysis and, in general, there was a reduction in the uncertainty surrounding the peak spawning estimates. The changes in the spawn timing estimates reflect the fact that they are intimately tied to the abundance estimates.

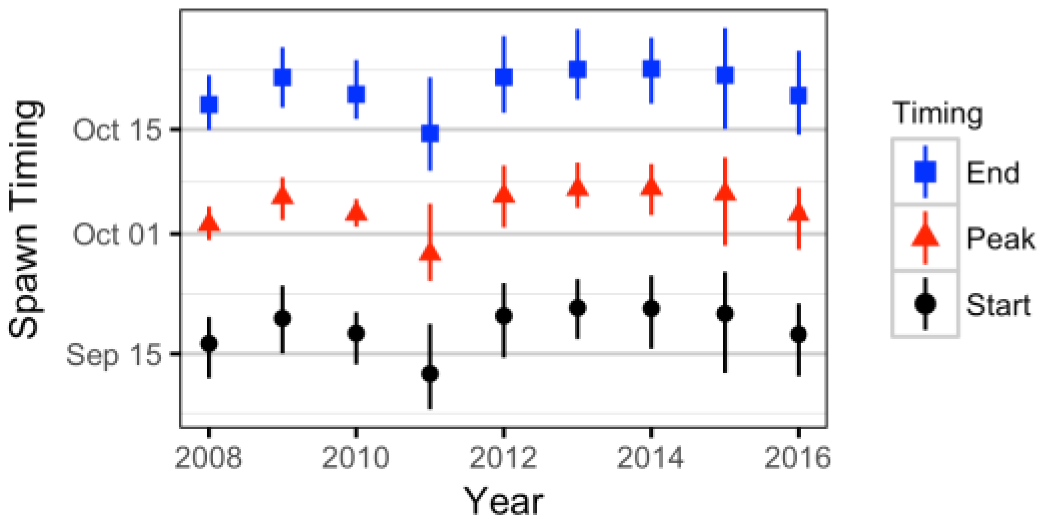

Figure 5: Predicted timing of LDR Kokanee peak spawning abundance by sampling year with 95% CIs.

Table 3: Estimated timing of annual peak counts for Kokanee spawning by sampling year in the LDR study area.

Year	Date of Peak Spawning	Lower 95% CI	Upper 95% CI
2008	Oct 2	Sep 30	Oct 4
2009	Oct 5	Oct 2	Oct 8
2010	Oct 3	Oct 1	Oct 5
2011	Sep 28	Sep 24	Oct 5
2012	Oct 6	Oct 1	Oct 10
2013	Oct 7	Oct 4	Oct 10
2014	Oct 7	Oct 3	Oct 10
2015	Oct 6	Sept 29	Oct 11
2016	Oct 3	Sept 28	Oct 7

3.3 Area Under the Curve Estimates

AUC estimates of daily and total LDR Kokanee spawner abundance for 2016 and all previous sampling years are presented in Figure 6 and 7, respectively. Estimated total spawner abundance in 2016 (4,341; 95% CI 1874, 9232) was higher than the 2015 abundance estimate (2,182; 95% CI 540, 4947), however still lower than all other years of the study (Table 4).

Due to the recalculation of the aerial and ground counts, as well as the modifications to the observer efficiency and AUC models, the abundance estimates for all years tended to decrease from estimates reported in all earlier DDMMON-4 reports although there is still substantial overlap between the newly calculated AUC estimates and AUC estimates calculated using the previous AUC calculation method.

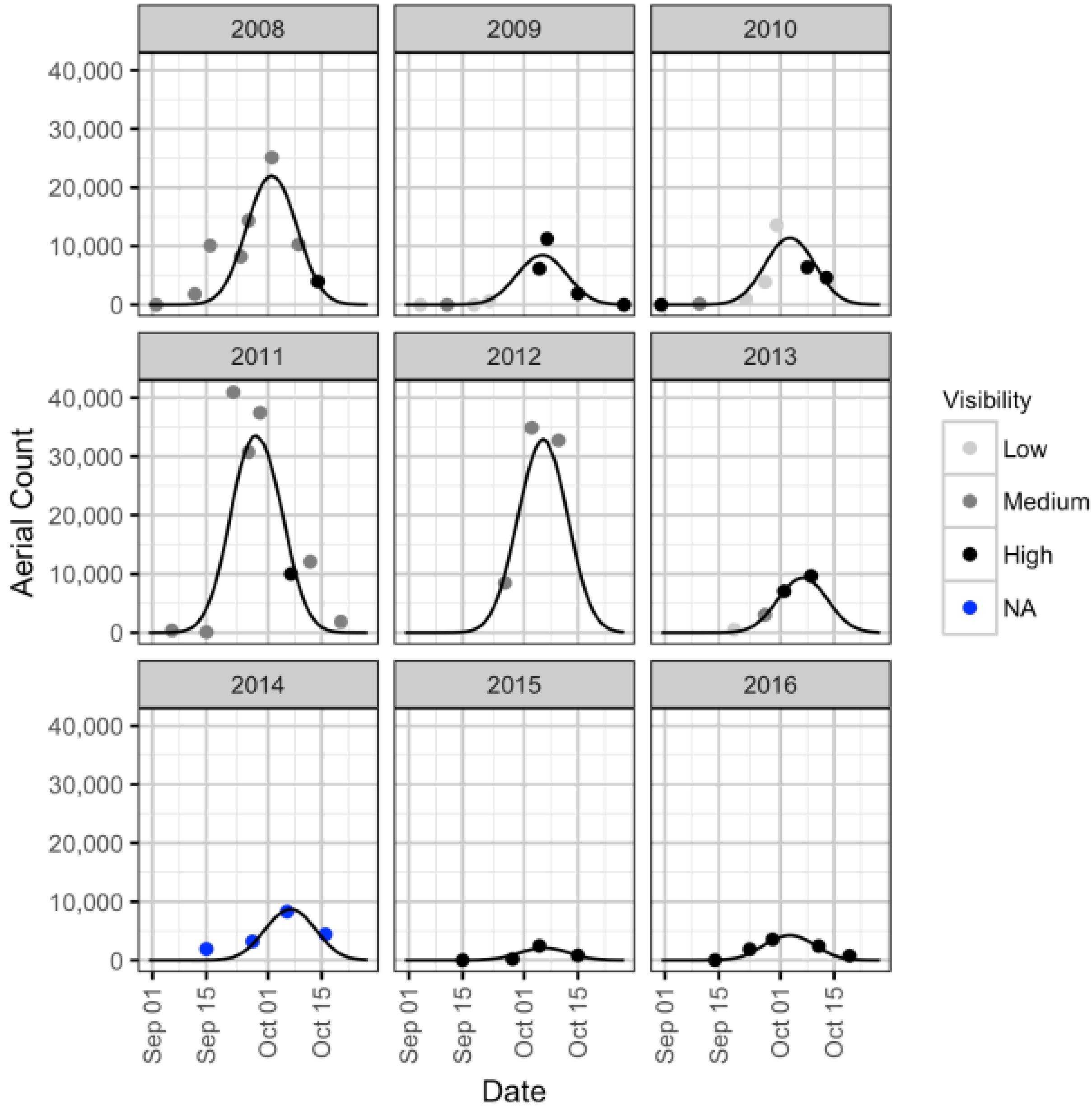

Figure 6: Kokanee spawner aerial counts (dots) with AUC estimated daily counts (black line) (gauged by low, medium and high visibility) by date and year within the LDR. Blue dots indicate visibility was not documented.

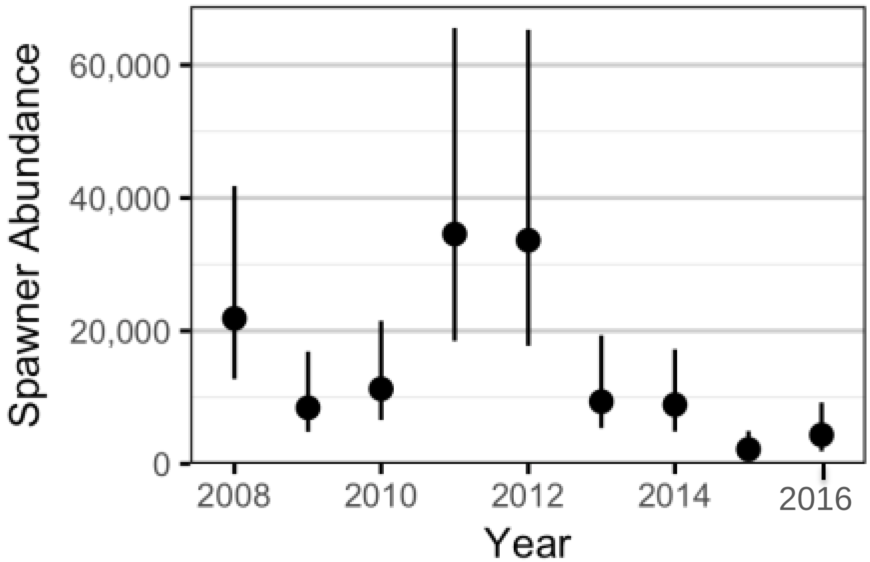

Figure 7: AUC estimated total LDR Kokanee spawner abundance by year with 95% CIs.

Table 4: AUC estimated peak Kokanee spawner abundance in the LDR from 2008–2016.

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI	SD	# of Surveys
2008	21,870	12,740	41,800	7,550	8
2009	8,430	4,800	16,900	3,070	8
2010	11,270	6,580	21,520	3,880	7
2011	34,570	18,460	65,580	12,530	8
2012	33,620	17,740	65,320	12,220	3
2013	9,360	5,370	19,340	3,570	4
2014	8,890	4,840	17,240	3,130	4
2015	2,182	540	4,947	1,272	4
2016	4,341	1,874	9,232	1,874	5

3.4 Relative Intensity of Kokanee Spawning in the Duncan River System

Total estimated number of spawning Kokanee for each location is presented in Figure 8. In 2016, the majority of the total estimated number of spawning Kokanee was from the Lardeau River (62%) while Meadow Creek contributed 27% and the LDR contributed 11% to the total estimated count (Table 5). Estimated spawner abundance distribution in 2016 was similar to previous years, when Kokanee escapement to Meadow Creek and Lardeau River represented >85% (2014) and >94% (2008-2013) of the total Duncan system Kokanee run; however, contribution from Meadow Creek Spawning Channel was higher than Lardeau River in earlier monitoring years (Figure 8, Table 5).

The combined Kokanee escapement estimate for all three segments of the Duncan system in 2016 (40,414) was the one of the lowest on record and represents only 2% of the largest escapement estimate of 1,804,044 Kokanee in 2011 (Figure 8, Table 5).

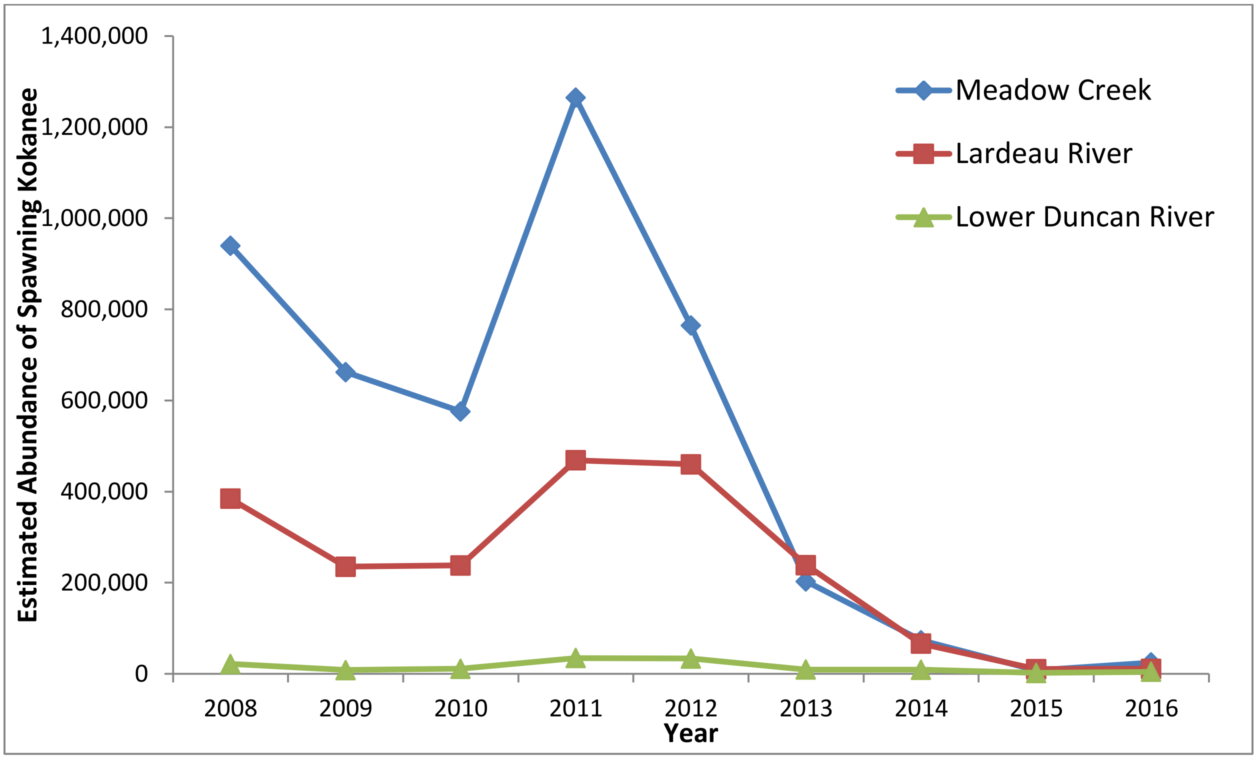

Figure 8: Estimated abundance of Kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008-2016 (source for Meadow Creek and Lardeau River: MFLNRO, M. Neufeld pers. comm./unpublished data; source for Lower Duncan River: AMEC 2013; Zimmer et al. 2015; Zimmer et al. 2016).

Table 5: Relative intensity of estimated Kokanee spawning abundance in the whole Duncan River system, 2008-2016.

Year	Meadow Creek (%)	Lardeau River (%)	Lower Duncan River (%)	Total Estimate
2008	69%	28%	2%	1,354,517
2009	72%	26%	2%	917,235
2010	69%	29%	2%	832,760
2011	70%	26%	4%	1,804,044
2012	59%	35%	6%	1,299,944
2013	44%	52%	4%	461,687
2014	45%	41%	14%	161,856
2015	29%	39%	32%	26,576
2016	27%	62%	11%	40,414

3.5 Migration, Holding and Spawning Behaviour

The initial survey conducted on September 14 showed low numbers of Kokanee in the LDR (Figure 9), all of which were holding within the main stem of the LDR. No spawning was observed in the initial survey. Spawning was observed in all subsequent surveys and the highest number of spawners were observed on September 29 (3,603). During the last survey on October 19, 746 Kokanee were observed spawning and there was no observations of holding Kokanee. No Kokanee were observed migrating during any of the surveys, nor were any dead Kokanee observed.

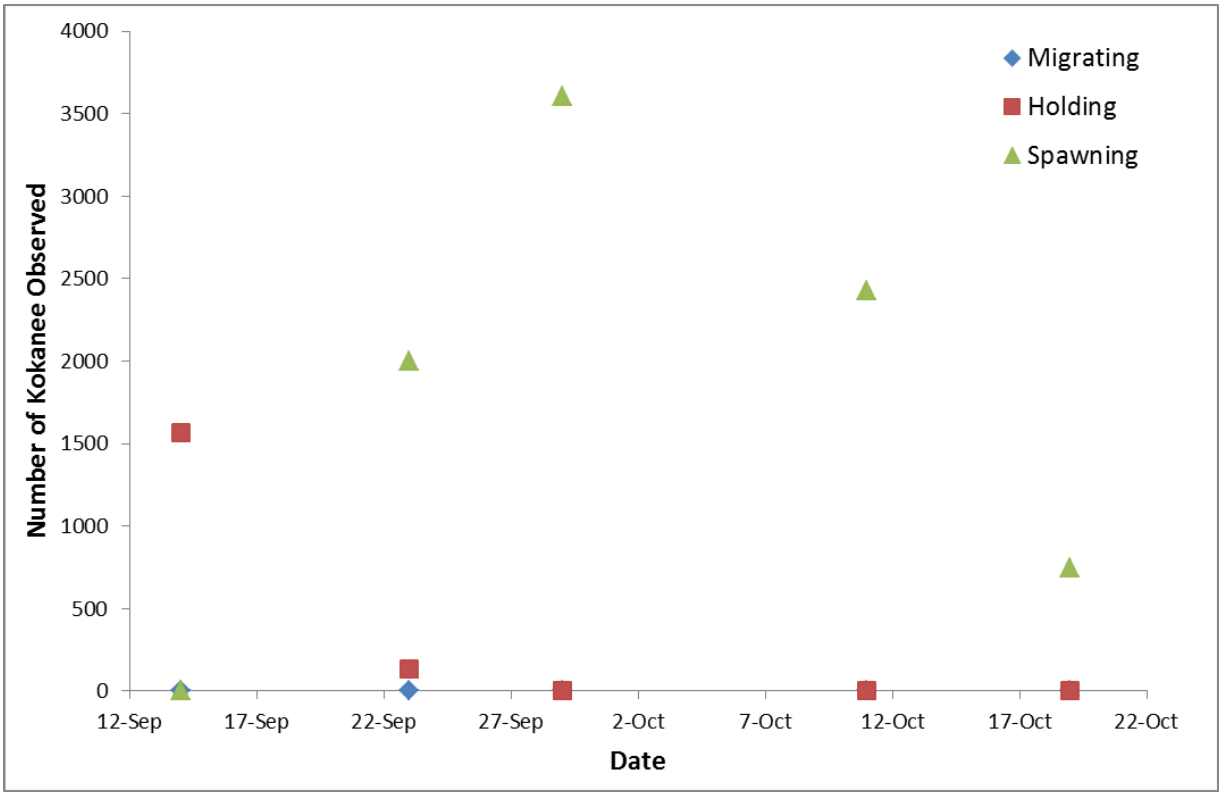

Figure 9: Number of migrating, holding and spawning Kokanee enumerated in the Lower Duncan River in 2016.

3.6 Spawner Distribution and Habitat Use in the LDR

As in previous years, Kokanee were observed to spawn in the upstream 70-80 % of the study area. Main concentrations of redds were observed between Kilometers 1.8-3.1, 4.9-5.2, 5.7-7.0, and 8.7-9.6 (See Appendix A). No redds were observed in the Duncan Dam discharge channel between Kilometer 0.8 and the dam, or from Kootenay Lake (downstream end of the study reach) up to Rkm 9.6. Side channel use for spawning was observed in side channels R4.1 and R4.4 during the aerial count on September 23 (pre-flow reduction)and again in side channels R4.1 and R4.4 on September 29 (post-flow reduction). (See Appendix A).

Table 6: Number of observed spawning Kokanee distributed in the LDR main stem and side channels for 2016.

Date	Main Stem (MS) or Side Channel (SC)	Holding (N)	Migrating (N)	Spawning (N)
14-Sep-16	MS	1497	0	0
	SC	69	0	0
23-Sep-16	MS	62	0	1837
	SC	0	0	34
29-Sep-16	MS	0	0	3542
	SC	0	0	2
11-Oct-16	MS	0	0	2359
	SC	0	0	68
19-Oct-16	MS	0	0	740
	SC	0	0	6

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

The 2016 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 23 and September 29, 2016. 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 240 m^3/s on September 21; down to 180 m^3/s on September 24 and further reduced to 100 m^3/s on September 25, 2016.

The total area used by spawning Kokanee pre-flow reduction in the LDR mainstem (13,564 m^2) and side channels (185 m^2) in 2016 was approximately 13,749 m^2, containing an estimated 206,746 eggs (AMEC fecundity estimate) or 719,400 (MFLNRO fecundity estimate) that were deposited (Table 7; see Section 2.5.4 for formulae). Total loss in spawning area was 6 m^2 and was evident only in side channel R3.5 (at R3.5 Rkm 0.01). Subsequent potential egg losses post-flow reduction occurred only in side channels (R3.5) and was calculated as 122 eggs (Side channel estimate - using AMEC's method, and based on 20.31 eggs/m^2) or 425 eggs (using FLNRO's data, and based on 70.66 eggs/m^2) (**Error! Reference source not found.**). Egg deposition in mainstem redds was 14.97/m^2 (AMEC fecundity) and 52.07/m^2 (FLNRO 2016 fecundity). No egg losses from flow reduction occurred in the mainstem.

Table 7: Total spawning area, area dewatered (difference), Potential Egg Deposition (PED), number of eggs dewatered and spawning success for side channel (SC) and main stem areas (MS) within the LDR study area before (Pre) and after (Post) Kokanee Protection Flows, 2009 to 2016 (adapted from AMEC 2013, Zimmer et al. 2015, Zimmer et al. 2016). (AMEC) or (FLNRO) denotes different fecundities as described in previous sections.

Year	Pre- or Post Flow Reduction	Total Spawning Area (m^2)		Potential Egg Deposition (N)	
		Side Channel	Main Stem	Side Channel	Main Stem
2016	Pre	185	13,564	3,757 (AMEC) or 13,073 (FLNRO)	202,989 (AMEC) or 706,327 (FLNRO)
	Post	179	13,564	3,635 (AMEC) or 12,648 (FLNRO)	202,989 (AMEC) or 706,327 (FLNRO)
	Difference	6	0	122 (AMEC) or 425 (FLNRO)	0
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 back calculating areas based on observed watered and dewatered side channel and main stem redds on one survey – October 2, 2013

[b] Main stem mapping was not conducted prior to the flow reduction. However, no dewatered redds were observed in the main stem 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.

3.8 Calibration of Observer Efficiency

The observer efficiency for 2016 was 92% based on calibration counts of fish holding in Meadow Creek. No fish could be observed in either the aerial or the ground counts in Side Channels 6.9R and 8.2L. A contingency of sampling a section of Meadow Creek was invoked in the event that none to very few Kokanee were observed during flights over Side Channels 3.5R, 6.9R, or 8.2L. During calibration ground counts, the gross majority (97 of 100) of Kokanee were counted in the contingency section of Meadow Creek, while very few (3 of 100) were observed in SC 3.5R.

Table 8 summarizes results of all DMMMON-4 ground calibration counts for the aerial counts from 2008 to 2016. Figure 10 and Figure 11 summarize the relationship between aerial versus ground counts and predicts through the linear relationship between the two variables that aerial counts are moderately higher than the ground counts mainly based on initial DDMMON-4 years from 2008-2010. Due to the changes in the ground counts and observer efficiency model, the estimate of the overall observer efficiency increased from 1.06 (95% CI 0.69, 1.50) in last years analysis to 1.44 (95% CI 0.95, 2.31) in the current analysis.

Table 8: Aerial and ground Kokanee calibration counts for standardized locations in the LDR from 2008-2016.

Date	Channel	Aerial Count	Ground Count
2008-09-24	6.9R	1710	1484
2009-09-22	3.5R	75	45
2009-10-02	3.5R	100	101
2009-09-22	8.2L	172	75
2009-10-02	8.2L	15	35
2009-10-09	8.2L	10	299
2010-10-06	3.5R	822	284
2011-09-29	3.5R	5720	2518
2011-09-29	6.9R	230	490
2014-09-27	3.5R	20	7
2014-09-27	8.2L	294	285
2016-09-23	3.5R	2	3
2016-09-23	MC	61	67
2016-09-29	MC	29	30

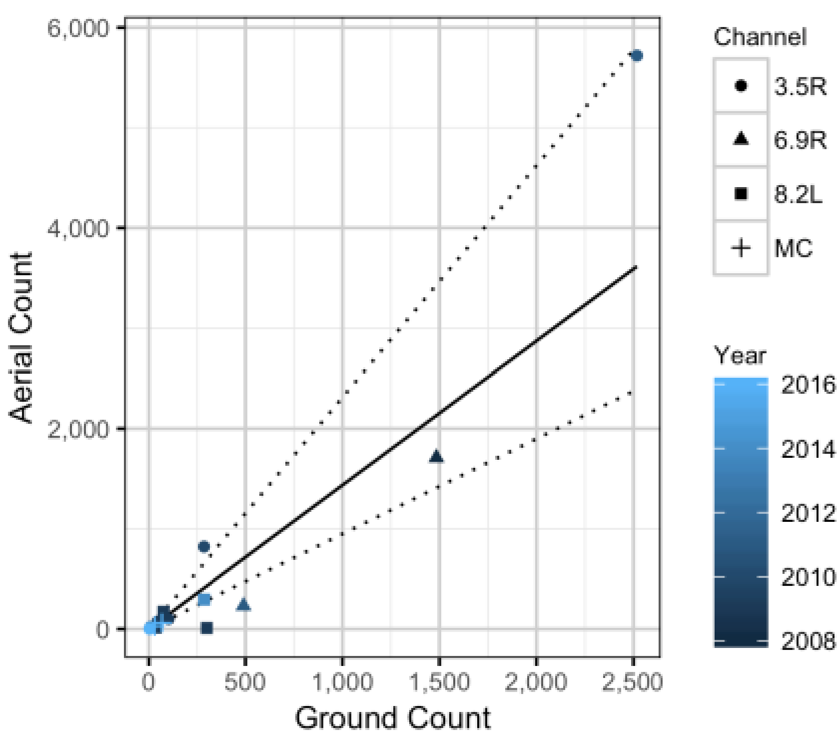

Figure 10: Aerial versus ground Kokanee spawner counts (points) and predicted ground count (solid line; dotted line 95% CRIs) by year and channel from 2008-2016.

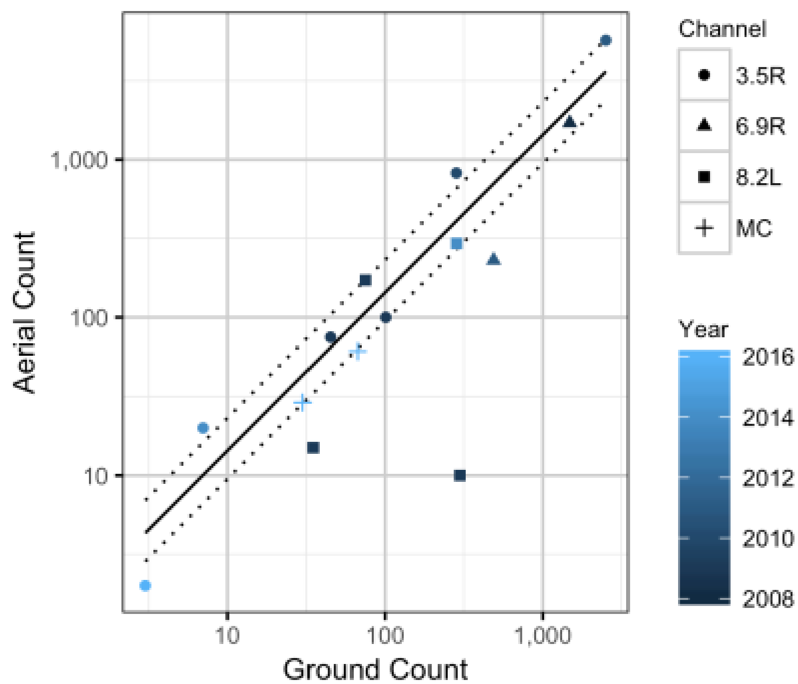

Figure 11: Aerial versus ground Kokanee spawner counts (points; log10 scale) and predicted ground count (solid line; dotted line 95% CRIs) by year and channel from 2008 to 2016.

4.0 DISCUSSION

The following discussion is structured along the management questions that were applicable to Year 9 of DDMMON-4.

4.1 Lower Duncan River Environmental Parameters: Temperature and Discharge

Water temperatures followed a similar trend to previous years showing a correlated decrease following the decrease in discharge and increasing slightly once water levels stabilized at the lower level. This pattern was very similar to the pattern observed in 2014 and 2015, 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 based on reductions in DDM discharge, thereby decreasing inflows from the warmer reservoir and receiving more influence from the colder and natural flow contribution of the Lardeau River. 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 reduces the temperature in the fall (AMEC and Poisson 2012). Further monitoring of Duncan Reservoir temperatures in contrast to 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 was regulated through DDM in consideration of Lardeau River flows in September and October 2016 to manage for protection of Kokanee spawning in the LDR. In 2016, Kokanee protection flows were initiated on September 23, four days earlier than typical. In 2016, discharge in the LDR underwent a two-step flow reduction from summer highs (240 m^3/s) down to around 100 m^3/s for the period September 23 to September 25. This was very similar, albeit slightly earlier, to the 2014 and 2015 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 14, 2016 with 1,566 Kokanee observed holding within the main stem LDR at the confluence with the Lardeau River. Although in 2016 a much smaller number of Kokanee were observed compared with previous observations 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. This first survey was also concurrent with higher Duncan Dam discharges preceding the initiation of annual discharge reductions for Kokanee spawning protection. The highest visual count of 3,544 Kokanee was observed on the third enumeration flight on September 29, 2016, which was earlier than the dates of the flights with the highest observed counts in 2015 (2,458 on October 5), 2014 (peak of 8,315 on October 6) and 2013 (peak of 9,662 on October 9). However, between 2002 and 2011 dates of the highest number of fish observed in an aerial survey have ranged from September 19 to October 7 (AMEC 2013). Peak count dates do not represent the estimated peak of the run but are the highest count observed in an aerial survey which likely does not represent the date that the run was estimated to peak at.

Continued surveys indicated a successive increase in the number of spawning Kokanee in the LDR from September 14 (first survey), to the peak count on the third survey (September 29), followed by a significant decrease on the final survey on October 19. 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 recommendation of increasing the survey period to a minimum of 30 days , compared to the 20 day period used in 2013 (Sept 19-Oct 9) which failed to capture the descending limb of spawner abundance.

4.3 Relative Intensity of 2016 Kokanee Spawning in the LDR

From 2008-2012, the majority (59-72 %) of Kokanee in the Duncan River watershed used to spawn in the Meadow Creek Spawning Channel. From 2013 on, along with decreasing total estimated run sizes, this picture changed and the majority of Kokanee in the system spawned in the Lardeau and the LDR combined. In 2015 and 2016, an estimated total of less than 41,000 fish spawned in all three spawning spawning tributaries of the Duncan system and due to the low numbers of spawners in the Meadow Creek Spawning Channel, the relative contribution of the LDR spawning rose from 2 % in 2008 to 32 % in 2015. In 2016, this number decreased to 11% due to a larger contribution from the Lardeau River, while the Meadow Creek Spawning Channel's contribution of 27 % remained far below the historic highs.

4.4 Area Under the Curve Estimates

Using a revised model in 2016, for Area Under the Curve (AUC) estimation, the 2016 Kokanee spawning population in the LDR was estimated to be 4,341 fish (±1,874; 1,874-9,232 95% CI). In comparison to previous years, the 2016 estimate is the second lowest on record, higher only than the 2015 estimate of 2,182 spawners. The highest spawner abundance estimates occurred in 2011 and 2012 estimating 34, 570 (±12,530) and 33, 620 (±12,220), respectively. Similarly, in 2016 the lowest combined escapement estimate of 40,414 Kokanee for all three segments of the Duncan system (Meadow Creek, Lardeau River and LDR) was recorded. The 2016 combined estimate represented only 2% of the largest combined escapement estimate of 1,804,044 Kokanee in 2011.

In 2016, the Area Under the Curve (AUC) model was modified so that the uncertainty varied with the annual spawner abundance. The refinement reduced the uncertainty around the abundance estimates particularly for years with lower counts. The reduction in uncertainty combined with the changes in observer efficiency resulted in substantially lower estimates of abundance which were nonetheless within the range of possible values from previous analyses. The reduction in uncertainty is considered an improvement because it accounts for the fact that the variation in abundance is greater in years with more fish.

4.5 Relative distribution of Kokanee spawners in the Lower Duncan River

In 2016, Kokanee were observed to spawn between Rkm 9.6 at the downstream end of the LDR, close to Kootenay Lake and Rkm 0.8 at the upstream end of the LDR close to Duncan Dam. The main concentrations of redds were observed in areas where substrate composition (gravel) and flow (estimated between 0.3-0.8 m/s) appeared ideal for Kokanee spawning. Many areas that also provided spawning habitat characteristics were not used in 2016 due to the low overall number of fish. The general spawning utilization of side-channels, even those that have only a slightly lower flow than the main channel, just like the overall number fish observed, was reduced when compared with previous years and limited to small sections of SCs 4.1R and 4.4R pre- and post-flow reduction (see Appendix A). The use of side channels with surface flow that was stopped as a consequence of the flow reduction was limited to three fish in SC 3.5R. It appears as if fish that are spawning in side channels with loss of surface flow during flow reduction may be decreasing in numbers over time likely based on the complete loss of their offspring by dewatering.

4.6 Kokanee Spawn Mapping, PED and Egg Losses

The total area used by spawning Kokanee in the LDR side channels and main stem in 2016 was approximately 13,749 m^2, containing an estimated 206,746 eggs using AMEC's methods or 719, 400 eggs using FLNRO's 2016 fecundity data. Total area of redd dewatering was estimated at 6 m^2 between the September 23 and 29 enumerations, and was limited to SC R3.5 only. Based on the 6 m^2 of flow reduction based dewatering, approximately 120 eggs (AMEC's methods) or 426 (FLNRO's fecundity data) were lost by dewatering. The calculated percentage egg loss of 3.2% (AMEC fecundity data) and 3.3% (FLNRO 2016 fecundity data) within side channel egg deposition, and a total of 0.06% (all mainstem and side channel spawning areas) egg loss appears to be low compared to past years. However, the low use of side channels may be a result of a continued drastic decrease in spawner escapement.

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 for spawning. Once flows are reduced, main stem habitats are more abundant and preferred (AMEC 2013). The main stem of the LDR was the preferred spawning habitat in 2016 Kokanee run, as only 108 (2%) spawners out of the total estimated run of 4,341 Kokanee were observed spawning in the side channels. Since mainstem spawning habitats remained watered after the flow reduction, it is no surprise that no dewatered redds were observed.

Egg loss from flow reductions were very low in 2016. Earlier DDM reductions in 2016 for Kokanee spawning protection was inconclusive with regard to decreasing egg loss due to redd stranding/dewatering. Significant factors that played a role include the very low numbers of Kokanee escapement to the LDR, which following low 2015 escapement, continues to be at all-time historical lows. Significant reductions in side channel use over the duration of the study further exacerbates the challenges in determining comparative egg losses specific to side channels. However, regardless of the low spawner abundance, loss of potential spawning habitat area due to dewatering was very low following the flow reduction (6 m^2). Additionally, the earlier flow reduction did significantly precede the peak spawning of October 3 (95% CI September 28 to October 7), which also likely reduced risk of dewatering.

Consideration should also be given to the apparent increase in individual Kokanee fecundity. In 2015, fish size appeared to be larger, an observation confirmed again in 2016 with visual observations from the both DDMMON 4 air and ground crews. Air crews cited that individual fish were more discernable in 2016. Meristic data collected by FLNRO at the MCSC confirm our observations of uniformly larger fish in 2016. FLNRO 2016 MCSC average length (FL) for female spawner kokanee was 38.0 cm, compared to 24.1 cm (AMEC 2009) and 20.0-25.0 cm (AMEC 2012). Similarly, 2016 fecundity data also collected by FLNRO showed a three-and-a-half times increase in egg deposition per female compared to AMEC's findings from 2012-2013. Given the prolonged decline in Kokanee escapement to the Duncan/Lardeau system from Kootenay Lake, there exists an opportunity for greater annual growth with the significant decrease in inter-cohort competition (Rieman and Myers 1992), and the response appears to be a larger average fish size at maturation and spawning.

4.7 Calibration of Observer Efficiency

The observer efficiency for 2016 relied heavily on a contingency site, as the standardized sites (SCs 6.9R, and 8.2L) held no fish and SC 3.5R held only three fish. Observer efficiency of air counts to ground counts over the three standardized sites (LDR Side Channels) and Meadow Creek was 92%. Ground counts were slightly higher than air counts most likely due to some fish holding in micro habitat features such as instream woody debris, overhanging vegetation and cut banks – positions likely occluded from aerial observers. Overall, the selection and use of a Meadow Creek contingency site was a balance between:

1) finding a section of water with Kokanee;
2) that had easily recognizable start and end points;
3) was visible from the air for the greater majority; and
4) was accessible from the ground.

5.0 RECOMMENDATIONS

1. Efficiency of Spawner Protection Flows: Annual Kokanee spawner protection flows provide a benefit to Kokanee spawning post-reduction each year but there is likely a measurable impact to that portion of the run that spawns in higher flows prior to implementing the protection flow regime, in years of high escapement. 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 to inform future Water Use Plan review processes on opportunities that minimize stranding while accommodating other important water use objectives.

2. Survey Period: By expanding the survey period by 10 days from 20 days before 2013, to 30 days in 2014 and 2015, we were able to observe the onset, peak and decrease in numbers of Kokanee spawners in the LDR in aerial counts. Further increasing the sampling period by an additional 5 days in 2016, as well as including an additional flight, improved the probability of capturing onset, peak, and conclusion of the LDR Kokanee spawning period. For 2017, we therefore plan to cover a total minimum period of 35 days with five aerial counts to capture the spawning peak from last week of September to first week of October and the annual DDM flow reduction period of September 24 – October 1.

3. Spawner Enumeration Methods: Current methods for spawner enumeration and redd surveys should be continued, including low elevation flights (>20 m). Additionally, future enumerations will aim to be completed by the same study team, replicating to the furthest degree possible the results from the most experienced core of the teams used in 2014 to 2016 surveys.

4. Ground Counts to Calibrate Aerial Counts: The calibration counts comparing the aerial survey with on the ground counts in standardized side-channels (SCs 3.5R, 6.9R, and 8.2L) should continue to maintain continuity with established methods. Communication should continue between air and ground crews to invoke contingency calibration sites and plan-on-the-fly in case that zero or very low counts are observed in standardized locations. The section of Meadow Creek used in 2016 suits this function. Sections of SCs 4.1R or 4.4R appear to also fit this description but may be high-flow limiting [safety] during pre-flow reduction ground truthing.

5. 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.

6. 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.

6.0 REFERENCES

AMEC. 2009. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 1 Data Report (2008). DDMMON#4. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 37 pp + 5 App.

AMEC. 2010. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) – Year 2 Data Report (2009). Prepared for BC Hydro – Castlegar, BC. 43 p. + 7 App.

AMEC. 2011. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) – Year 3 Report (2010). Prepared for BC Hydro – Castlegar, BC. 35 p. + 4 App.

AMEC. 2012. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 4 Synthesis Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 60 pp + 8 App.

AMEC. 2013. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 5 Synthesis Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 22 pp + 2 App.

AMEC and Poisson. 2012. Lower Duncan River Water Quality Monitoring (DDMMON-7): Year 2 Report. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 51 pp. + 4 App.

BC Hydro. 2004. Consultative Committee Report, Duncan Dam Water Use Plan – Executive Summary. Prepared by the BC Hydro Project Team and Duncan Dam Water Use Plan Consultative Committee. 10 pp.

BC Hydro. 2007. Duncan Dam Project Water Use Plan. December 20, 2007. Prepared for the BC Hydro Duncan Dam Water Use Plan Project, Burnaby, B.C.

BC Hydro. 2008. Duncan Dam Water Use Plan Monitoring Program Terms of Reference.

English, K. K., Bocking, R. C., and Irvine, J. R. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences. 49(10):1982–1989.

Hilborn, R., Bue, B., and Sharr, S.1999 Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences. 56(5): 888-896.

Kéry, M., Michael Schaub.2011. Bayesian population analysis using {WinBUGS} : a hierarchical perspective. Available: http://www.vogelwarte.ch/bpa.html

Lemay, M.A. and M.A. Russello. 2012. Neutral loci reveal population structure by geography, not ecotype, in Kootenay Lake kokanee. North American Journal of Fisheries Management 32: 282-291.

Rieman, B.E. and Myers, D.L. 1992. Influence of fish density and relative productivity on growth of Kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Societey 121, 178-191.

Plummer, M. 2012. {JAGS} version 3.3.0 user manual. Available: http://sourceforge.net/projects/mcmc-jags/files/Manuals/3.x/.

R Team.2013. R: a language and environment for statistical computing. Available: http://www.R-project.org.

Quamme, D. 2008. Meadow Creek Spawning Channel - Scarification Monitoring and Suspended Sediment Assessment 2003-2007. Prepared for Fish and Wildlife Compensation Program, Nelson, BC Prepared by Integrated Ecological Research, Nelson, BC. 26 pp + 7 app.

Quinn, T.P. 2005. Behavior and Ecology of Pacific Salmon and Trout. ISBN 0-7748-1127-7. American Fisheries Society – UBC Press. 378 pp.

Su, Z., Adkison, M, and Alen, B. 2001. A hierarchical Bayesian model for estimating historical salmon escapement and escapement timing. Canadian Journal of Fisheries and Aquatic Sciences. 58(8):1648-1662.

Thorley, J. 2014. jaggernaut: An R package to facilitate Bayesian analyses using JAGS (Just Another Gibbs Sampler). Available: https://github.com/joethorley/jaggernaut.

Wickham, H. 2009 ggplot2: elegant graphics for data analysis. Available: http://had.co.nz/ggplot2/book.

Zimmer, M., C. K. Whitney, J. Thorley and E. Plate. 2015. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 6 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 23 pp + 1 App.

Zimmer, M., K. Beach, J. Thorley and E. Plate. 2016. Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4) - Year 7 Data Report. Report Prepared for: BC Hydro, Burnaby. Prepared by: Okanagan Nation Alliance and LGL Limited. 35 pp + 1 App.

Water Survey of Canada. 2016. Search for water temperature and discharge levels in the Lower Duncan River below Duncan Dam. Available: https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08NH118. Accessed on: Date

Appendix A – Kokanee Spawner Mapping for the Lower Duncan River 2016 (6 maps)

MAP 1
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28
R1.1

5564000
5563000
MAP 2
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28
50°14'0"N
116°58'0"W
L2.7
R3.5

MAP 3
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28
R3.5
R4.1
R4.4

5561000
5560000
504000
116°57'0"W
50°12'0"N
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
0
0.1
0.2
0.3
0.4
0.5
0.57
MAP 4
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28

R6.9
R7.6
L8.2
MAP 5
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
0 100 200 300
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28

L8.2
MAP 6
Legend
River Kilometre
Side Channel Kilometre
Kokanee Spawning Use
Kokanee Holding
Kokanee Spawning Use - Area Lost
Kokanee Migrating (None in 2016)
1:5,000
Metres
BC Hydro
DDMMON - 4 Lower Duncan River Kokanee Spawning Monitoring
2016 Kokanee Spawning Areas and Areas Dewatered in the LDR
Ortho Date : October 2012
GIS File: LDR_5000_report2016data_20161128.mxd
Project Number: EA3745
DATE: 2016.11.28
PROJECTION: UTM Zone 11
REVISION DATE: November 2016
DATUM: NAD83
PRINTING DATE: 2016.11.28
116°56'0"W