Duncan Dam Project Water Use Plan

Lower Duncan River Kokanee Spawning Monitoring

Reference: DDMMON-4

Year 4 Synthesis Report (2011)

Study Period: September 2008 – February 2012

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Lower Duncan River Kokanee Spawning Monitoring - DDMMON#4 Year 4 Synthesis Report (2011)

Submitted to:
BC Hydro
Castlegar, BC

Submitted by:
AMEC Environment & Infrastructure
Nelson, BC

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EXECUTIVE SUMMARY

The Duncan Dam (DDM) Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area. During this process, several data gaps were identified with respect to kokanee spawning in the Lower Duncan River (LDR). Monitoring studies under the Duncan Dam (DDM) Water Use Plan (WUP) were initiated in September 2008 to enumerate kokanee and collect information on spawning habitats and use, as well as biological sampling of kokanee morphology in the LDR and the Lardeau River. The following report presents a synthesis of the entire four year program (2008 to 2011). The current state of knowledge for kokanee spawning with respect to BC Hydro's management questions for DDMMON-4 is provided in the following table.

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 for kokanee in the LDR occurs from late August to late October, with peak spawning estimated between September 27 and October 13. Environmental and operational cues, such as temperature and discharge, affecting this variable are not known at this time. Further analyses conducted under DDMMON-7 may help answer whether water temperature and discharge influence spawn run timing. Fry emergence timing in the LDR occurred in December/January, with ponding estimated in February/March. Fry emergence was approximately 3 months earlier in the LDR than that estimated for the Lardeau River and Meadow Creek. Fry emergence timing is dependent on water temperature, which is influenced by DDM operations. It is unknown whether earlier emergence is disadvantageous to LDR kokanee fry at this time. Relative Intensity: The majority of kokanee in the Duncan River system were observed to spawn in Meadow Creek (66%), followed by the Lardeau River (32%) and lastly the LDR (3%); this was similar to what has been observed from 2002 to 2007. The regulation of the LDR has caused substrate compaction and reduced the amount of spawning habitat for kokanee compared to that available historically, but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River. Relative intensity of kokanee spawning in the LDR is also highly influenced by in-lake adult and fry survival, lake fertilization, predation, density dependence, angling pressure and general lake conditions.
What are the timing/cues of kokanee spawners in Meadow Creek and Lardeau River systems?	Meadow Creek: Mid-August to late October with peak spawning during mid- to third week of September. Previous research suggests that water temperature may not influence spawn timing/arrival. Lardeau River: Early September to mid-October with peak

	during last week of September. There is a lack of information on cues in the Lardeau River.
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?	LDR: Spawning observed in the upper 9 km of the LDR likely because these areas have more suitable spawning gravels present compared to lower regions of the river, which are largely comprised of fines due to the regulation of Kootenay Lake. The regulation of the LDR has also caused substrate compaction and reduced the amount of spawning habitat for kokanee compared to that available historically, but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River (see above). Observations suggest that early spawning begins in side channel habitats, but by the peak of spawning kokanee are in side channel and mainstem habitats with approximately equal frequency. Kokanee move into side channels earlier than the mainstem likely because they are seeking out low velocity, cooler (shadowed) areas to minimize energy expenditure as has been observed for kokanee in Meadow Creek. There is preliminary evidence that water temperatures may vary along the left versus right bank of the LDR below the Lardeau River, but this temperature difference mixes by approximately Km 7.0 and it is unknown whether this influences the distribution of kokanee spawners at this time. Meadow Creek: The majority of spawning occurs in the 3 km spawning channel. Areas upstream and downstream of the spawning channel (SC) fence are also used when kokanee are no longer able to enter the channel (i.e., channel is closed due to maximum channel loading). Distribution is affected by the presence of the spawning fence, the waterfall barrier (2 km upstream of the SC) and silt substrates that are not well suited for spawning in the lower section of the river. The spawning channel likely provides more suitable spawning substrates, since it was specifically built in 1967 to compensate for half of the kokanee run lost due to DDM construction and now provides 3 km of spawning gravels specific to kokanee spawning. Lardeau River: Spawning occurs along the length of the river with most preferred areas in the uppermost side channels. Suitable spawning substrates are found in the Lardeau River based on the intensity of spawning observed (see above). In addition, the Lardeau River experiences a natural hydrograph and flushing flows aid in removing fine sediments that may build-up within substrate interstices.
What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended	A summary of physical works or operational constraints that could be implemented with rationale/benefits for kokanee spawning protection is provided. The physical works or operational constraints that may be necessary to minimize

kokanee spawning operations?	operational conflicts associated with kokanee spawning protection flows need to be reviewed within the context of current baseline operations at DDM. Current baseline operations at DDM were based on the WUP review process and recommendations from the Consultative Committee. Kokanee spawning protection flows occur during a portion of the actual spawning period and start later (October 1) compared to when peak spawning has been observed for kokanee during the present study (September 27 to October 13). These baseline conditions currently do not capture the majority of spawning observed in the LDR on average. In addition, baseline operations potentially result in the loss of 0.14% of the adult kokanee that may return to the overall Duncan River system.

1.0 INTRODUCTION

Duncan Dam (DDM) was built in 1967 as a storage facility under the Columbia River Treaty (CRT). Prior to the DDM Water Use Plan (WUP) implementation in 2007, flow management in the Lower Duncan River (LDR) below DDM was dictated by seasonal operating targets set by the CRT and, to a lesser degree, by water level requirements for Kootenay Lake set by the International Joint Commission. A number of flow management issues (e.g., CRT, fisheries, and recreational users) impose significant challenges for the operation of DDM. Four unregulated tributaries also influence the flow regime in the LDR (i.e., Lardeau River, Meadow Creek, Cooper Creek, and Hamill Creek; Figure 1). The DDM Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area. The DDM WUP Consultative Committee (CC) identified kokanee (*Oncorhynchus nerka*) spawning success in the LDR as an issue that could be impacted by DDM operations (BC Hydro 2007).

BC Hydro commitments to the DDM WUP and to meeting flow management targets set under the Columbia River Treaty restrict the timing and amount of flow that can be delivered in the fall during the kokanee spawning period (August to October). Flow targets set out by the DDM WUP specify a maximum target of 73 m^3/s flow from October 1 to 22 and increasing discharge hereafter as measured at the Water Survey of Canada (WSC) gauge (08N118) below the confluence of the Duncan and Lardeau rivers (BC Hydro 2007). Kokanee spawn monitoring studies under the Duncan Dam (DDM) Water Use Plan (WUP) were completed each fall from 2008 to 2011.

Prior to these studies, kokanee use in the LDR had been relatively unstudied (Baxter 2005). In 2002, BC Hydro retained AMEC to investigate the influence of DDM operations on kokanee use of the Duncan River below the Lardeau River confluence (AMEC 2003, 2004). Surveys suggested that high flows during the spawning period allowed kokanee to access areas that were later dewatered, which resulted in significant stranding of adult kokanee and dewatering of kokanee redds (AMEC 2003). Recommendations for flow reduction during peak kokanee spawning were made to limit the amount of habitat available to spawners and these spawning flows were applied from 1 to 21 October 2003 (AMEC 2003). Enumeration studies conducted in subsequent years indicated that kokanee spawn in the LDR between August 21 and October 21 and that spawning protection flows may protect spawning areas where dewatering had been observed in the past (Baxter 2005, Kootenay Environmental Services 2007). Past surveys (2002 to 2007) enumerated kokanee that were spawning in the LDR, and also counted migrating and holding fish that may have used Meadow Creek or the Lardeau River as the final spawning ground (AMEC 2003, 2004; Baxter 2005, 2006; Kootenay Environmental Services 2007). Studies conducted from 2008 to 2011 have distinguished between spawning, migrating and holding behaviours to provide more representative counts for spawning in the LDR.

2.0 OBJECTIVES

Specific objectives of the Lower Duncan River Kokanee Monitoring program as summarized from the Terms of Reference (TOR) were to:

1. Document the annual kokanee escapement to the Lower Duncan River, Lardeau River, Meadow Creek, and the 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 decision analyses.

Management questions outlined in the TOR include:

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?

To address the above management questions, the following **alternative hypotheses** were also outlined in italics (as directly taken from the TOR):

H01: Kokanee spawning in the Lower Duncan River mainstem is distinct from Meadow Creek and Lardeau River kokanee populations, as determined by statistically significant differences in spawning timing, physiology and/or habitat use.

The first four years of the monitoring program will be dedicated to defining the characteristics of the Duncan River kokanee population in comparison with runs in Meadow Creek and Lardeau River.

H02: Kokanee spawning success[1] in the Lower Duncan River is not significantly affected by Duncan Dam operating conditions (fall through spring) as observed through monitoring studies and reviewed using the population model (BC Hydro *in prep*).

The BC Hydro Castlegar office is working with a Simon Fraser University Masters student to develop a kokanee population model for the Lower Duncan River that will consider stranding impacts to determine if population impacts are measurable. Where the model fails to provide meaningful results, spawning success indicators will be reviewed with regulatory agencies to determine if any measurable deviations from natural success indicators are significant.

H03: Lower Duncan River kokanee spawning success monitoring over the 10-year review period is not significantly different from that observed prior to Water Use Plan operational changes.[2]

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[1] "For the purposes of this study, spawning success is the egg to fry survival that incorporates both natural success and potential regulated impacts that result in spawning areas being dewatered prior to emergence" (BC Hydro TOR 2008).

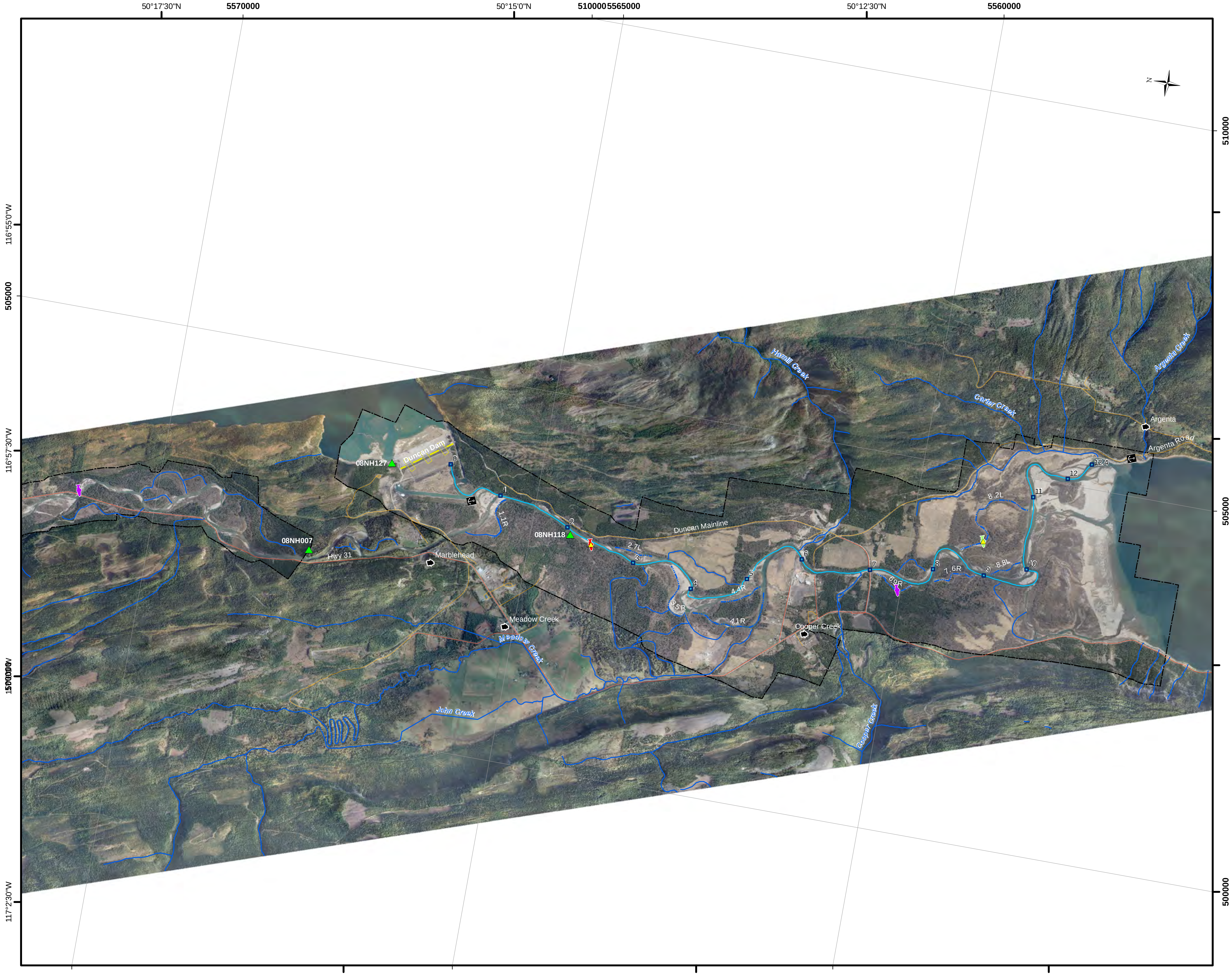
[2] It should be noted that the pre-WUP period (2003-2007) occurred prior to the onset of this program (2008) and spawning success during the pre-WUP period was not measured.

H04: Kokanee spawning success in the Lower Duncan River is not significantly affected by spawning outside of the kokanee spawning operations (73cms target 1 October to 21 October each year).

Two measures of spawning success, adult returns and calculated spawning area lost, will be monitored throughout the review period to determine if operations are affecting success. The key measure used in the WUP process to assess operational impacts was spawning success, not escapement, as there are non-operational factors that affect kokanee productivity in the Kootenay Lake drainage. Studies conducted prior to the monitoring program did not adequately monitor habitat loss during the spawning/incubation period, and therefore, direct before-after comparisons are not possible.

2.1 Purpose

The following report fulfills AMEC's commitment to provide BC Hydro with a synthesis report for the entire four year program conducted from 2008 to 2011 and adds to the dataset collected to support BC Hydro's Specific Objectives, Management Questions and Hypotheses outlined above.



Legend

- Biological Sample (2008)
- Biological Sample (2009)
- Biological Sample (2009 and 2011)
- Incubation Site
- Boat launch
- WSC gauge
- Communities
- River km (AMEC, 2009)
- Dam
- Reach breaks

Roads

- Paved
- Unpaved
- Named Sidechannel
- Streams
- Thalweg
- Extent of May 2009 Orthophotography

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Juvenile Habitat Survey: Poisson Consulting

CLIENT: BC Hydro

PROJECT: LDR Kokanee Spawning

Overview Map of Lower Duncan River

JOB No: VE51905	COMPILATION DATE: 2009/12/15	Figure 1
GIS FILE: LDR_overview.mxd	REVISION DATE: 2009/12/15	
PDF FILE: LDR_overview.pdf	PRINTING DATE: 2009/12/15	

PROJECTION:	DATUM:	ANALYST:	QA/QC:	REQ:
UTM Zone 11	NAD83	EO	LP	LP

Y:\GIS\Projects\VE\VE51905_Duncan_Mapping\Mapping\MXD\Drafts\AMEC\sample_summary\LDR_overview_summary.mxd

3.0 METHODS

3.1 Study Area

The Duncan River flows into the northern end of Kootenay Lake, north of Nelson in south-eastern British Columbia. The river drains both the Selkirk and Purcell mountains into Kootenay Lake. The study area for the Kokanee Spawning Monitoring program included the entire LDR from Duncan Dam (River Km 0.0) to Kootenay Lake (Km 12.4) and its associated side channels (Figure 1).

3.2 Environmental Parameters

Hourly discharge and water temperature records were obtained for DDM from the Water Survey of Canada (WSC) gauge (No: 08N118) below the Lardeau and Duncan rivers confluence (DRL) from BC Hydro's Access database. Water temperatures for the Lardeau River and Meadow Creek, collected every 30 minutes, were obtained from BC Hydro's DDMMON-7 LDR Water Quality Monitoring program, which was conducted from May 2010 to May 2012 (AMEC, *in prep*). Kootenay Lake elevations were also obtained from BC Hydro's Access database for the kokanee spawning period.

3.3 Sample Timing

A summary of sampling methods and dates for LDR kokanee spawn monitoring studies conducted from 2008 to 2012 is provided in Appendix A. Sampling included helicopter enumeration and mapping, biological sampling, habitat use measurements, egg and incubation sampling, and ground enumeration and mapping of selected sites for comparison to helicopter surveys. Further details for each sample method are provided below.

3.4 Helicopter Enumeration Surveys

Helicopter enumeration surveys were conducted to collect data specifically related to Specific Objectives #1 and #2, Hypotheses H01 and to obtain information to help answer Management Questions #1 through #3 for this program (Section 2.0). The following standardized methods were used to enumerate kokanee in the LDR system.

Helicopter surveys were used to enumerate adult kokanee in the LDR and within the lower 1 km of the Lardeau River (from the confluence to the DDM access road bridge). In 2010 and 2011, the lower 1 km of Meadow Creek was also included. The helicopter carrier used each year was dictated by BC Hydro (BCH), which varied by year due to changes in BCH safety policy standards, availability and logistics of regional carriers. A summary of helicopter carrier and type by year is provided in Appendix A.

Enumeration surveys covered the entire 12.4 km length of the LDR starting from the delta (confluence with Kootenay Lake) to approximately 0.6 km downstream of DDM (Figure 1). All side channels in the LDR were also surveyed and enumerated for kokanee. Enumeration surveys were not conducted in the DDM tailrace section between DDM and Km 0.6 as kokanee have not been historically observed to use this area for spawning. However, this area was surveyed during the September 24, 2008 and October 9, 2010 flight to confirm presence/absence of kokanee spawners in the discharge channel; kokanee were not observed during these two surveys. It was decided that the DDM discharge channel would not be included in regular enumeration surveys (T. Oussoren, BC Hydro Natural Resource Specialist, pers. comm., 2008).

Surveys were conducted during the historic spawning period from late August to late October (AMEC 2008). Additional spawning observations were also noted during other DDM programs, where possible. During each year of study, surveys occurred approximately every 7 to 10 days until the peak spawning period, when surveys were conducted approximately every 5 days, but this was dependent on weather conditions and helicopter availability. Survey frequency returned to approximately every 7 to 10 days, weather permitting, when the peak spawning period subsided (Appendix A).

A total of eight helicopter surveys were conducted in 2008, 2009 and 2011 (Appendix A). However, in 2010 only seven surveys could be carried out because the final survey planned for late October was cancelled, in discussion with BC Hydro, since BC Hydro approved helicopter carriers were not available for the remainder of the month (Appendix A).

Standard 1:4,000 detailed maps were used to conduct enumeration surveys in 2009, 2010 and 2011. These maps were divided into mainstem and side channel areas and location markings delineated every 100 m to identify areas where kokanee and spawning areas were present. Counters marked the location, number of kokanee, and spawning behaviour within 100 m sections on the orthophoto maps during each survey. Kokanee spawning behaviour was recorded as follows:

- **Holding** – Kokanee observed in a group/school that were stationary;
- **Migrating** – Kokanee observed in a group/school that were moving in an upstream direction (may include single fish moving upstream);
- **Spawning** – Kokanee observed in relatively stationary pairs and distributed evenly throughout an area; and,
- **Dead** – Kokanee were observed floating/drifting at the surface belly up.

In 2008, orthophotographic imagery was not available and photo mosaic maps provided by BC Hydro (M. Miles and Associates 2002) were used during each helicopter survey; these maps were used on past kokanee enumeration studies (e.g., AMEC 2003; Baxter 2005, 2006; Kootenay Environmental Services 2007). Counters marked the location and number of kokanee as above. In 2009, enumeration information collected in 2008 (i.e., on the photo mosaics) was transferred onto the standard 1:4,000 orthophoto maps so that data entry and analyses were consistent over the duration of the study.

Counts were separately conducted by two individuals sitting on the left-hand side of the helicopter (one in front and one directly behind). The helicopter was flown sideways, which permitted the main counters to view the entire width of the channel. The pilot also manoeuvred the aircraft as necessary to maximize the river view for the main counters. All flights were conducted approximately 20 m from the ground (i.e., just above the tree tops) and between 10 to 18 km/hr, depending on the terrain, safety hazards, and weather conditions. Each flight divided the LDR between the mainstem and its side channels, so that the entire mainstem was surveyed first (in an upstream direction) followed by individual side channels. The lower portions of the Lardeau River and Meadow Creek were grouped with the side channels. This method allowed for systematic surveys to be conducted and counters could better determine the spawning/fish locations. In all three years, the majority of counts were conducted by Clint Tarala, Murray Pearson (MOE), and Louise Porto. These helicopter methods are similar to those standards used for salmonid aerial counts throughout the Pacific Northwest (e.g., Jones et al. 2007).

3.4.1 Ground Truthing for Helicopter Enumeration Surveys

Opportunistic ground enumeration surveys were conducted throughout the program (2008-2011) at index sites for comparison to helicopter surveys. Ground surveys consisted of walking the sample area (e.g., side channel or section of mainstem) and counting kokanee. Two observers walked along the bank(s) and/or along the water's edge (depth permitting) within the sample area. Ground enumeration was conducted on the same day that helicopter counts were being conducted, with care taken not to disturb kokanee so that each was similar. Helicopter and ground enumeration counts were compared for efficiencies. Ground surveys were also conducted in selected side channels and mainstem habitats in the LDR (Figure 1).

In 2008, boat counts were also compared to aerial counts. Boat counts were half of that estimated by aerial counts along a mainstem site, and it was determined that the boat count was less accurate because fish were startled by the presence of the boat and engine noise and would seek cover (AMEC 2009). Also, boat counts were difficult to conduct because the entire site could not be viewed simultaneously and the angle of observation precluded accurate counting (AMEC 2009). Therefore, boat counts were eliminated from the sampling methodology after 2008.

3.5 Helicopter Spawn Mapping Surveys in the LDR

Spawn mapping surveys were conducted to obtain information to address Hypotheses H02 through H04, Specific Objective #2 and to help answer Management Question #3 (Section 2.0). Also, the TOR specified that a spawning success measure for the entire LDR be obtained to evaluate DDM flow management with respect to the kokanee spawning period.

In 2008, a preliminary measure of spawning success via ground counts was conducted within index side channel 6.9R (Figure 1). Boat surveys were also conducted in the mainstem LDR from km 0.6 to km 4.0 at this time (Figure 1), but this method was inappropriate, since engine noise and the presence of the boat scattered fish into hiding, which made it impossible to count and map spawning areas (AMEC 2009). Due to the size of the study area, it was recommended that spawn mapping be conducted via helicopter flights to determine spawning success throughout the LDR using appropriate orthophoto maps (AMEC 2009).

Spawn mapping was conducted throughout the entire LDR in 2009, 2010 and 2011 using 1:500 orthophoto maps to delineate kokanee spawning locations during the spawning period. The helicopter hovered as low as possible at each spawning location in order to accurately map the size and extent of the spawning area, while minimizing disruption to spawners. Kokanee redd and areas where kokanee were actively spawning were directly drawn onto the 1:500 orthophotos.

In 2009, spawn mapping was conducted to determine the applicability of this method in estimating egg losses between these two flows during two discharge events (Table 1). Four mapping events were conducted in 2010 to match each flow change during the kokanee spawning period (Table 1). In 2011, spawn mapping could not be conducted during each flow change as per 2010, but captured the pre-Kokanee Protection Flow and the post-Kokanee Protection Flow period (Table 1). Each flow period could not be mapped in 2011 because of the time required to enumerate kokanee prior to conducting spawn mapping as well as constraints imposed by the helicopter used. In 2011, the BO105LS twin engine helicopter employed for this program was bulkier and slower to manoeuvre compared to helicopters used in previous years resulting in multiple refuelling stops during most surveys. On three occasions after refuelling, weather changes limited and/or prevented spawn mapping: i) September 22, 2011 - maximum discharge of 250 m^3/s could not be mapped; ii) September 26, 2011 – only side channels could be mapped at maximum discharge of 190 m^3/s; and, iii) September 29, 2011 – only mainstem could be mapped at maximum discharge of 130 m^3/s (Table 1). Additional helicopter mapping surveys could not be scheduled in 2011 due to aircraft availability and since the program had a fixed budget for eight helicopter flights and spawn mapping was secondary to enumeration.

Table 1: Maximum target flows as measured in the Lower Duncan River downstream of the Lardeau River at the WSC gauge (08NH118). Spawn mapping by year during kokanee monitoring studies is also included.

Date Range	Maximum Discharge (m^3/s)	Spawn Mapping Year[a]
25 August to 24 September	250	2009, 2010
25 to 27 September	190	2010, 2011-sidechannels only
28 to 30 September	130	2010, 2011-mainstem only
1 to 21 October	73[b]	2009, 2010, 2011
22 October to 21 December	110	-[d]
22 December to 9 April	250[c]	-[d]
10 April to 15 May	120	-[d]
16 May to 31 July	400	-[d]

[a] Spawn mapping was conducted throughout the entire LDR unless otherwise specified.
[b] Note that during this period the maximum and minimum flow targets are identical.
[c] In the event that this maximum flow target does not allow BC Hydro to meet CRT reservoir level targets, then this maximum may increase to 300 m^3/s or the variance value approved by the US Army Corps of Engineers (BC Hydro 2005).
[d] Outside current program study period.

3.5.1 Ground Truthing for Helicopter Mapping Surveys in the LDR

Opportunistic ground mapping surveys were conducted throughout the program in conjunction with ground counts. Helicopter and ground mapping were compared for efficiencies and areas delineated during mapping surveys were digitized and measured for comparison. On February 3 and 7, 2012, ground surveys were also conducted in SC 3.5R and 6.9R to provide additional information for the kokanee winter rearing period to compare observations taken during ground surveys completed at these same locations on September 29, 2011. Information was also compared to spawn mapping observed on the Lardeau River at this time.

3.6 Spawn Mapping Surveys in the Lardeau River

Spawn mapping was conducted on the Lardeau River to determine egg losses and spawning success in a natural system during the kokanee spawning and egg incubation period. Ground mapping was conducted within side channel and mainstem areas located upstream and downstream of the Highway 31 bridge where previous biological sampling was conducted (2008-2010). On October 4, 2011, kokanee were enumerated within each area (number of dead and alive) by one observer while a second observer mapped the spawning area. A handheld Garmin GPS unit was used in track mode and the perimeter of the spawning area was traversed. In addition, spawning area start and end points were flagged for future surveys. Tracked areas were plotted on 1:2,000 orthophoto maps provided by BC Hydro (date: April 30, 2009) and the spawning areas were calculated (Appendix B). A second survey was conducted on February 3, 2012 to determine the condition of mapped spawned areas from October 2011. Orthophoto maps delineated with the October spawning areas were used to confirm observations in the field. A new GPS track log was created along the observed wetted edge in February 2012. In sites where snow and/or ice cover prevented exact determination of the wetted edge, a shovel was used to remove snow (and ice, if possible) to determine the probable location of the wetted edge. Orthophoto maps were updated to include areas observed to be wetted, dewatered and ice covered (Appendix B). Spawning areas observed in February 2012 were calculated and compared to October 2011. Potential egg deposition and spawning success was calculated as described in Section 3.10.6.

3.7 Biological Sampling

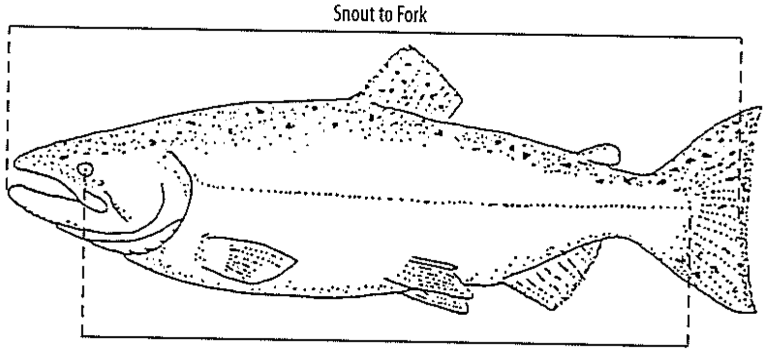
Biological sampling of kokanee was conducted to detect morphological differences between fish that spawn in the LDR, Lardeau River and Meadow Creek (Specific Objective #3 and Hypothesis H01). Biological sampling was conducted during ground surveys in 2008, 2009 and 2010, but was not required in 2011 because an adequate amount of data had been collected for morphological and DNA analyses.

In 2008, adult kokanee were sampled by beach seine and dip nets, whereas in 2009 and 2010, backpack electrofishing was permitted by MOE and used to sample kokanee spawners in the LDR and Lardeau River. Backpack electrofishing was more efficient and less time consuming compared to beach seine and dip net techniques (AMEC 2008 and 2009). In 2008 both males and females were collected, whereas in 2009 and 2010 female kokanee were targeted to maximize data collected for parameters to distinguish stock differences such as fecundity, egg retention, and egg size, which are key bio-measures to help determine stock differences (e.g., Acara 1970, Murray et al. 1989). However, a few males were accidentally sampled in 2009 and 2010 because they displayed external morphological characteristics more typical of females (e.g., less pronounced kype).

In the LDR, biological sampling was conducted in areas where spawning behaviour had been previously observed during helicopter enumeration flights, which ensured that only LDR fish were collected and not fish that were migrating to the other systems. In 2008, fish were collected in side channel 6.9R in coordination with enumeration and mapping activities. In 2009 and 2010, biological sampling was conducted in side channel 3.5R and in a wadeable section of the LDR mainstem located at Km 2.4R. Both sites were selected based on the number of spawning kokanee observed throughout the spawning period as well as accessibility and utility for the sites to be used for other streamside survey components. Fish sampled from the Lardeau River in all years were collected from side channels located both upstream and downstream of the Highway 31 bridge on the left bank, which is located approximately 10 km upstream from the confluence.

The number of fish collected and collection timing varied each year. In 2008, 50 adult kokanee (25 males and 25 females) were sampled each from the LDR and Lardeau River on September 24th and 25th, respectively (Appendix A). In 2009, the timing of biological sampling was chosen to represent early (September 23), peak (October 4-5), and late (October 14) spawning activity in case morphological differences varied with spawn timing (Appendix A). For example, larger spawners were noted later in the spawning season during studies conducted in 2002 (AMEC 2003). A total of 25 females from the LDR and 25 females from the Lardeau River were targeted during each biological sampling session in 2009. In the LDR, a total of 74 fish (73 females and 1 male) were collected, whereas in the Lardeau River 75 fish (74 females and 1 male) were captured in 2009. Based on preliminary morphological analyses conducted in 2009, additional data was collected in 2010 to further supplement the dataset (AMEC 2009). Therefore, in order to maximize the dataset, sampling in 2010 targeted females during peak spawning. In 2010, a total of 50 females were collected in the LDR (October 5), whereas 47 females and 3 males were sampled from the Lardeau River (October 6).

Kokanee collected were examined for marks or other external abnormalities and measured for fork length (FL), post-orbital hypural length (POHL) and body depth (BD) in centimetres. Fork length was measured from the tip of the snout to the observable fork in the tail section of each fish. POHL was measured from the tip of the snout to the hypural plate as depicted in Figure 2. This measurement was used because the tails of spawners, especially females, are frequently so worn out that the fork is difficult or impossible to locate (Crawford et al. 2007). It is also important to use POHL to avoid length distortion caused by jaw development (Crawford et al. 2007). Body depth was measured perpendicular from the anterior insertion of the dorsal fin to the abdomen. Prior to dissection, weight was taken in grams and a tissue sample was taken from the base of the dorsal fin (approximately 5 mm^2) and preserved in 100% ethanol for DNA analysis (Crawford et al. 2007). All captured fish were sexed. Males were distinguished by the presence of testes in the abdominal cavity and/or the expulsion of white fluid from the urogenital pore. Females were distinguished by the presence of eggs and/or skein tissue. The number of eggs in each female collected was counted by thoroughly examining the abdominal cavity. Egg diameter was obtained by measuring the length of 10 eggs and dividing the total by 10 in millimetres. All eggs were measured for spawned out females where less than 10 eggs were present. Lastly, otoliths were removed from a sub-sample of kokanee during each year. All biological measurements were taken by Louise Porto during each year of sampling in the LDR and Lardeau River.



Note: The hypural plate forms the last and largest vertebra in the spinal column and is located in the caudal peduncle. The obvious flex point of the tail at the posterior edge of the hypural plate is the point to which measurements are made (From Crawford et al. 2007).

Figure 2: Fish length measurements used during LDR Kokanee Spawning Monitoring 2008

Biological sampling in Meadow Creek was conducted by Murray Pearson (MOE) as per established MOE protocols and sample timing (Appendix A). Morphological measurements collected on kokanee sampled from Meadow Creek was similar to that collected during this program. However, POHL and body depth were not measured on fish obtained from Meadow Creek, since these were extra measures added for the current program. Also, MOE did not count eggs for each female sampled. Therefore, egg retention numbers did not have an associated length and weight recorded (M. Pearson, Meadow Creek Spawning Channel, MOE, pers. comm., 2010).

DNA samples were collected during each year in both the LDR and Lardeau River. In total 174 DNA samples were collected from kokanee in the LDR, whereas 175 samples were from the Lardeau River. Of these samples, 49 DNA samples each from the LDR and Lardeau River collected in 2010 were sent to M. Russello (UBC-Okanagan) for DNA analysis. In addition, 50 DNA samples were obtained from frozen 2010 Meadow Creek kokanee preserved by MOE and sent to UBC for further analysis.

Otoliths collected in the LDR and Lardeau River were sent to Hamaguchi Fish Aging Services (Kamloops, BC). In total, 246 otoliths have been aged for this program, including 121 from the LDR and 125 from the Lardeau River. For Meadow Creek kokanee, otolith sampling was conducted by M. Warren (UWO Graduate Student) as well as by MOE personnel. In total, 205 otoliths have been aged for the Meadow Creek population for the 2008 and 2009 spawning years (n=145 UWO; n=60 MOE) as well as 2010 (n=28 MOE); the UWO study was completed in 2009 and further sampling was not conducted in 2010.

3.8 Egg Incubation & Egg-to-Fry Survival

In order to help address management questions related to fry emergence timing and relative intensity of kokanee spawning (Management Question #1) and data deficiencies identified during our information review (AMEC 2008), an egg incubation study component was conducted in 2009. In conjunction with ground surveys during the low flow period, live kokanee eggs were collected on October 3 and 4, 2009. Eggs were placed in incubation capsules and left to mature and hatch until January 27, 2010 when they were retrieved after the predicted egg hatch for kokanee (see below).

The initial intention was to collect fertilized kokanee eggs from spawning redds using BC Hydro's hydraulic egg sampler from redds within the LDR. An initial sample was collected from SC 3.5R using the hydraulic egg sampler. Additional samples were also collected within the LDR mainstem at Km 2.4R using a shovel, while a seine net was fixed downstream to collect kokanee eggs (Figure 3). The manual shovel method was more portable in remote sampling areas and since quantitative egg numbers based on area sampled were not required as can be determined using the hydraulic egg sampler, the shovel/seine net method was used to further excavate kokanee eggs.

Figure 3: Redd excavation (left) and incubation capsules (right) used in egg to fry survival studies in the LDR.

Since pre-spawning males and females were also present during the pilot incubation study, mature eggs were also collected and manually fertilized in a bucket directly on-site. Manual fertilization enabled additional eggs to be obtained, since redd excavation required considerable efforts and a large number of eggs was required to ensure live eggs were placed into the incubation capsules. Therefore, incubation sites included separate sub-samples of both excavated (i.e., naturally fertilized) and manually/artificially fertilized eggs.

Two index sites were chosen for the incubation study based on observations of spawning kokanee and site accessibility: LDR mainstem at Km 2.4R and SC 8.2L at Km 0.3 (Figure 1 and Figure 4). At each site, 15 incubation capsules containing fertilized kokanee eggs were deployed. Twelve incubation capsules were buried within the gravel at an observed kokanee egg depth of approximately 15 to 20 cm directly within the spawning areas at each site. Three additional incubation capsules were deployed within the water column and left to rest on the bottom at each site.

Incubation capsules were made of closed, perforated and labelled PVC tubes approximately 25 cm long with a screw top attached to wire cable (Figure 3). These capsules had been previously used in similar incubation studies and were sterilized prior to use. The capsules were filled with new marbles and 30 kokanee eggs were distributed within each capsule. Each incubation capsule was numbered and information on the location of the capsule, number of eggs, type of eggs (i.e., excavated, naturally fertilized or artificial fertilization), and whether the capsule was buried within the gravel (or not) was recorded. Only live eggs (those that did not exhibit any clouding within 10 minutes of collection) were placed into incubation capsules.

Cable lines for each incubation capsule were attached to rebar posts pounded into the substrate. These cable lines also had a small styro-foam float to enable retrieval during higher flows (Figure 4). Floating incubation capsules were attached to a shoreline affixed to a permanent feature such as a large tree, where possible. Two Onset TidbiT v2 temperature loggers were deployed at each site: one was placed in an incubation capsule and buried at egg depth within the spawning area; and the other was placed in an incubation capsule and left floating on the surface of the substrate. Temperature loggers were attached to separate shoreline cables for retrieval and were set to record hourly water temperatures during the kokanee egg incubation and development period.


Figure 4: Egg capsules and temperature loggers deployed in the LDR mainstem at km 2.4R (left) and LDR side channel 8.2L at km 0.3 (right).

On November 17, 2009, incubation index sites were inspected to ensure temperature loggers were intact and to determine the stage of kokanee egg development within the naturally spawned redd area. Temperature loggers were downloaded and re-deployed as per initial deployment in October 2009. A small portion of the redd area was also excavated using the shovel-seine net method to collect and observe naturally spawned kokanee eggs.

The Salmonid Egg Incubation program IncubWin (Version 2.1) developed by researchers at DFO's Pacific Biological Station was run for sockeye salmon to determine the number of days required for hatch/emergence based on average gravel water temperatures downloaded from the LDR in 2009 at incubation sites. It was estimated that 50% of the eggs would hatch by January 2, 2010 based on a water temperature of approximately 6°C. Incubation capsules were retrieved on January 27, 2010, one week after flows were lowered at DDM, which permitted easier retrieval and when it was estimated that over 50% of the eggs had hatched (IncubWin). Incubation capsules were retrieved and processed at this time and the following parameters were recorded: site, capsule number, number of eggs/alevins alive and their stage (e.g., eyed, yolk), number of dead/fungused eggs/alevins and stage, and any other pertinent observations were also recorded. Temperature loggers were downloaded and re-deployed at each index site within the water column for further temperature monitoring in the LDR.

3.9 Habitat Use

Habitat use measurements were taken during ground surveys conducted within SC 6.9R and SC 8.2L in 2008 and at incubation sites in 2009 (see above). A boat survey was also conducted on October 10, 2008 within the LDR mainstem from the boat launch at Km 0.4 to approximately Km 4.0 at the log jam; the log jam prevented additional sampling in the lower portion of the river and additional surveys were not conducted as this method was not practical for kokanee enumeration and habitat use (see results below). Habitat measurements taken during 2008/2009 ground surveys included redd depth, velocity and substrates (dominant/subdominant) as well as % redd superimposition. Measurements during the 2008 boat survey were based on conditions present within an observed kokanee spawning area (length and width recorded). Depth and velocity categories were used during the boat survey because identifying individual redds was not possible or practical due to depth and velocity observed within the mainstem. The depth sounder was used to monitor depth over a spawning area and an average redd depth for that area was recorded. Velocity was visually estimated for the overall spawning area using the following categories: Back eddy; None; Low (>0-0.5 m/s); Moderate (>0.5-1.5 m/s); and, Fast (>1.5 m/s). After discussions with the BC Hydro contract authority, additional habitat use measurements were not collected in 2010 and 2011 since the DDMMON-3 hydraulic model will be able to generate this information based on kokanee spawning locations mapped during the present program (T. Oussoren, pers. comm., 2010).

3.10 Data Analyses

Enumeration, spawn mapping, habitat use, and biological sampling data were entered into an MS Access database developed specifically for this program. Incubation data was compiled in MS Excel. Data QA/QC was conducted via data sort and tabulation functions in MS Access and Excel and any data entry errors and/or inconsistencies in the data were verified and corrected. Data were summarized and tabulated and descriptive statistics using JMP 7.0 software (unless otherwise indicated) were used to discuss results by year and provide a comparison between years, where applicable. Water temperatures collected under DDMMON-7 were used to calculate accumulated thermal units (ATU) for emergence timing for the LDR, Lardeau River, and Meadow Creek. ATU's were calculated as the average daily water temperature added cumulatively from peak of spawning.

As mentioned, enumeration surveys conducted in 2008 were compiled on photo-mosaic maps available to the project at the time. Data collected in 2008 were transferred to the 1:4,000 maps used from 2009 to 2011, so that sites could be comparable between years. Transcribed data was entered into the MS Access database set up for this program. Due to translation of mapping sites and differences between mapping scales, slight differences in numbers and averages may have resulted compared to information reported in AMEC

(2009). Newly entered and updated data for 2008 was used for analyses presented herein for comparisons between years.

3.10.1 Area Under the Curve (AUC) Abundance Estimates

To refine spawn timing and escapement estimates (Specific Objectives #1 and Management Question #1), area-under-the-curve (AUC) abundance estimates were calculated using Bayesian methods to estimate aerial observer efficiency as well as peak spawn timing and spawner abundance of kokanee in the LDR from 2008 to 2011. An expansion factor for converting peak counts to total abundance was also calculated. Detailed statistical methods are provided in Appendix C.

3.10.2 Morphometrics Analysis

Kokanee morphometrics analysis was conducted on collected biosampling and aging data to determine whether any differences between the three systems occur (Specific Objective #3 and Hypothesis H01). A Bayesian linear modeling approach was used to assess whether any of the measured variables differed significantly amongst the three potential kokanee populations (i.e., LDR, Lardeau River, and Meadow Creek). Two models were run for each of the six continuous morphological variables and comparatively assessed using DIC (Deviance Information Criterion). As the current analyses do not include random effects DIC represents the Bayesian equivalent of the standard Akaike Information Criterion. Detailed methods used to conduct the statistical analyses are provided in Appendix D.

3.10.3 Fry Emergence Timing

Fry emergence timing was determined based on Accumulated Thermal Units (ATUs) which is defined as average daily water temperature added cumulatively from peak of spawning (AMEC 2008). Hatchery operations often calculate the number of ATUs that incubating eggs are exposed to in order to determine fry and alevin stages and time of emergence. AMEC (2008) summarized kokanee stages and corresponding ATUs observed during culture experiments at local spawning channels as well as ATUs for sockeye salmon. Incubation information collected during the present study also observed that kokanee eggs were eyed at approximately 400 ATU's, while hatch was closer to 700 ATU's, which follows typical development for kokanee and sockeye (AMEC 2008, 2010).

Water temperature data collected under DDMMON programs (2009 to 2012) was used to calculate ATUs for each year. Incubation studies conducted in 2009 indicated that gravel and water column temperatures in the LDR mainstem index site were similar and that slightly higher gravel temperatures observed at the side channel index site was within the error of the thermographs. Therefore, water temperatures measured in the water column were assumed to be similar to that within gravel where kokanee are developing. Also, egg-to-fry survival was similar between the mainstem and side channel index sites.

3.10.4 Environmental Variables and Spawn Timing

In-depth analyses to determine environmental cues (i.e., discharge and water temperature) that may influence spawn timing in the LDR, Meadow Creek, and Lardeau River (Management Question #1 and #2) will be included in the DDMMON-7 final report. The dataset required to conduct this analysis was not available at the time of reporting for this program. However, preliminary analyses and qualitative interpretation of temperature and discharge in relation to spawn timing was included, where possible.

3.10.5 Relative Intensity of Spawning

AUC abundance estimates were plotted with their upper and lower expansion factors for the LDR. Lardeau River peak counts were expanded by the mean, upper and lower expansion factors as calculated by the AUC analysis. Abundance estimates for Meadow Creek were based on actual counts at the MCSC enumeration fence plus the estimated number of kokanee in the Meadow Creek stream proper (MOE, unpublished). Counts for Meadow Creek proper were based on one peak count per year, but this count could not be expanded since this data was not available currently for each year (MOE, unpublished). Information was not included from enumeration surveys conducted from 2002 to 2007 because fish were not distinguished between migrating, spawning and holding in the LDR as per the present study.

3.10.6 Spawning Success

Spawning success was used to answer Hypotheses H02 and H03 as outlined in Section 2. Acara (1970) indicated that kokanee spawning success in the LDR may be defined by Potential Egg Deposition (PED) within an area. PED has been used at both the MCSC and at Hill Creek Spawning Channels to not only estimate spawning success, but to determine projected fry emergence and adult returns (e.g., Porto 2006).

Pre-Reduction PED was calculated as:

Number Female kokanee x (Fecundity – Egg Retention).

Mean fecundity and egg retention were calculated for all biosampling years (2008, 2009, 2010) and these values were used to calculate PED for each year. Previously, fecundity and egg retention observed during each biosampling year were used to calculate PED for the same spawn mapping year. However, biosampling was not conducted in 2011 so an overall average of these values was calculated. Therefore, to standardize spawning success and compare across years, PED was calculated using the overall average for the three biosampling years. This was similar for spawning success evaluation in the Lardeau River, where mean fecundity and egg retention over the three year biosampling period was also calculated to be representative for that system.

For the LDR it was determined that a simple calculation of PED was not representative of spawning success due to the observed dewatering of spawning areas during October flow reductions. Therefore, it was necessary to determine the area used by spawning kokanee versus the spawning area dewatered to estimate the potential number of fertilized kokanee eggs that were initially deposited in the LDR and remained wetted (i.e., alive) versus the number of eggs that were dewatered (i.e., dead) and would contribute to the adult spawning population in the future. Using the number of female kokanee in an area is a better method than redd enumeration due to inherent difficulties in counting redds and redd superimposition (AMEC 2009). Helicopter mapping (Section 3.5) was effective because the entire LDR could be mapped in approximately 1 to 2 hours and provided a relatively accurate means to determine area, since both boat and ground surveys were not suitable for determining spawning success in the entire LDR study area (AMEC 2009).

The following assumptions were made to estimate kokanee spawning success in the LDR:

1. Areas dewatered kill 100% of eggs once they are exposed.

2. Spawning success (i.e., PED) is based on a snapshot of the number of spawning females at a site immediately prior to flow reductions and does not consider spawning activity outside the survey period, redd superimposition, and does not include egg losses due to predation.
3. Females make one redd and spawn once in the area where they are observed. Information available on Meadow Creek kokanee indicates that females mostly construct one redd, but some may construct more (Morbey 2003, Morbey and Ydenberg 2003). Morbey and Ydenberg (2003) observed that approximately 30% of the kokanee redds in Meadow Creek were superimposed and that re-using redds likely caused a significant source of egg mortality. However, estimated mortality due to excavation was not available.
4. Sex ratios of kokanee in the LDR are similar to that reported for the MCSC (i.e., nearing 1:1), since this information was not available for the LDR (AMEC 2008). Therefore, enumeration counts can be divided evenly among the sexes.

After each spawn mapping survey, 1:500 orthophotos were scanned, digitized by GIS personnel and the digitized areas were measured. Area totals for each spawn mapping survey were used to determine spawning success in the LDR in conjunction with PED.

Post-reduction PED was calculated as:

$$[(PED_{before}*Area_{after})/Area_{before})]. \text{ And,}$$

Spawning success was calculated as:

$$[(PED_{after}/PED_{before})*100].$$

Since the majority of dewatering was observed to occur in side channel habitats compared to the mainstem LDR, PED was calculated separately for each habitat area (i.e., side channel versus mainstem) by year. Spawning success was then calculated for each habitat by year. In 2010, spawn mapping was conducted during the stepped flow changes that occurred in September as well as the October low flow period (Table 1). However, step changes could not be mapped in 2011 due to inclement weather during helicopter surveys (Section 3.5). Therefore, all spawn mapping comparisons were based on one September survey conducted closest to peak spawning as well as the October low flow survey.

For the Lardeau River, PED and spawning success were calculated as above for surveys conducted during peak spawning (October 2011) and during the low flow, winter period (February 2012) as described in Section 3.6.

3.10.7 Estimated Population Impact

The overall population impact of DDM operations on the expected adult returns was estimated for each of the project study years using PED, % spawning success in the LDR and survival estimates for each life stage.

The following calculations were used to estimate adult returns in the LDR with and without dewatering for each study year:

i) Number of Females = AUC abundance estimate ÷ 0.5;

ii) *Overall LDR PED (no dewatering) = #Females*(Fecundity - egg retention), where mean Fecundity observed during the program was 213 (SE=5) and mean Egg Retention was 5 (SE=0.3);*

iii) *LDR PED with Dewatering = Overall LDR PED*%dewatering observed, where % dewatering was spawning success calculated each year;*

iv) *Number of Fry = LDR PED with Dewatering*0.23, where 0.23 is the average egg-to-fry survival rate calculated during 2009 LDR in situ experiments (see below); and,*

v) *Number of Adults = Number of Fry*0.05, where 0.05 is the fry-to-adult survival rate estimated for Kootenay Lake (see below).*

Egg-to-fry survival rates were based on those calculated in the LDR in 2009 during incubation experiments, which averaged approximately 23%. In comparison, egg-to-fry survival at MCSC averaged 38% from 1985 to 2011 (MOE unpublished). Values reported for kokanee in a similarly regulated portion of the Flathead River system (Montana, USA) were 21% in 1982 and 35% in 1983 (Fraley et al. 1986). For a natural stream system, egg-to-fry survival is often estimated between 5 and 10% based on information collected at MOE spawning channels (FWCP unpublished; Porto 2005; Schindler et al. 2010). Fry-to-adult survival in Kootenay Lake has been estimated to average approximately 5% since fertilization of Kootenay Lake (Schindler et al. 2010). This estimate is based on adult returns to MCSC and hydroacoustic abundance inventories of kokanee in Kootenay Lake (Schindler et al. 2010). Limitations and assumptions of determining fry-to-adult survival for Kootenay Lake are outlined in Schindler et al. (2010).

4.0 RESULTS

4.1 Environmental Parameters

4.1.1 LDR Discharge and Water Temperature

Discharge patterns each year followed the maximum target flows for the kokanee spawning period (Table 1). In general, discharge in 2011 seemed to follow a more natural hydrograph with the larger peak in July/August, whereas in the other years two smaller discharge peaks were observed between May and August (Figure 5). Mean discharge over the September/October kokanee spawning period ranged from 140 to 156 m^3/s over the four year study period (Appendix E). Highest maximum discharge observed over the four years of study occurred in early August 2011 with a peak of 472 m^3/s (August 5, 2011), followed by 2008 which had the second highest discharge observed in late August with a peak of 327 m^3/s (August 25, 2008).

Overall, water temperature patterns in the LDR reach maximum temperatures in July or August, depending on the year and minimums during the winter period (Figure 5). Mean water temperature over the September/October kokanee spawning period ranged from 11°C to 12°C over the four year study period (Appendix E). Highest maximum water temperatures were observed between 17°C and 18°C in 2009 and 2010 in late July, whereas in 2008 and 2011 maximums reached approximately 15°C between late July and mid-August. Water temperatures in 2008 and 2011 also steadily declined from their maximums to approximately 9-10°C by the end of October. However, in 2008 and 2009 higher temperature pulses were observed during this decline period. For example in 2009 increased temperatures were observed around the end of August (14°C to 16°C) and mid-October (12°C to 16°C), whereas in 2010 one larger pulse was observed in mid-September (13°C to 15°C). Spill from DDM spillway gates was not occurring during any of these time periods and was likely not the cause of the water temperature pulses. Storm and/or weather events may have caused temperature fluctuations at these times.

4.1.2 Lardeau River Discharge and Water Temperature

The Lardeau River is unregulated and experiences highest inflows during freshet from late April to late July (Figure 6). Smaller discharge peaks may occur in the fall during storm events. Discharge over the September/October kokanee spawning period ranged from 26 to 43 m^3/s over the four year study period (Appendix E). Highest maximum discharge observed over the four years of study occurred in late June 2011 with a peak of 293 m^3/s (June 24, 2011), followed by 2008 with a peak of 237 m^3/s (May 21, 2008). In 2009, discharge peaked on May 17 (200 m^3/s), whereas in 2010 it reached its highest level on June 29 at 183 m^3/s (Figure 6).

Water temperature over the September/October kokanee spawning period ranged from 10°C to 13°C over the four years of study (Appendix E). Highest maximum water temperatures were observed between 18°C and 19°C in 2009 in August, whereas in 2010 and 2011 maximums reached approximately 15°C at this time (Figure 6). Water temperatures also steadily declined from their maximums to approximately 8-9°C by the end of October. Temperatures were not available in 2008.

4.1.3 Meadow Creek Discharge and Water Temperature

Discharge records for Meadow Creek are only available for the period of record from 1967 to 1973, after which time the Water Survey Canada (WSC) gauge was decommissioned. Therefore, discharge for Meadow Creek upstream of the John Creek diversion averaged for that period of record is shown in Figure 7 for comparison purposes. The John Creek diversion has been used for MCSC flows since 1967. Highest flows in Meadow Creek historically occurred in June/July and ranged between 40 to 46 m^3/s (Figure 7).

Water temperatures measured in MCSC were available from MOE in 2008, whereas in 2010 and 2011 temperatures were measured under DDMMON-7; water temperature was not available in 2009. Mean water temperature over the September/October kokanee spawning period ranged from 8°C to 9°C (2010 and 2011 data only; Appendix E). Maximum water temperatures were observed in July 2008 and were between 14°C and 16°C (Figure 7). In 2010 and 2011, maximum water temperatures were reached in August and ranged between 11°C and 13°C (Figure 7). Water temperatures began to decline from summer maximums in late August through September (2010/2011) and ranged between 3°C and 6°C by late October (Figure 7).

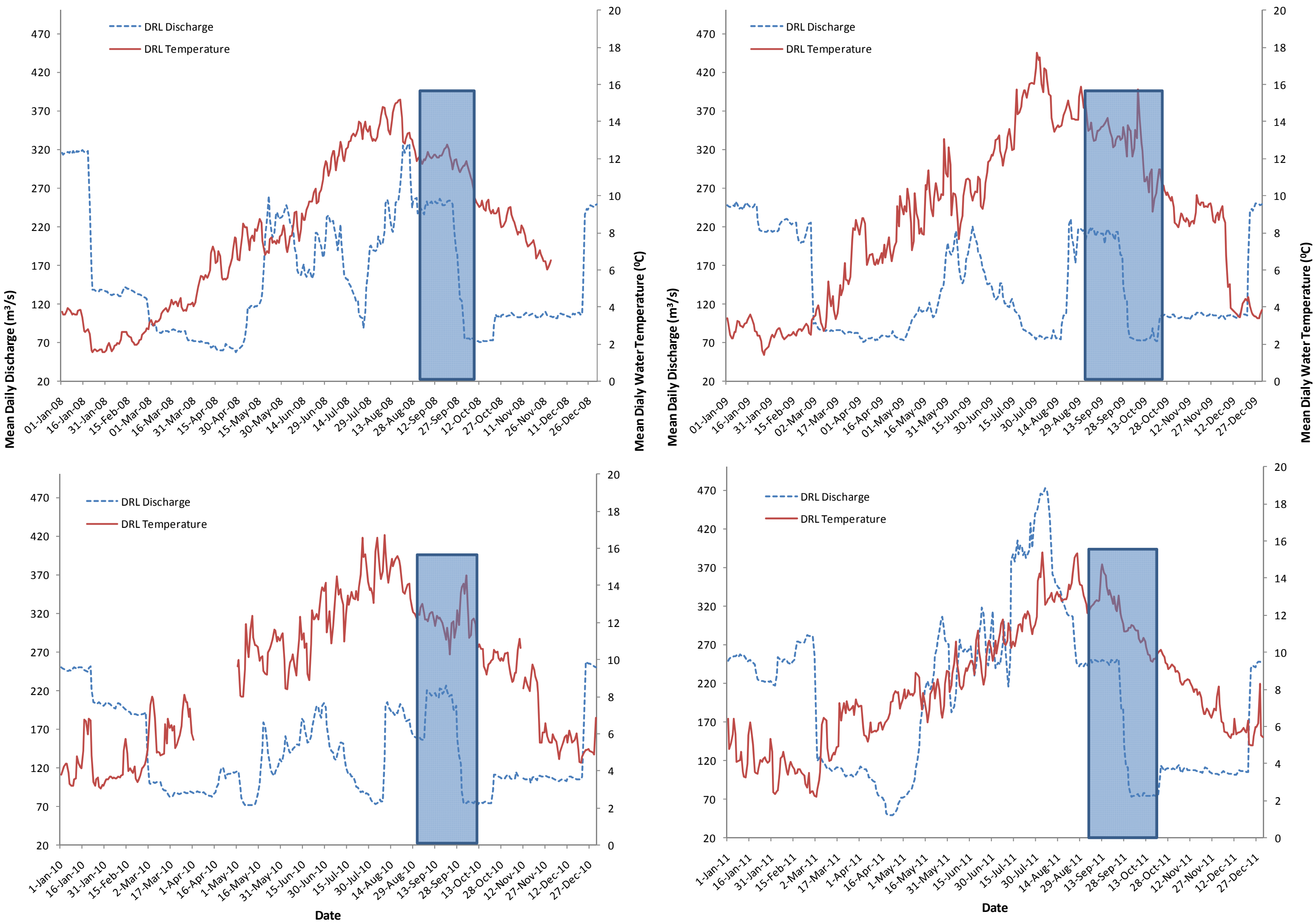


Figure 5: ***Mean daily discharge and water temperature at DRL (Water Survey of Canada gauge No: 08NH118), 2008-2011. Water temperatures were missing in April 2010. Shaded boxes represent the kokanee enumeration period.***

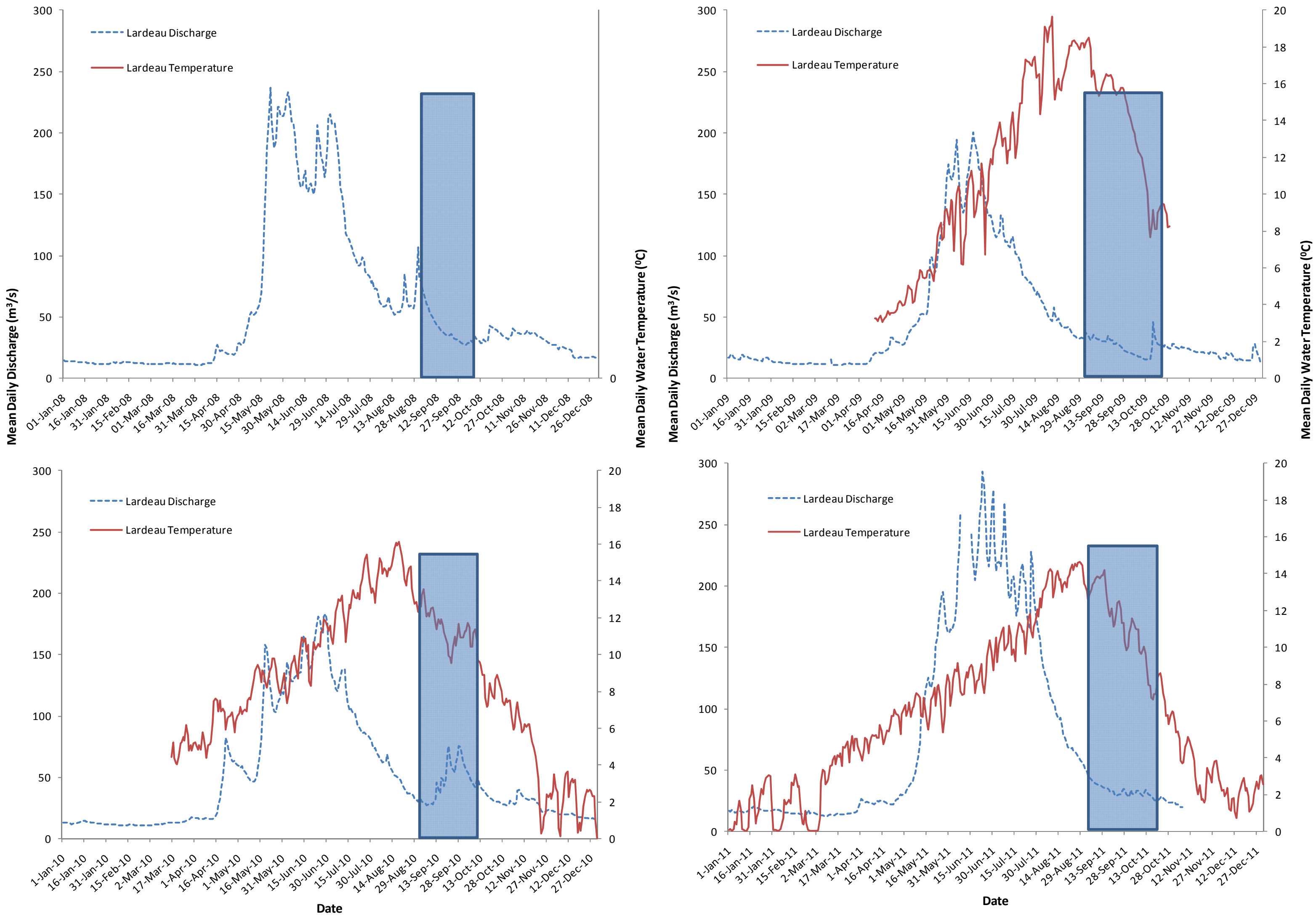


Figure 6: ***Mean daily discharge and water temperature for the Lardeau River as measured at the confluence, 2008-2011. Water temperatures were not available for 2008. Shaded boxes represent the kokanee enumeration period.***

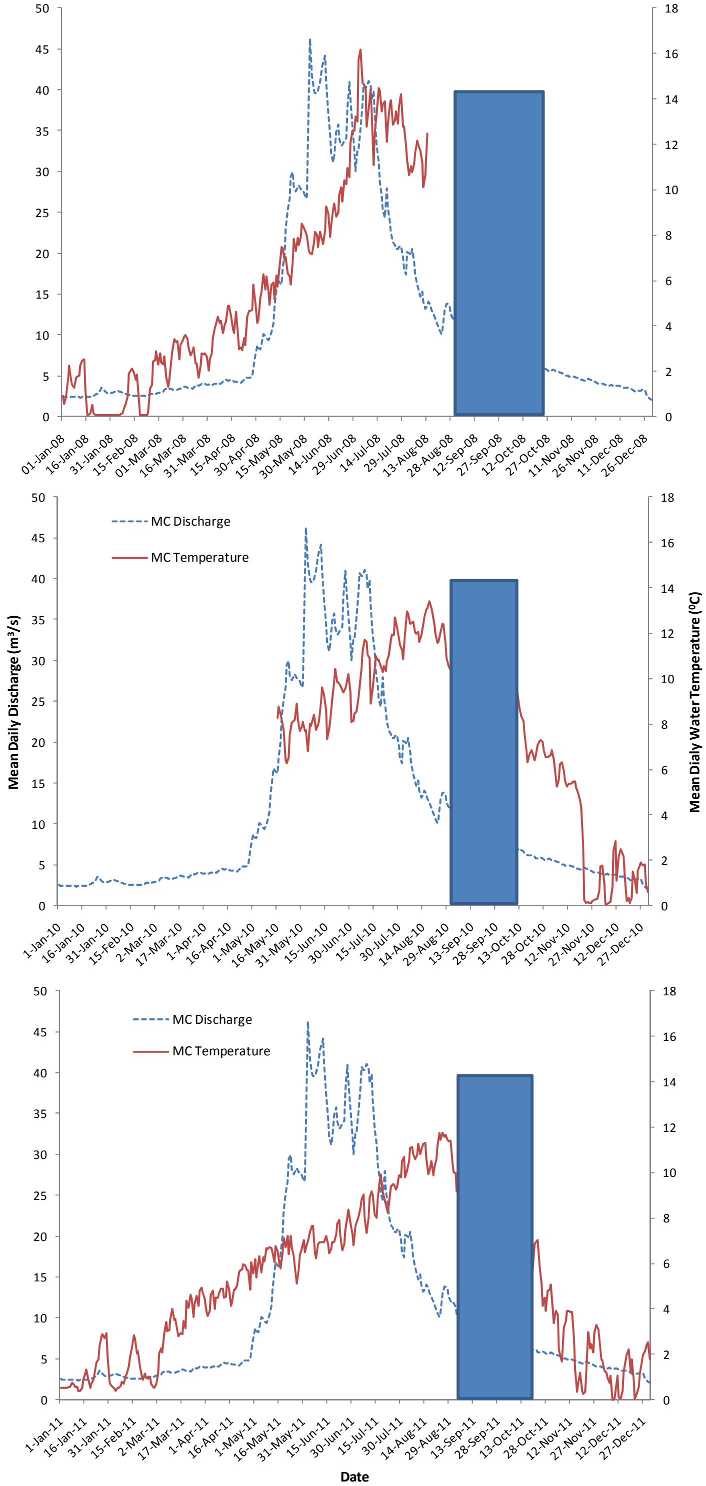


Figure 7: ***Mean daily discharge and water temperature for Meadow Creek. Average discharge (1967-1973) is depicted for comparison purposes on each graph because water stations were decommissioned in 1973 (WSC 08NH124). Water temperatures for Meadow Creek were not available for 2009. Shaded boxes represent the kokanee enumeration period.***

4.2 Kokanee Biological Characteristics

4.2.1 Size of Spawners

Spawner sizes measured during the current program for the LDR, Lardeau River and Meadow Creek are summarized in Figures 8 to 10. Length frequencies in Meadow Creek were bimodal, with one peak between 200 mm and <250 mm FL and the second peak at 250 mm FL (Figure 8). However, only one peak was observed for the LDR and Lardeau River (200 mm to <250 mm FL, Figure 8). Female weight by average FL varied by system with the heaviest spawners observed in Meadow Creek followed by the Lardeau River and then the LDR (Figure 9). Body depth by average FL for female spawners did not vary (Figure 10).

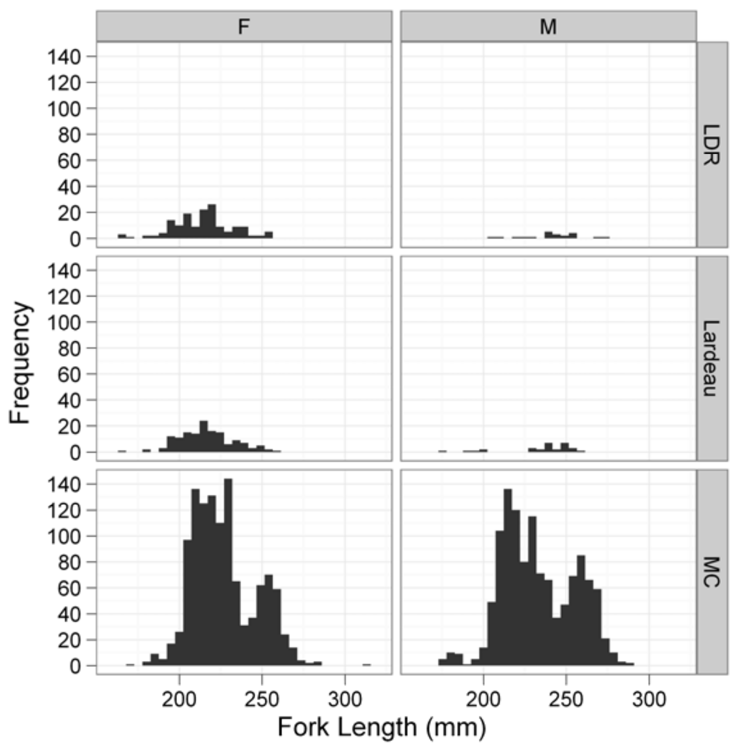


Figure 8: Length frequency for male and female kokanee in the LDR, Lardeau River and Meadow Creek, 2008 to 2010.

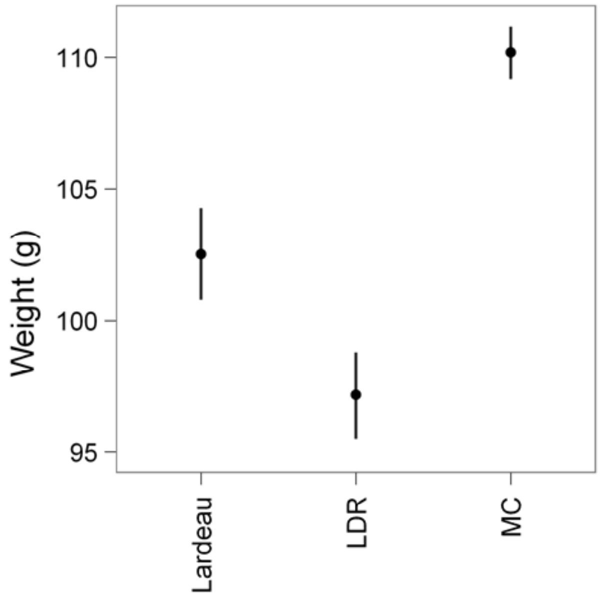


Figure 9: ***Female weight by average fork length with 95% credibility intervals for Lardeau River, LDR and Meadow Creek (MC), 2008 to 2010.***

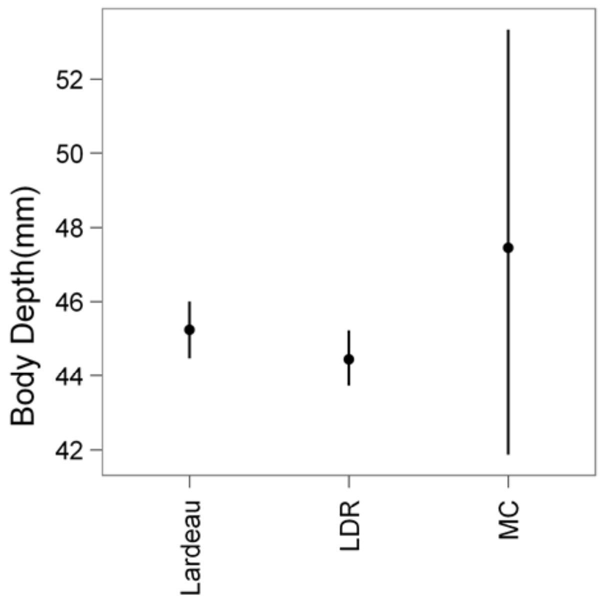


Figure 10: ***Female body depth by average fork length with 95% credibility intervals for Lardeau River, LDR and Meadow Creek (MC), 2008 to 2010. Note: Sample size for MC was low (n=2).***

4.2.2 Fecundity

Fecundity is the number of eggs potentially available for deposition in female kokanee. Fecundity was similar for Meadow Creek and Lardeau River fish and was lowest in the LDR (Figure 11).

4.2.3 Egg Retention

Egg retention is the number of eggs retained by female kokanee after spawning ceases. Egg retention for the Lardeau River and LDR were similar, but was highest in females sampled in Meadow Creek (Figure 12). However, egg retention in Meadow Creek was only available for four females that were measured for FL (n=3 in 2008; n=1 in 2010).

4.2.4 Age Composition

The majority of fish in the LDR and Lardeau River were observed as age-5, followed by age-4 (Figure 13). However, Meadow Creek spawners were dominated by age-4 followed by age-3 and age-5 (Figure 13).

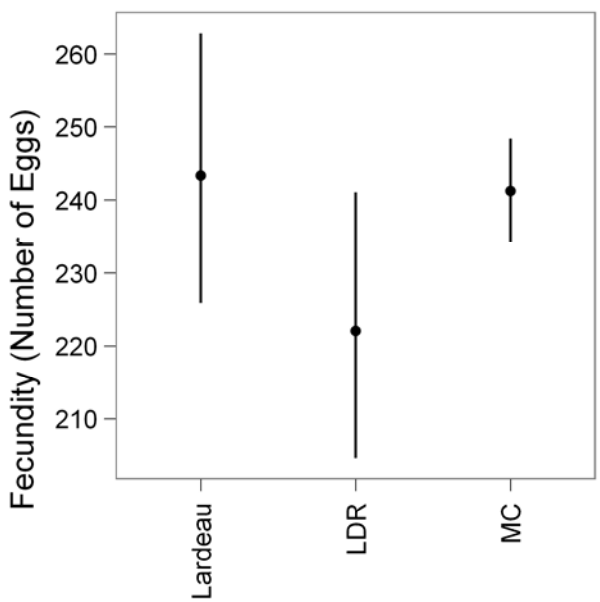


Figure 11: Female fecundity by average fork length with 95% credibility intervals for Lardeau River, LDR and Meadow Creek (MC), 2008 to 2010.

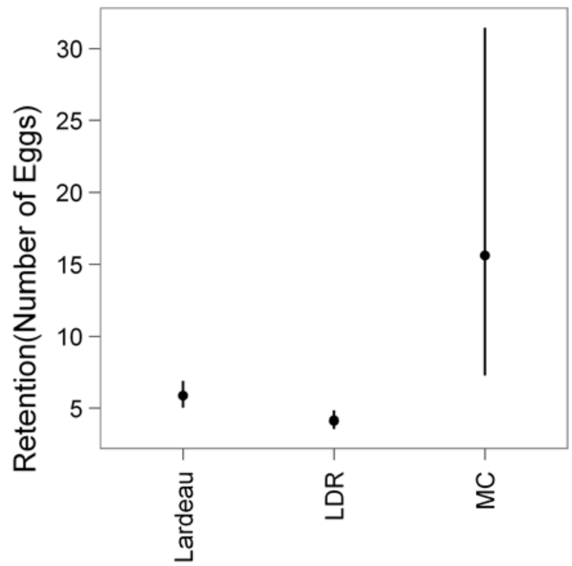


Figure 12: ***Female egg retention by average fork length with 95% credibility intervals for Lardeau River, LDR and Meadow Creek (MC), 2008 to 2010. Note: Sample size for Meadow Creek was low (n=4).***

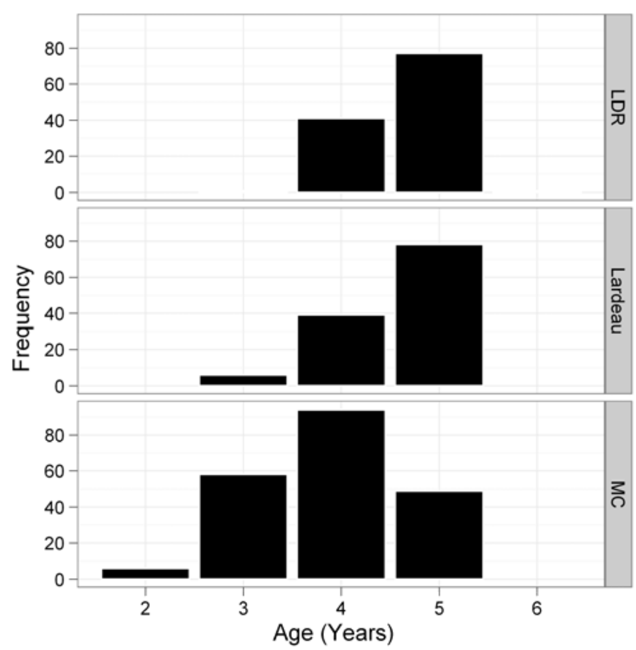


Figure 13: ***Age distribution of male and female kokanee from the aged subsample collected for Lardeau River, LDR and Meadow Creek (MC), 2008 to 2010.***

4.3 Adult Kokanee Morphological & DNA Comparisons in the Duncan River System

The model fitting suggested that there are morphological differences between individuals from the three populations, since the winning model in each of the cases was the model that included population as a predictor variable (further details are provided in Appendix D). Morphological differences were observed in body size, egg retention and age (Appendix D). For example, significant differences were found between spawning age for the LDR and Meadow Creek, and between Meadow Creek and the Lardeau River, but not between the LDR and Lardeau River. Kokanee from Meadow Creek were in better condition (weight for given length) than the other populations, but the fish from the Lardeau River were in higher condition than the LDR.

4.4 Incubation & Egg-to-Fry Survival

Eyed eggs were present in both the mainstem and side channel index sites during redd excavation on November 17, 2009 (Figure 14); incubation capsules remained undisturbed at this time. Eggs that survived the sampled incubation period likely reached the alevin stage, since only dead/fungused eggs and/or live alevins were present within the incubation capsules upon their retrieval in late January 2010 (Figure 15). It is possible that some eggs may have reached the eyed stage and then died while in the incubation capsules, but we could not determine this since they would have clouded over and become fungused prior to their observation. All alevins observed on January 27, 2010 still had their yolk sac intact and displayed hiding behaviour once removed from the incubation capsule (Figure 15).

Figure 14: Eyed eggs collected from sampled kokanee redds at index sites in the LDR, November 17, 2009. Black arrows indicate location of eyes in eggs.

Figure 15: Kokanee alevins with yolk sac collected from incubation capsules set in the LDR, October 3, 2009 to January 27, 2010.

Mean egg-to-fry survival from buried incubation capsules was 23% and ranged between 0% to 50% in both mainstem and side channel sites (Table 2). Survival did not seem to differ between artificially fertilized versus naturally spawned eggs (Table 2).

In comparison, kokanee egg-to-fry survival at MCSC in 2010 was 35%, but ranged from 6% to 64% from 1968 to 2011 (MOE unpublished). Survival estimates in the spawning channel are based on fry production from the study year divided by channel egg deposition from the previous year, which may not be directly comparable to the present study results. In controlled laboratory experiments, upper Arrow Lake kokanee survival for the fertilization to hatching period ranged from 61% to 97% and varied by temperature, with the highest embryo survival rate recorded at 6°C and the lowest at 2°C (Murray et al. 1989). Values reported for kokanee in a similarly regulated portion of the Flathead River system (Montana, USA) were 21% in 1982 and 35% in 1983 (Fraley et al. 1986). It was determined that the recovery of the kokanee population in this system would require an average egg-to-fry survival rate of 20% (Fraley et al. 1986).

Only two incubation capsules had zero egg-to-fry survival, and it is not clear as to why eggs did not survive at this time. No survival was observed at capsule #4 and #9 set within the mainstem site (Table 2). Capsule #4 was located in the mainstem site closest to the right bank and it was likely not exposed, since it was buried during the low flow period and other capsules in the same location along the bank had demonstrable survival. Capsule #9 was located closer to the middle of the channel and this area would not have become dewatered. Both capsule #4 and #9 contained artificially spawned eggs, but alevins were present in the other capsules containing artificial eggs, collection procedures did not vary between capsules, and eggs were mixed and added to the capsules randomly, so the collection procedure should not have influenced the results. These capsules also remained within the gravel for the duration of the egg incubation experiment.

Table 2: Egg-to-fry survival for incubation capsules set and retrieved at mainstem and side channel index sites in the Lower Duncan River, October 3, 2009 to January 27, 2010.

Site	Set Date	Retrieval Date	Incubation Capsule No.	Egg Fertilization Type	Incubation Capsule Position	Initial No. KO Eggs	Incubation Capsule Retrieval		% Survival
							No. Dead	No. Yolked Alevins	
Mainstem 2.4R	3-Oct-09	27-Jan-10	4	Artificial	Buried	30	30	0	0.0
	3-Oct-09	27-Jan-10	9	Artificial	Buried	30	30	0	0.0
	3-Oct-09	27-Jan-10	15	Artificial	Buried	30	21	9	30.0
	3-Oct-09	27-Jan-10	26	Artificial	Buried	30	18	12	40.0
	3-Oct-09	27-Jan-10	32	Artificial	Buried	30	17	13	43.3
	3-Oct-09	27-Jan-10	47	Artificial	Buried	30	19	11	36.7
					Subtotals	***180***	***135***	***45***	***25.0***
	4-Oct-09	27-Jan-10	5	Natural	Buried	30	19	11	36.7
	4-Oct-09	27-Jan-10	11	Natural	Buried	30	24	6	20.0
	4-Oct-09	27-Jan-10	17	Natural	Buried	30	26	4	13.3
	4-Oct-09	27-Jan-10	21	Natural	Buried	30	25	5	16.7
	4-Oct-09	27-Jan-10	40	Natural	Buried	30	24	6	20.0
	4-Oct-09	27-Jan-10	41	Natural	Buried	30	21	9	30.0
					Subtotals	***540***	***409***	***131***	***24.3***
	3-Oct-09	27-Jan-10	10	Artificial	Floating	30	27	3	10.0
	4-Oct-09	27-Jan-10	38	Natural	Floating	30	28	2	6.7
	3-Oct-09	27-Jan-10	46	Artificial	Floating	30	25	5	16.7
					Subtotals	***90***	***80***	***10***	***11.1***
Sidechannel 8.2L at Km 0.3R	4-Oct-09	27-Jan-10	7	Artificial	Buried	30	24	6	20.0
	4-Oct-09	27-Jan-10	12	Artificial	Buried	30	26	4	13.3
	4-Oct-09	27-Jan-10	25	Artificial	Buried	30	15	15	50.0
	4-Oct-09	27-Jan-10	28	Artificial	Buried	30	27	3	10.0
	4-Oct-09	27-Jan-10	35	Artificial	Buried	30	21	9	30.0
	4-Oct-09	27-Jan-10	44	Artificial	Buried	30	25	5	16.7
					Subtotals	***180***	***138***	***42***	***23.3***
	4-Oct-09	27-Jan-10	3	Natural	Buried	30	18	12	40.0
	4-Oct-09	27-Jan-10	29	Natural	Buried	30	20	10	33.3
	4-Oct-09	27-Jan-10	34	Natural	Buried	30	24	6	20.0
	4-Oct-09	27-Jan-10	37	Natural	Buried	30	24	6	20.0
	4-Oct-09	27-Jan-10	39	Natural	Buried	30	21	9	30.0
					Subtotals	***510***	***383***	***127***	***24.9***
	4-Oct-09	27-Jan-10	1	Artificial	Floating	30	25	5	16.7
	4-Oct-09	27-Jan-10	6	Artificial	Floating	30	22	8	26.7
	4-Oct-09	27-Jan-10	42	Natural	Floating	30	25	5	16.7
					Subtotals	***90***	***72***	***18***	***20.0***

4.4.1 Egg Development and LDR Water Temperature

Water temperatures recorded at the incubation index sites ranged from approximately 2.3°C to 11.5°C, but gravel and water column temperatures were not significantly different from each other when compared at each site (t-test; $p>0.05$). However, water temperatures within the gravel were significantly higher at the side channel site (mean=6.2; standard deviation (SD) =2.8°C) compared to the mainstem site (mean=5.7; SD=2.7°C; $p<0.05$); surface temperatures between index sites were not significantly different. Gravel water temperature differences between the two index sites may not influence egg-to-fry survival, since differences in survival between these sites was not apparent (Table 2), but small sample sizes may preclude observing any differences.

4.5 Kokanee Escapement

4.5.1 Helicopter Observer Efficiency

The ratios of the helicopter to ground counts used in the Bayesian aerial observer efficiency analysis are plotted in Figure 16. The Bayesian analysis estimated the median expected aerial observer efficiency to be 0.93 with a standard deviation of 0.29. The lower and upper 95% credibility intervals were 0.56 and 1.62 respectively. Visibility did not seem to affect observer efficiency since no relationship was found.

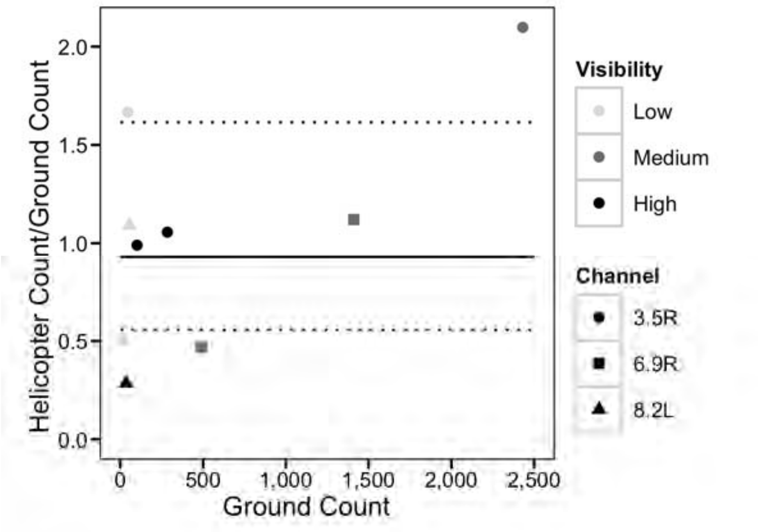


Figure 16: Ratios of helicopter and ground spawner counts in the LDR. The solid line is the median expected aerial observer efficiency and the dotted lines are 95% credibility limits.

4.5.2 Peak Counts

The number of spawning kokanee peaked in the LDR during the last week of September or first week of October during this study, which was similar to that observed since 2002 (Table 3). Peak spawning has been observed in early September at the Meadow Creek spawning channel and in late September in the Lardeau River (AMEC 2008).

Table 3: Annual peak kokanee spawner counts in the LDR study area, 2002-2011.

Year	Day	Peak Count[a]
2002	September 20	6,000
2003	October 6	26,069
2004	October 1	3,000
2005	September 27	2,200
2006	September 25	2,305
2007	September 19	24,320
2008	October 2	25,114
2009	October 7	19,850

Year	Day	Peak Count[a]
2010	September 30	18,658
2011	September 26[b]	30,728+

[a]Surveys conducted prior to 2008 did not distinguish between spawning, migrating, or holding fish and may not reflect actual number of kokanee spawning in the LDR. Surveys conducted since 2008 have counted kokanee based on spawning behaviour.
[b] The peak count is the estimated number of spawners in side channels of the LDR only, since the helicopter survey could not be carried out in the mainstem. This was the highest number of kokanee observed spawning in side channels in 2011.

4.5.3 AUC

The total aerial counts are plotted with the daily spawner abundance predicted by the hierarchical Bayesian AUC analysis in Figure 17. Visibility was not found to influence spawner abundance (Figure 17). The total annual spawner abundance estimates with 95% credibility intervals are plotted in Figure 18 and tabulated in Table 4. The timing of peak spawning with 95% credibility intervals is plotted in Figure 19. The ratios of the median expected annual spawner abundance to peak counts by year is plotted in Figure 20.

In summary, the results of the AUC analyses suggest that:

- the aerial observers are between 56% and 162% efficient;
- approximately 96,000 kokanee spawned in the LDR in 2011, compared to 22,000 in 2010, 17,000 in 2009 and 36,000 in 2008;
- peak spawning occurs between September 27 and October 13;
- the mean expansion factor for converting the peak count into the total spawner abundance is 1.2 although it could be as low as 0.8 or as high as 2.7.

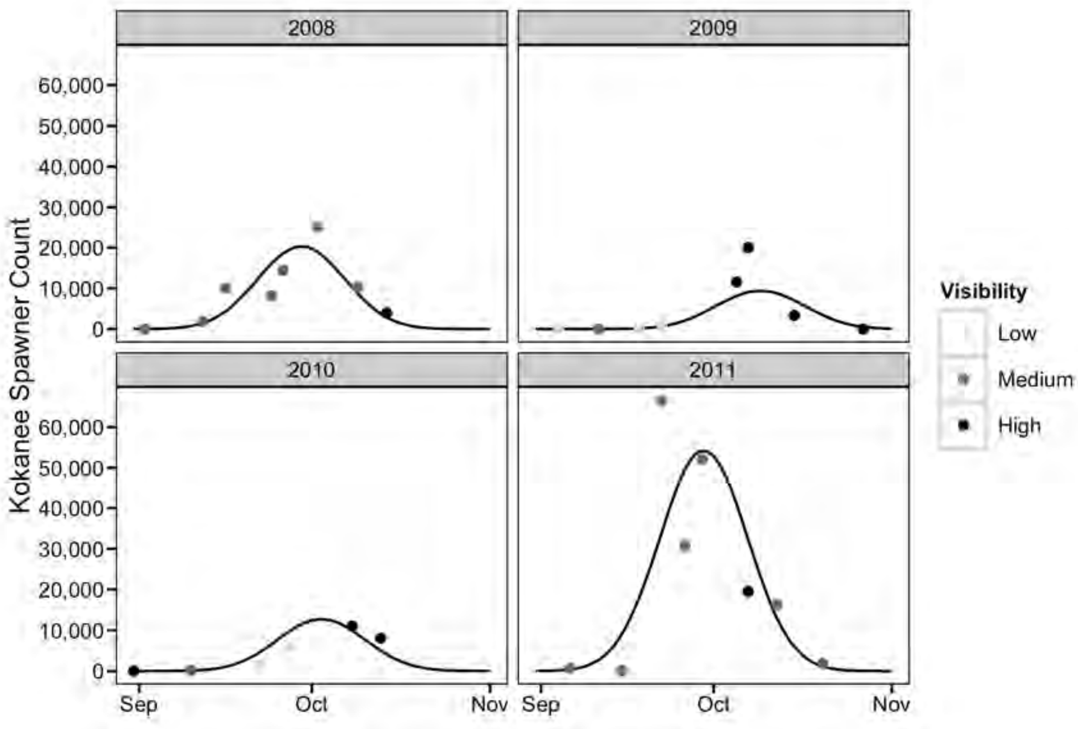


Figure 17 ***Aerial spawner counts by year in the LDR, 2008-2011. The solid line is the median expected number of spawners.***

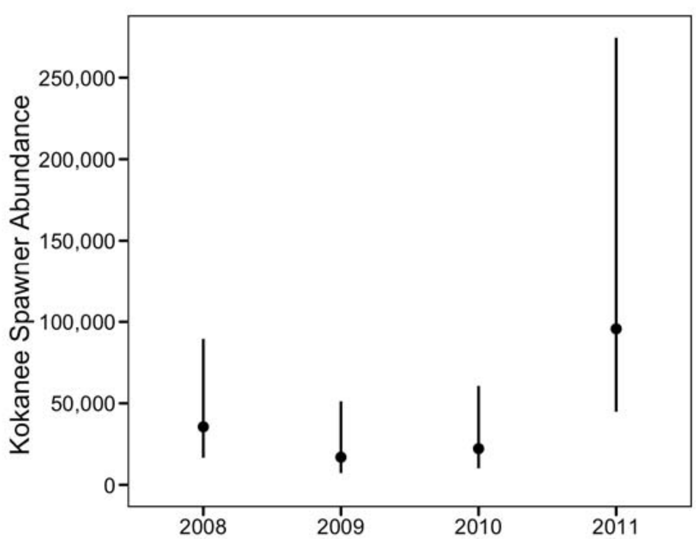


Figure 18 ***Median expected annual spawner abundance with 95% credibility intervals by year in the LDR, 2008-2011.***

Table 4: ***The median expected annual spawner abundance with 95% credibility intervals by year in the LDR, 2008-2011.***

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI
2008	35,600	16,600	89,600
2009	16,900	7,200	51,200
2010	22,200	10,100	60,700
2011	95,700	44,800	274,500

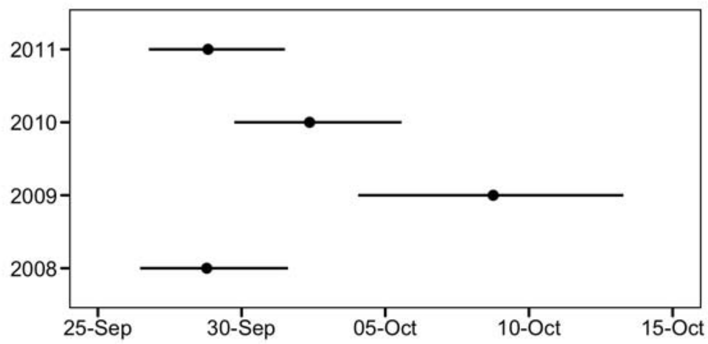


Figure 19: ***Estimated peak spawn timing with 95% credibility intervals for the LDR, 2008-2011.***

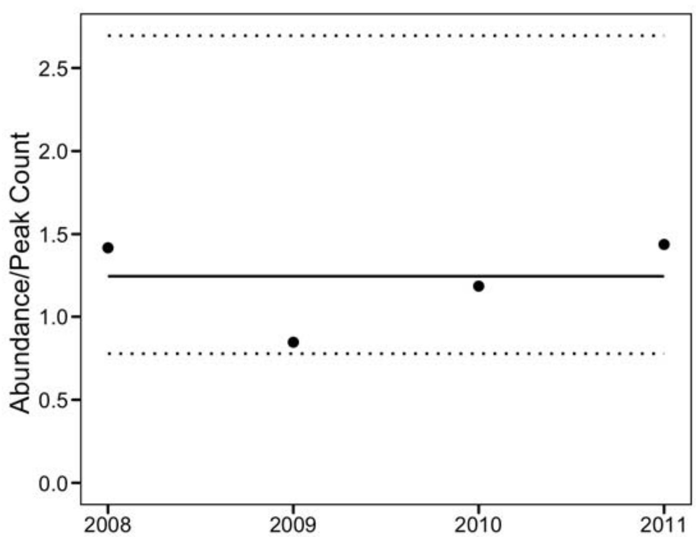


Figure 20: ***Ratios of the median expected spawner abundance to peak counts by year in the LDR, 2008-2011. The solid line is the median expected peak count expansion factor and the dotted lines are 95% credibility intervals.***

4.5.4 Relative Intensity of Kokanee Spawning in the Duncan River System

Meadow Creek accounted for approximately 66% of the observed total escapement within the Duncan River system followed by the Lardeau River (32%), and the LDR (3%; Figure 21).

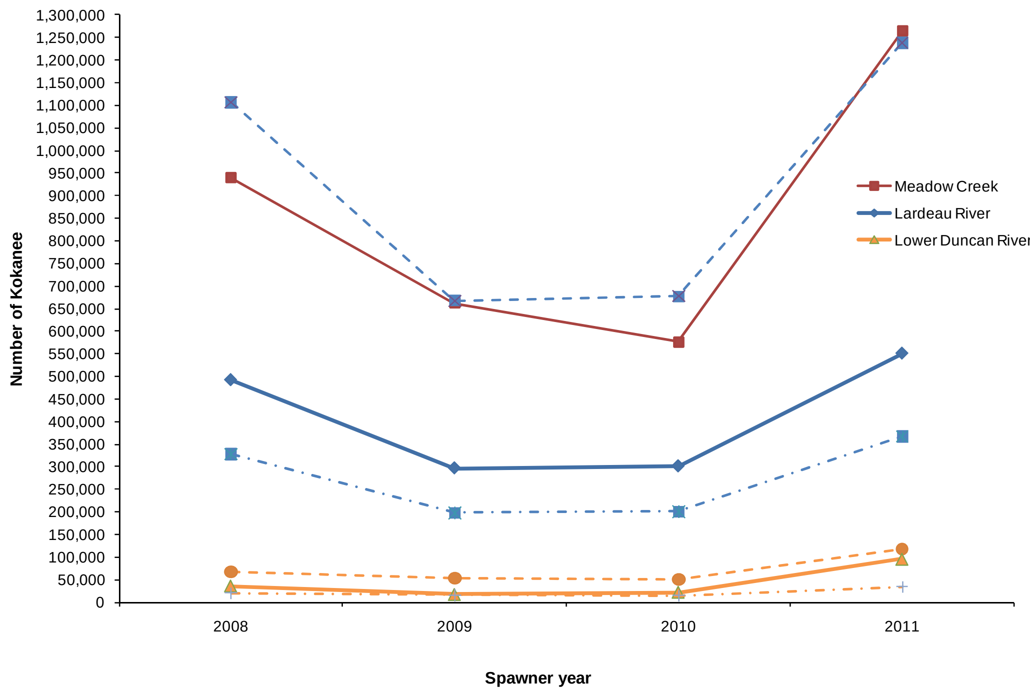


Figure 21: ***Estimated abundance of kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008 to 2011. Upper and lower abundance estimates are provided by dashed lines for the LDR and Lardeau River. Meadow Creek is based on counts at the MCSC enumeration fence in the creek proper.***

4.6 Migration, Spawning & Emergence

4.6.1 Migration, Holding & Spawning Behaviour

4.6.1.1 Lower Duncan River

Kokanee can be observed migrating from Kootenay Lake into the LDR in early or mid-August (M. Pearson, per. comm., 2011). In 2011, silver and red kokanee were observed throughout the LDR on August 19 and some spawning was observed during surveys conducted under DDMMON-7. At the onset of helicopter enumeration surveys conducted each year (late August/early September) there were generally higher numbers of holding/migrating fish in the LDR compared to the number observed spawning. For example, in 2010 almost 80,000 kokanee were holding in the LDR and no fish were spawning during the first survey conducted on August 31 (Figure 22). Most of these holding fish were located at the mouth of Meadow Creek at this time. Migrating and holding behaviour was observed to decline as spawning behaviour began to increase from mid- to late September each year. Fish observed holding near Meadow Creek during early September surveys, likely migrated and spawned there. Some fish observed holding in early and mid-September in the upper LDR may have also migrated and spawned in the Lardeau River.

Spawning behaviour was usually observed after the first week of September each year, but varied slightly (Figure 22). For example, in 2009 spawning was first observed 1.5 weeks later compared to other years. The number of spawners observed in the LDR increased over the duration of the enumeration surveys to reach a peak in late September/early October. Helicopter enumeration was completed in mid- to late-October each year when lower numbers of kokanee were observed. In 2009, kokanee were not observed in the LDR during the final enumeration survey conducted on October 27. However, low numbers of kokanee were still often observed spawning in the LDR after the completion of helicopter enumeration at the end of October and even into early November during other years (observations taken during DDMMON-2 field sampling).

4.6.1.2 Lardeau River

Based on observations taken in the lower 1 km of the Lardeau River each year, kokanee spawners were usually present during the second week of September. In 2010, helicopter enumeration commenced on August 31, but kokanee were not present in this section of the Lardeau River. Spawning activity was usually observed into late October during the end of helicopter enumeration. However, in 2008 spawners were not present in the Lardeau River enumeration area during the last survey on October 27.

4.6.1.3 Meadow Creek

Based on observations taken in the lower 1 km of Meadow Creek each year, holding and migrating kokanee were observed from late August to mid-September. In late September very few kokanee were observed in this lower section as they likely moved upstream to spawn in the Meadow Creek spawning channel or Meadow Creek proper. Spawning behaviour was never observed in the lower 1 km of Meadow Creek during helicopter enumeration.

Kokanee are let into the Meadow Creek spawning channel by mid- to late August and spawning is usually observed in late August (M. Pearson, pers. comm., 2011). However, in 2010 fish arrived one week earlier, which resulted in an earlier start and end to the spawning period (M. Pearson, pers. comm., 2010). Spawning is usually completed by mid- to late October each year at the channel (M. Pearson, pers. comm., 2010).

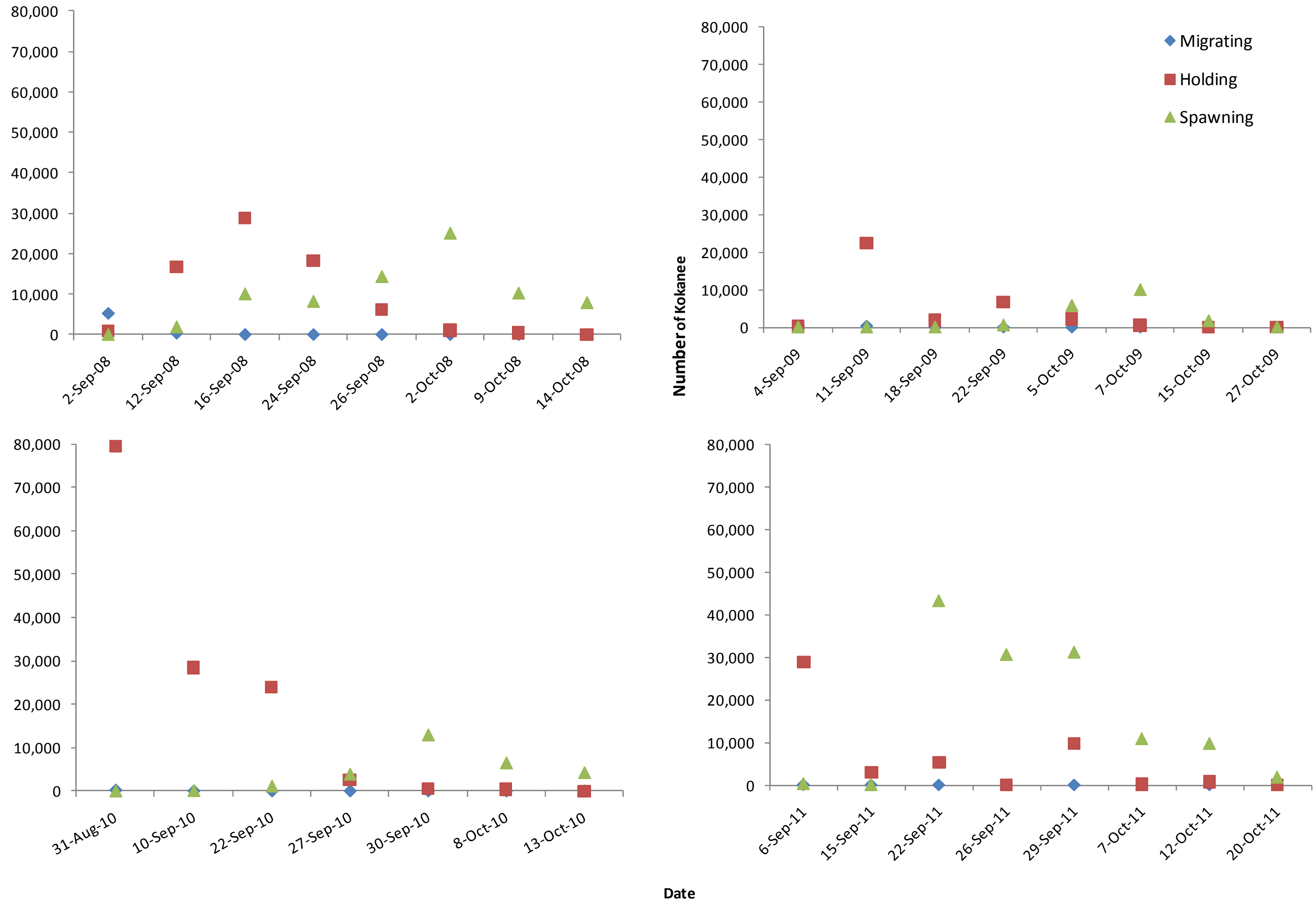


Figure 22: Number of migrating, holding and spawning kokanee enumerated by helicopter in the lower Duncan River, 2008 to 2011.

4.6.2 Comparison of Spawning, Incubation & Emergence Timing

Hatch and emergence for kokanee fry in the LDR was estimated to occur in December/January, whereas fry may begin ponding in February/March depending on water temperatures experienced during incubation (Table 5). Observations taken during 2009 incubation studies on the LDR indicated that the eyed and early emergence timing periods fell within the ATUs observed for Meadow Creek kokanee (Table 6). During the incubation study, eyed eggs were observed on November 17, 2009 (413 ATUs) in both side channel and mainstem sites, while yolked alevins in a hiding phase were observed on January 27, 2010 (692 ATUs; Table 6).

In the Lardeau River, hatch and emergence timing was estimated to occur in late March/early April, with ponding estimated in early May (Table 5). Hatch and emergence in Meadow Creek were estimated to occur in late March, with ponding in May (Table 5); this is similar to what is directly observed at the MCSC (AMEC 2008). Spawning generally occurred in September/October with incubation and development observed during the period of lowest discharge for all three systems (Figure 23).

Table 5: Estimated stage dates for kokanee in the LDR, Lardeau River and Meadow Creek. The eyed, hatch, emergence and ponding stages are based on compiled ATU data for kokanee (AMEC 2008). Water temperature data was provided by WSC Gauge for the LDR and DDMMON-7 (LDR Water Quality Monitoring) for the Lardeau River and Meadow Creek (May 2010 to February 2012).

Stage	ATU	LDR				Lardeau River			Meadow Creek	
Eyed	333	5-Nov-08	30-Oct-09	1-Nov-10	3-Nov-11	22-Oct-09	29-Oct-10	31-Oct-11	20-Oct-10	28-Oct-11
Hatch	700-780	17-Jan-09	14-Dec-09	25-Dec-10	28-Dec-11	-	25-Mar-11	-	23-Mar-11	-
Emergence	735-890	31-Jan-09	22-Dec-09	31-Dec-10	4-Jan-12	-	1-Apr-11	-	30-Mar-11	-
Ponding	950	30-Mar-09	17-Feb-10	21-Feb-11	-	-	9-May-11	-	11-May-11	-

-Data not available.
Notes: ATU's were calculated as average daily water temperature added cumulatively from peak spawning. Peak spawning was set as: LDR=October 2; Lardeau River=September 25; and, Meadow Creek=September 15.

Table 6: Kokanee stages and corresponding Acquired Thermal Units (ATUs) from culture and field studies for Meadow Creek and the LDR.

ATU	Stage	Comments
290	Eyed	1998 Meadow Creek kokanee (Kootenay Trout Hatchery)
333	Eyed	Meadow Creek (Acara 1970)
413	Eyed	Lower Duncan River Incubation Study 2009 (Section 4.4)
500-575	Hatch	Meadow Creek (Acara 1970)
692	Pre-emergence	Lower Duncan River Incubation Study 2009 (Section 4.4)
700	Hatch	1998 Meadow Creek kokanee (Kootenay Trout Hatchery)
735	Emergence	10% sockeye emergence (Weaver Creek Hatchery)
890	Emergence	Meadow Creek (Acara 1970)
950	ponding	1996 Meadow Creek kokanee (Kootenay Trout Hatchery)

Data from Kootenay Trout Hatchery (KTH) provided by D. Koller (KTH Technician, pers. comm.., 2009).
Data from Weaver Creek Hatchery (WCH) provided by V. Ewert (retired WCH manager, pers. comm., 2005).
Hatch = when head and tail appear.
Emergence = swimming out of gravel (also referred to as swim up).

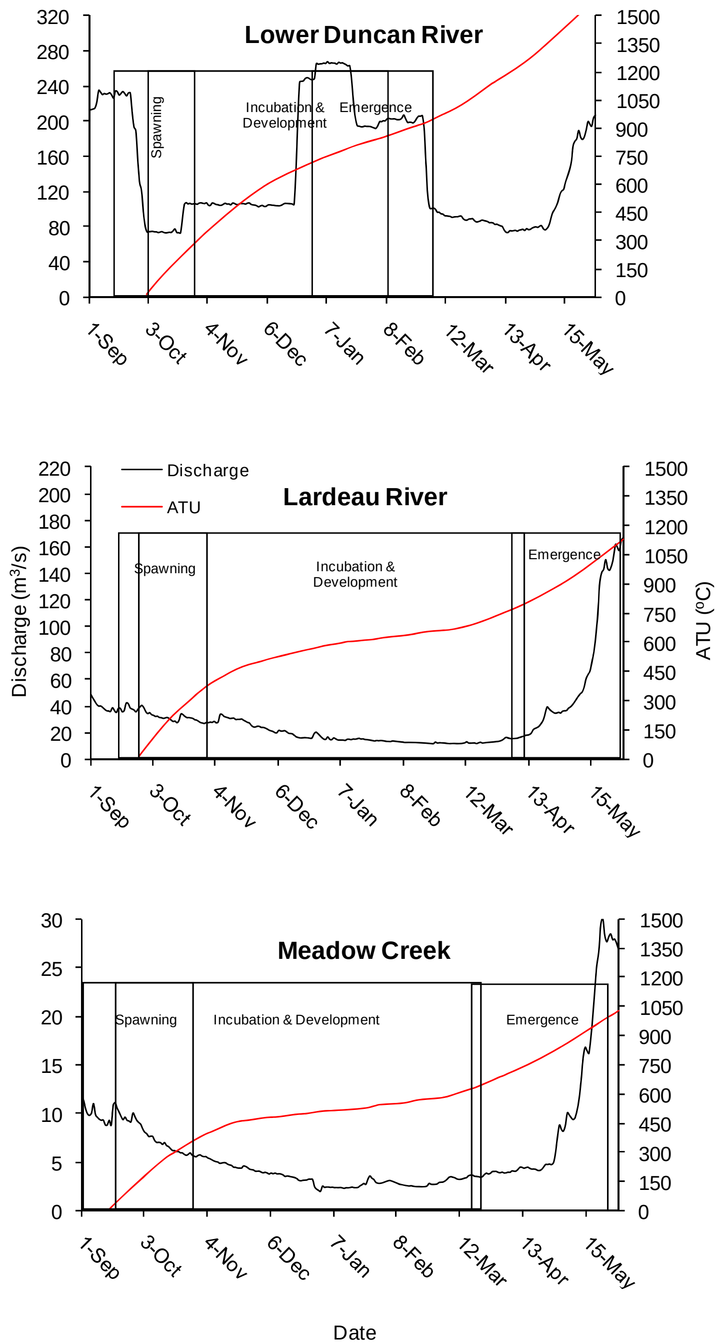


Figure 23: ***Comparisons of spawning through emergence timing based on average ATUs for the LDR, Lardeau River and Meadow Creek, 2008-2011. Discharge was averaged for all years of study, except for Meadow Creek, which was only available from 1967-1973. Blue line = Discharge; Red line = ATU.***

4.7 Spawner Distribution & Habitat Use in the LDR

Kokanee were observed to spawn in the upper 7 km of the LDR mainstem and in all side channels that remained wetted during all four years of study (Appendix F provides an example map from 2009). Spawning kokanee were usually not observed downstream of Km 7.0 or upstream of Km 0.6 in the LDR mainstem (including the discharge channel). However, a few spawners have been observed along the left bank at Km 8.0, 8.3 and 10.2 during years with high numbers of kokanee (i.e., 2008 and 2011). Very few kokanee have been observed at the lowermost portion of the discharge channel during snorkel surveys conducted under DDMMON-2 in mid-September, but these fish were not spawning; kokanee have not been observed at this location during helicopter enumeration. In 2009 and 2010, kokanee were not observed in side channel 6.9R, since this area was not wetted during the kokanee spawning period in an attempt to prevent egg losses.

A higher proportion of kokanee spawners were observed in LDR side channel habitats (90%) compared to mainstem areas prior to the peak spawning period (Appendix G). However, this finding changed during and after peak spawning where higher numbers of kokanee were observed spawning in mainstem habitats (60%) compared to side channels (40%) in 2008 and 2009. In 2010, the opposite occurred with a higher proportion of kokanee spawners enumerated in side channels (60%) versus the mainstem (40%) during peak spawning. Direct comparisons could not be made for data collected in 2011 as weather conditions prevented counts in both mainstem and side channel habitats on two occasions: i) September 15 only mainstem habitats were surveyed; and, ii) September 26 only side channels were enumerated.

4.8 Kokanee Spawn Mapping & Spawning Success

4.8.1 Spawn Mapping Methods Comparison

In 2008, spawn mapping was only conducted in an index site (SC 6.9R) to determine the feasibility and applicability of this method for determining spawning success in the LDR. During 2008 operations, the mapped SC 6.9R index site almost completely dewatered and spawning success in this side channel was only 4%. Therefore, subsequent changes to operating maximums during September flows were made in 2009 and 2010 to prevent dewatering of SC 6.9R to evaluate spawning success changes. It was determined that the methods employed in 2008 would provide an overview of spawning success in the LDR (AMEC 2009).

A comparison of ground and helicopter mapping of kokanee spawning areas within selected side channels was completed in 2009, 2010 and 2011. In general, helicopter mapping slightly overestimated the area mapped on the ground, but this varied by the site mapped and rated visibility. In 2009, helicopter mapping was observed to overestimate the side channel area mapped on the ground by an average of 30 m^2, whereas in 2010 these comparisons did not differ. Visibility during mapping comparisons in 2009 was rated as Medium due to turbid discharge from tributaries and visibility was observed to be higher on the ground compared to aerial surveys, while visibility in 2010 was rated as High. During surveys conducted in 2011, visibility was rated as High, but differences between ground and helicopter mapping varied depending on side channel conditions. For example, in 2011 helicopter mapping overestimated ground mapping in SC 3.5R by approximately 50 m^2, whereas in SC 6.9R helicopter crews missed approximately 625 m^2 of spawning area. Side channel 6.9R has a narrow channel that makes visibility difficult from the helicopter due to canopy cover, whereas SC 3.5R is wider and canopy cover does not impede visibility.

Ground mapping was conducted within a mainstem site at a small, wadeable area at Km 2.4 along the right bank in 2011. However, ground mapping could not be compared to helicopter mapping for this mainstem area because the helicopter crew had mapped a much larger section. Mainstem mapping comparisons were not made in 2009 and 2010.

Mapping during each flow reduction was only evaluated in 2010, since methods for the entire LDR were being tested in 2009 and in 2011 weather conditions prevented mapping during each flow reduction as discussed in Section 4.5. Mapping between each flow reduction in 2010 did not demonstrate a large difference between the number of spawning areas mapped compared to if only one pre- and post-Kokanee Protection Flow was mapped (as opposed to three pre- and one post-Kokanee Protection Flow). In 2010, only one small area (approximately 100 m^2) was mapped during the second flow reduction that may not have been mapped if only one pre-Kokanee Protection Flow survey was conducted. This area had approximately 16,900 eggs that potentially dewatered. However, it is unknown as to whether this result would vary between years.

4.8.2 Spawning Success at Index Sites in the Lardeau River

The majority of spawning area mapped at index sites on the Lardeau River was within side channel habitats (2222 m^2) because access to the mainstem was limited to wadeable areas (245 m^2). In total, 1,058 spawning kokanee were observed in the mapped index areas on the Lardeau River on October 4, 2011. Potential egg deposition was approximately 126,000. The survey conducted on February 3, 2012 observed that spawning areas were still wetted, thus spawning success was deemed to be 100% at these index sites. Ice cover precluded observation of a portion of the spawning area (Appendix B), but areas where the ice could be removed were still wetted beneath.

4.8.3 Spawning Success in the LDR

Overall, spawning success was rated as 84%, 96% and 92% for 2009, 2010 and 2011, respectively (Table 7). However, spawning success was rated as 100% in mainstem areas each year, whereas in side channel habitats it was rated as 67%, 94% and 86% for 2009, 2010 and 2011, respectively (Table 7). Dewatered spawning areas were not usually observed in mainstem habitats during helicopter spawn mapping, whereas areas observed to dewater in side channels ranged from 132 m^2 to 1000 m^2 (Table 7). The highest number of eggs that potentially dewatered was observed in 2011 followed by 2010 and 2009 (Table 7). Examples pre- and post-Kokanee Protection Flow spawning mapped areas are illustrated for a low PED year (2009; Appendix F) and a high PED year (2011; Appendix H).

Eggs deposited after October 1 each year were not expected to have become dewatered based on discharge records (Figure 5). A review of discharge records for the DRL staff gauge indicated that October flows remained relatively stable between approximately 72 and 76 m^3/s each year (Figure 5). However, in 2009 a slight increase in discharge occurred between October 17 and 18 from 75 m^3/s to approximately 88 m^3/s (Figure 5). Ground surveys in October 2009 and some observations taken during DDMMON-2 on November 7, 2011 observed additional dewatering compared to helicopter mapping, but these observations were not incorporated into spawning success calculations since observations were not consistent each year. From the end of October to the end of November, flows generally increased to just over 100 m^3/s, followed by an increase to approximately 250 m^3/s in December, potentially keeping kokanee eggs watered throughout this period (Figure 5). Additional ground surveys conducted on February 3 and 7, 2011 also observed that SC 3.5R and SC 6.9R were fully watered and flowing during the expected emergence period (Section 4.5.2).

Table 7: Total spawning area, area dewatered, Potential Egg Deposition, 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 2011.

Year	Period	Area (m^2)		PED		Spawning Success		
		SC	MS	SC	MS	SC	MS	Overall
2009	Pre	399	0	48,732	-	67	100	84[b]
	Post[a]	267	4,219	32,667	-			
	Difference	132	-	16,065	-			
2010	Pre	4,041	8,055	830,540	642,948	94	100	96
	Post	3,784	8,632	777,601	640,852			
	Difference	258	-577	52,939	2,096			
2011	Pre	6,902	88,172	3,253,621	2,372,672	86	100	92
	Post	5,902	88,172	2,781,955	2,372,672			
	Difference	1,001	-	471,666	-			

[a] Larger area was observed post-reduction because kokanee moved into side channels to spawn, but the information presented reflects the original spawning area dewatered and changes to PED.
[b] Average of SC and MS because PED for MS not available; 2010 and 2011 were based on original spawning success calculation.
- Spawning was not observed pre-Kokanee Protection Flow, therefore post-Kokanee Protection Flow spawning areas were not dewatered during mapping.

4.8.4 LDR Flow Targets & Kokanee Spawning Success

The flow targets set for the August 25 through September 24 period in 2009 and 2010 enabled side channel (SC) 6.9R to remain disconnected from the mainstem throughout the duration of the enumeration period so that kokanee were unable to enter and spawn at this location, thus potentially preventing kokanee eggs from dewatering. In contrast, during typical WUP flow conditions as observed in 2008 and 2011, SC 6.9R remained wetted during the kokanee spawning period. In 2008, approximately 1500 kokanee spawned in this side channel that was observed to mostly dewater during the planned flow reductions on October 1, 2008. Approximately 141,000 eggs potentially dewatered in SC 6.9R in 2008 due to the flow reduction. Similarly, in 2011, SC 6.9R was wetted through September and approximately 600 kokanee spawned there. In October 2011, this side channel was completely cut off from the mainstem and approximately 71,000 eggs were estimated to have dewatered though some spawning areas remained wetted. Unfortunately the entire LDR was not mapped in 2008 when very high PED was estimated for SC 6.9R, which might have impacted overall spawning success. High resolution orthophoto maps were not available for the kokanee field season in September/October 2008 and therefore only a test area could be mapped at this time.

4.9 Areas Prone to Dewatering in the LDR

Areas prone to dewatering in the LDR are provided below based on observations taken during the four year study period. The condition of each side channel based on modeling conducted throughout the LDR (NHC 2010) is also provided for comparison with actual observations during Kokanee Protection Flows (75 m^3/s). Table 8 summarizes the results of the modeling analyses that were found to provide reasonable estimates (error within less than 10% precision) for predicting side channel conditions (NHC 2010).

- SC 2.7L – This side channel received lowered flows at its inlet in October. Dewatering only occurred in 2010 along a gravel bar at Km 0.4R. Spawning area dewatered was approximately 45 m^2 and approximately 2,000 eggs were potentially dewatered (Appendix H- map #3). Hydraulic model indicated this side channel is ON during Kokanee Protection Flows.
- SC 3.5R – This side channel mostly dewatered from the inlet to Km 0.5, but some isolated pools usually remained wetted in October (2009, 2010, 2011). The outlet was usually backwatered, but less spawning was observed in this section. Spawning area dewatered ranged from 15 m^2 to 470 m^2 and the number of eggs dewatered ranged from 8,000 to 177,000 (Appendix H- map #3). Hydraulic model indicated this side channel is backwatered (BW) during Kokanee Protection Flows.
- SC 4.4R – Low water levels were observed at the inlet of this side channel in October, but small channels ran along its length from the mainstem to maintain flows throughout. Dewatered spawning areas of ~200 m^2 were observed in 2009 only closer to the inlet at Km 0-0.1 as well as at Km 0.4L (Appendix H – map #3), which potentially dewatered 11,500 eggs. Hydraulic model indicated this side channel is ON during Kokanee Protection Flows.
- SC 6.9R – This side channel can dewater in its entirety depending on the flow regime. In 2011, this side channel remained wetted at its outlet, whereas in 2008 it was completely dewatered during Kokanee Protection Flows. Small isolated pools were observed in October 2011 and 120 m^2 of spawning area and potentially 43,000 eggs were dewatered (Appendix H – map #5). In 2008, few isolated pools remained in October and approximately 1800 m^2 of spawning area and potentially 141,500 eggs were dewatered. It was dry prior to spawning in 2009 and 2010. Hydraulic model indicated this side channel is OFF during typical Kokanee Protection Flows.
- SC 7.6R – This side channel remained wetted in October from its inlet to Km 0.1. Isolated pools were present from Km 0.2 to 0.5 and it remained connected at its outlet, where habitats may be backwatered up to Km 0.5 (LWD precludes observations between Km 0.5-0.55). Areas were dewatering in 2011 only at Km 0, 0.3R, 0.4R, and 0.5R and ~109 m^2 of spawning habitat was observed to dewater (Appendix H – map#5). Hydraulic model indicated this side channel is OFF during Kokanee Protection Flows.
- SC 8.2L – This side channel was dewatered from the inlet to Km 0.8. Backwatering at the outlet was observed. Small isolated pools have been observed throughout the dewatered section. Dewatered spawning areas were

observed in 2009 and 2011 at Km 0.1L, 0.2L, 0.3L, 0.5R, 0.6R, 0.8L which totalled ~58 m^2 (3,600 eggs) and 340 m^2 (36,700 eggs), respectively (Appendix H – map#5 and map#6). Hydraulic model indicated this side channel is backwatered (BW) during Kokanee Protection Flows.

- One small area (22 m^2) at the upstream end of a mid-channel gravel bar within the mainstem at Km 1.5L (DDMMON-2 survey conducted on November 7, 2011; Appendix H – map#1). Hydraulic model not applicable for this comparison.
- A small (16 m^2) braided area with LWD on the left bank of the mainstem that is between Km 3.1L and SC 2.7L (observed in 2010 only; Appendix H – map#3). Hydraulic model not applicable for this comparison.

Table 8: Side channel hydraulic assessment results to compare the conditions observed during kokanee spawning. Table taken from Northwest Hydraulic Consultants (NHC 2010).

Side Channel	DRL Gauge Flow (m^3/s)																	
	3	6	9	15	20	30	50	75	100	130	150	175	205	230	255	280	305	330
1.1R	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW	BW
2.7L	BW	BW	BW	BW	BW	BW	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
3.5R	OFF	BW	BW	BW	BW	BW	BW	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
4.1R	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
4.4R	BW	BW	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
6.9R	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON
7.6R	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	ON	ON
8.2L	BW	BW	BW	BW	BW	BW	BW	BW	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON
8.8L	OFF	OFF	OFF	OFF	OFF	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON

BW = Backwatered condition where the outlet and a portion of the side channel is watered, but there is no surface flow entering the side channel inlet. Flows and depths within the side channel are reduced and seepage and shallow groundwater are the only sources of flow.
ON = Represents a fully flowing state where surface flows are entering the channel and the side channel is fully connected.
OFF = Side channel is not flowing and is not connected (this definition was not provided in NHC 2010, but has been assumed herein).

4.10 Population Impact of Dewatering in the LDR

The percent Potential Egg Deposition (PED) lost from the LDR compared to overall PED for the entire LDR system, including Meadow Creek and the Lardeau River, was estimated to average 0.14% (Table 9). The average number of adult returns based on the average PED lost from the LDR due to dewatering (Table 9) is approximately 2,000 fish or 0.14% of the overall average estimated adult returns to the Duncan River system.

The difference between the estimated number of adult returns each year in the LDR with and without dewatering ranged between 1,053 and 9,194 fish (Table 10). If a natural stream system had similar PED as the LDR each year, it is estimated that adult returns for each cohort would be much lower compared to that observed for the LDR with and without dewatering (Table 11). This difference is due to the lower egg-to-fry survival that is estimated for natural streams in the Kootenay region (5%) versus the actual LDR egg-to-fry survival estimated during kokanee incubation experiments (23%) conducted during this program.

Table 9: Potential Egg Deposition (PED) estimated for kokanee in the LDR system including Meadow Creek, Lardeau River and the LDR compared to PED lost from the LDR due to dewatering, 2009-2011.

Year	Total LDR System PED	PED Lost from LDR due to Dewatering	Remaining PED for Overall System	% Lost
2009	131,147,408	16,065	131,131,343	0.01
2010	46,191,924	55,035	46,136,889	0.12
2011	198,109,891	471,666	197,638,225	0.24
Average	***125,149,741***	***180,922***	***124,968,819***	***0.14***

Notes: PED for Meadow Creek was based on information provided by MOE (unpublished). PED for Lardeau River was calculated based on yearly abundance estimates; average fecundity and egg retention were based on results obtained from biosampling during this program. PED lost from the LDR due to dewatering was obtained from Table 7. PED Lost for 2008 was not available, since estimates were not obtained for the entire LDR until 2009.

Table 10: Estimated adult returns to the LDR with and without dewatering of kokanee eggs during the October flow reduction, 2008-2011. PED estimates with dewatering based on average % spawning success presented in Table 6.

Year	AUC Abundance Estimate for LDR	No. Females	Potential Egg Deposition (PED)	With Dewatering			Without Dewatering		Difference
				LDR Spawn Success	LDR Egg-Fry Survival (23%)	Fry-Adult Survival (5%)	LDR Egg-Fry Survival (23%)	Fry-Adult Survival (5%)	
2008	36,000	18,000	3,747,600	3,447,792	792,992	39,650	861,948	43,097	3,448
2009	17,000	8,500	1,769,700	1,486,548	341,906	17,095	407,031	20,352	3,256
2010	22,000	11,000	2,290,200	2,198,592	505,676	25,284	526,746	26,337	1,053
2011	96,000	48,000	9,993,600	9,194,112	2,114,646	105,732	2,298,528	114,926	9,194

Table 11: Estimated adult returns for a natural stream system in the Kootenay Region based on Potential Egg Deposition (PED) in the LDR, 2008-2011

Year	AUC Abundance Estimate for LDR	No. Females	Potential Egg Deposition (PED)	Egg-Fry Survival (5%)	Fry-Adult Survival (5%)
2008	36,000	18,000	3,747,600	187,380	9,369
2009	17,000	8,500	1,769,700	88,485	4,424
2010	22,000	11,000	2,290,200	114,510	5,726
2011	96,000	48,000	9,993,600	499,680	24,984

5.0 DISCUSSION

The following discussion is structured along the management questions. The hypotheses outlined for this program are also provided below for further clarification of the results.

5.1 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?

5.1.1 Spawn Run Timing

Spawn run timing for kokanee in the LDR occurs from late August to late October, with peak spawning estimated between September 27 and October 13. Environmental and operational cues, such as temperature and discharge, affecting this variable are not directly known at this time. Water temperature was not found to influence the onset of spawning for mature kokanee in Meadow Creek (Morbey and Ydenberg 2003). However, flow and temperature have been correlated with the arrival of sockeye salmon (a species that has similar life history as kokanee) at Bonneville Dam on the Columbia River (Quinn et al. 1997). Preliminary information indicates that water temperatures in Meadow Creek are slightly cooler during the September/October kokanee spawning period than those observed in the LDR and the Lardeau River, but it is unknown whether this may influence spawn timing. Further analyses conducted under DDMMON-7 may help answer whether water temperature and discharge influence spawn run timing.

5.1.2 Fry Emergence

Kokanee fry emergence timing in the LDR occurred in December/January, with ponding estimated in February/March. Fry emergence was approximately 3 months earlier in the LDR than that estimated for the Lardeau River and Meadow Creek. Fry emergence timing is dependent on water temperature (i.e., ATUs), which is influenced by DDM operations. For example, LDR water temperatures from October 2010 through January 2011 were higher than those measured in the Lardeau River during this time period (AMEC 2011). This may explain the earlier fry emergence timing observed for the LDR, since warmer water temperatures would promote faster egg development, earlier hatch times, increased alevin development and yolk sac absorption, which would lead to the emergence of fry to start exogenous feeding.

It is unknown whether early emerging fry are at a disadvantage compared to fry that emerge later. A temporary disadvantage for early emerging fry has been observed within the hatchery environment with embryos noted as being ‘weaker’ and having a larger yolk sac in relation to their body size compared to embryos that hatch later (Becker et al. 1983). However, early emerging sockeye salmon fry were not observed to be at a disadvantage when entering Lake Washington (WA) up to three months earlier than peak abundance of their preferred prey because they were able to feed on other prey available at that time (Beauchamp et al. 2004). Survival of early emerging fry from the LDR may be dependent on predation and prey availability in Kootenay Lake. It is unknown at this time whether LDR fry entering Kootenay Lake in late winter would have adequate food resources for growth and survival because zooplankton sampling has not been conducted during this period (E. Schindler, Limnologist, Ministry of Environment, pers. comm., 2012).

5.1.3 Relative Intensity of Kokanee Spawning in the LDR

The relative intensity of kokanee spawning in the LDR has been low in comparison to Meadow Creek and the Lardeau River. The majority of kokanee in the Duncan River system were observed to spawn in Meadow Creek (66%), followed by the Lardeau River (32%) and lastly the LDR (3%); this was similar to what has been observed from 2002 to 2007 (AMEC 2008).

Prior to the construction and operation of DDM, approximately 62% of the spawning escapements were from the Duncan River itself, followed by the Lardeau River (30%) and Meadow Creek (32%; Acara 1970; AMEC 2008). The change in the proportion of spawners to the Duncan River has been attributed to the construction of DDM (Acara 1970, Vonk 2001). Lower numbers of kokanee spawners began to be observed in 1966 during dam construction and likely remained at these lower levels until present (Acara 1970, Vonk 2001, AMEC 2008).

The regulation of the LDR has also caused substrate compaction (NHC 2010) and reduced the amount of spawning habitat for kokanee compared to that available historically (Vonk 2001), but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River. Adult returns to the Duncan River system are also highly influenced by in-lake factors such as adult and fry survival, fertilization inputs, lake conditions and angling pressure (AMEC 2008). Vonk (2001) indicated that returns to MCSC have also been negatively affected by channel conditions such as siltation, redd superimposition, predation and loss of water supply. Kokanee spawner year-class strength has also been related to other in-lake factors such as food availability and growth, density dependence and interactions between other kokanee stocks and predation (e.g., Fraley et al. 1986, Grover 2006).

5.2 What are the timing/cues of kokanee spawners in Meadow Creek and Lardeau River systems?

Spawning in Meadow Creek occurred from mid-August to late October with peak spawning during mid- to the third week of September. In the Lardeau River, spawning occurred from early September to mid-October with peak spawning during the last week of September.

It is not known whether any physical cues are used by kokanee spawners in Meadow Creek and the Lardeau River. Previous research suggests that water temperature may not influence spawn timing/arrival in Meadow Creek, but there is a lack of information on cues for the Lardeau River. For example, Morbey and Ydenberg (2003) observed that early arriving females waited approximately two weeks prior to nest settlement at MCSC and this wait time declined seasonally with less waiting time observed for later arriving females. Water temperatures during this period did not show a seasonal decline, perhaps indicating that this wait period was not temperature dependent (Morbey and Ydenberg 2003). Water temperatures in 2010 and 2011 were observed to be lower at the confluence of Meadow Creek compared to the LDR and Lardeau River. Water temperatures in the LDR and Lardeau River in 2010 and 2011 were relatively similar until the end of September when LDR temperatures became slightly warmer. Further analyses using data collected under DDMMON-7 may help determine whether water temperature and discharge are related to spawn timing observed in these systems.

5.3 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?

5.3.1 LDR

Kokanee spawn in the upper 9 km of the LDR below DDM from Km 0.8 to 7.1 in the mainstem and in all side channels that remained wetted during the spawning season (1.1R; 2.7L; 3.5R; 4.1R; 4.4R; 6.9R; 7.6R; 8.2L; and, 8.8L). It is likely that kokanee spawn within the upper river because these areas have more suitable spawning gravels compared to lower regions of the river, which are largely comprised of fines due to the regulation of Kootenay Lake (NHC 2010). The regulation of the LDR has also caused substrate compaction (NHC 2010) and reduced the amount of spawning habitat for kokanee compared to that available historically (Vonk 2001), but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River (Section 5.1.3). Lestelle et al. (2006) indicated that a lack of flushing flows due to river regulation may make the gravels less suitable, so fish may avoid spawning in these areas and find better habitats elsewhere.

Observations suggest that early spawning begins in side channel habitats, but by the peak of spawning kokanee are in both side channel and mainstem habitats in approximately equal proportions. Kokanee move into side channels earlier than the mainstem likely because they are seeking out low velocity, cooler (shadowed) areas to minimize energy expenditure as has been observed for kokanee in Meadow Creek (Morbey and Yedenberg 2003).

There is preliminary evidence that water temperatures may vary along the left versus right bank of the LDR below the Lardeau River, but this temperature difference disappears by approximately Km 7.0 (AMEC 2011) and it is unknown whether this influences the distribution of kokanee spawners. Further analyses using data collected under DDMMON-7 may help determine whether water temperature and discharge are related to spawning distribution observed.

5.3.2 Meadow Creek

The majority of spawning in Meadow Creek occurs within the 3 km spawning channel, which is approximately 6 km from its confluence with the LDR. Kokanee have also been observed to spawn both upstream and downstream of the Meadow Creek spawning channel (MCSC) mostly because kokanee are no longer able to enter the SC (i.e., channel is closed due to maximum channel loading). The uppermost spawning area is just below a waterfall (located approximately 2 km upstream of the MCSC), which is a barrier to kokanee migration, but not to bull trout (Vonk 2001). The lower section of Meadow Creek (4 km) is composed mostly of fines and does not provide suitable spawning habitat (Vonk 2001). Therefore, distribution in Meadow Creek is affected by the presence of the spawning fence (as mentioned above), presence of the waterfall barrier and silt substrates that are not suitable for spawning in the lower section of the river.

Higher proportions of kokanee spawn in Meadow Creek, compared to the LDR and Lardeau River, likely because the spawning channel provides more suitable spawning substrates, since it was specifically built in 1967 to compensate for half of the kokanee run lost due to DDM construction and now provides approximately 3 km of spawning gravels specific to kokanee spawning (Redfish Consulting Ltd. 1999). Spawning gravels in the MCSC are also scarified yearly to prevent sediment build-up and ensure that substrate interstices are available for egg deposition each year (M. Pearson, pers. comm., 2012).

5.3.3 Lardeau River

The only information available on kokanee spawning distribution in the Lardeau River are anecdotal observations by M. Pearson (MCSC operator, MOE) and a report by Vonk (2001) where it was noted that spawning occurred along the length of the river, with the most preferred areas in the uppermost side channels. Anecdotal information collected in 2010 indicated that kokanee spawned in areas where they were not normally observed due to higher water levels that inundated these locations (M. Pearson, pers. comm., 2010). To the best of our knowledge kokanee spawning habitat and behaviour have not been studied for the Lardeau River system in detail (AMEC 2008). However, one peak kokanee count is conducted yearly in the Lardeau River from the confluence with the LDR to Trout Lake, indicating that they are present throughout the system (MOE, unpublished).

Cues affecting distribution may include the presence of suitable spawning substrates. The relative abundance of kokanee spawning in the Lardeau River was the second highest for the overall LDR system. Therefore, suitable spawning substrates are found in the Lardeau River. In addition, the Lardeau River experiences a natural hydrograph and flushing flows aid in removing fine sediments that may build-up within substrate interstices that would interfere with kokanee egg deposition.

5.4 What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended kokanee spawning operations?

A summary of physical works or operational constraints that could be implemented with rationale/benefits for kokanee spawning protection is provided in Table 12. The physical works or operational constraints that may be necessary to minimize operational conflicts associated with kokanee spawning protection flows need to be reviewed within the context of current baseline operations at DDM. Current baseline operations at DDM were based on the WUP review process and recommendations from the Consultative Committee (BC Hydro 2007; Figure 24). Kokanee spawning protection flows occur during a portion of the actual spawning period and start later (October 1) compared to when peak spawning has been observed for kokanee during the present study (September 27 to October 13). These flows do not currently capture the majority of kokanee observed spawning in the LDR during the September/October period (Section 5.5). In addition, these baseline conditions potentially result in the loss of 0.14% of the overall number of adult kokanee that may return to the Duncan River system yearly.

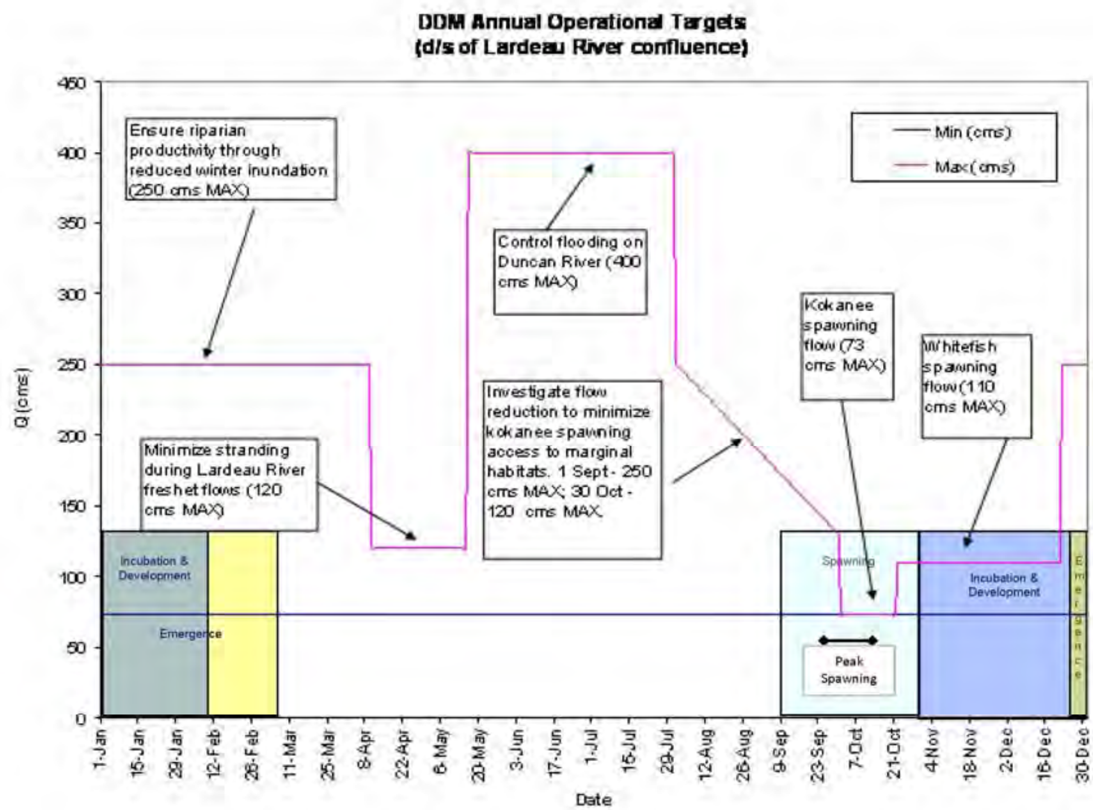


Figure 24: Summary of DDM Annual Operational Targets (downstream of the Lardeau River confluence) based on WUP recommendations (taken from Figure 4 in DDMMON-15 (Poisson & Golder 2012)). LDR Kokanee spawning, incubation/development and emergence periods depicted in Figure 23 have been overlaid.

Table 12: Summary of operations and physical works with rationale/benefits for kokanee spawning in the LDR.

Type	Description	Rationale/Benefits	Comments
Operation	WUP Kokanee Spawning Protection Flows (73 m^3/s 1-21 October); without dewatering of side channel 6.9R prior to spawning period.	These baseline operations have resulted in kokanee egg dewatering of less than 1% of the total overall PED for the Duncan system (potentially 2,000 adults, which is 0.14% of total adult returns). If you only look at the LDR, then approximately 4-16% of the PED each year has potentially been dewatered during these operations; this was approximately 14% for side channels and 0% for mainstem areas. Operations during kokanee development through to emergence (Sept to Jan/Feb) stays over the 75 m^3/s (Figure 24) minimum flow target. Therefore, egg depositional areas should have adequate flow coverage for development and hatching kokanee in the LDR should not be stranded during this period.	Is the potential loss of 0.14% adult returns to the entire Duncan River system affecting the overall population?
Operation	WUP Kokanee Spawning Protection Flows (73 m^3/s 1-21 October); with dewatering of side channel 6.9R prior to spawning period.	These modified baseline operations have resulted in kokanee egg dewatering of less than 1% of the total overall PED for the Duncan system (potentially 2,000 adults, which is 0.14% of total adult returns). If you only look at the LDR, then approximately 8% of the PED each year has potentially been dewatered during these operations; this was approximately between 6% and 33% for side channels and 0% for mainstem areas. Operations during kokanee development through to emergence (Sept to Jan/Feb) stays over the 75 m3/s (Figure 24) minimum flow target. Therefore, egg depositional areas should have adequate flow coverage for development and hatching kokanee in the LDR should not be stranded during this period.	Lowered egg losses in side channels, but translates to similar adult returns as above.

Operation	WUP Kokanee Spawning Protection Flows (100 m^3/s 1-21 October).	The DDM Hydraulic Model estimated that kokanee spawning weighted useable area (WUA) increased with flows at 100 m^3/s (NHC 2010). In addition to this predicted increase, side channel 3.5R is predicted to go from a backwatered condition to fully ON (Table 8), which may prevent egg losses during kokanee protection flows; in 2009 it was estimated that approximately 16,000 eggs were dewatered in this side channel, which may potentially translate to approximately 184 adult kokanee. Operations during kokanee development through to emergence (Sept to Jan/Feb) stays over the 75 m^3/s (Figure 24) minimum flow target. Therefore, egg depositional areas should have adequate flow coverage for development and hatching kokanee in the LDR should not be stranded during this period.	The hydraulic model is limited at this time for kokanee spawning WUA and needs to be further validated in the field. For example, the model depicts Reach 5 as having increased spawning WUA over 75 m^3/s; this reach isn't used by kokanee. However, if you remove this Reach from the results the remaining river reaches do show an increase in spawning WUA over 100 m^3/s. That is, recalculating spawning WUA totals there is an increase in kokanee spawning area from 7,831m^2 at 75 m^3/s to 11,645 m^2 at 100 m^3/s (Appendix 5 in NCH 2010).
Operation	WUP Kokanee Spawning Protection Flows (73 or 100 m^3/s September 27 - October 13).	Change operations to match the estimated peak of kokanee spawning between September 27 and October 13, since majority of spawning in LDR was observed prior to 1 October on average (Section 5.5). Operations during kokanee development through to emergence (Sept to Jan/Feb) stay over the 75 m^3/s (Figure 24) minimum flow target. Therefore, egg depositional areas should have adequate flow coverage for development and hatching kokanee in the LDR should not be stranded during this period.	Further hydraulic modeling and field confirmation is required to determine if this shift would improve kokanee spawning success/egg dewatering.
Physical	Exclusion Fencing	Prevent kokanee from spawning in side channels that become dewatered during DDM WUP spawning protection flows. Based on spawn mapping conducted during the current program, this may reduce the amount of the egg depositional area that was dewatered in side channels. The maximum area observed to dewater was approximately 2700 m^2, but depended on the year. This may translate to between 16,000-470,000 eggs dewatered.	Difficult to set up and maintain in the LDR due to the braided nature of the system and influence of rain events, which cause increased tributary flows and movement of debris in September. Is the potential loss of 0.14% adult returns to the entire Duncan River system affecting the overall population?

Physical	Egg Excavation & Use of Artificial Redds	This method is currently used on the lower Columbia River for rainbow trout with high success (J. Baxter, Owner/Technician, Mountain Water Research, pers. comm., 2012). Similar methods could be used to remove kokanee eggs from recently spawned areas within side channels that have the potential to dewater. Egg incubation capsules could be placed within protected mainstem areas that will not dewater during kokanee spawning protection operations.	Artificial redds may be feasible, but would require a large amount of effort to excavate eggs. Is the potential loss of 0.14% adult returns to the entire Duncan River system affecting the overall population?
Physical	Recontouring of side channel habitats	Recontouring of areas within the lower Columbia River (e.g., Genelle) has reduced the amount of area that may become dewatered during the rainbow trout spawning period. Similarly, the recontouring of side channels within the LDR may prevent egg losses by keeping areas wetted during kokanee spawning protection operations.	Requires the use of an excavator within fish habitats. Limited to side channels that have road access: 3.5R and 6.9R only. These two areas combined may limit the dewatering of kokanee eggs (3.5R: between 7,800 and 170,000 observed dewatered during study; 6.9R was wetted in 2008 and 2011 and potentially 141,500 and 43,000 eggs may have been dewatered, respectively). These losses translate to 0.14% (or less) adult returns to the overall Duncan River system. Is this affecting the overall population?

5.5 Hypotheses

The following is a brief discussion regarding the hypotheses outlined for this program.

H01: *Kokanee spawning in the Lower Duncan River mainstem is distinct from Meadow Creek and Lardeau River kokanee populations, as determined by statistically significant differences in spawning timing, physiology and/or habitat use.*

Answer: ***Not Likely***

Spawn timing was similar between these systems with peak spawning occurring in mid- to late September for Meadow Creek, in late September for the Lardeau River, and in late September to mid-October for the LDR. It is unlikely that statistical differences in spawn timing exist and statistical testing may not be biologically significant. In sockeye salmon populations where stock differences have been observed, a significant temporal separation between spawning runs occurred. For example, in Alaska, sockeye salmon run timing in the Chignik and Tustumena watershed tributaries are separated by at least one month (Creelman et al. 2011 and Woody et al. 2000, respectively). In contrast, spawn timing was usually only separated by approximately 1-2 weeks in the Duncan River system.

Although this program studied mostly morphological attributes, indirect physiological attribute measurements included the functioning of gonads through measurement of fecundity and egg retention as well as growth and development by measuring age-at-maturity and spawning condition. Differences in egg retention, age-at-maturity and spawning condition were observed between the three systems. Woody et al. (2000) indicated that consistent differences in quantitative life history traits related to fitness, such as age and size at maturity, and in genetic markers indicated reproductive isolation among sockeye salmon spawning aggregations in different habitats. However, recent genetic analysis determined that kokanee spawners from the LDR, Lardeau River and Meadow Creek were not genetically distinct and can be considered from the same stock (Lemay and Russello 2011).

Habitat use was only recorded for kokanee in the LDR system and not for the other systems. However, it is assumed that the Meadow Creek spawning channel provides the most suitable spawning substrates, since it was specifically built in 1967 to compensate for half of the kokanee run lost due to DDM construction and now provides approximately 3 km of spawning gravels specific to kokanee spawning preferences (Redfish Consulting Ltd. 1999). Spawning gravels in the Meadow Creek SC are also scarified yearly to prevent sediment build-up and ensure that substrate interstices are available for egg deposition each year (M. Pearson, pers. comm., 2012). Further information on kokanee distribution and habitat use is provided in Section 5.3.

H02: *Kokanee spawning success in the Lower Duncan River is not significantly affected by Duncan Dam operating conditions (fall through spring) as observed through monitoring studies and reviewed using the population model (BC Hydro in prep).*

Answer: ***Inconclusive***

Overall spawning success (fall through spring) was not reviewed using the BC Hydro population model, since it was not directly applicable at this time (T. Oussoren, BC Hydro Natural Resources Specialist, pers. comm., 2011). Egg dewatering observed during the study program due to DDM operations may result in the loss of 0.14% of the overall number of adult kokanee that potentially return to the Duncan River system yearly. Whether this is significant to the overall population is unknown at this time. The hatch and emergence periods for kokanee fry in the LDR were estimated to occur approximately three months earlier compared to the other two systems. It is unknown whether this earlier emergence time is disadvantageous for LDR kokanee fry, but kokanee fry emergence in December/January should not be affected by DDM operations because there is adequate flow coverage at current operational levels to prevent stranding.

H03: *Lower Duncan River kokanee spawning success monitoring over the 10-year review period is not significantly different from that observed prior to Water Use Plan operational changes.*

Answer: ***Inconclusive***

It should be noted that the pre-WUP period (2003-2007) occurred prior to the onset of this program (2008) and spawning success during the pre-WUP period was not measured. In addition, Kokanee Spawning Protection Flows were initiated during the pre-WUP period (Figure 25) and kokanee enumeration was not conducted prior to this period for comparison. Although the number of kokanee spawners seem to be higher post-WUP compared to pre-WUP (Figure 25), it is difficult to attribute this to changes in flow operations as many in-lake factors influence adult returns (Section 5.1.3). Higher numbers of kokanee in the LDR during a particular year also corresponded to higher numbers in Meadow Creek and the Lardeau River (Section 4.5.4).

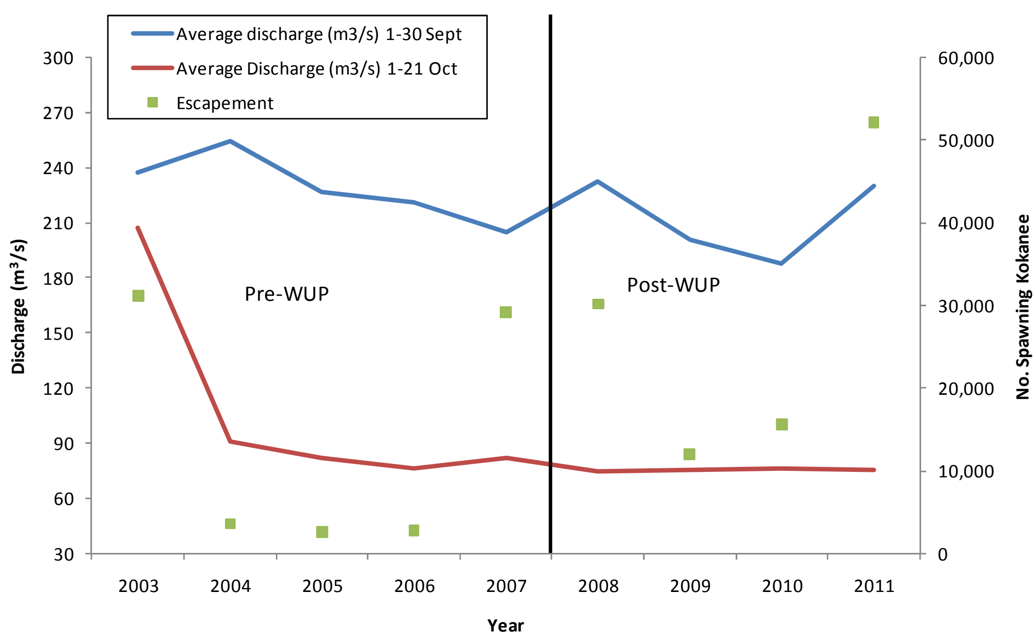


Figure 25: Average discharge during the September 1-30 and October 1-21 (Kokanee Spawning Protection) periods for pre-WUP (2003-2007) and post-WUP (2008-2011) years.

H04: *Kokanee spawning success in the Lower Duncan River is not significantly affected by spawning outside of the kokanee spawning operations (73cms target 1 October to 21 October each year).*

Answer: ***Reject***

Kokanee spawning protection flows did not capture the majority of spawners on average (Table 13). In 2008 and 2009, kokanee spawning protection flows captured the majority of spawners, but in 2010 and 2011 this operation did not (Table 12).

Table 13: Proportion of spawning kokanee before (1-30 Sept) and during the Kokanee Protection Flow operation (1-21 Oct) at DDM, 2008-2011.

Year	Spawning Proportions	
	1-30 Sept	1-21 Oct
2008	44%	56%
2009	3%	97%
2010	63%	37%
2011	82%	18%
Average	***63%***	***37%***

6.0 RECOMMENDATIONS

The following are recommendations for future kokanee spawning monitoring:

1. Determine the influences of temperature and discharge on kokanee spawning/emergence period in the three systems from water temperature data collected under DDMMON-7; this will be included in the DDMMON-7 final report.
2. Review the results of this monitoring program with regulatory agencies to determine if kokanee egg losses/adult returns from the LDR impact the overall kokanee population in the Duncan River system.
3. Conduct a minimum of three enumeration surveys to capture peak spawning in the LDR to monitor yearly spawner abundance. Three surveys would allow for the peak spawning period (September 27 to October 13) to be covered. That is, one survey each on start (September 27) and end (October 13) of peak spawning, plus one additional survey in between these dates would help to depict the abundance curve to pin point peak spawning.
4. Changes to current DDM operations likely require field verification of the hydraulic model with observations of kokanee spawning/egg depositional areas and dewatering.

7.0 REFERENCES

Acara, A. H. 1970. The Meadow Creek spawning channel. Department of Recreation and Conservation Fish and Wildlife Branch, Victoria, B. C. 36 p.

AMEC 2003. Duncan River kokanee and fall flow assessment – Fall 2002.Prepared for BC Hydro and Power Authority, Castlegar, BC.

AMEC 2004. Duncan River kokanee and fall flow assessment – Fall 2003.Prepared for BC Hydro and Power Authority, Castlegar, BC.

AMEC 2008. Duncan Dam Water Use Plan: Lower Duncan River Kokanee Spawning Monitoring – Information Review (Year 1). DDMMON#4. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, British Columbia. 38 pp. + 5 App.

AMEC 2009. Lower Duncan River kokanee spawning monitoring; 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 water quality monitoring Information Review. DDMMON#7. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 41 pp + 2 App.

AMEC 2011. Lower Duncan River water quality monitoring: Year 1 Data Report- 2011. DDMMON#7. Prepared for BC Hydro – Kootenay Generation Area, Castlegar, B.C. 41 pp + 2 App.

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 (TOR). DDMMON-4: Lower Duncan River Kokanee Spawning Monitoring. 28 May 2008. 13 pp.

Baxter, J. 2005. Kokanee Escapement to the Lower Duncan River: Fall 2004. BC Hydro Columbia Generation Area. July 2005. 6 pp. + 1 app.

Baxter, J. 2006. Kokanee Escapement to the Lower Duncan River: Fall 2005. BC Hydro Columbia Generation Area. July 2005. 6 pp. + 1 app.

Beauchamp, D. A.; Sergeant, C. J.; Mazur, M. M.; Scheuerell, J. M.; Schindler, D. E.; Scheuerell, M. D.; Fresh, K. L.; Seiler, D. E. & Quinn, T. P. 2005. Spatial-Temporal Dynamics of Early Feeding Demand and Food Supply for Sockeye Salmon Fry in Lake Washington. Transactions of the American Fisheries Society, 133:1014-1032.

Creelman, E. K., L. Hauser, R. K. Simmons, W. D. Templin, & L. W. Seeb. 2011. Temporal and Geographic Genetic Divergence: Characterizing Sockeye Salmon Populations in the Chignik Watershed, Alaska, Using Single-Nucleotide Polymorphisms Transactions of the American Fisheries Society. 140:749-762

Fraley, J. J., S. L. McMullin, and P. J. Graham. 1986. Effects of hydroelectric operations on the kokanee population in the Flathead River System, Montana. North American Journal of Fisheries Management 6: 560-568.

Golder Associates Ltd. 2011. DDMMON-16 Lower Duncan River fish stranding impact monitoring: Year 3 summary report (April 2010 to April 2011). Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 10-1492-0110F: 27 p. + 3 app.

Grover, M. C. 2006. Evaluation of a Negative Relationship between Abundance during Spawning and Size at Maturity in Kokanee. Transactions of the American Fisheries Society. 135:970-978

Jones, E. L., S. Heinl and K, Pahlke. 2007. Aerial Counts. Pages 399-410 in: D.H. Johnson, B. M. Shrier, J. S. O'Neil, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Kootenay Environmental Services, 2007. Kokanee escapement to the Lower Duncan River: Fall 2006. Prepared for BC Hydro and Power Authority, Castlegar, BC.

Lemay, M. A. and M.A. Russello. 2011. Genetic stock identification for Kootenay Lake kokanee to inform operational impact assessment (EC10-408956). Report prepared for BC Hydro. University of British Columbia. 25 pp.

Lestelle, L. C., B. Watson and G. Blair. 2006. Species-Habitat Rules: Supporting Documentation for Updated Flow Rules for Application in EDT. Prepared for United States Bureau of Reclamation. 46 pp. + 5 app.

M. Miles and Associates Ltd. 2002. Channel stability assessment – lower Duncan River. Prep. For BC Hydro and Power Authority, Castlegar, B.C. (Photo mosaics provided by BC Hydro)

McMichael, G. A., C. L. Rakowski, B. B. James, & J. A. Lukas. 2005. Estimated Fall Chinook Salmon Survival to Emergence in Dewatered Redds in a Shallow Side Channel of the Columbia River. North American Journal of Fisheries Management. 25:876-884.

Morbey, Y. E. 2003. Pair formation, pre-spawning waiting, and protandry in kokanee, *Oncorhynchus nerka*. Behav. Ecol. Sociobiol. 54: 127-135.

Morbey, Y. E., and R. C. Ydenberg. 2003. Timing games in the reproductive phenology of female Pacific Salmon (*Oncorhynchus spp*.). The American Naturalist. 161(2): 284-298.

Murray, C. B., J. D. MCPhail, and M. L. Rosenau. 1989. Reproductive and developmental biology of kokanee from upper Arrow Lake, British Columbia. Transactions of the American Fisheries Society 118: 503-509.

Northwest Hydraulic Consultants Ltd. (NHC). 2010. Duncan Dam Water Use Plan. Lower Duncan Hydraulic Model – DDMMON-3. Report Prepared for BC Hydro, Burnaby, BC. NHC Report No: 34991. 90 pp. + 7 App.

Poisson Consulting Ltd. and Golder Associates Ltd. 2010. DDMMON#1 - Lower Duncan River ramping rate monitoring: Phase V investigations. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 08-1480-0054F: 41 p. + 6 app.

Poisson Consulting Ltd. and Golder Associates Ltd. 2012. DDMMON-15 - Duncan River Reservoir Stranding Protocol Development and Finalization. Information provided by T. Oussoren, Natural Resource Specialist, BC Hydro, Castlegar, May 4, 2012; report not available publically at this time.

Porto, L. 2006. Hill Creek Spawning Channel Fry Enumeration – 2005. Prepared for the Columbia Basin Fish and Wildlife Compensation Program, 18 p.

Quinn, T. P., S. Hodgson and C. Peven. 1997. Temperature, flow and the migration of adult sockeye Salmon *Oncorhynchus nerka* in the Columbia River. Can. J. Fish. Aquat. Sci. 54: 1349-1360.

Ramstad, K. M., C. J. Foote, J. B. Olsen, and D. Rogers, D. 2003. Genetic and Phenotypic Evidence of Reproductive Isolation between Seasonal Runs of Sockeye Salmon in Bear Lake, Alaska. Transactions of the American Fisheries Society. 132: 997-1013.

Schindler, E., Sebastian, D., Andrusak, H., Vidmanic, L., Harris, S., Andrusak, G., Pick, F., Ley, L., Hamilton, P., Johner, D., Woodruff, P., Bassett, M., and Ashley, K. 2010. Kootenay Lake Nutrient Restoration Program, Year 16 (North Arm) and Year 4 (South Arm) (2007) Report. Prepared for Environmental Stewardship - Fish and Wildlife, Ministry of Environment, BC. 250 p.

Thorley, J, J. Baxter, R. Irvine, J. Hagen and L. Porto. 2011. Lower Duncan River Habitat Use (DDMMON-2). Year 2 Final Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Earth & Environmental Ltd., Poisson Consulting Ltd., Mountain Water Research and John Hagen and Associates Ltd. 131 pp.

Woody, C. A. J. B. Olsen, J. Reynolds, and P. Bentzen. 2000. Temporal Variation in Phenotypic and Genotypic Traits in Two Sockeye Salmon Populations, Tustumena Lake, Alaska. Transactions of the American Fisheries Society. 129: 1031-1043.

Vonk, P. 2001. Status of knowledge report – Duncan Dam. A fisheries assessment and planning study. Prepared for BC Hydro Kootenay Generation Area. August 2001. 107 p.

APPENDIX A
Field Schedule 2008-2012

Appendix A: DDMMON-4 Field Schedule, 2008-2012.

Study Year	Date	Sample Type	Agency[a]	Helicopter Craft/Carrier
2008	22-27 Aug, 28-Aug, 30-Aug	Meadow Creek Biological Sampling	MOE	
	28-29 Aug	Meadow Creek Biological Sampling	UWO	
	2-Sep	LDR Helicopter Enumeration	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	6-Sep	Meadow Creek Biological Sampling	MOE	
	12-Sep	LDR Helicopter Enumeration	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	16-17 Sep	LDR Helicopter Enumeration	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	19, 21 Sep	Meadow Creek Biological Sampling	UWO	
	24-Sep	LDR Helicopter Enumeration, Biological Sampling & Ground Habitat Use Surveys	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	25-Sep	LDR Helicopter Enumeration & Habitat Use Surveys; Lardeau River Enumeration (confluence to Trout Lake); Lardeau River Biological Sampling	AMEC/MOE	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	26-Sep	LDR Helicopter Enumeration	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	29-Sep	Meadow Creek Biological Sampling	MOE	
	2-Oct	LDR Helicopter Enumeration	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	6-Oct	Meadow Creek Biological Sampling	MOE	
	9-Oct	LDR Helicopter Enumeration & Ground Habitat Use Surveys	AMEC	Twinstar AS 355 F1; Eclipse Helicopters, Penticton, BC
	10-Oct	LDR Boat Habitat Use Survey	AMEC	
2009/2010	26-31 Aug	Meadow Creek Biological Sampling	MOE	
	1-2 Sep	Meadow Creek Biological Sampling	MOE/UWO	
	4-Sep	LDR Helicopter Enumeration	AMEC	Bell 206; High Terrain Helicopters, Nelson, BC
	10-Sep	Meadow Creek Biological Sampling	MOE	
	11-Sep	LDR Helicopter Enumeration	AMEC	Bell 206; High Terrain Helicopters, Nelson, BC
	18-Sep	LDR Helicopter Enumeration	AMEC	A-Star; High Terrain Helicopters, Nelson, BC
	20-Sep	Meadow Creek Biological Sampling	MOE	
	22-Sep	LDR Helicopter Enumeration & Spawn Mapping; Ground Truthing	AMEC	Bell 206; High Terrain Helicopters, Nelson, BC
	23-Sep	LDR & Lardeau River Biological Sampling; LDR Habitat Use	AMEC	
	27-Sep	Meadow Creek Biological Sampling	UWO	
	2-Oct	Meadow Creek Biological Sampling	MOE	
	3, 4 Oct	LDR Incubation Capsules Set	AMEC	
	4-Oct	LDR Biological Sampling & Ground Habitat Use	AMEC	
	5-Oct	LDR Helicopter Enumeration; Lardeau River Enumeration (confluence to Trout Lake); Lardeau River Biological Sampling	AMEC/MOE	A-Star; High Terrain Helicopters, Nelson, BC
	7-Oct	LDR Helicopter Enumeration & Spawn Mapping	AMEC	A-Star; High Terrain Helicopters, Nelson, BC
	14-Oct	LDR Habitat Use & Biological Sampling	AMEC	
	15-Oct	LDR Helicopter Enumeration	AMEC	A-Star; High Terrain Helicopters, Nelson, BC
	27-Oct	LDR Helicopter Enumeration	AMEC	A-Star; High Terrain Helicopters, Nelson, BC
	17-Nov	LDR Check Incubation Capsules and egg development	AMEC	
	27-Jan-10	LDR Incubation Capsules Retrieved	AMEC	
2010	August 18-21, 23-24, 26-27, 30	Meadow Creek Spawning Channel Biological Sampling	MOE	
	31-Aug	LDR Helicopter Enumeration	AMEC	EC120;Finnair, Naramata, BC
	1, 7 Sept	Meadow Creek Spawning Channel Biological Sampling	MOE	
	10-Sep	LDR Helicopter Enumeration	AMEC	EC120;Finnair, Naramata, BC
	22-Sep	LDR Helicopter Enumeration & Spawn Mapping	AMEC	A-Star; Highland Helicopters, Castlegar, BC
	27-Sep	LDR Helicopter Enumeration & Spawn Mapping; Meadow Creek Spawning Channel Biological Sampling	AMEC/MOE	EC120;Finnair, Naramata, BC
	30-Sep	LDR Helicopter Enumeration & Spawn Mapping	AMEC	EC120;Finnair, Naramata, BC
	4-Oct	Lardeau River Biological Sampling	AMEC	
	5-Oct	Lardeau River Enumeration; LDR Biological Sampling	AMEC/MOE	
	8-Oct	LDR Helicopter Enumeration & Spawn Mapping	AMEC	EC120/Finnair, Naramata, BC
	13-Oct	LDR Helicopter Enumeration	AMEC	A-Star; Highland Helicopters, Castlegar, BC

Study Year	Date	Sample Type	Agency[a]	Helicopter Craft/Carrier
2011/2012	6-Sep	LDR Helicopter Enumeration	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	15-Sep	LDR Helicopter Enumeration (mainstem only)	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	22-Sep	LDR Helicopter Enumeration	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	26-Sep	LDR Helicopter Enumeration & Spawn Mapping (sidechannels only)	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	29-Sep	LDR Helicopter Enumeration & Completion of Spawn Mapping in mainstem; LDR Enumeration & Spawn Mapping Ground Truthing	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	4-Oct	Lardeau River Spawn Mapping	AMEC	
	7-Oct	LDR Helicopter Enumeration	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	12-Oct	LDR Helicopter Enumeration & Spawn Mapping	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	20-Oct	LDR Helicopter Enumeration	AMEC	BO105LS (Twin); Dam Helicopters, Castlegar, BC
	February 3 and 7, 2012	LDR & Lardeau River Ground Spawn Mapping	AMEC	

[a] MOE = Ministry of Environment; UWO = University of Western Ontario Graduate Student

APPENDIX B
Lardeau River Spawn Mapping

50°17'30"N

Legend

- Both Feb and Oct GPS Track
- Feb GPS Only
- Ice

Roads

- Paved
- Unpaved

Scale:1:2,000

50 25 0 50 100

Meters

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Juvenile Habitat Survey: Poisson Consulting

Disclaimer

CLIENT:
BC Hydro

PROJECT:
LDR Kokanee Spawning

Lardeau River Spawning Area

JOB No: VE51905			COMPILATION DATE: 2009/12/15	
GIS FILE: LDR_overview.mxd			REVISION DATE: 2009/12/15	
PDF FILE: LDR_overview.pdf			PRINTING DATE: 2009/12/15	
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: LP

Y:\GIS\Projects\VE\VE51905_Duncan_Mapping\Mapping\MXD\Drafts\AMEC\GPS\LDR_GPS_3.mxd

APPENDIX C
AUC Analysis Memo

LDR Kokanee Spawning Monitoring:

Area-Under-the-Curve Analysis of Kokanee Spawner Abundance in the Lower Duncan River

Final Memorandum

January 31, 2012

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Introduction

Weekly aerial counts of spawning kokanee have been conducted in the Lower Duncan River (LDR) every fall since 2008 as part of DDMMON-4. Spawner counts can be analysed using Area-Under-the-Curve (AUC) methods to estimate spawn timing and, if observer efficiency and spawner residence time are known, absolute spawner abundance (Hilborn et al. 1999; Su et al. 2001). The uncertainties that DDMMON-4 was developed to address include the spawn timing in the Lower Duncan River and the relative distribution of kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River.

The current memorandum uses Bayesian methods to estimate the aerial observer efficiency as well as the peak spawn timing and spawner abundance of kokanee in the LDR from 2008 to 2011. The memorandum also estimates the expansion factor for converting peak counts to total abundance.

Methods

The data were provided in the form of an Excel 2007 spreadsheet by AMEC Earth & Environmental. The data were manipulated (Spector 2008), analysed and plotted (Wickham 2009) using the software package R 2.14.0 (R Development Core Team 2011) which interfaced with the Bayesian program JAGS 3.1.0 (Plummer 2003) using the rjags and runjags libraries.

JAGS distributions and functions are defined in Table 1. The Bayesian analyses assumed low information (Nztoufras 2009), uniform, or normal prior distributions. The posterior distributions, which were estimated using Gibbs sampling (Ntzoufras 2009), were derived from 1,500 Markov Chain Monte Carlo (MCMC) simulations thinned from the second halves of three MCMC chains. Model convergence was confirmed by ensuring that R-hat (the Gelman-Rubin Brooks potential scale reduction factor) was less than 1.05 for each of the primary parameters in the analyses (Gelman & Rubin 1992; Brooks & Gelman 1998; Gelman et al. 2004). Model adequacy was checked through examination of the residuals.

Table 1: JAGS distributions and functions used in the Bayesian analyses

Distribution/Function	Definition	Description
$\mathrm{dlnorm}(\mu, \tau)$	$\sqrt{\tau/(2\pi)}\, x^{-1}\exp(-\tau/2(\log x - \mu)^2)$	Log-normal distribution
$\mathrm{dnorm}(\mu, \tau)$	$\sqrt{\tau/(2\pi)}\, \exp(-\tau(x - \mu)^2/2)$	Normal distribution
$\mathrm{dunif}(a, b)$	$1/(b - a)$	Uniform distribution
$\log(x)$	$\log(x)$	Natural logarithm function
$\mathrm{phi}(x)$	$P(X \leq x), \quad X \sim N(0,1)$	CDF of standardized normal
$\mathrm{pow}(x, z)$	x^z	Power function
$\mathrm{round}(x)$	Round to the closest integer	Round function
$\mathrm{step}(x)$	$f(x) = 1 \text{ when } x \geq 0; 0 \text{ otherwise}$	Binary indicator function

The observer efficiency during the helicopter surveys was estimated by a Bayesian analysis of the ratio of the aerial counts to the bank counts for particular sections of sidechannel.

Key assumptions of the Bayesian analysis of aerial observer efficiency included:

- The sidechannel bank counts are unbiased;
- The aerial observer efficiency does not vary systematically with abundance or channel type, i.e., sidechannel versus main channel.
- The residual variation in the aerial to bank count ratios is log-normally distributed.

Key variables and model parameters in the Bayesian efficiency analysis are listed in Table 2. The prior probability distributions are listed in JAGS-style syntax in Table 3 and the dependencies (both stochastic and deterministic) between variables and parameters are listed in JAGS-style syntax in Table 4. Together, Tables 2 to 4 provide a full description of the analysis. The MCMC chains were 10^4 iterations in length. The Bayesian analysis estimated the aerial observer efficiency to be 0.93 with a standard deviation of 0.29.

Table 2: Key variables and parameters in the Bayesian observer efficiency analysis

Variable/Parameter	Definition
$G_{s,d,y}$	The ground count at the s_{th} section on the d_{th} survey in the y_{th} year (individuals)
$H_{s,d,y}$	The helicopter count at the s_{th} section on the d_{th} survey in the y_{th} year (individuals)
μ	The expected aerial observer efficiency
σ	The standard deviation of the log aerial observer efficiency

Table 3: Key prior probability distributions in the Bayesian observer efficiency analysis in JAGS-style syntax

Parameter	Prior Distribution
μ	dunif(0.2,5)
σ	dunif(0,4)

Table 4: Key relationships between the variables and parameters in the Bayesian observer efficiency analysis in JAGS-style syntax

Variable/Parameter	Relationship
$H_{s,d,y}/G_{s,d,y}$	dlnorm(log(μ), pow(σ ,-2))

The spawner abundance and timing of peak spawning were estimated using hierarchical Bayesian AUC methods.

Key assumptions of the hierarchical Bayesian AUC analysis included:

- The mean spawner residence time (longevity) ranged between 7 and 14 days (Acara 1970; Morbey and Ydenberg 2003);
- The observer efficiency was 0.93 with a standard devation of 0.29 (as estimated by the Bayesian efficiency analysis);
- Spawner arrival timing was normally distributed (Hilborn et al. 1999);
- The mean of the spawner arrival timing in each year is drawn from an underlying normal distribution (Su et al. 2001);

- The residual variation about the expected counts is normally distributed and increases linearly with the expected number of spawners.

Key variables and model parameters in the hierarchical Bayesian AUC analysis are listed in Table 5. The prior probability distributions are listed in Table 6 and the dependencies between variables and parameters are listed in Table 7. In order to achieve convergence the MCMC chains were 10^5 iterations in length.

Table 5: Key variables and parameters in the hierarchical Bayesian AUC analysis

Variable/Parameter	Definition
π	The mean observer efficiency
r	The mean residence time (days)
m^{μ}	The mean of the mean spawner arrival time (days)
m^{σ}	The standard deviation of m^{μ} (days)
y	The y_{th} year (years)
i	The i_{th} day (days)
T_1	The first day of the spawning period (days)
T_n	The last week of the spawning period (days)
m_y	The mean spawner arrival time in in year y (day of the year)
s	The standard deviation of the spawner arrival time in year y (days)
n_y^{i}	The mean spawner abundance in day i in year y (individuals)
N_y	The total spawner abundance in year y (individuals)
ε^{σ}	The standard deviation of the residual variation (individuals)
ε^{β}	The increase in ε^{σ} with the expected number of spawners
a_y^i	The total number of spawners that have arrived in year y by day i (individuals)
b_y^i	The total number of spawners that have died in year y by day i (individuals)
C_y^{i}	The spawner count on day i in year y (individuals)

Table 6: Key prior probability distributions in the hierarchical Bayesian AUC analysis in JAGS-style syntax

Parameter	Prior Distribution
π	$\mathrm{dnorm}(0.93,\mathrm{pow}(0.29,-2))$ T(0.1,)
r	$\mathrm{round}(\mathrm{dunif}(7,14))$
m^{μ}	$\mathrm{dunif}(250,310)$
m^{σ}	$\mathrm{dunif}(0,30)$
s	$\mathrm{dunif}(0,15)$
ε^{σ}	$\mathrm{dunif}(0,25)$
ε^{β}	$\mathrm{dunif}(0,10)$
$\log(N_y)$	$\mathrm{dunif}(7,14)$

Table 7: Key relationships between the variables and parameters in the hierarchical Bayesian AUC analysis in JAGS-style syntax

Variable/Parameter	Relationship
m_y	$\text{dnorm}(m^{\mu}, \text{pow}(m^{\sigma}, -2))$
b_y	$\text{phi}((T_1 - m_y)/s\ \ )$
e_y	$\text{phi}((T_n - m_y)/s\ \ ) - b_y$
a_y^i	$N_y *(\text{phi}((i - m_y)/s\ \ ) - b_y)/e_y$
d_y^i	$N_y *(\text{phi}((i - r - m_y)/s\ \ ) - b_y) * \text{step}(i - \text{r} - T_1 - 1)/e_y$
n_y^i	n_y^i<-$a_y^i - d_y^i$
C_y^{i}	$\text{dnorm}(n_y^i * \pi\ \ , \text{pow}(\varepsilon^{\sigma} + \varepsilon^{\beta} * n_y^i, -2))$

The expansion factor for converting annual peak counts into an absolute spawner abundance was estimated from the ratios of the median expected abundance from the AUC analysis to the observed peak count for each of the years from 2008 to 2011. The expansion factor was estimated by Bayesian analysis.

Key assumptions of the Bayesian analysis of the peak count expansion factor included:

- The median expected abundance from the AUC analysis is the actual abundance;
- The residual variation in the ratios is log-normally distributed.

Table 8: Key variables and parameters in the Bayesian peak count expansion factor analysis

Variable/Parameter	Definition
N_y	The median expected spawner abundance in the y_{th} year (individuals)
P_y	The observed peak count in the y_{th} year (individuals)
μ	The expected expansion factor
σ	The standard deviation of the log expansion factor

Table 9: Key prior probability distributions in the Bayesian peak count expansion factor analysis in JAGS-style syntax.

Parameter	Prior Distribution
μ	dunif(0.2,5)
σ	dunif(0,2)

Table 10: Key relationships between the variables and parameters in the Bayesian peak count expansion factor analysis in JAGS-style syntax.

Variable/Parameter	Relationship
N_y / P_y	$\text{dlnorm}(\log(\mu\ \ ), pow(\sigma\ \ , -2))$

Results

The ratios of the helicopter to ground counts used in the Bayesian aerial observer efficiency analysis are plotted in Figure 1. The Bayesian analysis estimated the median expected aerial observer efficiency to be 0.93 with a standard deviation of 0.29. The lower and upper 95% credibility intervals were 0.56 and 1.62 respectively.

The total aerial counts are plotted with the daily spawner abundance predicted by the hierarchical Bayesian AUC analysis in Figure 2. The total annual spawner abundance estimates with 95% credibility intervals are plotted in Figure 3 and tabulated in Table 11.

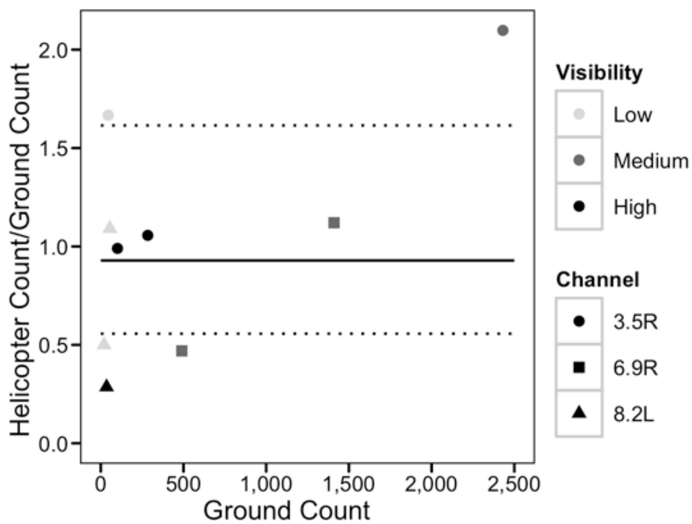

Figure 1: The ratios of the helicopter to ground spawner counts. The solid line is the median expected aerial observer efficiency and the dotted lines are 95% credibility limits.

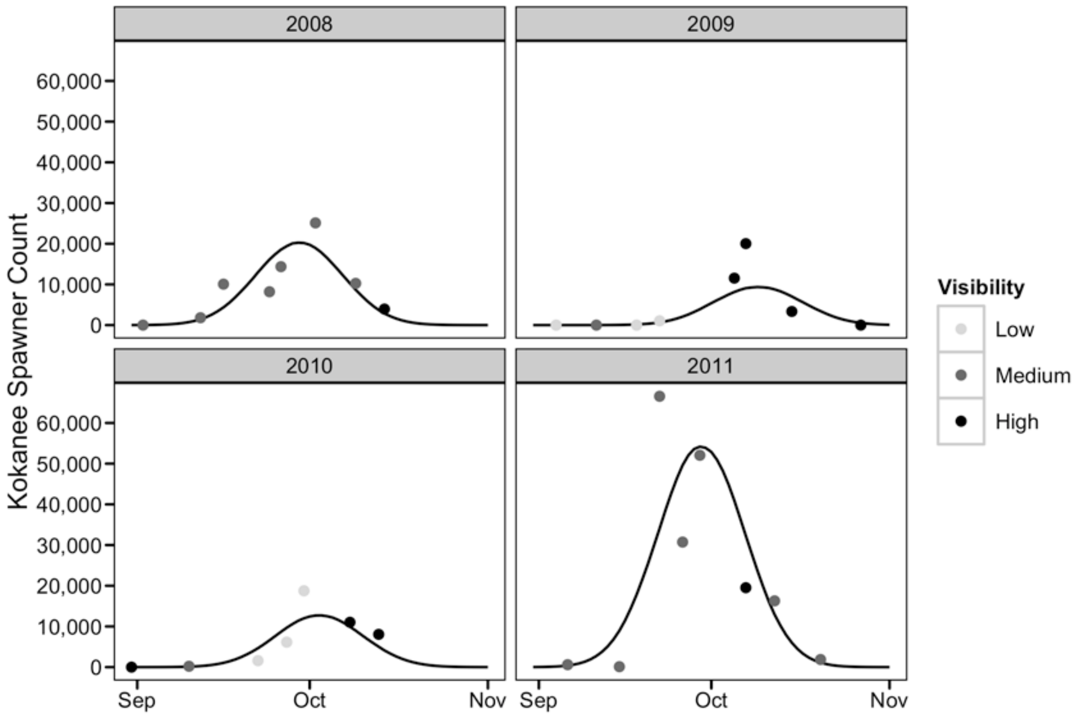

Figure 2: The aerial spawner counts. The solid line is the median expected number of spawners.

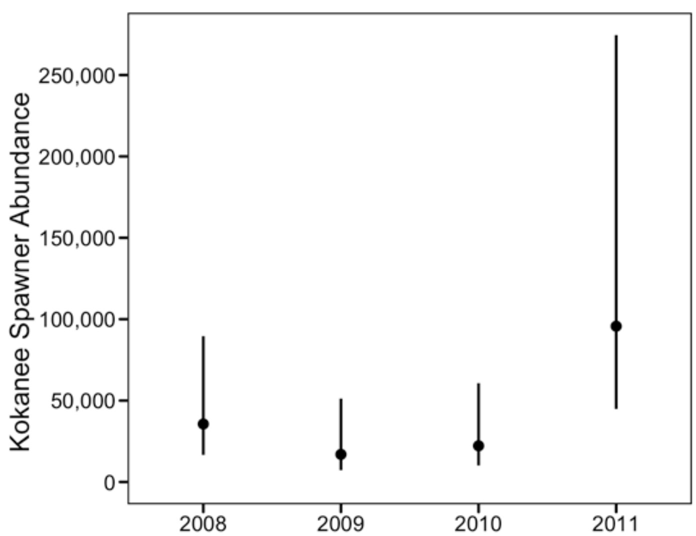

Figure 3: The median expected annual spawner abundance with 95% credibility intervals by year.

Table 11: The median expected annual spawner abundance with 95% credibility intervals by year.

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI
2008	35,600	16,600	89,600
2009	16,900	7,200	51,200
2010	22,200	10,100	60,700
2011	95,700	44,800	274,500

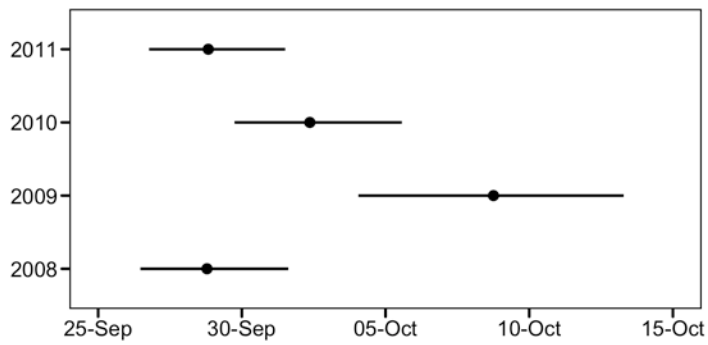

Figure 4: The median expected timing of peak spawner abundance with 95% credibility intervals.

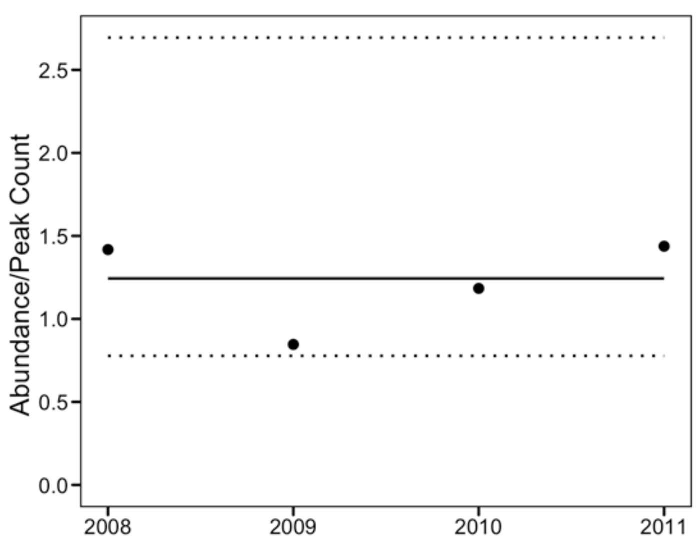

Figure 5: The ratios of the median expected annual spawner abundance to the peak counts by year. The solid line is the median expected peak count expansion factor and the dotted lines are 95% credibility intervals.

Discussion

The current analyses represent an improvement over the previous year's analyses in that the estimates of the aerial observer efficiency and the peak count expansion factor are now based on the assumption that the residual variation in the ratios is log-normally distributed. In 2010 the assumption that the residual variation was Poisson distributed caused the uncertainty in the aerial observer efficiency and peak count expansion factor to be underestimated.

The results of the analyses suggest that

1) the aerial observers are between 56% and 162% efficient;
2) approximately 96,000 kokanee spawned in the LDR in 2011 compared to 22,000 in 2010, 17,000 in 2009 and 36,000 in 2008;
3) peak spawning occurs between September 27 and October 13;
4) the mean expansion factor for converting a peak count into a total spawner abundance is 1.2 although it could be as low as 0.8 or as high as 2.7.

Closure

This report is to the best of my knowledge accurate and correct. If you have any questions regarding its contents please contact the undersigned.

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References

Acara, A. H. (1970). The Meadow Creek Spawning Channel. Unpublished Report. Fish and Wildlife Branch. Victoria, BC.

Brooks, S. and A. Gelman (1998). Alternative methods for monitoring covergence of iterative simulations. *Journal of Computational and Graphical Statistics* **7**: 434-455.

Gelman, A. and D. Rubin (1992). Inference from iterative simulation using multiple sequences. *Statistical Science* **7**: 457-511.

Gelman, A., J. B. Carlin, H. S. Stern and D. B. Rubin (2004). *Bayesian Data Analysis*. Second Edition. Boca Raton, Florida, CRC Press.

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

Morbey, Y.E and Ydenberg, R.C. (2003). Timing Games in the Reproductive Phenology of Female Pacific Salmon (*Oncorhynchus* spp.). *The American Naturalist* **161**: 284-298.

Ntzoufras, I. (2009). *Bayesian Modeling Using WinBUGS*. Hoboken, New Jersey, John Wiley & Sons, Inc.

Plummer, M. (2003) *JAGS: A Program for Analysis of Bayesian Graphical Models using Gibbs Sampling*. Proceedings of the 3rd International Workshop on Distributed Computing (DSC 2003). Vienna, Austria.

R Development Core Team (2011). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Spector, P. (2008). *Data Manipulation with R*. New York, Springer.

Su, Z., M. D. Adkinson and B. W. V. Alen (2001). A hierarchical Bayesian model for estimating historial salmon escapement and escapement timing. *Canadian Journal of Fisheries and Aquatic Sciences* **58**: 1648-1662.

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*. New York, Springer.

APPENDIX D
Morphology Analysis Memo

DDMMON#4 –LOWER DUNCAN RIVER KOKANEE SPAWN MONITORING:

MORPHOMETRIC ANALYSIS OF KOKANEE FROM MEADOW CREEK, THE LDR AND THE LARDEAU RIVER

DRAFT MEMORANDUM

DECEMBER 21, 2010

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Introduction

Mature kokanee were sampled from the Lower Duncan River, the Lardeau River and Meadow Creek in the 2008, 2009 and 2010 spawning seasons. A range of morphological measurements were taken to assess whether there were any statistically significant morphological differences between individuals from the three systems. Morphological differences may be indicative of genetic differentiation. The statistical analyses presented here serve to partially address the first hypothesis from the terms of reference which is:

H01: Kokanee spawning in the lower Duncan River mainstem are distinct from Meadow Creek and Lardeau River kokanee populations, as determined by statistically significant differences in spawn timing, physiology and/or habitat use.

Methods

Data

The morphological characteristics recorded for the mature fish were length, weight, body depth, age, post-ocular hyplural plate length (POHL) and spawning condition (pre, post or currently spawning). Egg size and the number of eggs present (equivalent to fecundity prior to spawning and egg retention after spawning) were also recorded for female kokanee. Not all measurements were recorded for all fish. For example, the Meadow Creek population lacked data on POHL and body depth and only a sub-sample of fish were aged from each of the three systems. Since the focus of field data collection for the past two years was on female kokanee, the analytic focus is solely on females this year. See the analysis Appendix in the 2010 AMEC report for summary statistics and plots on the male kokanee differences amongst the three systems. Basic summary data plots are shown for both sexes in this report.

Exploratory data plotting was conducted to identify measurement or data entry errors and corrections were made to the database prior to the final analysis.

Table 1 lists the number of measured fish by variable, sex and system. Egg retention was the number of eggs in females of post spawning condition while fecundity was the number of eggs in pre-spawning females. The egg counts from those females that were considered as currently spawning were not included as they could not be easily categorized into either fecundity or retention.

Table 1. The number of fish measured by variable, sex and system.

Variable	Sex	System: Lardeau	LDR	MC
Weight	Female	146	153	1135
Weight	Male	30	21	1135
Fork Length	Female	146	153	1176
Fork Length	Male	30	21	1184
Body Depth	Female	146	153	2
Body Depth	Male	30	21	0
POHL	Female	146	153	2
POHL	Male	30	21	0
Age	Female	97	103	172
Age	Male	26	17	35
Spawning Condition	Female	146	153	1376
Spawning Condition	Male	30	21	0
Fecundity	Female	22	18	255
Egg Retention	Female	80	113	4
Egg Size	Female	83	50	143

Analysis

A Bayesian linear modeling approach was used to analytically ask whether any of the measured variables differed significantly amongst the three potential kokanee populations. As described in the analytic Appendix's methods section in the 2010 report for DDMMON-4, the main benefits of Principal Components Analysis as recommended in the TOR were nullified by the data limitations of the data collected on the kokanee populations so this method was not practical. In the 2010 analysis, a classical statistical approach was taken to linear regression modeling to assess whether there was a discernable difference between the three potential kokanee populations for the factors of weight, egg size, fecundity, egg retention, body depth and POHL (Post Ocular Hyplural Length). In this year's analysis, the analyses were performed within a Bayesian framework. In the current context, an advantage of the Bayesian approach is its ability to produced unbiased estimates even with small sample sizes. The same suite of models were also fitted in the classical realm to ensure that qualitative model rankings were the same between the classical and Bayesian approaches; only the Bayesian results are presented here.

Two models were run for each of the six continuous morphological variables and comparatively assessed using DIC (Deviance Information Criterion). As the current analyses do not include random effects DIC represents the Bayesian equivalent of the standard Akaike Information Criterion. The first model fitted included the explanatory variables of fork length (as each of the morphological measurements was expected to vary with size) and year to account for the inter-annual variation in biometric measurements. The second model fitted included both fork length and year as well as population, a categorical factor with three levels representing each of the three river systems. Population was included in the second model to quantify the extent to which its inclusion increased the explanatory power of the model.

To control for the allometric relationship between weight and fork length, both variables were log transformed prior to model fitting. Fecundity and egg retention were also log transformed since they scale allometrically as well. All other models were fitted to untransformed variables and model adequacy was assessed by inspection of the residuals.

The posterior probability distributions were derived from 1,000 Markov Chain Monte Carlo (MCMC) simulations (Ntzoufras 2009) drawn from the second halves of three MCMC chains of 1,000 iterations in length. Convergence was confirmed by ensuring that $\hat{R}$ (the Gelman-Rubin-Brooks potential scale reduction factor) was 1.0 for each of the parameters in the model (Ntzoufras 2009).

The continuous variable analyses were performed within a Bayesian framework using R 2.11.1 (R Core Team 2010) and WinBUGS 1.4.3 (Gilks et al. 1994). Plots were produced with ggplot2 (Wickham 2009).

Age (at maturity) is a categorical variable with few levels (ages range from 2-6 for kokanee in the three systems) and was consequently analyzed using chi-squared tests. The null expectation was that the proportion of fish in each age class was the same in each sampled river system. This analysis was only conducted on females since very few males were aged and because the program maximized efforts to focus on collecting data that is required for determining stock differences including fecundity, egg retention, and egg size (e.g., Murray et al. 1989, Ramstad et al. 2003). The categorical analysis was conducted in R 2.11.1 (R Core Team 2010).

Results

Summary plots of the length frequency by sex and river system (Figure 1) and the age distribution by river system (Figure 2) show the relative distributions of the sampled kokanee.

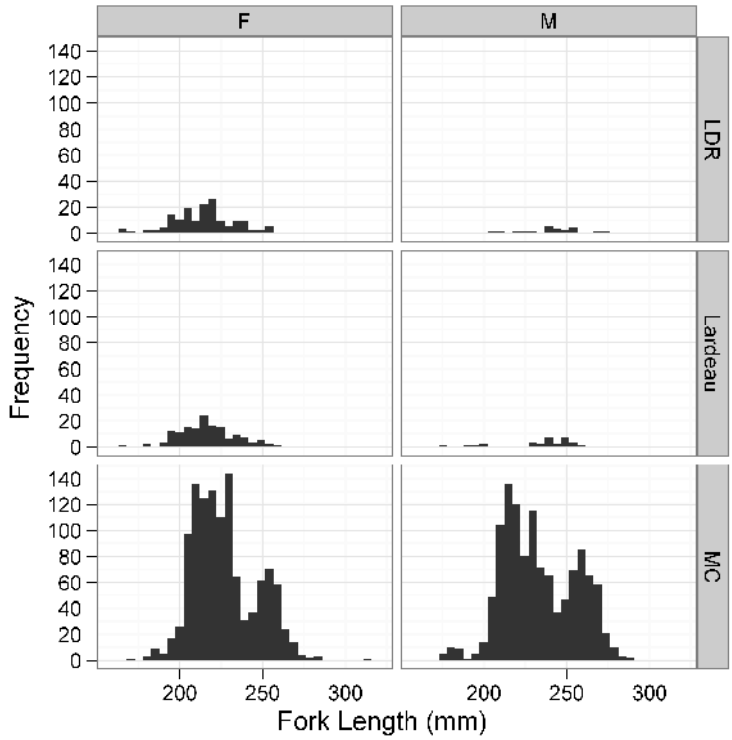

Figure 1 – The length-frequency data for male and female kokanee in each of the three river systems.

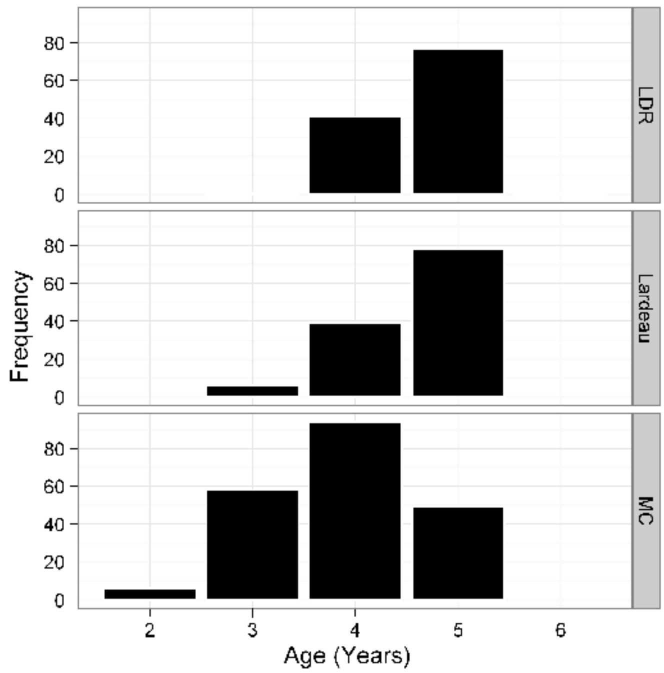

Figure 2 –The age distribution of both male and female fish from the aged subsample of kokanee for each of the three river systems.

The model that garnered the most support as represented by the DIC was consistently the model that included fork length, year and population as explanatory variables (Table 2). The fitted relationships for the top ranked model are plotted below for each morphometric variable (Figures 3-8).

Table 2. Deviance Information Criterion (DIC) values for each continuous kokanee morphological variable modeled for models including Fork Length (FL), Year and the system from which the fish were sampled (Population).

	Model		
Variable	FL + Year	FL + Year + Population	ΔDIC
log(Weight)	-2305.4	-2513.1	207.7
Body Depth	1673.1	1672.9	0.2
POHL	1909.3	1900.1	9.2
log(Fecundity)	-158.4	-158.8	0.4
log(Egg Retention)	406.3	385.1	21.2
Egg Size	192.9	192.4	0.5

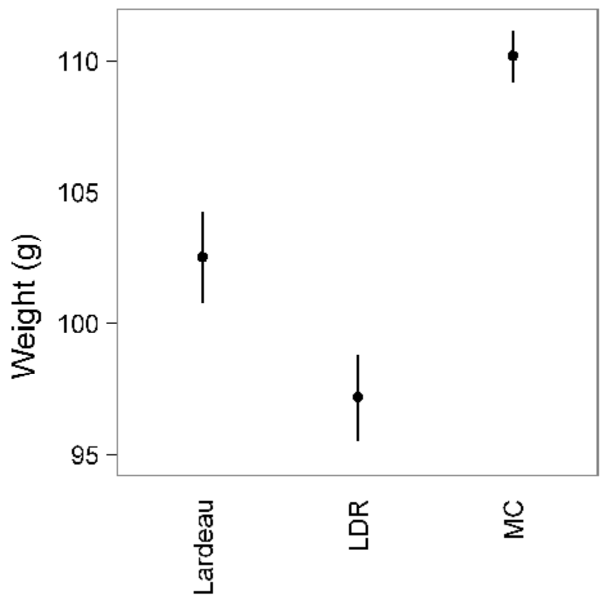

Figure 3 –The predicted relationship between body weight for female kokanee plotted for the average fork lengthed fish by population.

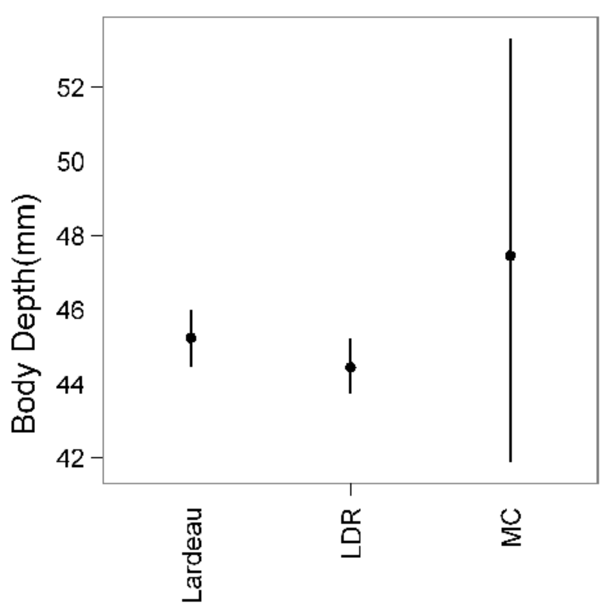

Figure 4 –The predicted relationship between body depth for female kokanee plotted for the fish of average fork length by population.

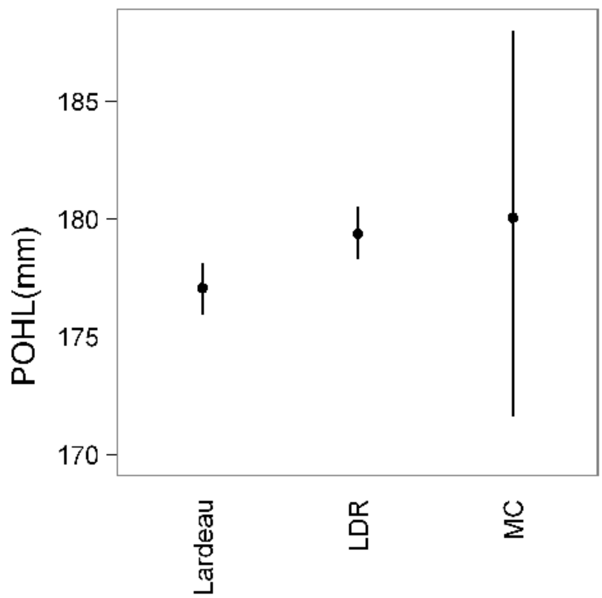

Figure 5 –The predicted relationship between POHL for female kokanee plotted for the fish of average fork length by population.

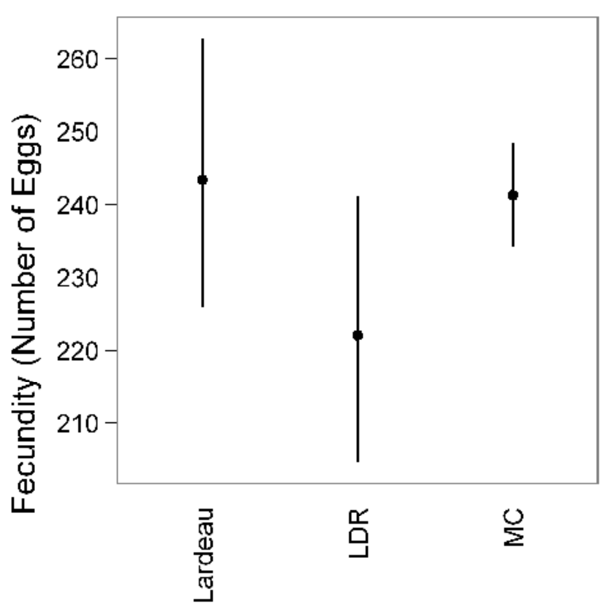

Figure 6 –The predicted relationship between fecundity for female kokanee plotted for the fish of average fork length by population.

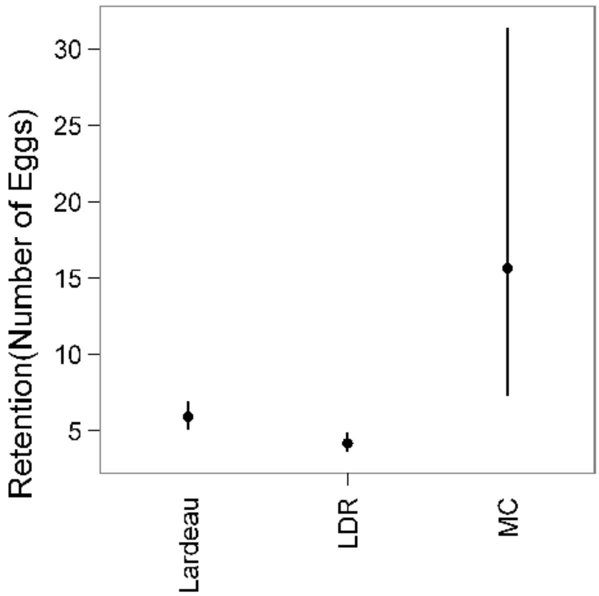

Figure 7 –The predicted relationship between egg retention for female kokanee plotted for the fish of average fork length by population.

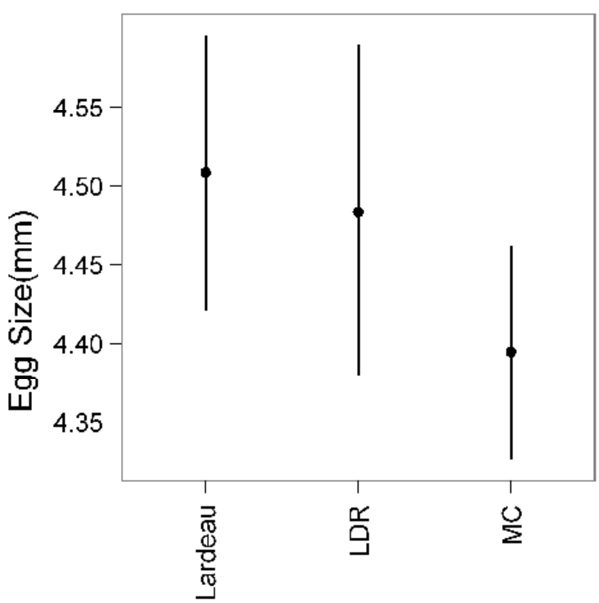

Figure 8 – The predicted relationship between egg size for female kokanee plotted for the fish of average fork length by population.

The chi-squared test on female age indicated that the proportions of fish in each age class were significantly different among the systems (p<0.001). The plot of the proportions by age illustrates the differences among populations. Further analysis showed significant differences between the Lower Duncan River and the Meadow Creek populations and between the Meadow Creek and Lardeau River populations, but not between the Lower Duncan River and Lardeau River populations.

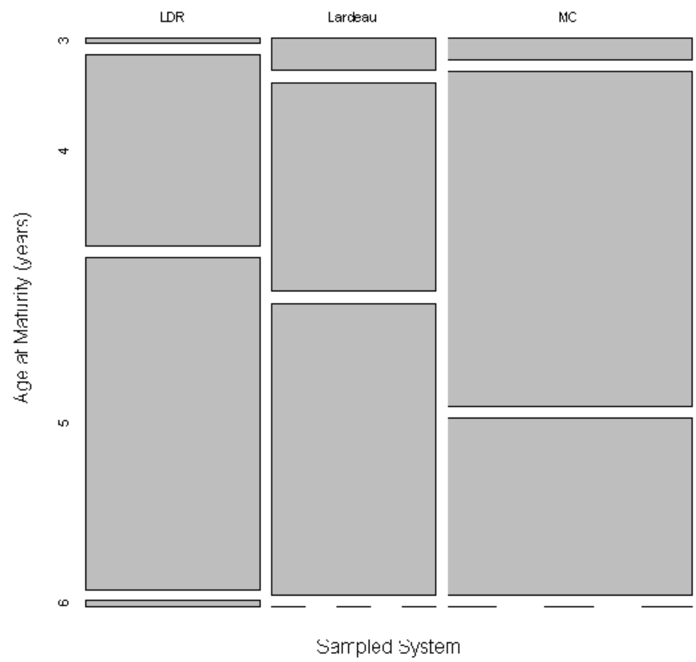

Figure 9 – The age at maturity for female kokanee for each of the three river systems.

Discussion

The model fitting suggests that there are morphological differences between individuals from the three populations since the winning model in each of the cases was the model that included population as a predictor variable (Table 2). For body weight, POHL and egg retention, the model including population as an explanatory variable was substantially better (ΔDIC > 7) than the model with only fork length and year as explanatory variables. The Meadow creek fish had substantially greater condition (weight for a given length) than the Lardeau fish which were in turn in better condition than the kokanee sampled from the LDR. For the POHL measurement, the Lardeau kokanee had a shorter POHL than those found in the LDR. Due to the low sample size there was substantial uncertainty concerning the POHL of Meadow Creek fish. Egg retention was highest in the Meadow Creek system, but the very wide credibility intervals around the mean estimate for this system are due to the very low sample size. The egg retention for the Lardeau is higher than for the LDR. For the other morphological variables of egg size, fecundity, and body depth, either model could be considered as the top ranked model due to the small difference in DIC (<2) between the two models (Ntzoufras 2009).

Discriminating populations of fish using morphometric analysis is relatively common and has a long history of being applied to distinguish different stocks of fish (Cadrin 2000). The results of this analysis on the kokanee in the lower Duncan River, Lardeau River and Meadow Creek indicate that there are likely morphometric differences amongst the three populations. It is highly recommended that this morphometric analyses be supported by the completion of a genetic analysis of the three populations prior to program completion and if possible, the collection of additional morphometric measures from the Meadow Creek population in order to better compare it to the populations from the lower Duncan River and the Lardeau River.

Closure

This report is to the best of my knowledge accurate and correct. If you have any questions regarding its contents please contact the undersigned.

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References

Cadrin, S. X. (2000). Advances in morphometric identification of fishery stocks. *Reviews in Fish Biology and Fisheries* **10**: 91-112.

Gilks, W. R., A. Thomas and D. J. Spiegelhalter (1994). A language and program for complex Bayesian modelling. *The Statistician* **43**: 169-178.

Murray, C. B., J. D. MCPhail, and M. L. Rosenau. 1989. Reproductive and developmental biology of kokanee from upper Arrow Lake, British Columbia. Transactions of the American Fisheries Society 118: 503-509.

Ntzoufras, I. (2009). Bayesian Modeling Using WinBUGS. Hoboken, New Jersey, John Wiley & Sons, Inc.

Ramstad, K. M., C. J. Foote, J. B. Olsen, and D. Rogers. 2003. Genetic and Phenotypic evidence of reproductive isolation between seasonal runs of sockeye salmon in Bear Lake, Alaska. Transactions of the American Fisheries Society 132: 997 – 1013.

R Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*. New York, Springer.

APPENDIX E
Discharge and Water Temperature Summary Statistics

Appendix E. Summary statistics for discharge and water temperature for the September-October kokanee spawning period in the LDR, Lardeau River and Meadow Creek, 2008-2011.

Lower Duncan River (LDR)

2008 Discharge		2008 Temperature		2009 Discharge		2009 Temperature		2010 Discharge		2010 Temperature		2011 Discharge		2011 Discharge	
Mean	156.6	Mean	10.9	Mean	142.0	Mean	12.5	Mean	140.2	Mean	11.5	Mean	156.7	Mean	11.4
Std Dev	80.0	Std Dev	1.4	Std Dev	61.9	Std Dev	1.6	Std Dev	60.4	Std Dev	1.2	Std Dev	78.6	Std Dev	1.5
Std Err Mean	10.2	Std Err Mean	0.2	Std Err Mean	7.9	Std Err Mean	0.2	Std Err Mean	7.7	Std Err Mean	0.2	Std Err Mean	10.1	Std Err Mean	0.2
upper 95% Mean	177.1	upper 95% Mean	11.2	upper 95% Mean	157.8	upper 95% Mean	12.9	upper 95% Mean	155.7	upper 95% Mean	11.9	upper 95% Mean	176.8	upper 95% Mean	11.8
lower 95% Mean	136.1	lower 95% Mean	10.5	lower 95% Mean	126.1	lower 95% Mean	12.1	lower 95% Mean	124.8	lower 95% Mean	11.2	lower 95% Mean	136.5	lower 95% Mean	11.0
N	61	N	61	N	61	N	61	N	61	N	61	N	61	N	61

Lardeau River

2008 Discharge		2008 Temperature - no data		2009 Discharge		2009 Temperature		2010 Discharge		2010 Temperature		2011 Discharge		2011 Discharge	
Mean	38.6			Mean	26.4	Mean	13.5	Mean	42.8	Mean	10.3	Mean	32.2	Mean	10.5
Std Dev	11.6			Std Dev	6.7	Std Dev	3.3	Std Dev	14.3	Std Dev	1.8	Std Dev	6.0	Std Dev	2.5
Std Err Mean	1.5			Std Err Mean	0.9	Std Err Mean	0.4	Std Err Mean	1.8	Std Err Mean	0.2	Std Err Mean	0.8	Std Err Mean	0.3
upper 95% Mean	41.6			upper 95% Mean	28.1	upper 95% Mean	14.3	upper 95% Mean	46.5	upper 95% Mean	10.8	upper 95% Mean	33.8	upper 95% Mean	11.1
lower 95% Mean	35.6			lower 95% Mean	24.7	lower 95% Mean	12.6	lower 95% Mean	39.2	lower 95% Mean	9.9	lower 95% Mean	30.7	lower 95% Mean	9.9
N	61			N	61	N	59	N	61	N	61	N	61	N	61

Meadow Creek

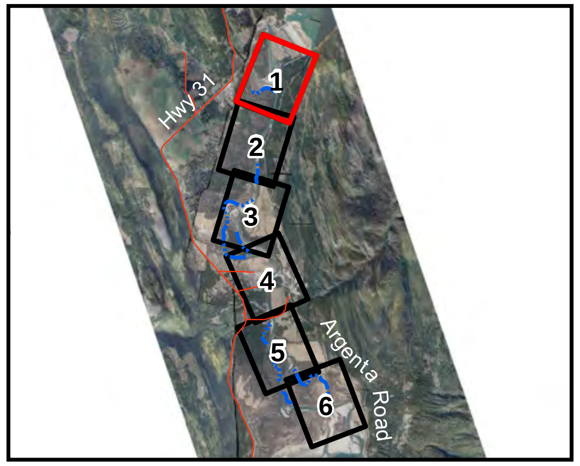
2008 Discharge - no data		2008 Temperature - no data		2009 Discharge - no data		2009 Temperature - no data		2010 Discharge - no data		2010 Temperature		2011 Discharge - no data		2011 Discharge	
										Mean	9.2			Mean	8.1
										Std Dev	1.6			Std Dev	2.1
										Std Err Mean	0.2			Std Err Mean	0.3
										upper 95% Mean	9.6			upper 95% Mean	8.6
										lower 95% Mean	8.8			lower 95% Mean	7.5
										N	61			N	61

APPENDIX F
2009 Kokanee Spawning Locations & Areas Observed to Dewater

Legend

- River km (AMEC, 2009)
- Low to moderate use spawning area (≤100 spawning Kokanee 2009)
- Moderate to high use spawning area (>100 spawning Kokanee 2009)
- Named Sidechannel
- Low to moderate use mapped spawning areas observed to dewater
- Low to moderate use mapped spawning area
- Moderate to high use mapped spawning area
- "A": Refers to spawn mapping sites (see Table 8 and 9 in text)

Note:
Mapped areas not to scale



Scale:1:5,000

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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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PROJECT: DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring				
2009 Kokanee Spawning Locations and Areas Observed to Dewater				
JOB No: VE51905		COMPILATION DATE: 2010/01/07		
GIS FILE: kokanee_spawning.mxd		REVISION DATE: 2010/01/07		
PDF FILE: kokanee_spawning.pdf		PRINTING DATE: 2010/01/07		
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: CL

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Legend

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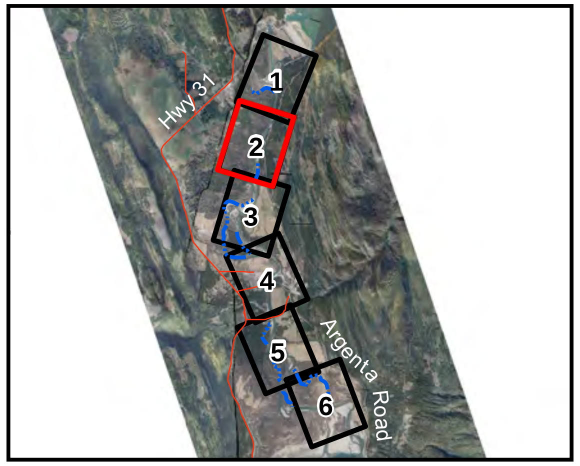

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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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2009 Kokanee Spawning Locations and Areas Observed to Dewater

JOB No: VE51905			COMPILATION DATE: 2010/01/07		
GIS FILE: kokanee_spawning.mxd			REVISION DATE: 2010/01/07		
PDF FILE: kokanee_spawning.pdf			PRINTING DATE: 2010/01/07		
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: CL	

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Legend

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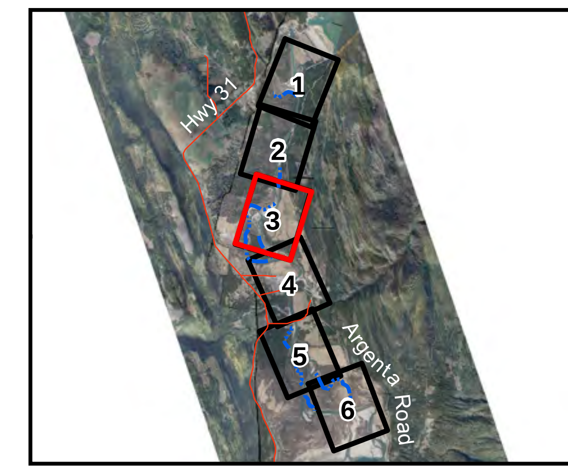

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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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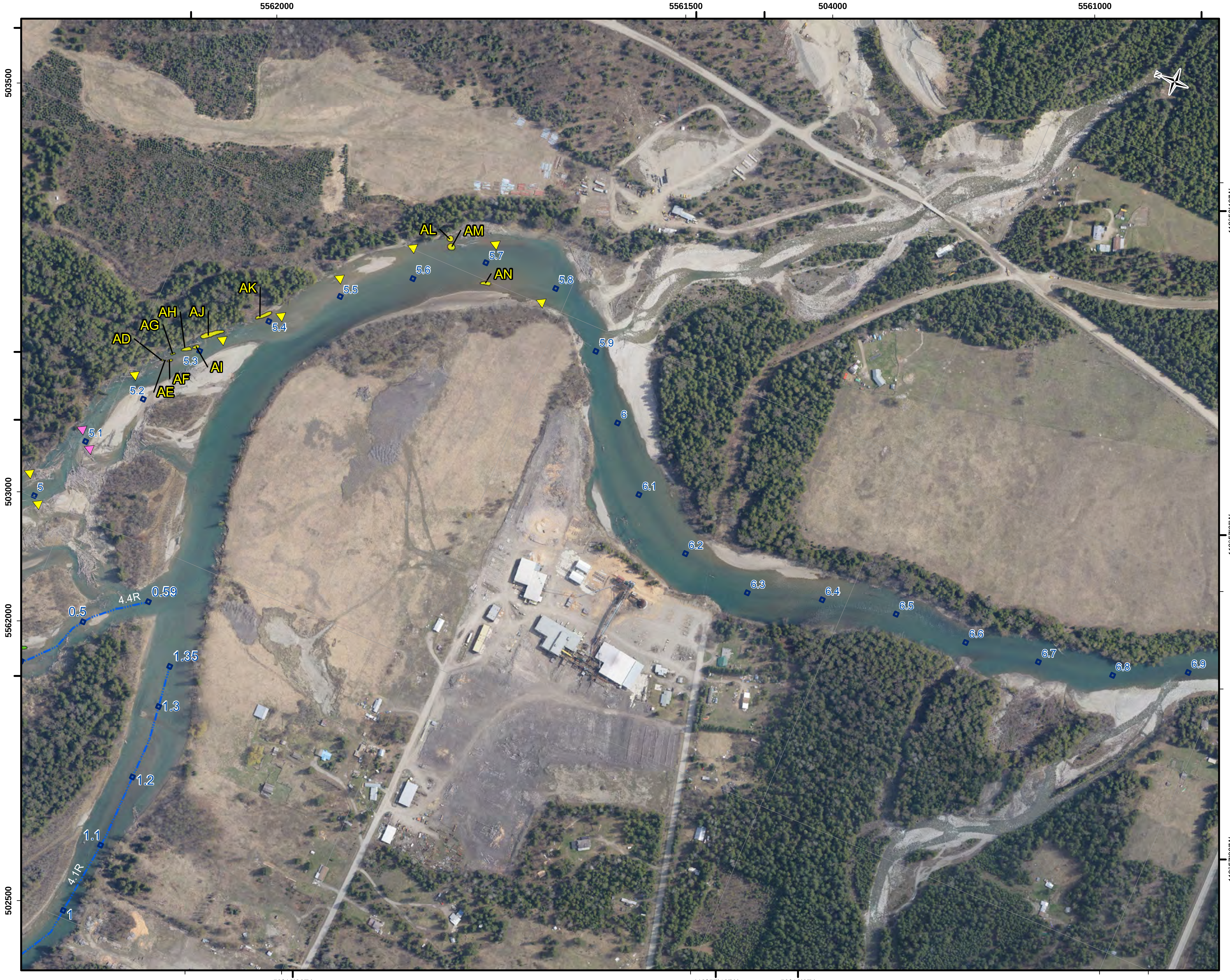

Legend

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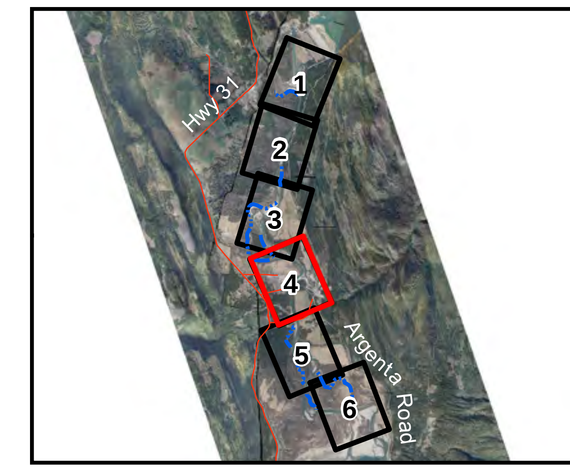

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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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	2009 Kokanee Spawning Locations and Areas Observed to Dewater

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GIS FILE: kokanee_spawning.mxd		REVISION DATE: 2010/01/07		
PDF FILE: kokanee_spawning.pdf		PRINTING DATE: 2010/01/07		
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: CL

amec

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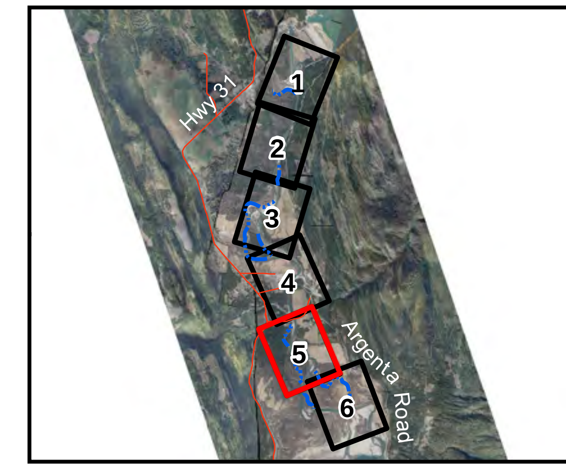

Scale:1:5,000

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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

2009 Kokanee Spawning Locations and Areas Observed to Dewater

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PDF FILE: kokanee_spawning.pdf			PRINTING DATE: 2010/01/07	
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: CL

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Legend

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"A": Refers to spawn mapping sites (see Table 8 and 9 in text)

Note:
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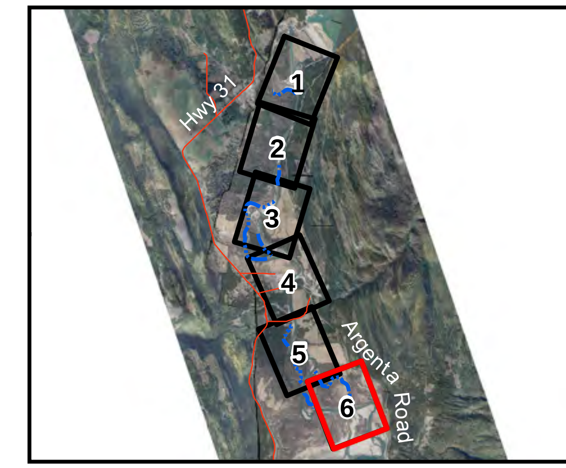

Scale:1:5,000

100 50 0 100 200

Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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PROJECT: DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

2009 Kokanee Spawning Locations and Areas Observed to Dewater

JOB No: VE51905	COMPILATION DATE: 2010/01/07
GIS FILE: kokanee_spawning.mxd	REVISION DATE: 2010/01/07
PDF FILE: kokanee_spawning.pdf	PRINTING DATE: 2010/01/07

PROJECTION:	DATUM:	ANALYST:	QA/QC:	REQ:
UTM Zone 11	NAD83	EO	LP	CL

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APPENDIX G
Kokanee Spawning in Side Channels vs. Mainstem Areas

Appendix G.The number of spawning kokanee distributed in sidechannels (SC) and the LDR mainstem (MS),

Date	SC	MS
2-Sep-08	20	0
12-Sep-08	2,045	72
16-Sep-08	3,352	600
24-Sep-08	6,125	2,477
26-Sep-08	7,122	7,665
2-Oct-08	6,097	19,062
9-Oct-08	2,169	8,024
14-Oct-08	978	2,818
4-Sep-09	0	0
11-Sep-09	0	0
18-Sep-09	0	0
22-Sep-09	505	50
5-Oct-09	2,995	4,740
7-Oct-09	4,048	7,225
15-Oct-09	490	1,275
27-Oct-09	0	0
31-Aug-10	0	0
10-Sep-10	95	0
22-Sep-10	1,146	0
27-Sep-10	3,898	0
30-Sep-10	6,830	6,168
8-Oct-10	3,742	2,758
13-Oct-10	2,693	1,560
6-Sep-11	358	5
15-Sep-11	-a	110
22-Sep-11	27,016	16,435
26-Sep-11	30,728	-b
29-Sep-11	16,128	15,157
7-Oct-11	3,827	7,110
12-Oct-11	1,297	8,508
20-Oct-11	645	1,228

[a] Only mainstem could be enumerated due to inclement weather that arose during helicopter survey

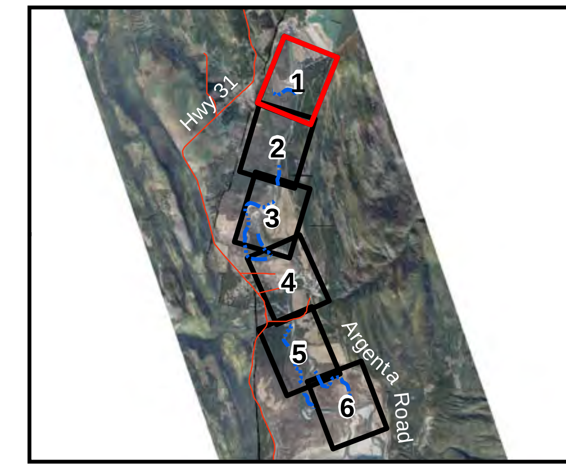
[b] Only sidechannels could be enumerated due to inclement weather that arose during helicopter survey

APPENDIX H
2011 Kokanee Spawning Locations & Areas Observed to Dewater

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning Use
- Kokanee Spawning Use - Area Lost

Note:
Mapped areas not to scale



Scale:1:5,000

100 50 0 100 200

Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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CLIENT:	BC Hydro
PROJECT:	DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring
	2011 Kokanee Spawning Areas and Areas Dewatered in the LDR
JOB No: VE51905	COMPILATION DATE: 2012/01/02
GIS FILE: kokanee_spawning_2011_combined.mxd	REVISION DATE: 2012/01/02
PDF FILE: kokanee_spawning_2011_combined.pdf	PRINTING DATE: 2012/01/02

PROJECTION:	DATUM:	ANALYST:	QA/QC:	REQ:
UTM Zone 11	NAD83	EO	LP	CL

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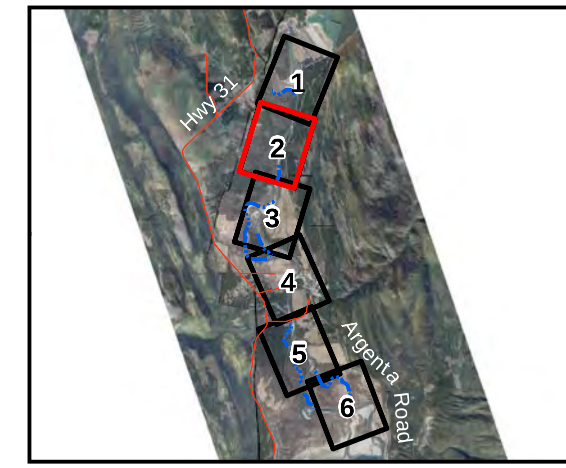
Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning Use
- Kokanee Spawning Use - Area Lost

Note:
Mapped areas not to scale



Scale:1:5,000

100 50 0 100 200

Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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CLIENT: BC Hydro

PROJECT: DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

2011 Kokanee Spawning Areas and Areas Dewatered in the LDR

JOB No: VE51905			COMPILATION DATE: 2012/01/02		
GIS FILE: kokanee_spawning_2011_combined.mxd			REVISION DATE: 2012/01/02		
PDF FILE: kokanee_spawning_2011_combined.pdf			PRINTING DATE: 2012/01/02		
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: EO	QA/QC: LP	REQ: CL	

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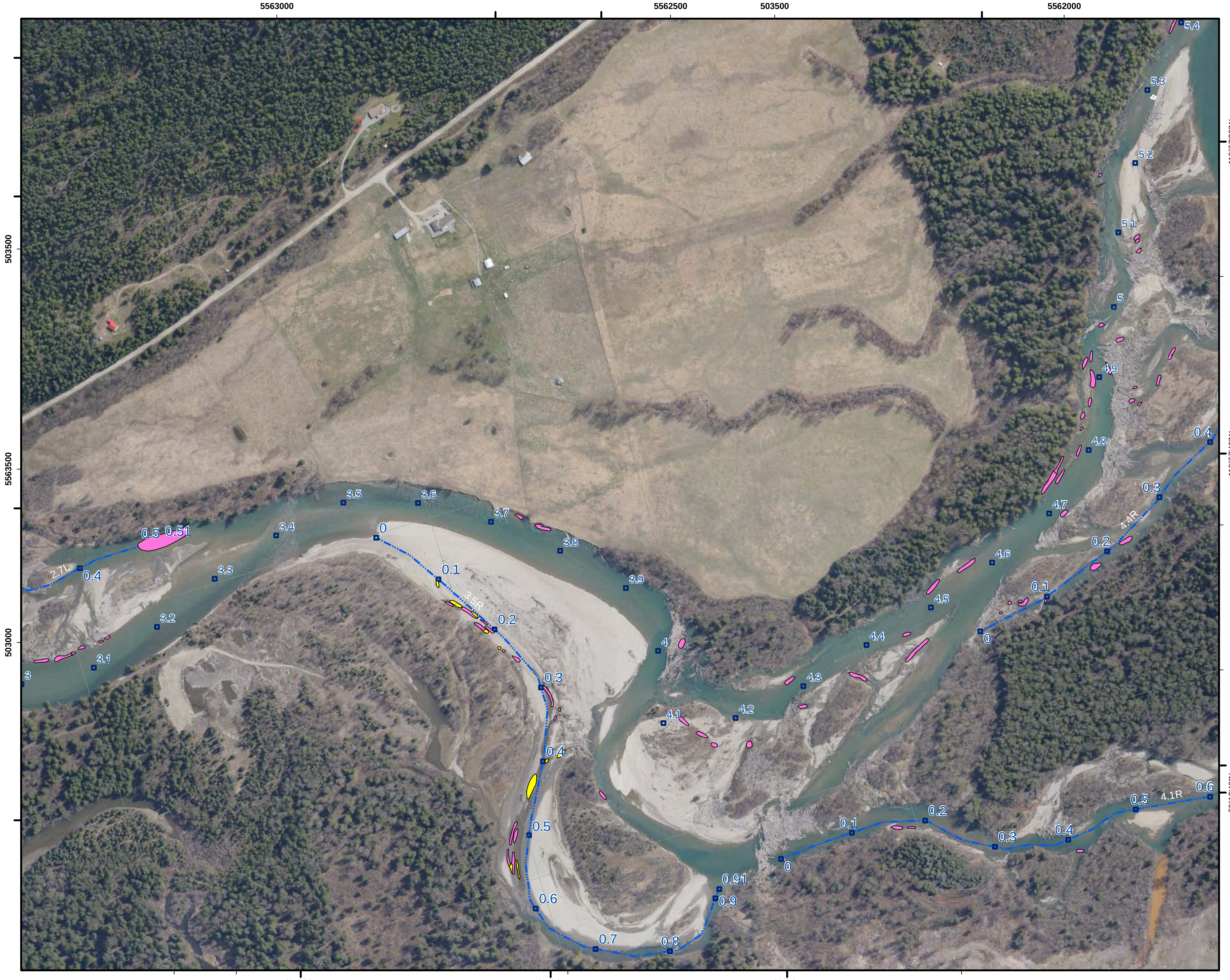

Legend

- River km (AMEC, 2009)
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- Kokanee Spawning Use
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Note:
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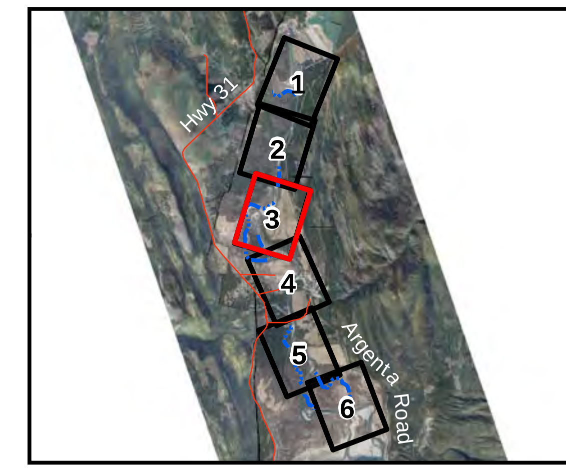

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Meters

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Legend

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- Kokanee Spawning Use
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Note:
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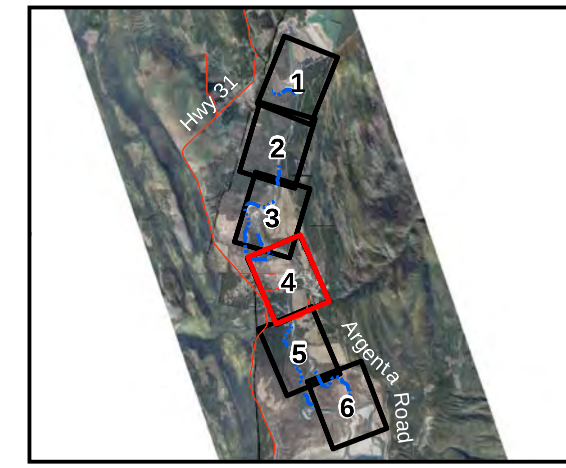

Scale:1:5,000

100 50 0 100 200

Meters

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Legend

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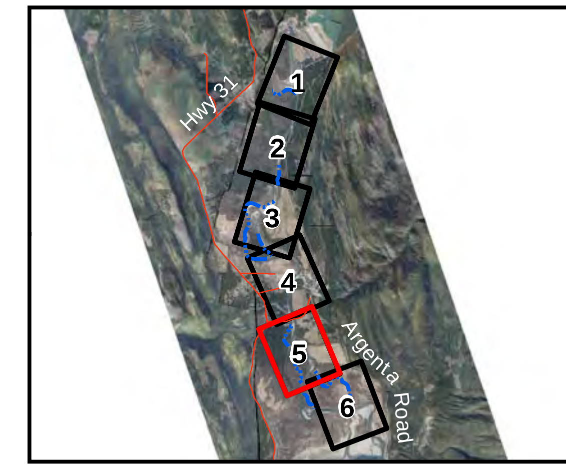

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Meters

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amec

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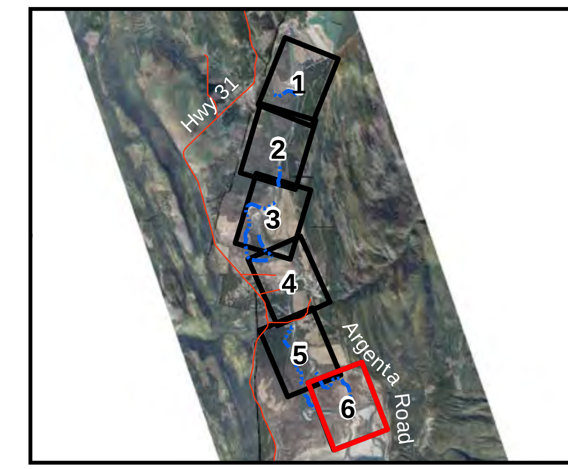

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