Duncan Dam Project Water Use Plan

Lower Duncan River Habitat Use Monitoring

Implementation Year 3

Reference: DDMMON-2

AMEC Environment & Infrastructure
A division of AMEC Americas Limited,
Poisson Consulting Ltd., and
Mountain Water Research

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Lower Duncan River Habitat Use Monitoring (DDMMON-2)

Year 3 Report
FINAL

Submitted to:

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Mountain Water Research

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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 fish habitat use and productivity in the Lower Duncan River (LDR). The LDR Habitat Use (DDMMON-2) program's main objective was to collect information on the life history and habitat use for three target fish species (rainbow trout (RB), mountain whitefish (MW), and burbot) that may be affected by water level fluctuations resulting from daily and seasonal operation of DDM.

The rainbow trout adult spawning program was conducted in 2009 and 2010 under DDMMON-2 (Thorley et al. 2011) and in 2011 and 2012 was continued under separate funding (Thorley and Baxter 2011). Mountain Whitefish spawn monitoring was conducted during the spawning period from 2010 to 2012, whereas juvenile habitat use surveys were completed in fall 2009 and 2010 and winter 2011/2012 and in spring 2012 as part of a separate program. Field studies were not initiated during this program for burbot, since it was determined that they were not required for the duration of this program based on the information review and discussions with the regulatory agencies (Porto et al. 2009). The following is an interpretive report based on the current state of knowledge for RB, MW and juveniles of these species with respect to BC Hydro's management questions for DDMMON-2 as summarized in the following table.

Management Question	Status		
	Rainbow Trout Spawning	**Mountain Whitefish Spawning**	**Juvenile Rainbow Trout and Mountain Whitefish Habitat Use**
What is the life history timing, frequency distribution [abundance] and relevant environmental cues for juvenile rainbow trout and mountain whitefish using the lower Duncan River mainstem and side channels?	Spawn Timing: Rainbow trout (RB) spawners stage at the top of Kootenay Lake in March/April and approximately 50% of the individuals are detected below Duncan Dam from mid-March to mid-April. Most individuals are also detected at Gerrard from mid-April until the end of May. Redd construction can occur in the tailout area from mid-March to late May. Frequency Distribution (abundance): Cumulative redd count and spawn timing results suggest that during the past eight years between 26 and 160 redds have been annually constructed in the DDM tailout area. In contrast, annual spawner abundance at Gerrard was between 1,200 and 3,000 fish during the same period. If it is assumed that 50% of the fish at Gerrard are females and each female constructs two redds then over the past eight years spawning activity in the tailout area as a percentage of that at Gerrard has ranged from 1.6% in 2009 to 5.2% in 2011. Environmental Cues: Spawn timing in the tailout area in the post-WUP period (2008 onwards) appears to be correlated with the date at which the mean weekly water temperature at DRL exceeds 5°C. Discharge does not appear to affect spawn timing although it may influence the amount of spawn activity.	Spawn Timing: The spawning period for mountain whitefish (MW) on the LDR generally ranges from October 15 to December 21 based on analysis of two years of MW Gonado-Somatic-Index (GSI) data. It was estimated that approximately 2.5% of the spawning was complete by October 22, whereas 97.5% of the spawning was complete by December 14^{th}. Peak spawning was estimated to occur November 17, 2010 and November 20, 2011. Frequency Distribution (abundance): Relative spawner abundance within the index site peaked at ~340 MW on November 14^{th} during the 2011 spawn year. Comparable estimates are not available for the 2010 spawn year though the trial night spotlighting survey on November 19^{th}, 2010 enumerated 299 MW within the index site. Environmental Cues: The reproductive cycle of MW is driven by changes in photoperiod; temperature only acts to modulate metabolic processes of gametogenesis. Spawning occurs approximately 1-2 weeks after water temperatures drop below 10°C and eggs have an optimal development range from 4-6°C. Little is known about the influence of river stage or velocity as spawning cues for MW.	Life History Timing: Juvenile rainbow trout utilize the LDR year round. RB fry enter the lower Duncan River from late May until the end of June as they emerge from the gravels. Later in the summer, they are joined by fry that emerged at Gerrard or other spawning locations in the Lardeau River. Abundance estimates suggest that during their first winter RB overwintering survival is 0.25. Mountain whitefish eggs in the LDR hatch between February and May. Juvenile MW numbers in the LDR are high during the fall and appear to decline precipitously (90-99%) during the winter although the possibility that the low MW counts are due to extremely low observer efficiencies cannot currently be excluded. Frequency Distribution (abundance): The hierarchical Bayesian analyses of the snorkel count data estimated that there were 44,000 RB fry, 5,500 RB parr and 38,000 MW fry in the LDR below the confluence with the Lardeau River during Fall 2010. The same analyses estimated that during Spring 2012 there were 10,000 RB fry, 4,200 RB parr and 126 MW fry. Environmental Cues: The environmental cues for outmigration timing are unknown, but are likely to involve photoperiod, temperature and discharge.
What are the habitats and habitat preferences associated with the majority of fish species of interest using the lower Duncan River?	Habitat use curves for RB in the DDM tailout area showed that the majority of RB spawned at depths between 0.25 and 0.75 m and mean column water velocities between 0.3 and 0.8 m/s. RB can spawn in deeper areas though the frequency of this was difficult to determine due to poor visibility in the DDM tailout from peak spawning onwards. Rainbow trout spawners seem to specifically target the DDM tailout area for reasons other than suitable depths, velocities or substrate. Although 17 sites in the LDR other than the tailout area were identified as suitable spawning habitat and surveyed on multiple occasions during the 2009 and 2010 spawning periods, the only spawning activity was two redds in channel 4.1R on May 14, 2010.	Habitat use curves derived for MW showed that LDR MW spawned in 0-2 m of water with peak use at 0.9 m depth. Velocity ranged from 1-1.48 m/s with peak use at 0.68 m/s. MW in the LDR were most often observed in aggregations above cobble (67%) and large gravel (32%) substrate during the spawning period. In addition, 20% of MW observed in spawning aggregations >6 were proximal to large woody debris.	Preliminary data analysis indicated that, in general, juvenile RB and MW do not exhibit a significant preference for main or side channel habitat with one exception: during high overwinter flows the number of RB parr in side channel 2.7L increased. The habitat use curves for depth indicated that RB fry used shallower water than MW fry, which in turn preferred shallower water than the parr of either species. The habitat use curves for velocity suggest that, with the possible exception of mountain whitefish parr, juveniles on the LDR almost exclusively utilize water slower than 0.5 m/s.

Management Question	Status		
	Rainbow Trout Spawning	**Mountain Whitefish Spawning**	**Juvenile Rainbow Trout and Mountain Whitefish Habitat Use**
What operations (flow releases, timing, and gate operations) would minimize habitat dewatering and reduce the impact on species life histories as constrained by the DDM WUP?	Dewatering of RB redds may occur during DDM flow reductions during the RB spawning period. It should be possible to use the Bayesian stage-discharge model to predict redd dewatering if its ability to accurately predict stage during periods of low discharges from both DDM and the Lardeau River can be improved. RB redds were irrigated and excavated during DDM operations that dewatered RB redds in the DDM tailout area. It is currently uncertain whether the poor resultant survival of the excavated eggs related to the source redd or handling or whether eggs suffer high mortality in the tailout area irrespective of whether they remain wetted. Until this uncertainty is resolved it is unclear whether it is possible to mitigate for redd dewatering without changes to DDM operations. Reduction of DDM discharge prior to the onset of freshet in the Lardeau River, as occurred in April 2011, may increase the amount of suitable spawning area in the DDM tailout area. In order to inform Duncan Dam operations it is recommended that future research programs estimate egg survival under the current operating regime and further refine the stage-discharge model so that it better predicts the magnitude of dewatering.	Water temperatures in the LDR during fall may be elevated over pre-dam levels due to the release of warmer reservoir water, which may affect egg mortality particularly for the fish that spawn prior to peak dates. In addition, increased flow from DDM at the end of December may disturb incubating eggs or may prompt early emergence and may also limit the availability of MW rearing habitat. The warmer temperatures will influence egg incubation period as well.	Due to uncertainties in the inlake survival and numbers of outmigrating RB fry, the extent to which changes in operations could influence the productivity of the fish population is currently unclear. A similar situation exists with mountain whitefish.

1.0 BACKGROUND

Duncan Dam (DDM) was built in 1967 as a storage facility under the Columbia River Treaty (CRT). Flow management in the lower Duncan River (LDR) below DDM is dictated by seasonal operating targets set by the CRT and, to a lesser degree, 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 (Figure 1-1). The Duncan Dam Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area.

During the DDM WUP process, fish productivity in the LDR was identified as one objective that should be maximized within the operating potential of DDM (BC Hydro 2005). Fish performance measures (Table 1-1) were also developed and revised as appropriate throughout the DDM WUP process, but limited data were available that were representative of fish habitat and flow relationships (BC Hydro 2005).

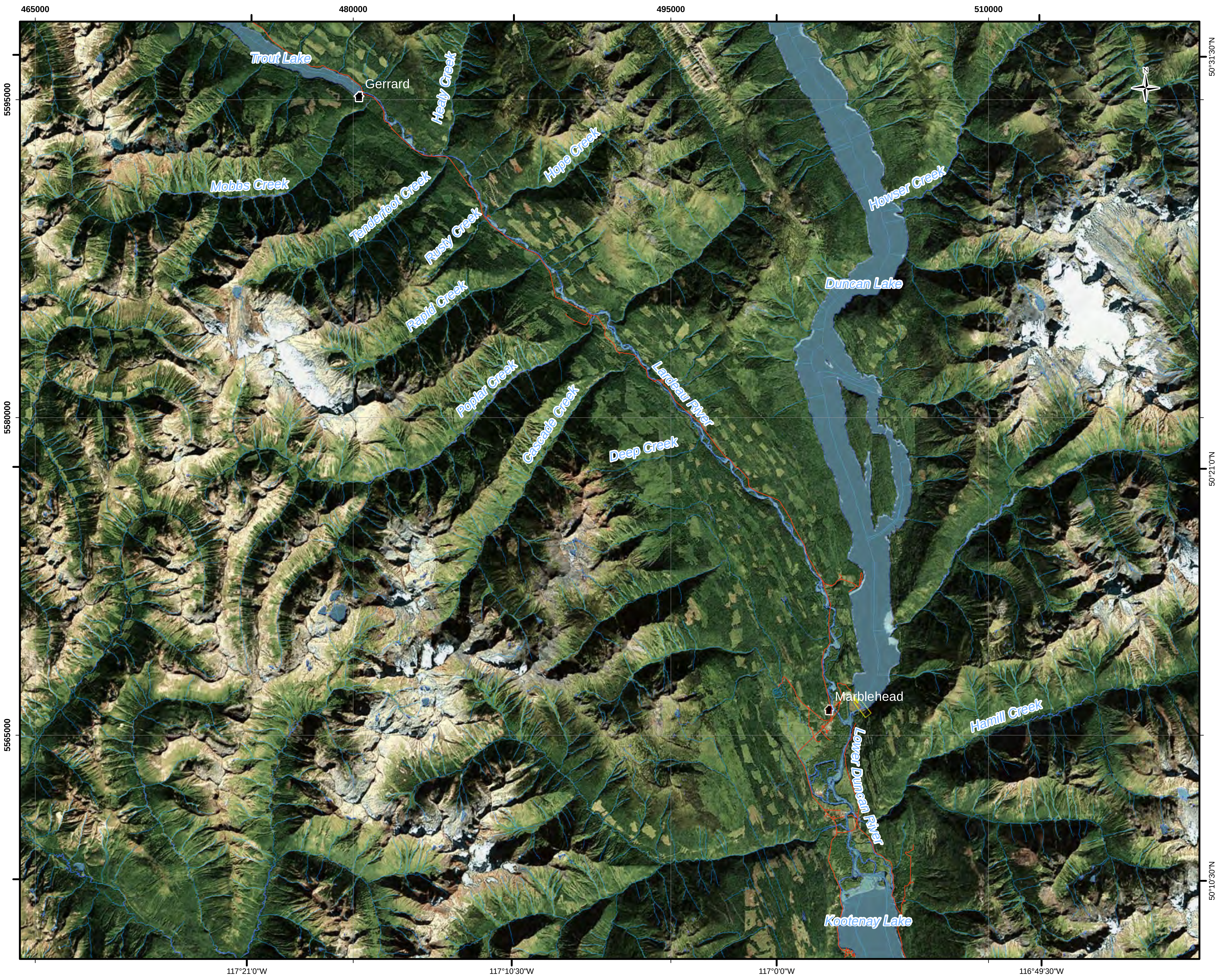
Table 1-1: Fish Performance Measures Developed During DDM WUP for the Lower Duncan River (BC Hydro 2005)

Location	Performance Measure	Units of Measure
LDR Side Channel	Kokanee Effective Spawning Habitat Lost	Hectares of effective spawning habitat lost
	Kokanee Effective Rearing Habitat Lost	Hectares of effective rearing habitat lost
	Rainbow Trout Effective Rearing Habitat	Hectares of effective rearing habitat
	Rainbow Trout Effective Rearing Habitat Lost	Hectares of effective rearing habitat lost
LDR Mainstem	Whitefish Effective Spawning Habitat	Hectares of effective spawning habitat
	Whitefish Effective Spawning Habitat Lost	Hectares of effective spawning habitat lost
	Kokanee Effective Spawning Habitat	Hectares of effective spawning habitat
	Rainbow Effective Rearing Habitat Lost	Hectares of effective spawning habitat lost
	Total Gas Pressure Days	Number of days TGP >115%
	Total Gas Pressure Events	Number of events TGP >115%
	Significant Events	Number of significant operational changes >0.20 m; number of significant operational changes > 0.45 m

During the DDM WUP process, hydraulic models were used with professional assumptions around life history and habitat use of various species to define habitat availability (a proxy for fish production) in the LDR. However, since information on life history and habitat use for target species was limited, the WUP Consultative Committee (CC) recommended that habitat use by fish species in the mainstem and side channel habitats be assessed (BC Hydro 2008). Fish stranding in the LDR, particularly in side channels, was also realized as a key impact of DDM operations (BC Hydro 2008).

As part of the DDM "Adaptive Stranding Protocol Development" program, the current program (DDMMON-2) formed one of five separate monitoring programs on the LDR (BC Hydro 2008). This program was developed to "identify the timing and habitat use preferences of the LDR fish populations" (BC Hydro 2008), in particular, adult rainbow trout (*Oncorhynchus mykiss*) and mountain whitefish (*Prosopium williamsoni*), as well as juvenile stages of these two species. This program also included the determination of adult burbot velocity barriers within the LDR (see Porto et al. 2009). Bull trout (*Salvelinus confluentus*) were also identified as a target species. However, bull trout migration, spawning, and juvenile recruitment monitoring were considered under separate programs and were not included under DDMMON-2.

Completion of this study will result in partial fulfillment of requirements ordered by British Columbia's Comptroller of Water Rights, and, in conjunction with the other studies in the Adaptive Stranding Protocol Development program, will specifically address clause 5(e) of BC Hydro's Duncan Dam Conditional Water License 27027 (BC Hydro 2008).



Legend

- Communities
- Dam
- Watercourse
- Road

Scale:1:175,000

4 2 0 4 8

Kilometres

Reference

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

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CLIENT:
BC Hydro

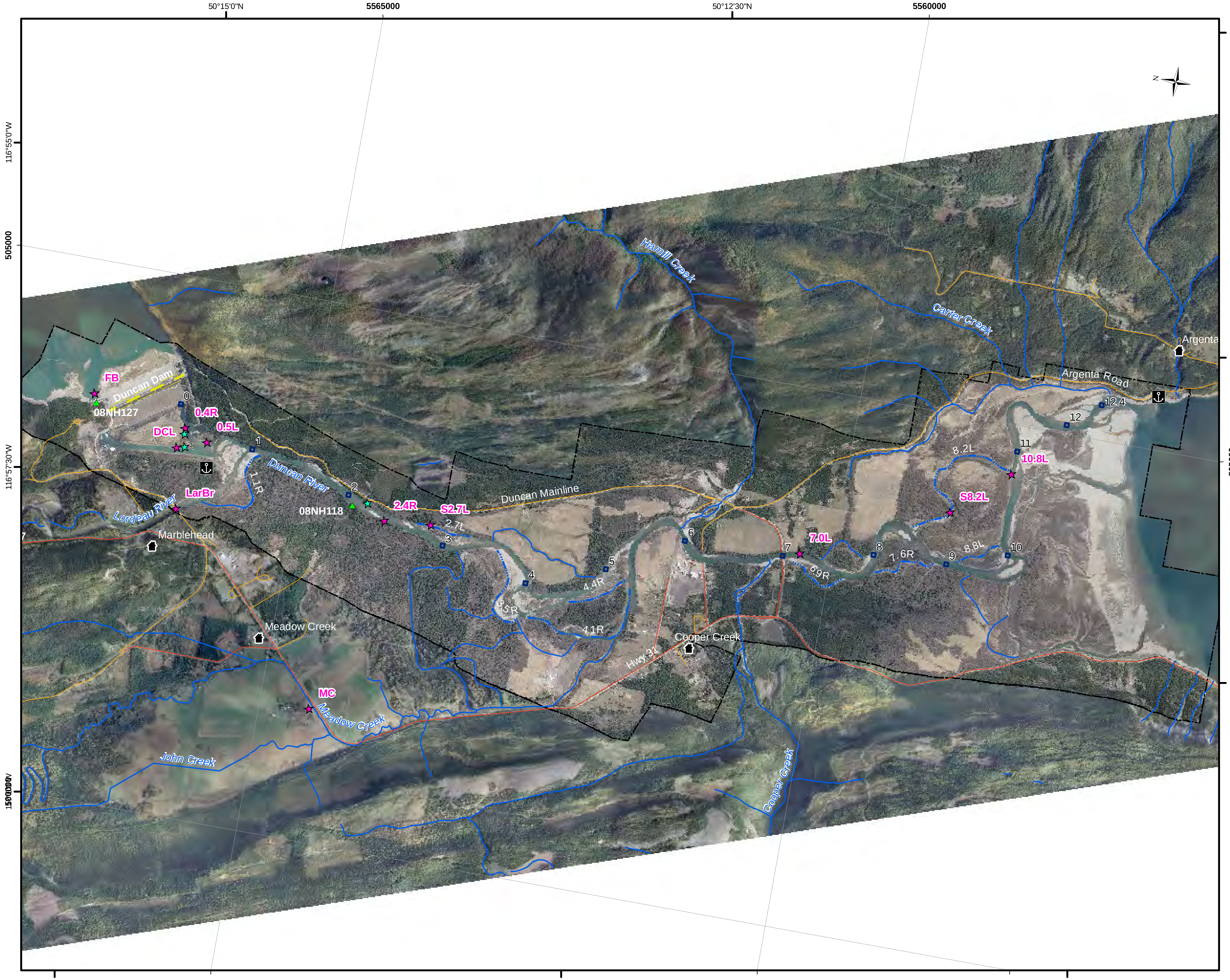
PROJECT:
DDMMON-2 Lower Duncan River Habitat Use Monitoring

Overview Map of the Lardeau River and the Lower Duncan River Including Parts of Trout Lake, Duncan Lake and Kootenay Lake

JOB No: VE51873.2011.337	COMPILATION DATE: 2011/01/05	Figure 1-1
GIS FILE: duncan_lardeau_overview_v2.mxd	REVISION DATE: 2012/09/05	
PDF FILE: duncan_lardeau_overview_v2.pdf	PRINTING DATE: 2012/09/05	

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

Y:\GIS\Projects\VE\VE51873_LDR_HabMapping\MXD\Drafts\duncan_lardeau_overview_v2.mxd



Legend

- Temperature Monitoring Location and Name
- TGP/Temperature Monitoring Location
- WSC Gauge
- Boat launch
- Communities
- River km (AMEC, 2009)
- Dam

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

Scale:1:35,000

500 250 0 500 1000

Meters

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms

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CLIENT: BC Hydro

PROJECT: DDMMON-2 Lower Duncan River Habitat Use

Overview Map of the lower Duncan River from Kootenay Lake including tributaries, side channels and termperature monitoring stations deployed under DDMMON-7

JOB No: VE51974	COMPILATION DATE: 2011/04/05	Figure 1-2
GIS FILE: study_sites_year_1_v4.mxd	REVISION DATE: 2012/08/16	
PDF FILE: study_sites_year_1_v4.pdf	PRINTING DATE: 2012/08/16	
PROJECTION: UTM Zone 11 / DATUM: NAD83 / ANALYST: KS	QA/QC: CL / REQ: LP	

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1.1 Key Management Questions

The main objective of DDMMON-2 was to collect information on the life history and habitat use of the target fish species in the LDR that may be affected by water level fluctuations resulting from daily and seasonal operation of DDM. Specific management questions pertaining to this study included (BC Hydro 2008):

1. What are the typical life history timing, frequency distribution, and relevant environmental cues for identified fish species of interest using the Duncan River mainstem and side channels?
2. What are the habitats and habitat preferences associated with the majority of fish from each species life history period?
3. What operations (flow releases, timing, and gate operations) would minimize habitat dewatering and reduce the impact on species life histories as constrained by the DDM WUP?

As described in the BC Hydro (2008) for this program: "These management questions are broad and pertain to several monitoring programs under the DDM WUP umbrella. It is anticipated that the information collected for this monitoring program will be integrated with other investigations to derive operating parameters for interim implementation (i.e. ramping rates minimum flow levels during critical life history phases) and/or for future water planning processes. Because of limited time and resources associated with the approved monitoring program budget, this monitoring program focused on testing/validating models and assumptions used in the Duncan Dam Water Use Planning process, and did not assess operational effectiveness. This approach assumed that by addressing these management questions, they will be effective for the species life histories of interest."

1.2 Summary of Experimental Hypotheses

As directly taken from (BC Hydro 2008): "The following hypotheses will be investigated in this monitoring program with the goal of addressing the management questions above. Those hypotheses that require further study to address (specifically, fish response to flow reduction operations) will be identified in other studies within the DDM WUP Monitoring Programs package.

H01: Life history timing and distribution timing of species of interest in the lower Duncan River does not differ significantly from those defined for the DDM WUP.

The timing for life histories suggested in (DVH Consulting 2001) *were evaluated and revised in consideration of information from site evaluations by area biologists and operational requirements. The timing of Mountain whitefish spawning in particular was in question at the time of the WUP decision process. Rainbow spawning habitat requirements and timing has also become a significant management issue below Duncan Dam.*

H02: The habitat uses of life histories for species of interest in the lower Duncan River are not significantly different than those assumed for the DDM WUP.

Habitat modeling integrated rudimentary habitat use assumptions which included the assumption that all habitats meeting literature reviewed depth and velocity requirements for *salmonids in the mainstem and side channels would be suitable for spawning and rearing fish. This led to, among other constraints, the need to keep the majority of side channel habitats wetted throughout the year to minimize stranding risk and optimize fish habitat availability. This study will determine if the assumptions were correct, and define how and where the areas of habitat use differs with model assumptions.*

Investigating these hypotheses will result in the direct assessment of performance measure assumptions applied in the Water Use Plan. Because the performance measures were integral to the decision process, it is assumed that this information will be relevant to future water planning processes. Management Question #3, relating to the flow targets and operating conditions, will incorporate information collected here, specifically habitat use preferences and timing, with habitat flow modeling to be conducted in a separate study (DDMMON-3). The habitat use studies herein will help calibrate the modeling study to specifically determine if the integration of hydraulic attributes with habitat preferences results in an accurate interpretation of spatial habitat values, leading to the third and fourth hypotheses:

H03: Usable habitats identified in this study do no significantly differ from those predicted in the hydraulic model developed for the DDM WUP.

H04: The hydraulic modeling conducted in DDMMON-3 accurately predicts habitat availability according to monitoring indicators in this study.

Monitoring indicators collected in this monitoring program will include habitat variables such as depth, velocity, cover and substrate quality attributed to habitat use of life histories for species of interest. Where the habitat uses and habitat locations observed in this study (and previous studies) differ from those predicted from hydraulic modeling, modeling parameters will be calibrated to reflect empirical results. The timing of this study's completion and hydraulic modeling calibration (DDMMON-3) will be coordinated to occur in Year 3 of the review period.

H05: Local operations (i.e. specific gate operations) currently employed at Duncan Dam are effective at minimizing fish stranding in the Lower Duncan River.

Where opportunities identified in the ASPD study program can be accommodated by refining Duncan Dam gate operations (timing, rate of gate change and/or gate order), this hyopothesis will be refuted and a gate operation rule will be recommended in this study to improve environmental performance.

Finally, the last hypothesis will be tested to assess burbot passage during migration:

H06: Duncan Dam WUP provisions do not restrict burbot passage through the Lower Duncan River corridor[1].

[1] It was determined that burbot do not require the use of the LDR as a migration corridor during the spawning period and if they did that modeled flows did not impede passage. Findings were discussed with the regulatory agencies and it was concluded that additional field studies on burbot were not required for the duration of this program (Porto et al. 2009).

During WUP deliberations, uncertainty was expressed whether there were velocity barriers to burbot that would be migrating through the Lower Duncan River prior to spawning mid-winter. A simple field evaluation of burbot passage will be conducted on the Lower Duncan River, with a comparison with hydraulic model results (from DDMMON#3 – Lower Duncan River Hydraulic Model Development) using velocity criteria defined in the literature and summarized for this study.

Not all aspects of these hypotheses will be addressed within the study timing proposed."

1.3 Critical Uncertainties to be Addressed

"Critical uncertainties highlighted in the WUP process will be addressed first, and those gaps identified in the final report for this study program will serve as recommendations for data collection in future planning processes (BC Hydro 2008)." The critical uncertainties for this study program are as follows (BC Hydro 2008):

- Life history timing, habitat requirements, and locations for mountain whitefish and rainbow trout spawning and incubation;
- Juvenile rearing habitat requirements and locations for mountain whitefish, rainbow trout, and bull trout, where applicable; and,
- Adult burbot migration requirements and LDR migration bottlenecks.

Three years of habitat use monitoring are proposed for this study program and during that time the following will be undertaken (BC Hydro 2008):

- Rainbow trout and Mountain whitefish juvenile rearing use in the mainstem and side channels will be monitored to map and document/estimate the relative abundance of juvenile fish throughout the system;
- Rainbow trout and Mountain whitefish adult spawning use and timing will be monitored in the mainstem to document habitat use preference, relative spatial distribution, and to determine spawning timing; and,
- Burbot migration and spawning will be assessed to determine the timing, location, and flow thresholds critical to burbot migration in the LDR.

1.4 Purpose

The following fulfills our commitment to provide BC Hydro with an interpretive report for studies conducted under DDMMON-2. The RB adult spawning program was conducted in 2009 and 2010 (Thorley et al. 2011) under DDMMON-2 and in 2011 and 2012 was continued under separate funding (Thorley and Baxter 2011). Mountain Whitefish spawn monitoring was conducted during the spawning period from 2009 to 2012, whereas juvenile habitat use surveys were completed in fall 2009 and 2010 and winter 2012 and in spring 2012 as part of a separate program. As mentioned previously, field studies were not initiated during this program for burbot, since it was determined that they were not required for the duration of this program based on the information review and discussions with the regulatory agencies (Porto et al. 2009).

2.0 OVERVIEW

2.1.1 Study Area

The study area encompassed the approximately 12.5 km section of the Duncan River that runs from the Duncan Dam to its confluence with Kootenay Lake as well as the 10.7 km of side and secondary channels (Figure 1-1). The Duncan River flows into the northern end of Kootenay Lake, north of Nelson in south-eastern British Columbia (Figure 1-1). The river drains both the Selkirk and Purcell mountains into Kootenay Lake (Vonk 2001) and has a watershed area of approximately 4,750 km^2. Additional information on the study area is provided in Porto et al. (2009). Detailed information for each component of this program is provided within their respective sections below.

2.1.2 Physical Parameters

In order to assess the potential effects of dam operations on species of interest various environmental parameters such as discharge and water temperature were monitored. Additional information on environmental parameters measured for each component is also provided within their respective sections below.

2.1.3 Operational Range

The target flow protocol outlines the flows that must be provided below the confluence of the Duncan and Lardeau Rivers under the current DDM WUP (Table 2-1). Flows can be within 5% of the minima and maxima outlined in the protocol as long as the 3 day average meets the target levels (BC Hydro 2005).

Table 2-3: Target flow protocol for flows below the confluence of the Duncan and Lardeau Rivers as per DDM Water Use Plan (BC Hydro 2005).

Dates	Cubic Metres per Second (m^3/s)	
	Minimum	Maximum
August 1- August 24	73	400
August 25 – September 24	73	250
September 25-27	73	190
September 28-30	73	130
October 1-21	73	76
October 22 – December 21	73	110
December 22 – April 9	73	250
April 10- May 15	73	120
May 16 – July 31	73	400

2.1.3.1 Discharge

Hourly discharge records were obtained for DDM and the Water Survey of Canada (WSC) gauge (08N118) at Km 2.1 on the right downstream bank below the Lardeau and Duncan rivers confluence (DRL) from BC Hydro's Access database for the period of record 2004 to 2012. Subtracting the discharge at DDM from the DRL discharge provided the discharge coming from the Lardeau River. The discharge was considered separately for years prior to the implementation of the WUP flows and after the order was received in December 2007 from the Comptroller of Water Rights. For two years prior to the receipt of the order, WUP flow targets were opportunistically implemented. This opportunistic period is considered to range from December 2005 until December 2007.

2.1.3.2 Water Temperature

Water temperature recorded hourly at the WSC gauge at DRL was accessed from the BC Hydro Access database, which has water temperature from December 2003 to present. Temperature was also being recorded at several stations throughout the study area as part of the DDMMON-7 study. Temperature monitoring stations were in place in the LDR from April 2010 to May 2012 as outlined for the DDMMON-7 program (Porto and Lawrence 2010; Figure 1-2). Different temperature regimes occur on the left and right banks of the LDR at least in the first few kilometres of the LDR and depending upon discharge levels and operational permutations from DDM and the Lardeau River, the different thermal regimes may persist further downstream at times (Lawrence et al. 2012). Water temperature data at Gerrard in the spring of 2009 and 2011 was provided by the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), Nelson, BC.

Water temperature data from DRL has some aberrant data with high variability in recent years, so may not be reliable for long term comparison of trends related to water temperature in the LDR (Lawrence et al. 2012). Therefore wherever possible conclusions and analyses related to water temperature uses the data from the DDMMON-7 instrumentation.

2.1.4 Frequency Distribution (Abundance)

Following Thorley et al. (2011) the term 'frequency distribution' in Management Question 1 is interpreted as meaning abundance, i.e., frequency of individuals distributed through space and time.

2.1.5 Habitat and Habitat Use

The second management question asks for the habitats and habitat preferences associated with the majority of fish for each species life history period. When answering this question it is important to be aware that habitats and habitat preferences are hierarchical with the patterns of use dependent on macro-, meso- and microhabitat availability and preferences (Rosenfeld 2003). In the current context, sections of the LDR represent macrohabitat while features within the sections such as side and secondary channels represent mesohabitat. At the finest scale the depths and velocities experienced by individual fish and redds represent micro-habitat.

Furthermore it is important to be aware that habitat use does not necessarily indicate habitat preference and that preference does not in turn necessarily indicate requirement (Rosenfeld 2003). For example spawning fish may utilize slow water because the preferred faster water is not available as appears to be the case at Gerrard in recent years (Thorley and Bowers 2006, Thorley 2006). Thus in order to interpret a habitat use curve as a suitability curve it is necessary to establish that the full range of habitats are available.

Depth and velocity microhabitat use for rainbow trout and mountain whitefish spawning and rearing was estimated via a Bayesian model (Appendix A) key assumptions of which included:

- The habitat use curves are adequately described by a third order polynomial;
- Depth use is independent of velocity and vice versa; and,
- The residual variation is log-normally distributed.

3.0 RAINBOW TROUT SPAWNING

3.1 Introduction

The Gerrard rainbow trout of Kootenay Lake, which represent a morphologically and genetically distinct (Keeley et al. 2005, 2007) population of rainbow trout (*Oncorhynchus mykiss*), support a major trophy fishery (Andrusak 2007). Prior to construction of DDM in 1967, a population of large adfluvial rainbow trout from Kootenay Lake spawned in the Duncan River at the outflow of Duncan Lake (Peterson and Withler 1965, Northcote 1973). Northcote (1973) estimated the run to be up to 100 fish (although the basis for this estimate is unclear) and Peterson and Withler (1965) noted several gravel beds below Duncan Lake's outflow and observed 24 spawners during very poor visibility conditions. After the construction of Duncan Dam, rainbow trout continued to aggregate below the dam for a number of years with the final staging recorded in 1971 or 1972 (Northcote 1973, Andrusak and Fleck 1976). As the natural spawning run below DDM was considered to have been extirpated, rainbow trout spawning was only considered in the status of knowledge report in a historical context (Vonk 2001).

However, in the spring of 2004, large rainbow trout were discovered spawning at night in the area of gravels between the end of the armoured DDM discharge channel and the confluence with the Lardeau River (Hagen et al. 2010a). This main spawning area is referred to as the 'tailout' area and redd surveys have been conducted here annually since 2005 (Baxter 2008, Thorley et al. 2010, 2011, Thorley and Baxter 2011). Prior to this discovery, it was assumed that almost all large rainbow trout spawned in the Lardeau River, with the majority utilizing a 500 m section of gravels at the outflow of Trout Lake beside the old townsite of Gerrard (Hartman 1969, Hartman and Galbraith 1970, Irvine 1978). The continued observation of large rainbow trout and redds over the past nine years indicated that the DDM tailout area may also be a significant spawning location for these large adfluvial fish (Thorley and Baxter 2011).

In 2009 and 2010, rainbow trout spawners and redds were monitored as part of DDMMON-2 (Thorley et al. 2009, Thorley et al. 2011) while in 2011 and 2012, redds were monitored under a separate complementary program (Thorley and Baxter 2011). The key management questions for the rainbow trout spawning component of DDMMON-2 are outlined in Section 1.1. In addition, the following three sub-objectives were added as part of the separate complementary program and included under DDMMON-2: 1) to develop a long-term annual index monitoring program for documenting spawners in the LDR tailout area; 2) to document the spatial distribution and elevation of redds to determine the risk of redd dewatering based on DDM operations; and, 3) to support a redd mitigation strategy in the event that specific flow changes are required (Thorley and Baxter 2011).

3.2 Methods

3.2.1 Study Area

The study area was located in the LDR between the end of the armoured discharge channel and the confluence with the Lardeau River (Figure 3-1). This area, which is referred to as the tailout area, was chosen as the main rainbow study site as it is the primary location on the LDR where spawning has been documented (Baxter 2008, Hagen et al. 2010a, Thorley et al. 2011). In 2009 and 2010, daytime redd surveys were also conducted by surface observation (boat and shoreline) in areas of the LDR and its side channels having suitable spawning habitat. Five side channels and 12 mainstem locations with suitable spawning habitat were selected as index monitoring sites and surveyed in 2009 and 2010 (Thorley et al. 2011). However, the only spawning recorded was in side channel 4.1R when a pair of spawners and two redds were observed on May 14, 2010 (Thorley et al. 2011).

3.2.2 Physical Parameters

In order to assess the potential effects of dam operations on rainbow trout spawning, the physical parameters of discharge, river stage, water temperature and turbidity were monitored. Details on each parameter are provided below. Additional information on the LDR is also found in Porto et al. (2009).

3.2.2.1 River Stage

River stage in the tailout area was recorded every 15 minutes by the Duncan Above Lardeau (DAL) digital collection platform (DCP) from March 2011 to present (Figure 3-1). Manual readings of river stage, as measured from the staff gauge in the tailout area, were also recorded during each spawning survey (see Thorley et al. 2009, Thorley et al. 2011 and Thorley and Baxter 2011 for spawning survey dates prior to 2012).

The relationship between river stage in the tailout and discharge was estimated using Bayesian analysis (Appendix A). As the Lardeau River inundates the tailout area during high flow, the mean hourly river stage was modeled using the mean hourly discharge from both Duncan Dam and the Lardeau River. To ensure that the stage heights were recorded under relatively stable flow conditions, stage values that occurred immediately before or after a change in discharge >10 m^3/s from either Duncan Dam or the Lardeau River were removed from the dataset. The resultant stage and discharge values were then analysed using a Bayesian polynomial regression model (Appendix A). Key assumptions of the model included:

- The discharge from the Lardeau River is the discharge at DRL minus the discharge from DDM;
- The stage height in the tailout area is affected by the discharge from Duncan Dam and the Lardeau River;
- The stage-discharge relationship is adequately described by third-order polynomials with second order interactions; and,
- The residual variation in the hourly stage values is adequately described by a normally distributed first-order autoregressive process with a coefficient of 0.4.

3.2.2.2 Turbidity

In 2012, at the request of BC Hydro, turbidity at the staff gauge in the tailout area was measured during each survey using a fully calibrated Analite NEP 160 Turbidity Meter with a NEP 260 Probe. Spot measurements were collected as part of BC Hydro's turbidity monitoring program (Watts 2010, Moffat 2011).

Legend

- BCH Turbidity Meter
- Digital Collection Platform
- Staff Gauge
- Temperature Logger
- Tailout Point VR2W Receiver
- Boat Launch
- River km (AMEC, 2009)
- Named Sidechannel
- Dam

Roads

- Paved
- Unpaved

Scale:1:5,000

100 50 0 100 200

Metres

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Rainbow Trout Redd, Piezometer,
Temperature Logger: Mountain Water Research

CLIENT: BC Hydro

PROJECT: DDMMON-2 Lower Duncan River Habitat Use Monitoring

Locations of Environmental Monitoring Equipment and Acoustic Receivers in the Tailout Area and the Mouth of the Lardeau River

JOB No: VE51873.2011.337	COMPILATION DATE: 2012/06/14	Figure 3-1
GIS FILE: stations_v2.mxd	REVISION DATE: 2012/09/05	
PDF FILE: stations_v2.pdf	PRINTING DATE: 2012/09/05	

PROJECTION:	DATUM:	ANALYST:	QA/QC:	REQ:
UTM Zone 11	NAD83	KS	JB	JB

amec

Y:\GIS\Projects\VE\VE51873_LDR_Hab\Mapping\MXD\Drafts\stations_v2.mxd

3.2.3 Rainbow Trout Spawners

3.2.3.1 Redd Surveys and Abundance

Rainbow trout spawning in the tailout area has been monitored since 2005 by systematic redd surveys. The surveys are undertaken by boat and shore-based observers during daylight hours to collect information on the spatial and temporal distribution of spawning activity. Prior to each survey, water clarity is recorded using a Secchi disk and the visibility categorized as Good (≥2 m), Poor (1-2 m) or Very Poor (<1m). When water clarity less than 0.6 m or wind chop on the surface of the water prevented the crew from reliably identifying redds a redd survey was not conducted.

Since 2009 the location of each redd has been marked with an individually numbered weighted tag and georeferenced using a handheld Garmin GPS unit. The fading of each marked redd is recorded on each visit (Table 3-1).

Table 3-1: Redd fading classification.

Redd Fading	Description
Fresh	Fresh, clean and unfaded with bright sorted substrate
Clear	Still very clear but not fresh, some settling of substrate
Apparent	Still apparent but starting to fade or flatten
Visible	Faded and flattened but just visible.
Indistinguishable	Indistinguishable from surrounding substrate

3.2.3.2 Spawn Timing

The spawn timing was estimated from the redd survey data using Bayesian analysis (Appendix A). More specifically the spawn timing, which was assumed to be normally distributed, was estimated from the cumulative redd counts. Other key assumptions included:

- Observer efficiency is 100%;
- Redd survey life is greater than one month (the maximum time between surveys);
- Peak spawn timing varies between years;
- The duration of spawning is constant between years; and,
- The residual cumulative redd counts are normally distributed.

The spawn-timing model also estimated the expected annual cumulative redd count for each survey if it had continued until the end of the spawning period.

In order to examine the relationship between spawn timing and water temperature, the date when the mean weekly water temperature first exceeded 5°C (Temperature Date) was estimated at DRL for each year from 2005 to 2009. As the DRL water temperature data appeared to be unreliable from 2010 onwards, the Temperature Date from 2010 to 2012 was calculated from the water temperature data for the DDMMON7 logger at 2.4R. The

Temperature Date was then plotted against the Spawn Date, which was the spawn-timing model's lower 95% credibility limit. A linear regression was fitted to the post-WUP (2008 onwards) data.

3.2.3.3 Emergence Timing

The expected annual emergence timing in the tailout area was calculated from the estimated spawn timing and recorded water temperature under the assumption that Gerrard rainbow trout embryos require 480 accumulated thermal units (ATUs) to reach the emergence stage (K. Scheer and O. Schoenberger, Freshwater Fisheries Society of BC, pers. comm., 2010). In 2009 and 2010 temperature loggers were buried in the gravels at depths of 0.15 and 0.30 m. Comparison with the surface water temperatures in the tailout indicate that the ATUs experienced by the developing embryos can be reliably calculated from the surface water temperatures although the diel temperature variation was greater in the surface water (Thorley et al. 2011)

Visual inspection of plots of the spawner counts at Gerrard in Hagen et al. (2010a) suggests that in recent years peak spawning below DDM has preceded that at Gerrard by approximately two weeks. For comparative purposes the emergence timing at Gerrard was calculated from the surface water temperatures at Gerrard under the assumption that in any given year spawning is delayed by exactly two weeks relative to that in the tailout.

3.2.3.4 Spawner Movements

From 2008 to 2011 the Kootenay Lake Exploitation Study acoustically tagged 118 large (≥ 500mm FL) rainbow trout in Kootenay Lake (Thorley and Andrusak 2009, 2010, Andrusak and Thorley 2011, 2012). Each spring a proportion of these tagged fish enter the Duncan-Lardeau system to spawn, which provides an opportunity to collect information on spawner movements. An acoustic receiver has been present at the North end of Kootenay Lake since before the programs inceptions. In addition, in 2009, the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) began deploying acoustic receivers at Gerrard and since 2010 acoustic receivers have been deployed in the tailout area (Figure 3-1). The current years MNFLRO receiver detections were not available at the time of writing.

3.2.3.5 Habitat Use

Since 2007 the depth of each redd has been recorded and from 2009 to 2011 the mean column water velocity of each redd was recorded using a Swoffer Current Velocity Meter (Model 2100). Habitat use curves were estimated from the depth and velocity data using a Bayesian habitat use model (Section 2.1.24 and Appendix A). To reduce the chances that depth and velocity conditions may have changed between redd construction and first encounter, only redds that were classified as fresh or clear were included in the analysis.

3.2.3.6 Redd Dewatering

Since 2009, the recorded river stages at the staff gauge have been related to the water depths over the observed redds and the minimum stage elevation that would ensure all known redds remained wetted has been calculated. This information has been relayed to BC Hydro personnel who monitored the staff gauge at their discretion during flow reductions. At BC Hydro's request, crew members have been present in the tailout area during three flow reductions. During the reductions, all dewatered redds are enumerated and irrigated and any redds that are not likely to be rewetted by the subsequent flow increases are salvaged and the recovered eggs reburied in wetted gravels.

In order to begin testing whether the stage-discharge relationship produced by the Bayesian analysis of the DAL DCP stage data could be used to reliably predict redd dewatering, the predicted river stage heights were compared to the relative redd elevations. The relative redd elevations were calculated by subtracting the depth of each redd from the predicted stage height at the time the redd depth was recorded. If the stage-discharge relationship is reliable and if changes in stage at the DCP represent changes in depth at the redds then the comparison predicts that a redd should be dewatered whenever the predicted river stage drops below the redds' relative elevation.

3.2.3.7 Egg Survival

A preliminary assessment of egg survival in the tailout area was conducted in 2011 (Thorley and Baxter 2011). During the preliminary assessment a total of 175 pink eggs, which were recovered from a redd excavated during a redd dewatering event on April 19, 2011, were approximately evenly distributed between three egg capsules. The capsules were then buried in the tailout area adjacent to the original redd at a gravel depth of 0.15 m where the surface water was 0.75 m with a mean column velocity of 0.45 m/s. The three egg capsules were recovered on May 30, 2011, when the eggs were estimated to have reached the alevin stage of development, i.e., they were calculated to have experienced 320 Accumulated Thermal Units (ATUs). Survival of the ova in the three egg capsules was 0%. The eggs were covered in fine sediment.

Another assessment was planned for the 2012 field season. However, exceptionally high water levels prevented the 2012 assessment from taking place.

3.3 Results

3.3.1 Physical Parameters

3.3.1.1 Discharge

In most years, hourly discharge from Duncan Dam at the onset of the rainbow trout spawning period was close to the minimum flow target at DRL of 73 m^3/s (Table 2-1) as Lardeau flows are generally low at this time (Figure 3-2). In some years, both pre-WUP (e.g., 2006) and post-WUP (e.g., 2008 and 2011) water levels have been reduced to below the minimum flow target at DRL in April (Figure 3-2). Discharge from DDM is then typically reduced to near the minimum mean daily flow of 3 m^3/s below DDM in May or early June as flows from the Lardeau increase due to spring freshet (Figure 3-2).

3.3.1.2 Water Temperature

In each of the past four years, water temperature in the tailout and the lower reach of the Lardeau River has exceeded 5°C at the beginning of April (Figure 3-3). In contrast, water temperature in the upper Lardeau at Gerrard has not exceeded 5°C until the beginning of May.

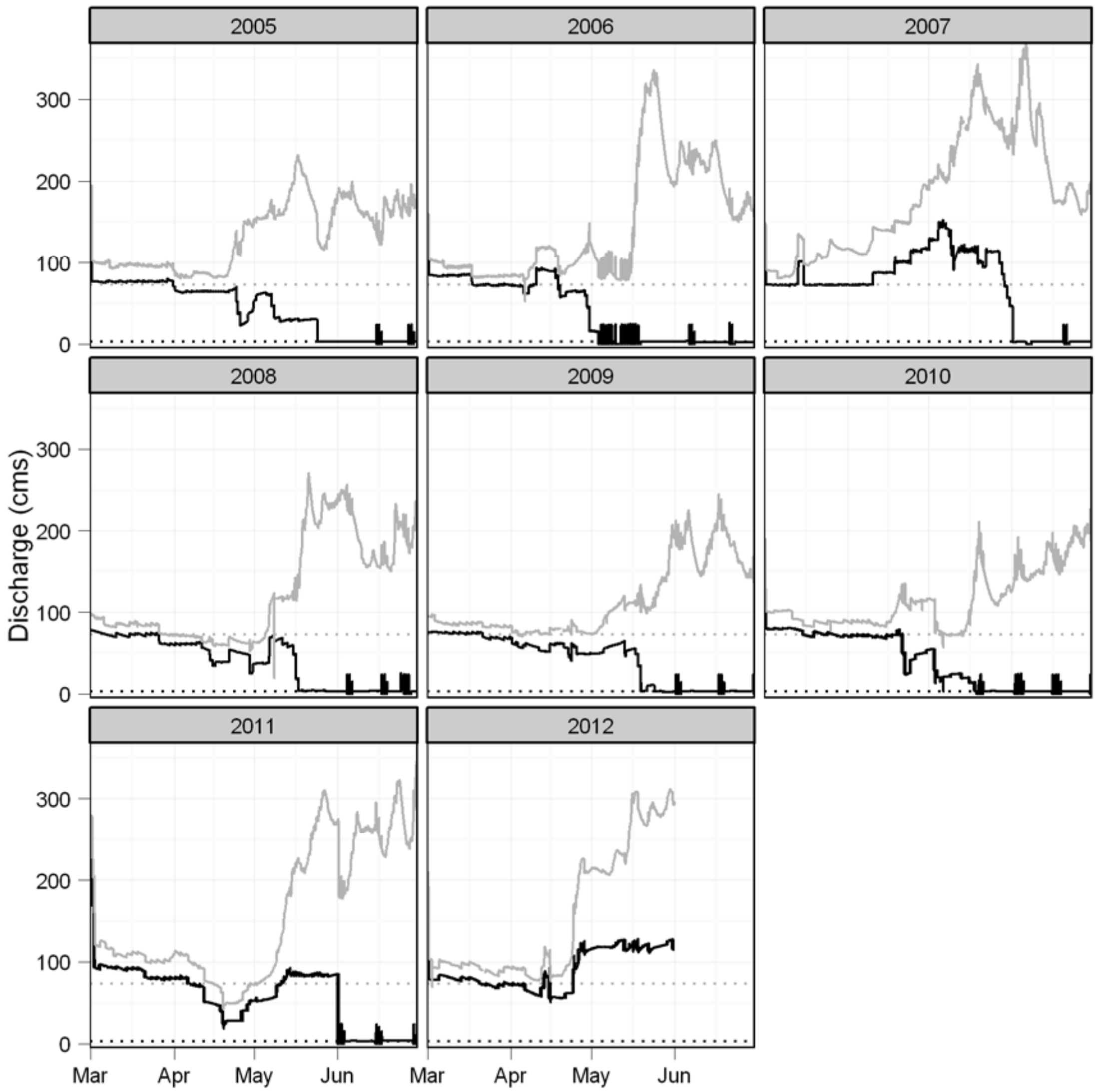


Figure 3-2: ***Hourly discharge from DDM (black) and at DRL (grey) during the rainbow trout spawning and incubation period, 2005 to 2012. The lower dotted line indicates the target minimum mean daily discharge of 3 m^3/s from DDM; the upper dotted line indicates the target minimum discharge of 73 m^3/s at DRL.***

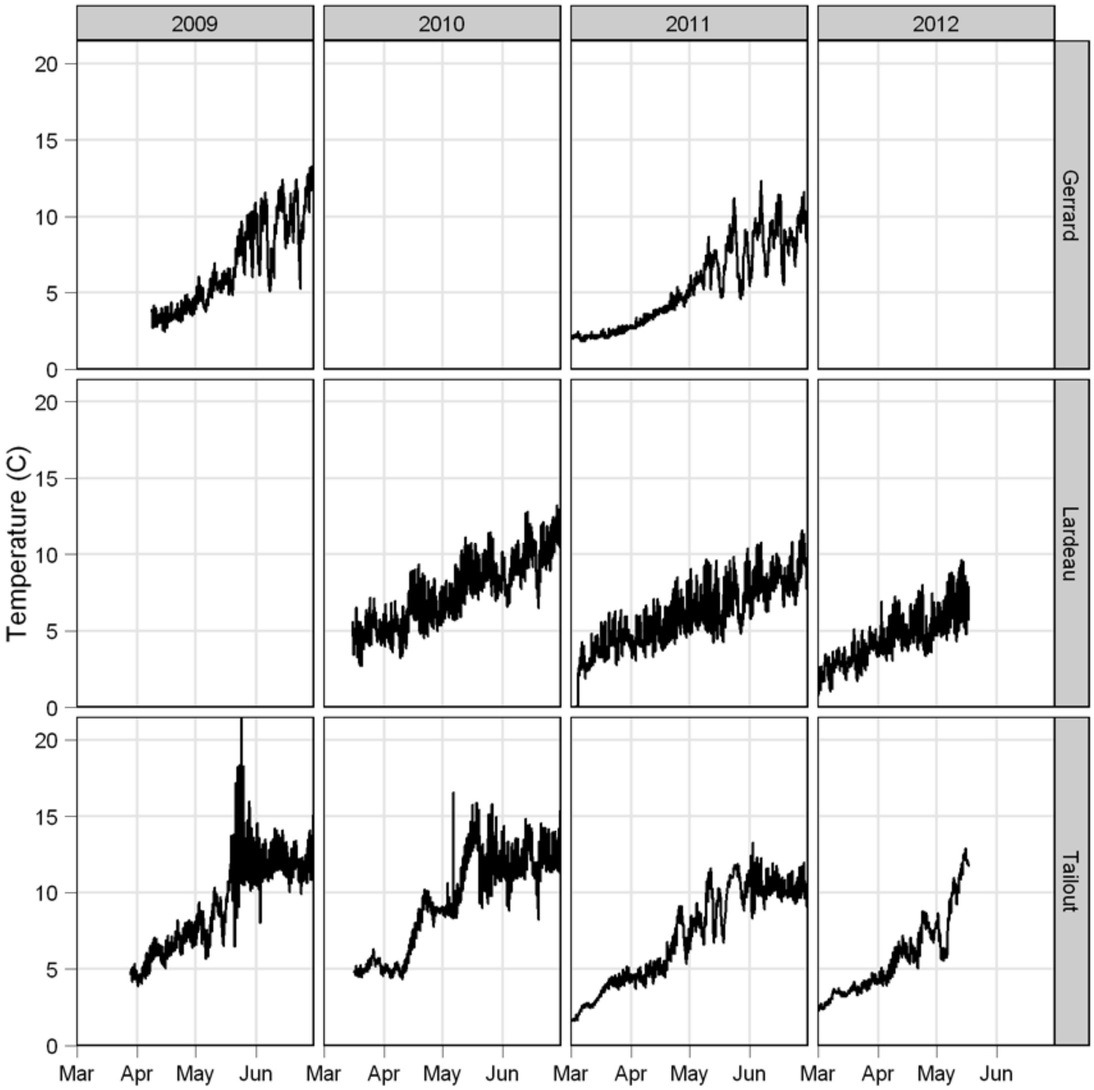


Figure 3-3: Hourly water temperature in the tailout area, mouth of the Lardeau River and at Gerrard during the rainbow trout spawning and incubation period, 2009 to 2012.

3.3.1.3 River Stage

The model predicted that a river stage elevation of 1.5 m (544.06 m ASL) can be produced by just over 100 m^3/s from Duncan Dam or approximately 200 m^3/s from the Lardeau River (Figure 3-4).

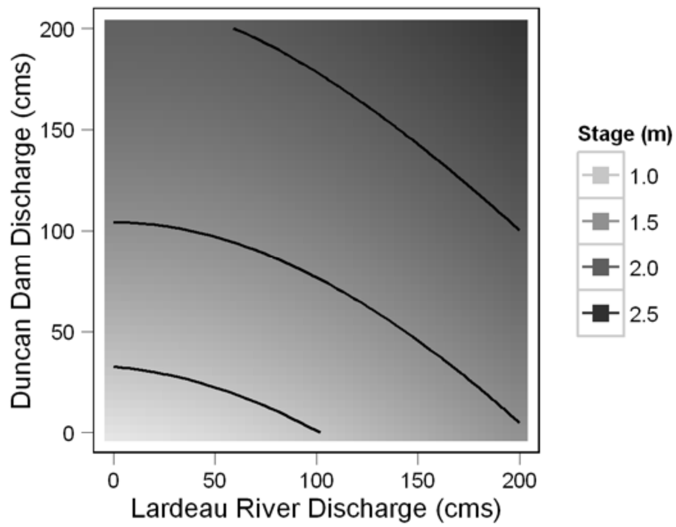


Figure 3-4: Predicted stage height (m) in the tailout area by discharge from DDM and the Lardeau River. Stage height is indicated by shading with contour lines at 1.0, 1.5, and 2.0 m.

3.3.1.4 Turbidity

Turbidity at the tailout area was lowest on April 3 (2.8 NTU) and was highest on April 24 (27.0 NTU) during the 2012 spawning period (Table 3-2). Thorley et al. (2011) estimated the relationship between turbidity and secchi depth in the tailout area to be described by a power law relationship of the form: Turbidity = 2.34 * Secchi$^{-0.65}$.

Table 3-2: Turbidity spot measurements and secchi depth readings in the tailout area, 2012.

Date	Turbidity (NTUs)	Secci Depth (m)
April 3	2.8	2.0
April 10	3.0	2.0
April 18	2.7	1.4
April 24	27.0	0.2
April 30	5.4	0.6
May 8	6.8	1.2
May 16	10.5	0.3
May 23	4.5	1.0
June 13	3.5	1.4

3.3.2 Rainbow Trout Spawners

3.3.2.1 Redd Surveys and Abundance

The location and timing of established rainbow trout redds observed in the tailout area during surveys conducted in 2011 and 2012 are mapped in Figures 3-7 and 3-8. In 2012, redd surveys in the tailout area began on March 19 and were conducted on a weekly basis until June 13. Surveys conducted on April 24, April 30 and May 16 could not be completed due to very poor water clarity (Figure 3-5).

Total redd counts as estimated by the rainbow trout spawn timing model indicated that spawning activity in the tailout area remained relatively constant between 2005 and 2010 but more than doubled in 2011 before halving in 2012 (Figure 3-6). In contrast, spawner abundance estimated at Gerrard, which are based on an expansion factor of 3.08, have increased every year since 2005 (Figure 3-6).

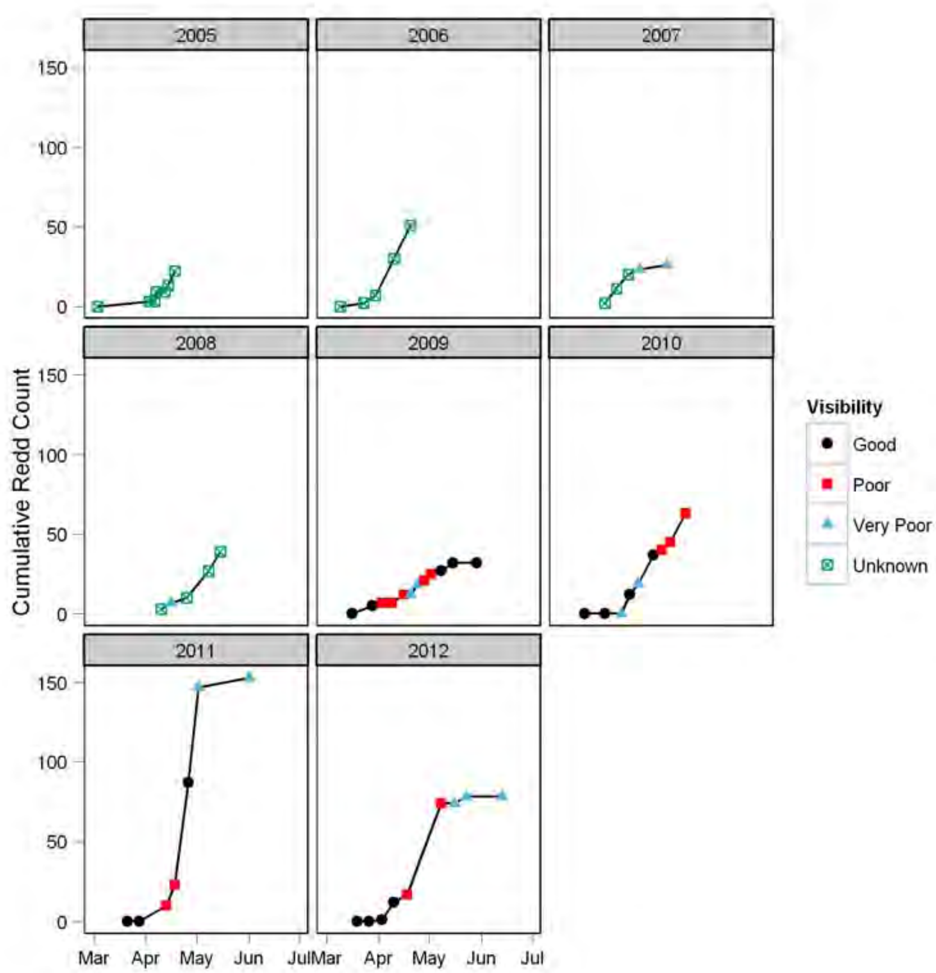


Figure 3-5: Cumulative rainbow trout redd counts in the tailout area, 2005 to 2012. Visibility was classified as Good (≥2 m), Poor (1-2 m) or Very Poor (<1m) based on the Secchi Depth.

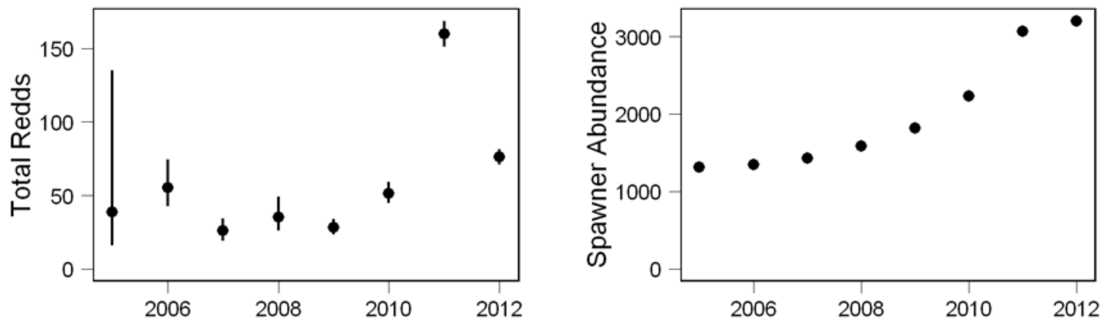
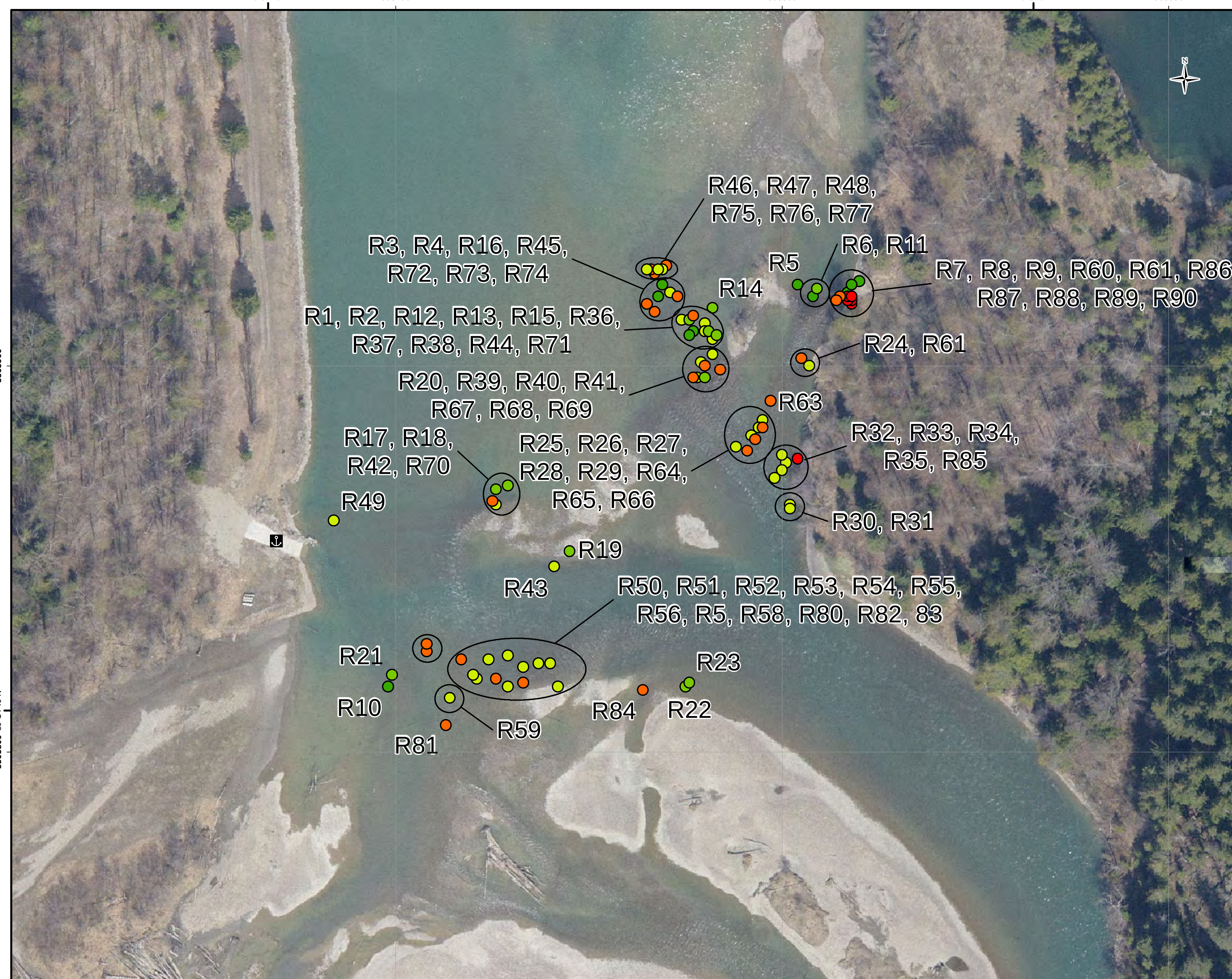


Figure 3-6: Estimated total cumulative redd counts (with 95% credibility intervals) in the tailout area (left) and spawner abundance at Gerrard (right), 2005 to 2012.



Legend

Rainbow Trout Redd and Enumeration Date
- 13/04/2011
- 18/04/2011
- 26/04/2011
- 02/05/2011
- 01/06/2011

Boat Launch

Scale:1:1,000

20 10 0 20 40

Metres

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Rainbow Trout Redd, Piezometer,
Temperature Logger: Mountain Water Research

Disclaimer

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PROJECT: DDMMON-2 Lower Duncan River Habitat Use Monitoring

Positions and Timing (Represented by Colour) of Rainbow Trout Redds in the Tailout Area, 2011

JOB No: VE51873.2011.337	COMPILATION DATE: 2012/06/14	**Figure 3-7**
GIS FILE: redd_location_2011_v2.mxd	REVISION DATE: 2012/09/05	
PDF FILE: redd_location_2011_v2.pdf	PRINTING DATE: 2012/09/05	

PROJECTION:	DATUM:	ANALYST:	QA/QC:	REQ:
UTM Zone 11	NAD83	KS	JB	JB

amec

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Legend

Rainbow Trout Redd and Enumeration Date

- 4/3/2012
- 4/10/2012
- 4/18/2012
- 5/8/2012
- 5/23/2012

Boat Launch

Scale:1:1,500

20 10 0 20 40

Metres

Reference

Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Rainbow Trout Redd, Piezometer,
Temperature Logger: Mountain Water Research

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Positions and Timing (Represented by Colour) of Rainbow Trout Redds in the Tailout Area, 2012

JOB No: VE51873.2011.337	COMPILATION DATE: 2012/06/14	**Figure 3-8**
GIS FILE: redd_location_2012_v2.mxd	REVISION DATE: 2012/09/05	
PDF FILE: redd_location_2012_v2.pdf	PRINTING DATE: 2012/09/05	
PROJECTION: UTM Zone 11; DATUM: NAD83; ANALYST: KS	QA/QC: JB; REQ: JB	

Y:\GIS\Projects\VE\VE51873_LDR_Hab\Mapping\MXD\Drafts\redd_location_2012_v2.mxd

3.3.2.2 Spawn Timing

The spawn timing model estimated that, depending on the year, redd construction can begin in mid-March and persist until late-May (Figure 3-9). The model's estimates also suggest that in the post-WUP period (2008 onwards) spawning has occurred approximately one to two weeks later than in the pre-WUP period (2005-2007). This pre- versus post-WUP difference in spawn timing does not however appear to be due to a difference in discharge (Figure 3-2) or temperature (Figure 3-10) although the timing of spawning in the post-WUP period does appear to be drive by temperature (Figure 3-10).

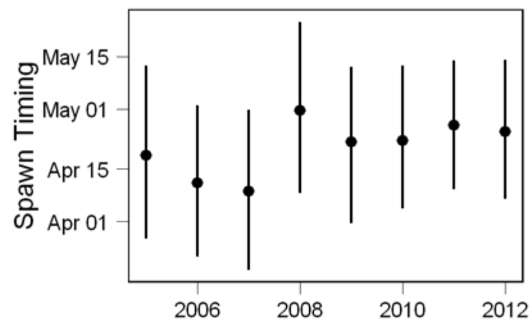

Figure 3-9: Spawn timing estimates (with 95% credibility intervals) for the tailout area, 2005 to 2012.

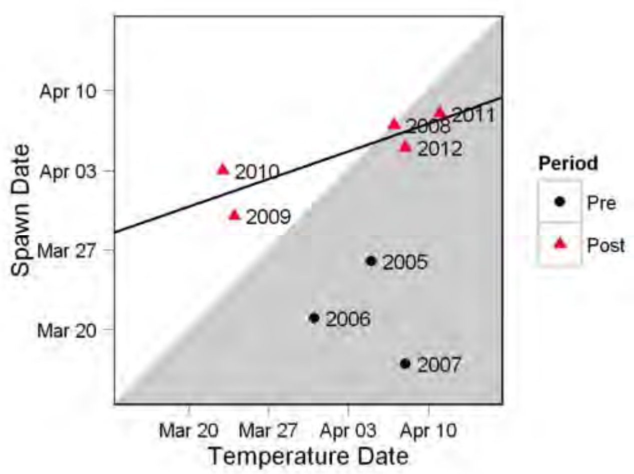

Figure 3-10: Scatterplot of the date when the mean weekly water temperature at DRL first exceeded 5°C (Temperature Date) versus the estimated spawn timing lower 95% credibility limit (Spawn Date). The solid black line indicates the estimated relationship between Spawn Date and Temperature Date for the Post-WUP period. The grey triangle indicates the data points for which the Spawn Date was earlier than the Temperature Date.

3.3.2.3 Emergence Timing

It was estimated that rainbow trout embryos emerged below Duncan Dam from late May until the end of June (Figure 3-10). In contrast, emergence timing estimated for Gerrard occurred from late June until the middle of July (Figure 3-10). The later emergence timing at Gerrard is due partly to the assumption of a two week delay in spawning but also cooler water temperatures at the outflow of Trout Lake.

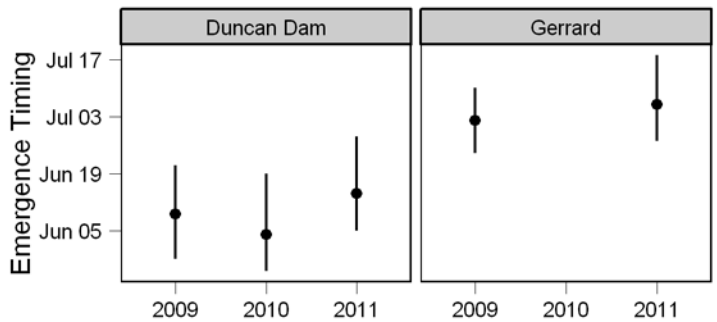

Figure 3-11: Emergence timing estimates (with 95% credibility intervals) for the tailout area and Gerrard, 2009 to 2012.

3.3.2.4 Spawner Movements

The detections of 28 acoustically tagged rainbow trout in the Duncan-Lardeau system suggest that fish moved to the North end of Kootenay Lake in March and then entered the Lardeau-Duncan system in April (Figure 3-11). Approximately half of the fish were detected below Duncan Dam within a few days of leaving the lake, where they remained for less than an hour to more than 10 days. Fish were detected at Gerrard from mid-April until the end of May. However, it is important to be aware that the following apply to Figure 3-11:

- a receiver was not deployed below Duncan Dam in 2009;
- the receiver below Duncan Dam malfunctioned just after the middle of April 2010;
- receivers at Gerrard were pulled just after the middle of May 2010; and,
- detections at the Gerrard receiver were not available for 2012 at the time of writing of this report.

When interpreting Figure 3-11 it is also important to note that fish were considered to be resident at a location (as indicated by the lines between points) until either more than 24 hours passed without a detection or they were detected at a different location.

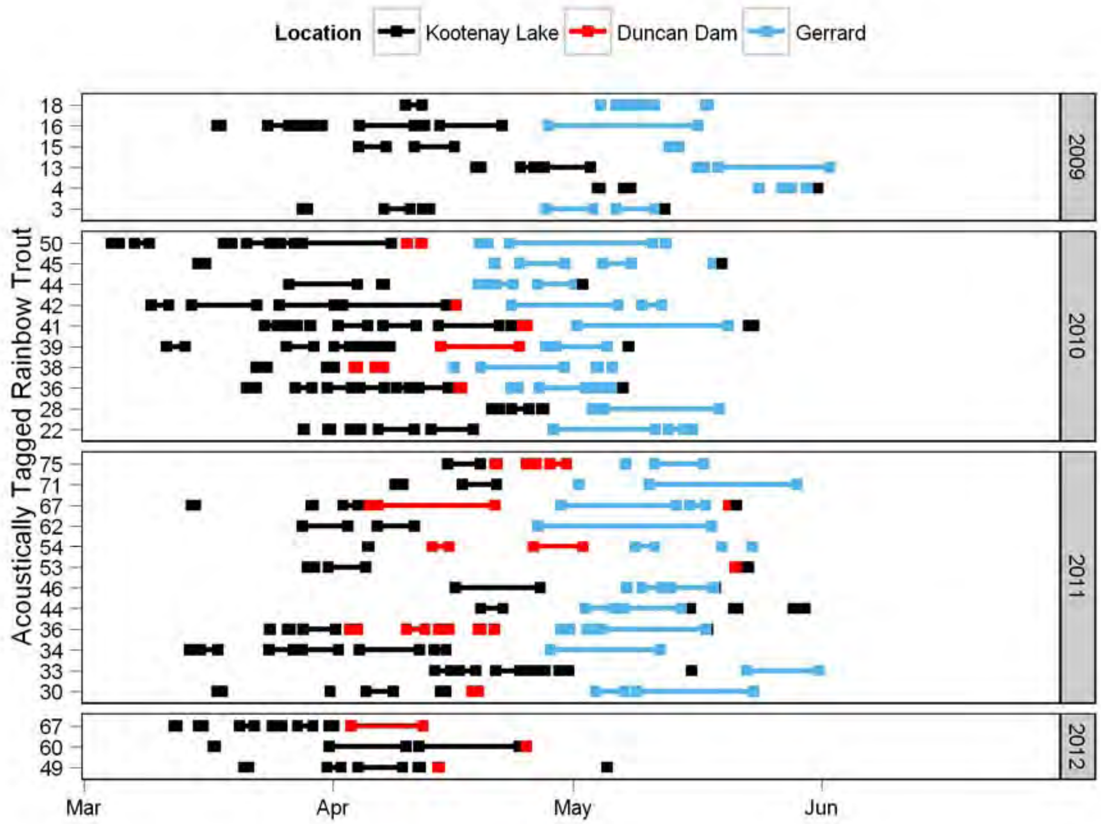

Figure 3-12: ***Detections of acoustically tagged rainbow trout at the North end of Kootenay Lake, below Duncan Dam and in the Lardeau River at Gerrard, 2009 to 2012. The points indicate the timing of arrivals and departures while the lines indicate the periods during which fish were considered to be resident at the location.***

Rainbow trout detected by the receivers were between 535 and 735 mm fork length and 4 and 7 years of age at the time of tagging (Table 3-3).

Table 3-3: Acoustically tagged rainbow trout detected in the Duncan-Lardeau system during the rainbow trout spawning period, 2009-2012 (Andrusak and Thorley 2012).

Fish	Date Tagged	Length	Age	Sex
3	2008-05-19	593	5	-
4	2008-05-19	535	5	-
13	2008-05-30	720	7	-
15	2008-06-01	695	7	-
16	2008-06-01	635	6	-
18	2008-06-09	600	6	-
22	2009-05-02	621	5	-
28	2009-05-06	712	6	-
30	2009-05-06	615	5	-
33	2009-05-21	598	6	-
34	2009-05-21	559	-	-
36	2009-05-22	617	5	-
38	2009-05-26	660	6	-
39	2009-05-27	731	7	-
41	2009-05-27	709	7	-
42	2009-05-27	735	5	-
44	2009-10-22	705	7	-
45	2009-10-23	713	-	-
46	2009-10-23	650	5	-
49	2009-11-19	597	6	-
50	2009-11-19	732	6	-
53	2010-04-07	665	7	Male
54	2010-04-15	666	5	Male
60	2010-04-27	559	4	Female
62	2010-05-03	639	-	Female
67	2010-05-17	702	6	Male
71	2010-05-20	678	6	Male
75	2010-05-27	735	7	Female

3.3.2.5 Habitat Use

Habitat use curves developed for RB in the tailout area indicate that freshly encountered redds were at depths between 0.25 and 0.75 m and velocities between 0.3 and 0.8 m/s (Figure 3-12).

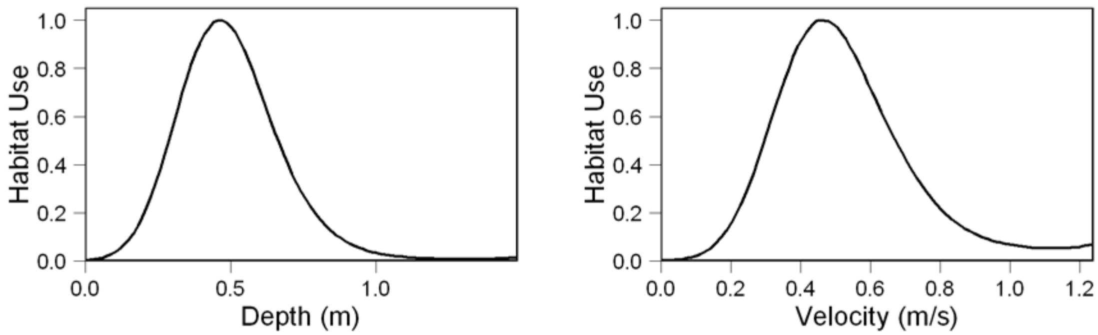

Figure 3-13: Rainbow trout spawning depth and velocity habitat use curves as estimated by the Bayesian habitat use model.

3.3.2.6 Redd Dewatering

Three flow reduction events were observed during rainbow trout spawning assessments:

i) May 6, 2010 - discharge from DDM was reduced to 3 m^3/s for three hours;

ii) April 19, 2011 - discharge from DDM was reduced to 19 m^3/s for four hours; and,

iii) June 1, 2011 - discharge from DDM was reduced to 0 m^3/s for 23 hours.

The first two flow reductions caused redd dewatering because discharge from the Lardeau River was insufficient to inundate the spawning gravels at that time. During the May 6, 2010 reduction, 26 redds (approximately 65% of those present at the time) required irrigation with one of the 26 redds being salvaged (Baxter 2010). During the April 19, 2011 reduction two redds (approximately 9% of those present at the time) dewatered and both were salvaged although only one contained eggs (Thorley and Baxter 2011).

The model predicted that a redd was dewatered if the estimated stage height dropped below the redd's calculated relative elevation after the redd's first encounter date (Figure 3-13). Although the stage-discharge model correctly identified the two known redd dewatering events, it estimated that just two redds were dewatered during the May 6, 2010 flow reduction, which is substantially less than 26 observed. For the April 19, 2011 event, the model estimated that one redd was dewatered, which is comparable to the two observed.

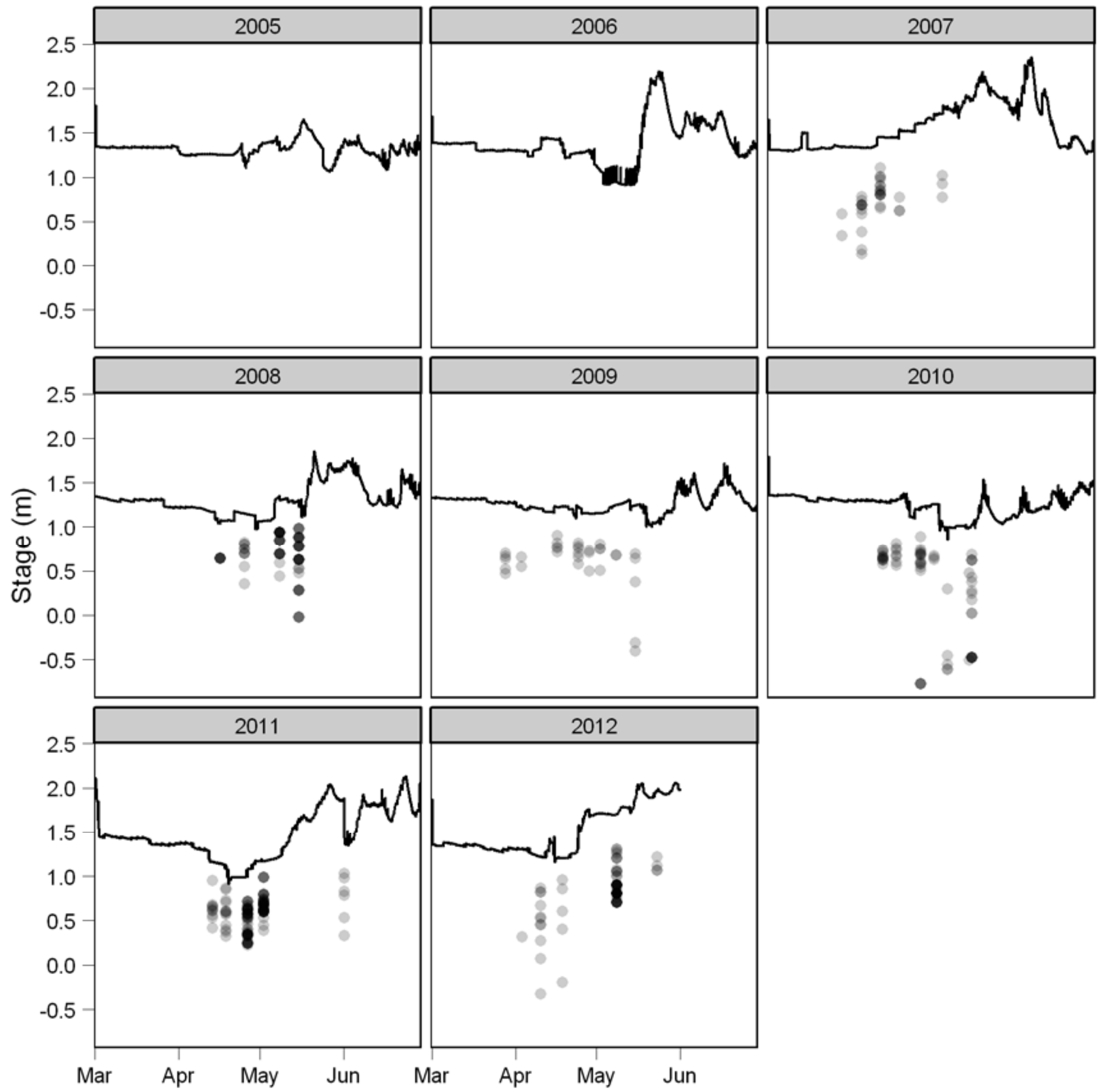

Figure 3-14: Predicted stage height in the tailout area and relative elevations of the observed redds by year and date of first encounter. Multiple redds are indicated by darker points, 2005 to 2012. Redd depths were not recorded in 2005 and 2006.

3.4 Discussion

The following discussion is structured in terms of the three management questions and their sub-questions followed by considerations for future water management planning and operations in the LDR.

3.4.1 Management Question 1

The first management question asks for the typical life history timing, frequency distribution (abundance) and relevant environmental cues for rainbow trout spawners using the Duncan River mainstem and side channels.

3.4.1.1 Life history timing

Taken together the current results indicate that rainbow trout spawners stage at the top of Kootenay Lake in March/April and approximately 50% of the individuals entering the Duncan-Lardeau system are detected below Duncan Dam from mid-March to mid-April. Most individuals are also detected at Gerrard from mid-April until the end of May. The embryos deposited below Duncan Dam were estimated to emerge from the end of May to the end of June, while those at Gerrard were estimated to emerge from late June until the middle of July.

3.4.1.2 Frequency Distribution (Abundance)

Cumulative redd count and spawn timing results suggest that during the past eight years between 26 and 160 redds have been annually constructed in the tailout area. In contrast, annual spawner abundance at Gerrard was between 1,200 and 3,000 fish during the same period. If it is assumed that 50% of the fish at Gerrard are females and each female constructs two redds then over the past eight years spawning activity in the tailout area as a percentage of that at Gerrard has ranged from 1.6% in 2009 to 5.2% in 2011.

The fact that most fish that are detected in the tailout area are later detected at Gerrard strongly suggests that rainbow trout spawning in the Duncan-Lardeau system constitutes a single genetic population. Additional support for this conclusion is provided by a DNA analysis, which found no genetic differences between juveniles from the LDR versus the Lardeau River (Hagen and Decker 2006).

3.4.1.3 Environmental Cues

In his review of the reproductive biology of rainbow trout spawning at Gerrard, Hartman (1969) stated that: “Fish appear to move onto spawning areas when temperatures reach about 5°C and the water level first begins to rise.” Further support for the importance of water in excess of 5°C is provided by the current study: during the post-WUP period the estimated date of the commencement of spawning was correlated (R^2: 0.75) with the date on which the mean weekly water temperature at DRL exceeded 5°C with the former occurring soon after or just before the latter. Why the pre-WUP spawn timing was estimated to be one to two weeks earlier than in the post-WUP period is unclear as there were no obvious differences in temperature or discharge. One possible explanation is that the data for the first three years of the study are unreliable as they were collected opportunistically by inconsistent crews and did not continue throughout the spawning period. The importance of water temperature as an environmental cue would also explain why spawning is delayed at Gerrard; the 2009 and 2011 water temperatures at the outflow of Trout Lake did not reach 5°C until May.

Although there is good support for the importance of temperature as an environmental cue, there is no obvious relationship between discharge and spawner movements or spawn timing. In fact discharge from Duncan Dam typically declined early in the spawning period while the Lardeau River flows did not increase to compensate for the lowered discharge at DDM until the second half of April. Nonetheless it should be noted that while the discharge does not appear to influence the spawning timing, it may influence the amount of spawning activity as discussed in Section 3.6.

3.4.2 Management Question 2

The second management question is concerned with the habitats and habitat preferences associated with the rainbow trout spawning period.

3.4.2.1 Habitats

Rainbow trout spawners seem to specifically target the tailout area for reasons beyond suitable depths and velocities and the presence of appropriate spawning substrate. For example, in 2009 the Lower Duncan River was surveyed for gravel and cobble sites with suitable depths and velocities for rainbow trout spawning (Thorley et al. 2010). Although 17 sites were identified as suitable and surveyed on multiple occasions during the 2009 and 2010 spawning periods the only spawning activity recorded outside of the tailout area was two redds in side channel 4.1R on May 14, 2010 (Thorley et al. 2011). Consequently, surveys in areas of the LDR other than the tailout area were discontinued from 2011 onwards.

Interestingly, from early to mid-April water temperature in the LDR (from DDM to below the confluence of the Lardeau River) and lower Lardeau River do not differ, which also suggests that spawners are targeting the tailout area for reasons other than temperature. A possible explanation is that spawning in the tailout area represents a residual ancestral behaviour – that prior to the construction of Duncan Dam, rainbow trout were selected to spawn in the area of gravels with relatively stable discharge at the outflow of Duncan Lake. If this explanation is correct then it suggests that fish spawning in the outflow of historical Duncan Lake did not represent a genetically distinct population, otherwise the behavior would have been lost when the run ceased.

3.4.2.2 Habitat Preferences

The majority of rainbow trout in the tailout area spawned at depths between 0.25 and 0.75 m and mean column water velocities between 0.3 and 0.8 m/s. As depth and velocity was not measured at the exact time of redd construction, but when each redd was first encountered, it is possible that the measured values are not completely representative of the actual conditions selected by female rainbow trout. However, any differences are likely to be small due to the frequency of the redd surveys, the relatively stability of DDM discharge levels and the fact that only the depths and velocities of recently constructed (i.e., fresh or clear redds) were included in the analyses. In addition, habitat use results are consistent with previous studies on the Duncan-Lardeau system (Hartman and Galbraith 1970, Thorley and Bowers 2006, Thorley 2006, Baxter 2008).

If it is assumed that all habitats were equally available, the habitat use curves can be directly interpreted as habitat suitability curves (Thorley et al. 2011). Although this is considered to be reasonable for the velocity habitat use curve, in the case of the depth curve the decline in habitat use with water deeper than 0.5 m may have been due to the relatively poor visibility in the tailout area from peak spawning onwards. Deep water spawning has been documented on the Lower Columbia (Baxter and Thorley 2010) and Colorado Rivers (Korman 2009).

In April 2011, an exceptionally late freshet resulted in a reduction of DDM discharge to approximately 27 m^3/s for one week, while discharge in the Lardeau River was still low. During this period, a large number of widely distributed redds were observed in the tailout area. Although the high counts were partly due to increased visibility of previously deep water redds the lower discharge likely also stimulated spawning through an increase in the area of suitable habitat.

3.4.3 Management Question 3

The third management question is concerned with minimizing redd dewatering through changes to operations within the constraints of the DDM WUP. In addition, the complementary monitoring programs sub-objectives included: 1) the development of a long-term annual index of abundance; 2) an assessment of the risk of redd dewatering as well as 3) the development of a redd mitigation strategy.

3.4.3.1 Redd Dewatering Monitoring

Although the Bayesian stage-discharge model correctly identified the two known redd dewatering events it dramatically underestimated the drop in river stage during the first event on May 6, 2010. This result indicates that the model is currently unable to accurately predict stage during very low discharge from both Duncan Dam and the Lardeau River. As additional data accumulates during low discharge periods the model’s predictions should improve. We are hopeful that the stage information provided by the DCP, when combined with redd depths to get relative redd elevations, will be able to provide a reliable tool for predicting and monitoring redd dewatering.

3.4.3.2 Redd Dewatering Mitigation

During the past two redd dewatering events, the field crew demonstrated the feasibility of irrigating and excavating dewatered redds (Baxter 2010) although the mortality of excavated eggs that were monitored as part of the egg survival study was high (Thorley and Baxter 2011). Due to the small sample size (175 eggs from a single redd) and lack of a control it is currently uncertain whether the 100% mortality was related to the source redd or handling or whether eggs suffer high mortality in the tailout area irrespective of whether they remain wetted. Until this uncertainty is resolved it is unclear whether it is possible to mitigate for redd dewatering without changes to DDM operations.

3.4.3.3 Egg Survival

In a typical year, as the discharge from the Lardeau River begins to increase and inundate the tailout area, the discharge from DDM is reduced to the minimum mean daily operating requirement of 3 m^3/s. As a result the water velocity over the redds drops to close to 0 m/s which likely results in reduced delivery of dissolved oxygen (DO) to the developing embryos (Arntzen et al. 2006). In addition fine sediment intrusion from the suspended solids (Watts 2010, Moffat 2011), which can clog embryo membranes and reduce hyporheic flow (Greig et al. 2005) and episodes of high water temperatures (Figure 3-3) may further lower DO concentrations in the egg pocket. The source of the suspended solids is uncertain although Moffat (2011) concluded that the data suggest that there is no relationship associated with turbidity and reservoir stage. The high water temperatures are suspected to occur when very low discharge from DDM combined with high discharge from the Lardeau River causes the tailout area to become a backwater (Arscott et al. 2001) that is susceptible to solar and/or conductive heating. The results of the preliminary assessment of egg survival suggest that embryo mortality in the tailout can be extremely high although this result should not be considered definitive due to the limited sample size and the absence of a control (Thorley and Baxter 2011).

3.4.3.4 Annual Abundance Index

Eight years of redd counts, the correct identification of which has been confirmed by excavations, has demonstrated the feasibility of the approach while also highlighting its limitations. In particular, the frequent occurrence of poor viewing conditions (Table 3-2 and Figure 3-5) means that the count may adequately represent an index of shallow water spawning activity in the tailout area, but likely does not capture spawning use of deeper water areas (e.g., > 0.5 m) as effectively.

3.5 Recommendations for Future Research

In order to inform Duncan Dam operations it is recommended that future research programs further refine the stage-discharge model so that it better predicts the magnitude of dewatering, especially at low discharge levels from DDM and the Lardeau River (i.e., below 40 and 100 m^3/s, respectively). It is also recommended that future research programs estimate egg survival under the current operating regime. In particular it may be possible to distinguish between little to no egg survival versus at least partial egg survival by estimating fry densities in the LDR prior to the emergence of fry in the Lardeau River.

3.6 Considerations for Future Water Management Planning and Operations in the Lower Duncan River

As the fish spawning in the tailout area do not appear to be genetically distinct from those in the rest of the system, it may not be important from a population-level perspective whether or not fish spawn in the tailout area provided both the Lardeau River and LDR are fully repopulated by fry each year (Acara 1969). However, managing DDM operations to maximize the number of large rainbow trout spawning in the tailout could reduce the risk of recruitment failure by both extending the emergence period and increasing the number of spawning locations.

In the spring of 2011, discharge from DDM was reduced to approximately 27 m^3/s for a week in mid- to late April pre-freshet. The drop not only revealed the presence of deeper redds, but may also have stimulated spawning in previously unused areas. This result tentatively suggests that when the discharge in the Lardeau River is low (e.g., around 25 m^3/s), DDM discharge level of approximately 27 m^3/s increases the amount of suitable spawning habitat relative to dam discharge levels in excess of 50 m^3/s. It may therefore be possible to increase spawning activity in the tailout area by holding discharge levels at low levels during the pre-freshet period although additional flow manipulations are required to determine optimal levels.

4.0 MOUNTAIN WHITEFISH SPAWNING

4.1 Introduction

Mountain whitefish (*Prosopium williamsoni*) is a sportfish species of the family Salmonidae, subfamily Coregoninae that is widely distributed throughout western North America and with a native population in the Lower Duncan River (LDR). Mountain whitefish (MW) is one of six species of the genus found in North America and the LDR population provides a winter recreational fishery opportunity in the LDR. MW may be an important forage fish for piscivorous species such as bull trout (*Salvelinus confluentus*) and Gerrard rainbow trout (*Oncorhynchus mykiss*) as well as being an integral part of the aquatic ecosystem of the LDR.

Mountain whitefish in the LDR had not been extensively studied prior to the WLR study period (Vonk 2001) and substantive data gaps in the information about this population of fish were identified by the consultative committee (CC) for the DDM WUP (BC Hydro 2005). The CC report noted that there was insufficient information on life history timing for MW spawners to capture inter-annual variation adequately.

The management questions of WLR study DDMMON-2 as they pertained to adult mountain whitefish (Section 1) were focused on delineating spawn timing, frequency distribution, environmental cues for spawning, and habitat use by the spawning adults. The collection of mountain whitefish life history and environmental data was to inform operations of DDM within the WUP's constraints to minimize operational impacts on the MW spawning and incubation in order to address the third management question. The 2011/2012 field season was the second and final field season for assessing the spawn timing and habitat use of adult mountain whitefish in the LDR in relation to DDM operations under WLR study DDMMON-2.

4.2 Methods

4.2.1 Study Area

The study area encompassed the approximately 12.5 km section of the lower Duncan River from Duncan Dam to its confluence with Kootenay Lake. Further information on the LDR is provided in the DDMMON-2 study needs document (Porto et al. 2009) and the MW addendum to that document (Irvine and Porto 2010). Only the mainstem of the LDR was investigated in relation to MW spawning according to the scope defined in the Terms of Reference for this program. The upper 4 km of the LDR were the main focus of the field program due to the navigational hazard at Km 4.1 that made the river impassable at lowered flows or at night (Figure 1-2). The log jam at this point in the river has been passable in previous years, but additional material and compaction has made the only possible passage through a shallow side channel on river right that was not passable at lower flows or in deeper draft boats. Access below the log jam is logistically difficult since the nearest boat launch is located near the town of Lardeau along Kootenay Lake, which is approximately 5 km downstream of the LDR confluence; this is not useable during winter months due to water levels and snow issues.

4.2.2 Study Timing

Based on historical data and the methods utilised, field study timing was arranged to run from September to the end of December to capture the extent of mountain whitefish spawning and to obtain pre-spawning biometric information. In the 2010/2011 field season, multiple methods were used to assess the adult mountain whitefish population in order to determine which methods worked best for this species in this river system (Thorley et al. 2011a). In 2011/2012, the focus was narrowed based on the first year's findings. The methods employed were night spotlighting, habitat use measurements and angling or electrofishing to capture fish for gonado-somatic index calculation to determine spawn timing. A summary of methods used during the 2011/2012 field season and sample timing is provided in Table 4-1. Further details are provided below.

Table 4-1: Observation and survey methods used for the adult mountain whitefish spawning study program and dates of survey, 2011/2012

Date	Methods
March 31, 2011	Angling for baseline data
September 2, 2011	Boat electrofishing, angling, daytime observations
October 14, 2011	Angling, daytime observation, night spotlighting, habitat use measurements
October 27, 2011	Angling, daytime observation, night spotlighting, habitat use measurements
November 7, 2011	Angling, daytime observation, night spotlighting, habitat use measurements
November 15, 2011	Angling, daytime observation, night spotlighting, habitat use measurements, boat electrofishing
November 21, 2011	Angling, daytime observation, night spotlighting, habitat use measurements, boat electrofishing
November 29, 2011	Angling, daytime observation, night spotlighting, habitat use measurements
December 5, 2011	Angling, daytime observation, night spotlighting, habitat use measurements
December 12, 2011	Boat electrofishing, daytime observations

4.2.3 Environmental Parameters

In order to address the management questions outlined for this program (Section 1) information was collected on discharge, river stage, and water temperature. Details on each parameter are provided below.

4.2.3.1 Discharge

See Section 2.1.3.1.

4.2.3.2 River Stage

River stage was recorded hourly at the WSC gauge at DRL. This was the only consistent and long term measure of stage throughout the LDR and will be used as the primary data source for further discussion related to river stage. The gauge at Duncan Above Lardeau (DAL) was primarily installed for stage recording in the key Gerrard Rainbow Trout spawning area and was not considered as relevant to mountain whitefish, since no spawning aggregations of MW have been observed in this area over the past two years.

4.2.3.3 Water Temperature

Data from temperature loggers placed for the duration of DDMMON-7 at 2.4R and S2.7L as well as a logger at 7.0L were plotted for the spawning and incubation season for MW (October 15 to May 30) for 2010/2011 and 2011/2012 to assess water temperatures experienced by MW in the LDR. Data from the logger at 7.0L were selected for the analyses because they reflected an intermediate temperature relative to those at 2.4R and S2.7L Further, it was selected because MW have been observed aggregating throughout the spawning season as far downstream as Km 9.0, which suggests they may utilise the entire LDR. The logger at 7.0L allowed the assessment of water temperatures experienced by fish using the middle and downstream reaches. General information on water temperature can also be found in Section 2.1.3.2.

4.2.4 Spawn Timing

Adult mountain whitefish spawn timing was estimated primarily by the use of the Gonado-Somatic Index (GSI) calculated from captured fish. Additional lines of evidence that were used in parallel to the GSI to determine if non-lethal approaches would be effective as well were night spotlighting and life history and daytime observations.

4.2.4.1 Gonado-Somatic Index

GSI was calculated for MW captured during both years of the DDMMON-2 field program. It has been used successfully to refine estimates of spawn timing in a range of species with the basic theory being that gonadal investment increases to a peak just prior to spawning and then drops off rapidly immediately after spawning. Laboratory studies on another coregonid species used GSI to assess monthly gonadal development, while investigating the effects of photoperiod and temperature on gonad maturation (Gillet 1991a). In the analysis of the 2010/2011 data, one year of GSI data gave more precise estimates of spawn timing than 4 years of egg mat data (Thorley et al. 2011). Egg mats can not only capture the eggs that are being released in a current spawning event, but can also capture any drifting eggs that are uplifted from the substrate by changes in flow. Egg staging completed for the eggs captured on mats in the MW study on the lower Columbia River showed that a minimum of 12% of the eggs captured by mats were from the drift (Hildebrand 2011a). Based on this information, the dates of latest spawning from egg mat programs without egg staging may generate biased data that would place the spawn period later than it actually is. The egg mat programs on the Duncan (Baxter 2007a, Thorley et al. 2011a) did not use staging so timing data may be unreliable. Therefore, in the 2011/2012 field season, GSI was selected as the primary method for assessing MW spawn timing and egg mat methods were not used.

GSI is a unitless measure since it divides weight of gonads by total body weight of the fish and is defined as:

*Gonado-Somatic Index (GSI) = (Gonad Weight/Total Corrected Body Weight) * 100*

The spawn timing was estimated from the GSI values using Bayesian analysis (Appendix A). Key assumptions of the analysis included:

1. Spawn timing is normally distributed;
2. Peak spawn timing varies between years;
3. The duration of spawning is constant between years;
4. Individual female fish are spawned out after one event; and,
5. Individual male fish can be partially spent for multiple events as defined by a continuous variable.

Spawn timing was defined by spawn year. For example for 2010 fry would emerge in 2011, but the fish spawned in 2010. All plots reflect this convention.

The general spawn timing window was estimated with a Bayesian model of the GSI data and the peak spawning date was also estimated for each year. The mean or peak spawning date had 95% credibility intervals estimated around the estimated mean values.

4.2.4.2 Spotlighting Surveys

Night spotlighting surveys conducted from a jet boat commenced one hour after sunset and were conducted throughout the spawning season in order to provide: 1) an estimate of relative spawner abundance (i.e., the frequency of individuals distributed through space and time); and, 2) locations of adult mountain whitefish to determine habitat usage by this species and life stage. For the first objective, the assumption was that the number of mountain whitefish observed in night surveys would increase until peak spawning was reached and would then dwindle as MW moved into overwintering habitat out of the mainstem or the LDR. It was seen as a corroborative line of evidence to the GSI method for the estimation of spawn timing. For the second objective the assumption had to be made that fish aggregating were engaging in pre-spawning or spawning behaviour and were making use of the habitat in which they were observed.

Background information indicated that spotlighting surveys may not be effective for counting MW due to their evasive response to lights (Brown 1952, Hildebrand 2010), but for the MW population of the LDR it was an effective method for enumerating relative abundance and locating the habitats in which MW were spawning. The method was tested in 2010/2011 and was the most effective method to locate and observe spawners and their associated habitat use of the methods tested. Mountain whitefish in pre-spawning condition were mildly averse to the spotlights, but oblique angles of spotlighting even at this stage were effective for enumeration. Once the whitefish were engaged in spawning behaviours, they were largely unaffected by spotlighting and would hold position even with direct lighting. Spotlighting surveys were therefore used as the primary method for determining the location and number of adult spawners.

Seven night spotlighting surveys were conducted from October 13 until December 4 (Table 4-1) during the 2011/2012 field season to assess habitat use and relative abundance of MW in the LDR. One index section was selected based on the first year's study. The index site was on river left and was 1 km in length and extended from Km 1.5 to Km 2.5 (Figure 1-2).

This site was selected because during the first study year MW had consistently been observed and eggs had been captured within this section during previous studies (Baxter 2007b). During the initial spotlighting survey, the boundaries of the index site were marked with flagging tape to ensure consistency in subsequent surveys. In addition to the index site, which was completed each night of sampling, other randomly selected sites were surveyed until spotlight battery life was exhausted. Initially, the study design called for sites throughout the river to be surveyed, but due to the navigational hazard at Km 4.1, the majority of the sites were completed above the log jam. The sites were selected using a stratified random approach where substrate type comprised the stratum and sites within each substrate type were picked randomly.

During each survey, a Garmin 60CSx was set to plot a track and sections of between 500 m and 1.2 km in length or approximately 5 minutes in time were surveyed with three observers. The boat followed an upstream zig zag pattern out to the thalweg and back to the bank. Fish were observed from the bow, stern and starboard of the vessel and communication amongst the three observers prevented double counting fish. Surveys were only conducted with visibility greater than 3m; visibility during winter on the LDR is usually excellent and all planned surveys were conducted. Behaviour was noted as well. Counts were converted to lineal density (fish/km of shoreline sampled) and were mapped to provide an index of relative abundance within the surveyed sections.

The lineal density (fish/km) at the index site was calculated for each of the seven surveys and plotted through time to assess whether the relative abundance of mountain whitefish in a known area of spawning could be used to characterize spawn timing. The lineal density was only calculated for the one bank that was surveyed.

4.2.4.3 Fish Capture, Life History Sampling & Observations

Mountain whitefish were captured using boat electrofishing and angling. The permit process allowed unlimited angling sessions until the maximum collection number of 300 MW was reached, but only four bouts of boat electrofishing were allowed to be conducted on the LDR. The field study therefore attempted to optimize the use of boat electrofishing to obtain data during all phases of the spawn: pre-spawn, peak-spawn and post-spawn.

Angling was conducted in areas where MW aggregations were observed and sites throughout the river were angled during the field season though most angling occurred above the navigational obstruction at Km 4.1. Spin cast and fly rods were baited with live and dead maggots, roe bags, Jensen eggs, and wet flies of several types.

CPUE was calculated for each session and averaged among sessions by capture technique: boat electrofishing (4 sessions) and angling (9 sessions).

In 2010/2011, all fish were retained in order to determine the age at maturity for male and female mountain whitefish and to derive length frequency relationships for adult and immature fish and the GSI for adult MW in the LDR. During the 2011/2012 field season, fish that were estimated to have lengths less than 230 mm were released if in good condition, since no fish less than that length were found to be sexually mature (Thorley et al. 2011) and the focus of the management questions was on adult spawning MW.

Captured fish were immediately euthanized and stored on ice or in a cool environment until dissection. Fish were dissected the afternoon or evening after capture and measured for: total weight; fork length; stomach content weight; and, gonad weight. All length measurements were taken to the nearest millimeter and weight was measured to the nearest tenth of a gram. The corrected weight was calculated by subtracting stomach weight from total fish weight; this was used in the gonado-somatic index (GSI) calculation. All euthanized fish had scales removed (left side of the fish, 3 rows above the lateral line just posterior to the dorsal fin) as described in (Brown 1952) for aging purposes. Scales were sent to Hamaguchi Fish Aging Services (Kamloops, BC) for aging.

The presence or absence of tubercles was carefully noted on all dissected fish to see if these could potentially be used as a non-lethal binomial indicator of spawning readiness and thus estimate spawn timing for future studies. Additional observations were made during both field seasons to provide supplemental information on MW spawning behaviour in the LDR, since there is limited information on this species in the literature (Irvine and Porto 2010). General behavioural and condition characteristics (e.g., spawning colouration and tubercles present) were observed by crew members during sampling. Generally, mountain whitefish were quite cryptic during daylight hours, but daytime observations by consistent observers still provided a general trend as to the stage of the spawning season. Daylight observations were made while angling or boat electrofishing or while moving from site to site on the river.

4.2.5 Emergence Timing

The thermal units needed from fertilization to emergence for various mountain whitefish populations ranges from 365 to 495ºC-days with the majority of fry emerging around 400ºC-days (Brown 1952; Rajagopal 1979; Brinkman and Vieira 2009). The value used historically was 444°C-days as estimated by Rajgopal (1979), but more recent work has demonstrated the high variability in the ATUs required for MW emergence. Lacking LDR specific data on MW incubation timing, the following approach was used. The ATU of 400ºC-days was used to estimate peak emergence and 95% credibility intervals were estimated around the emergence based on 400 ATUs. However, because incubation to emergence could take as long as 495ºC-days or as short a time as 365ºC-days additional credibility intervals were also estimated as if the fish took the shortest or longest possible time to emerge. This was deemed the most conservative estimation method to assess the period of time over which MW may be emerging into the LDR. Mountain whitefish are broadcast spawners, so their eggs experience the river's water temperature more strongly than groundwater temperature.

The GSI data from 2010 and 2011 were first used to derive the mean date of spawn timing and 95% credibility intervals for spawn timing. The point at which 2.5% of the fish had spawned (the lower limit of the 95% credibility interval), the peak spawning date and the point at which 97.5% of the fish had spawned (the upper limit of the 95% credibility interval) were then used to estimate the range of potential emergence timing for the LDR MW. The ATU period of 400°C-days needed for hatch and emergence of mountain whitefish was then used in conjunction with temperature logger information from three locations within the LDR as well as water temperature data from the DRL WSC gauge for the 2010 and 2011 spawn years to provide estimates of the peak emergence timing and 95% credibility intervals. The intervals were then extended for the extreme possibilities of emergence based on the range of ATUs for the species from the literature.

4.2.6 Habitat Use

4.2.6.1 Habitat Use Surveys

Habitat use surveys were conducted each day following a night spotlighting session. During each night spotlighting survey, a uniquely numbered weight was dropped and a GPS waypoint taken in any area where more than 6 mountain whitefish were observed engaging in spawning behaviour. Surveys were completed from October 14 to December 5, 2011 and 90 sites were observed and measurements taken. Due to the size of the eggs and the fact that MW are broadcast spawners and do not prepare redds, it was impossible to say with complete certainty that the MW were spawning, but all indications from movement, groupings, colouration and timing were used as a weight of evidence to characterize the observed MW as spawners. The day after the spotlighting survey, the crew would go to each waypoint, retrieve the weight and record the depth, velocity at the substrate, mean column velocity and dominant substrate at the site, as well as proximity to large woody debris. Definitions of each habitat parameter and measurement methods are briefly outlined below.

Depth

Depth over the sites where multiple mountain whitefish were observed was measured in meters using a Humminbird 997c si GPS sonar unit.

Water Velocity

Velocity (m/s) was measured at each site where aggregations of spawning MW were observed to determine the range of usable velocities for this life stage of MW. Mean column and bottom velocity (15 cm above the substrate) were measured at each site where aggregations of mountain whitefish had been observed. A March-McBirney FloMate 2000 was used to measure water velocity. Velocities were averaged over a 3 second measurement period. Mean column velocity was used for estimating habitat use curves to allow comparability to previous work (e.g., Lewis and Healey 2009) and other species or life stages within this study.

Substrate

Dominant substrate was assessed qualitatively during habitat use surveys in areas where multiple mountain whitefish engaged in spawning behaviour had been observed. Substrate definitions followed those outlined in the Forest Practices Code Fish Stream Identification Manual (Forest Practices Code of British Columbia 1998) where the substrate classes were: 1) fines: clay, silt or sand (≤ 2.0 mm diameter); 2) gravel: > 2.0 to 64.0 mm; 3) cobble: > 64 to 256 mm; 4) boulder: > 256 mm; and, 5) bedrock.

Proximity to Large Woody Debris

Each site where a MW aggregation had been noted was assessed for its proximity to large woody debris (LWD). LWD was defined as any piece of wood with a diameter of greater than 10 cm and LWD was considered to be present and proximal if it was within 2 m of the marked site.

4.2.6.2 Habitat Use Curves

In the 2011/2012 field season, the measurement of habitat used by spawning MW was a priority in order to answer the second management question, which relates to habitat use of spawning adult mountain whitefish (Section 0). Habitat use curves generated as part of DDMMON-3 showed a wide range of habitat types that could be used by spawning MW (Lewis and Healey 2009); the data utilized in that analysis were from the US Fish and Wildlife Service. The literature on MW makes note often of the plasticity of the species so it was important to develop habitat use curves specific to the LDR MW population (Irvine and Porto 2010 and references therein).

Habitat use curves were estimated from the recorded depths and mean column velocities where adult MW were observed with night spotlighting engaging in what was presumed to be spawning behaviour. The curves were estimated using a Bayesian habitat use model (Section 2.1.4 and Appendix A).

4.3 Results

4.3.1 Environmental Parameters

4.3.1.1 Discharge

Hourly discharge levels (mean, minimum, maximum) prior to and after the ordering of the WUP are illustrated in Figure 4-1. The target flow protocol for DRL (Duncan River at Lardeau) as outlined in the DDM WUP has maximum flows of 76 m^3/s from October 1 to October 21 for kokanee protection flows, after which maximum flows increase to 110 m^3/s until December 21 (Figure 4-1). The majority of mountain whitefish spawners experience flow levels of 76-110 m^3/s. Egg incubation will occur throughout the high flow winter period with minimum discharge levels of 73 m^3/s and a typical maximum discharge of 250 m^3/s in the LDR. During the winter period the operating order states that the discharge can go to a maximum of 300 m^3/s at DRL if certain conditions are met with respect to the Columbia River Treaty (T. Oussoren, pers. comm., 2010). Discharge variability during the fall and winter periods is reduced in the post-WUP flows as compared to pre-WUP conditions as evidenced by the grey band in Figure 4-1.

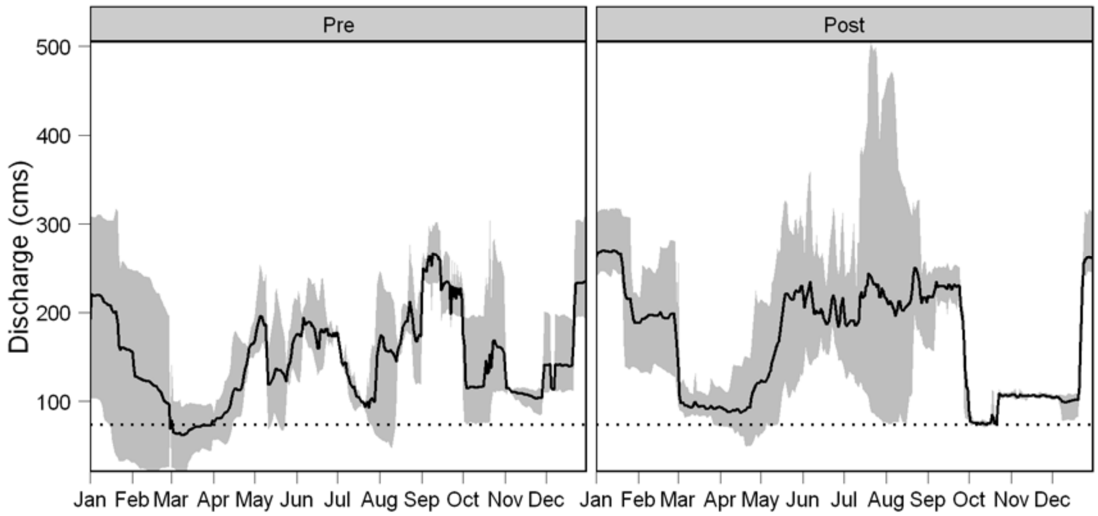

Figure 4-1: Hourly river discharge at the DRL WSC gauge for the pre-WUP period (2003-2005) and the post-WUP period (2008-2012). The grey band indicates the minimum and maximum discharge while the black line is the mean discharge. The dashed line is at the Order Table's minimum discharge level of 73 m^3/s.

4.3.1.2 River Stage

Decreased variability in river stage was observed after the implementation of DDM WUP flows as depicted by the narrower band of grey that indicates minimum and maximum stage levels (Figure 4-2). The incubation period for MW spans from mid-October to early May. During the incubation and hatching period the stage remained steady or increasing until March when it gradually decreased and dropped below the stage it was at during the spawning period. There was a large step change at the end of December when the river stage increased by 0.5-0.8 m and a similar step decrease in late February (Figure 4-2).

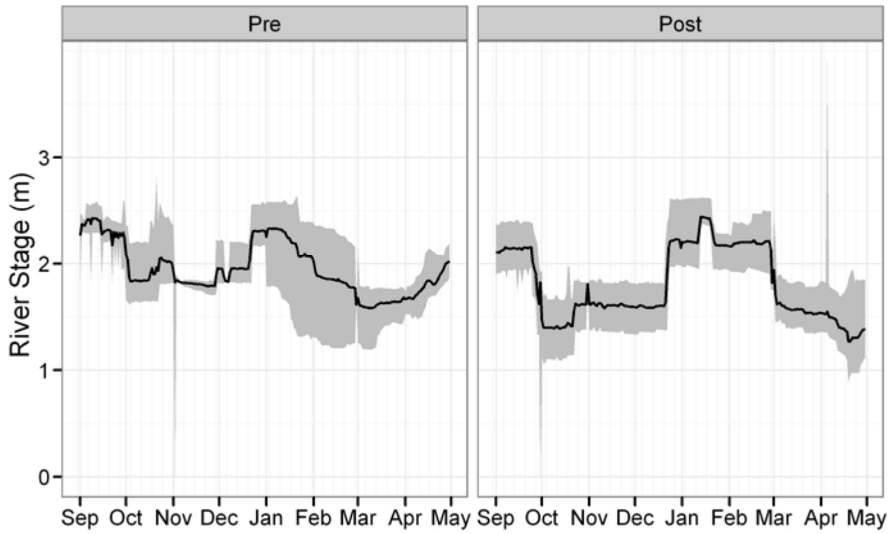

Figure 4-2: Hourly river stage at the DRL WSC gauge during the mountain whitefish spawning and incubation periods for the pre-WUP period (2003-2005) and the post-WUP period (2008-2012). The grey band indicates the minimum and maximum stage while the black line is the mean stage.

4.3.1.3 Water Temperature

Hourly mean, minimum and maximum water temperatures from the WSC gauge during the pre-WUP period and post-WUP flows are shown during the potential spawning and incubation periods in Figure 4-3. Previously, it had been assumed that the increased variability observed in water temperature at DRL was due to changes in operations, but the extensive data analysis in DDMMON-7 (Lawrence et al. 2012) and the presence of other temperature loggers nearby the WSC gauge point to errors in this gauge with unexplained variability and higher temperatures than proximal loggers in recent years (Figure 4-4). Therefore, results focused on water temperatures obtained by the DDMMON-7 instrumentation. The loggers at S2.7L, 2.4R and 7.0L provide a full range of the temperatures that would be experienced by MW spawning in the LDR (Figure 4-5). Water temperatures fell below 10°C by mid-October in both 2010 and 2011 and below 6°C by mid-late-November or early December depending upon year and location within the LDR (Figure 4-5). The right bank of the river cooled sooner (2.4R logger) than the left bank and the mainstem cooled prior to any side channels that were monitored (Figure 4-5).

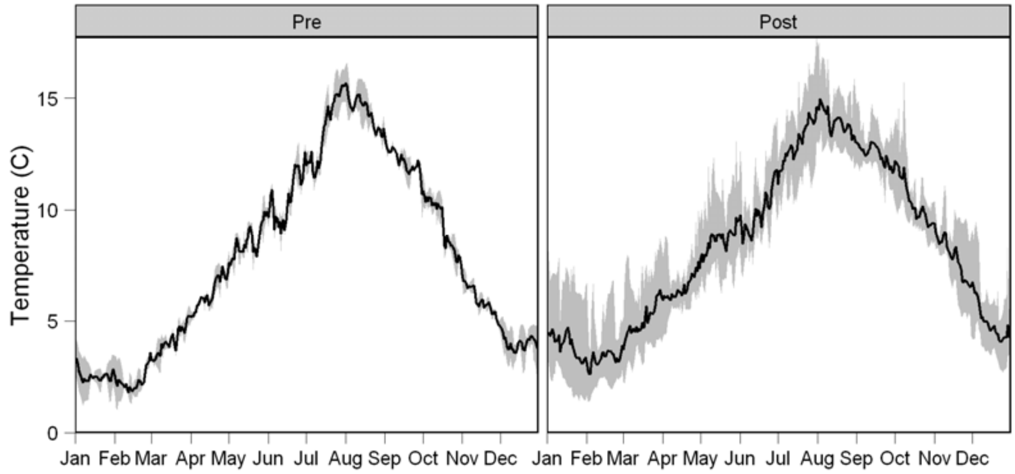

Figure 4-3: Hourly water temperature at the DRL WSC survey station in the pre-WUP period (2003-2005) and the post-WUP period (2008-2012).

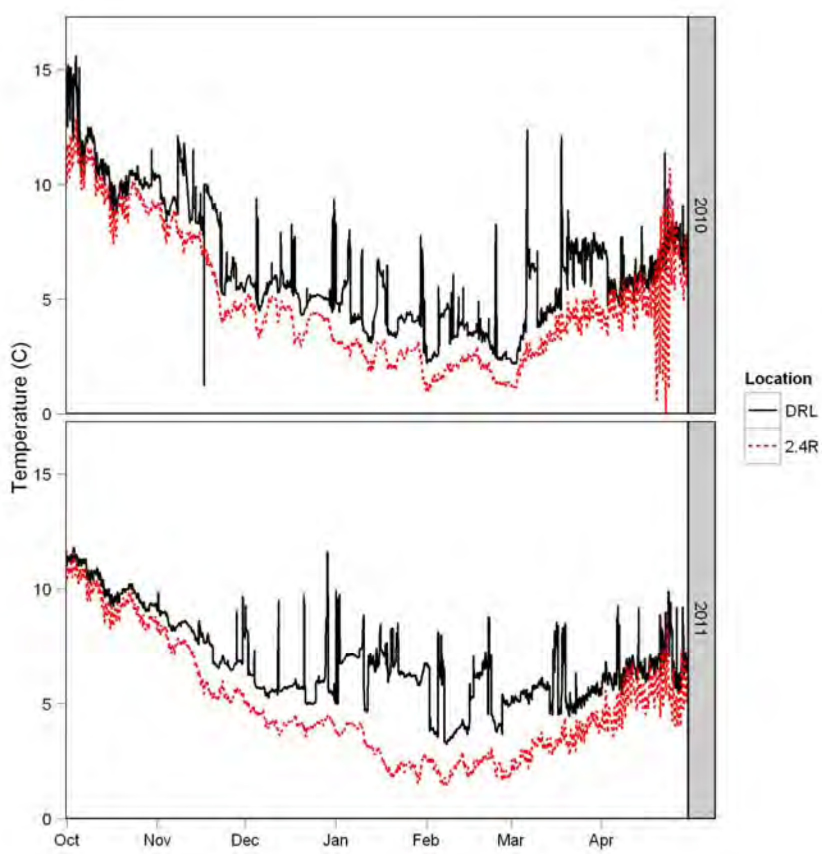

Figure 4-4: Hourly water temperature at the DRL WSC survey station and the DDMMON-7 logger at 2.4R located on the same bank approximately 300 m downstream, 2010 and 2011.

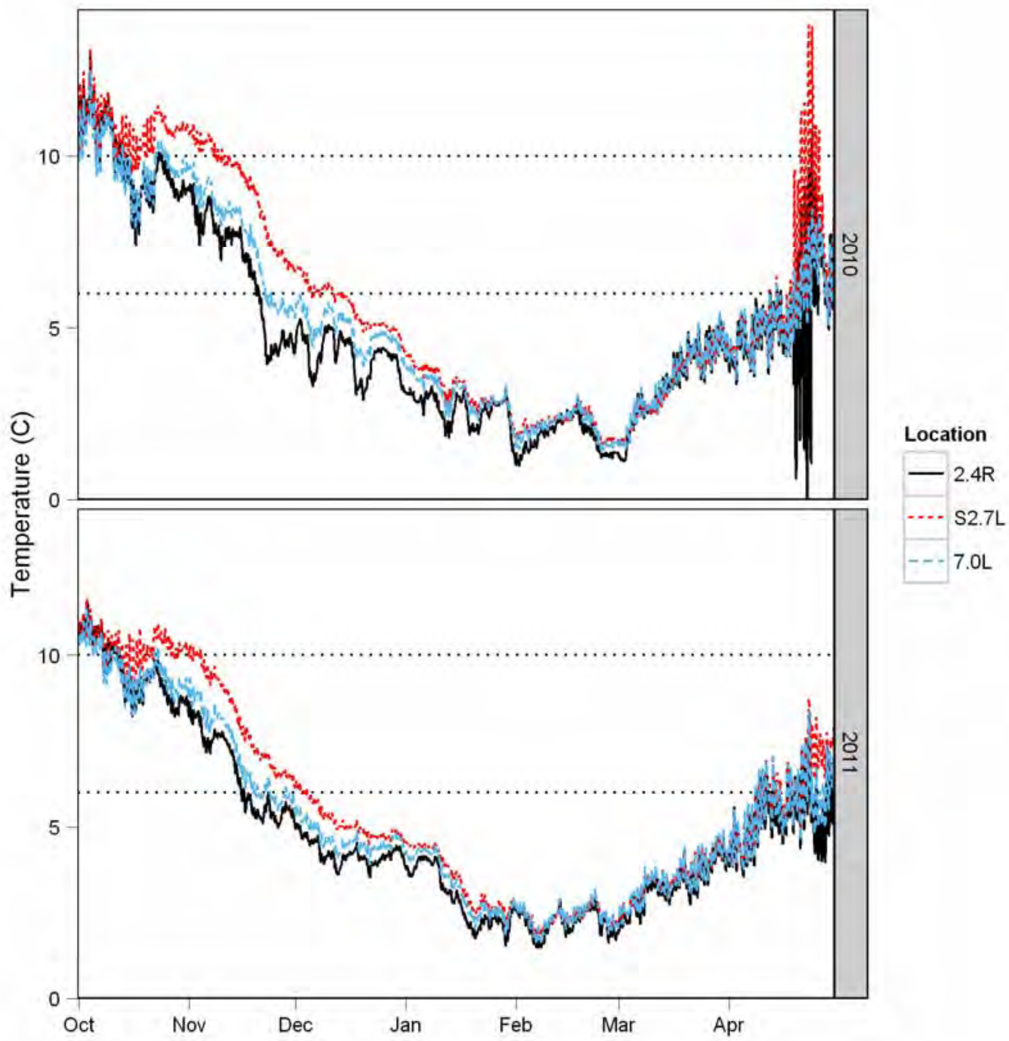

Figure 4-5: Hourly water temperature at 2.7L (side channel), 2.4R and 7.0L during mountain whitefish spawning and incubation periods. The year of the graph is the spawning year. Horizontal lines indicate the temperature for spawning initiation (10ºC) and for optimal egg incubation success (6ºC).

4.3.2 Spawn Timing

4.3.2.1 Gonado-Somatic Index (GSI)

The GSI calculated for each mature fish captured in the 2011 spawn year ranged in value from 0.005-30.47. This was a wider range than observed for the 2010 spawn year where it ranged from 0.083-19.35. The sample size was greater (n=137 mature fish) in the second field season than in the first (n=49 mature fish). GSI values were consistently higher for females in both years and dropped off more dramatically after spawning in females as well (Figure 4-6). A difference between male MW was evident in that they retained milt for multiple events, which was depicted as a gradual decline in GSI during the spawn window rather than a sudden drop (Figure 4-6).

The estimated mean spawning date in 2010 was November 17th with the 2.5% of spawning completed by October 22nd (lower end of 95% credibility interval) and 97.5% of spawning completed by December 11th (the upper end of the 95% credibility interval) (Figure 4-7). Peak spawning in 2010 could be as early as November 13th or as late as November 21st (Figure 4-8). In 2011, mean date of spawning was November 20th with the 95% credibility interval spanning from October 27th to December 14th (Figure 4-7). Peak spawning in 2011 could be as early as November 17th or as late as November 22nd (Figure 4-8).

The Bayesian estimated mean date of spawning and 95% credibility intervals for each year of egg mat sampling for the four years of egg mat data are shown in Figure 4-9.

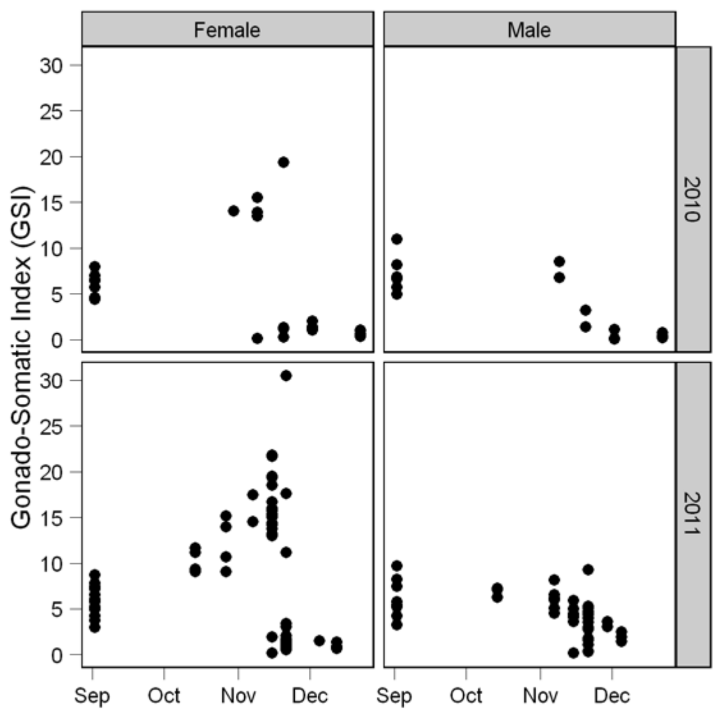

Figure 4-6: Gonado-Somatic Index (GSI) for female and male fish by spawn year on the LDR.

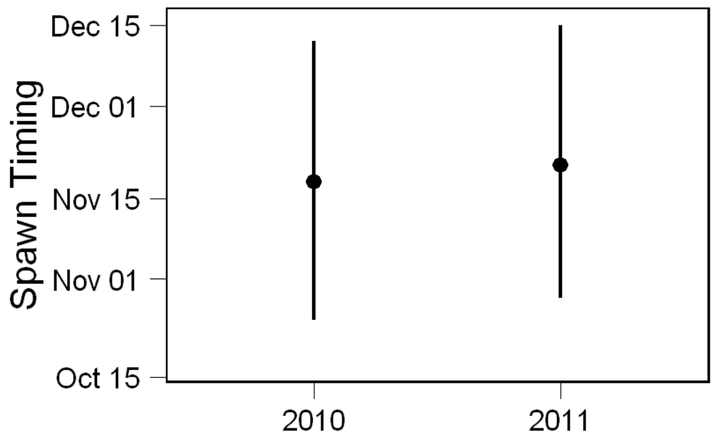

Figure 4-7: Mountain whitefish spawn timing in the LDR for spawn years 2010 and 2011 with mean timing and 95% credibility intervals.

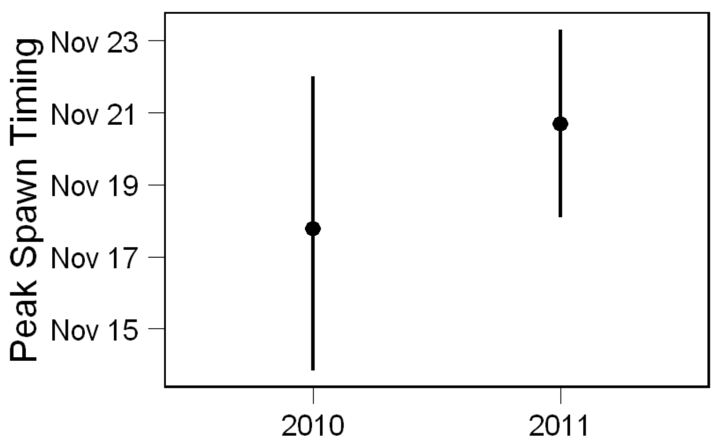

Figure 4-8: Estimated peak spawn timing for LDR mountain whitefish for spawn years 2010 and 2011 with estimated date of peak spawning by year and 95% credibility intervals for the date of peak spawning.

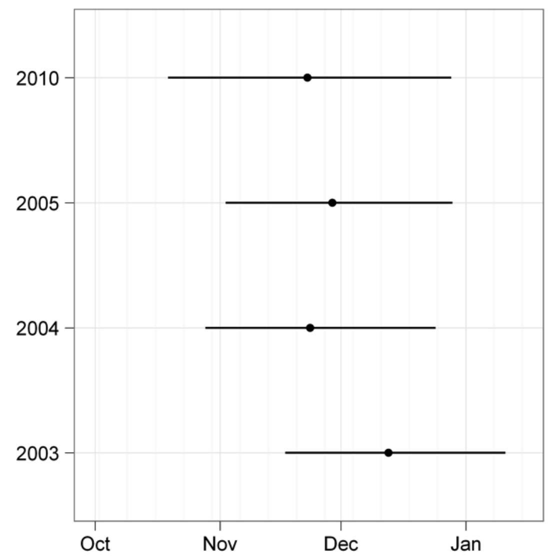

Figure 4-9: ***Estimated mean date of LDR MW spawning and 95% credibility intervals for commencement and termination of spawning period for each year of egg mat surveys, 2003-2005 and 2010.***

4.3.2.2 Night Spotlighting Surveys

The estimated abundance within the index site was plotted through time for aggregations of spawning mountain whitefish as well as areas that they dispersed to post-spawning (Figure 4-10). Maps illustrating locations of aggregations are provided in Appendix B.

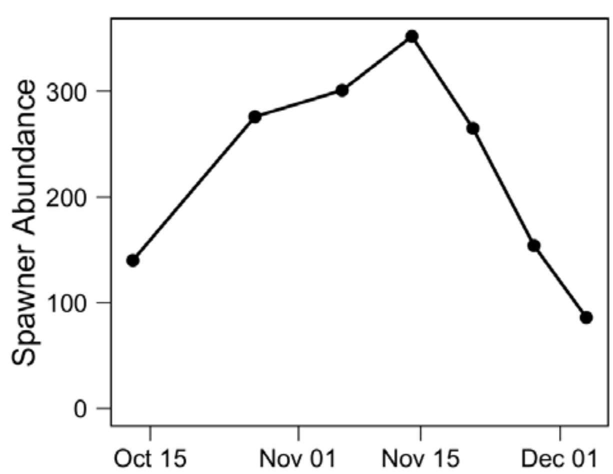

Figure 4-10: ***Mountain whitefish spawner abundance in the index site located from Km 1.5 to 2.5 (left bank) as estimated from night spotlighting during surveys conducted from October 13 to December 4, 2011.***

4.3.2.3 Fish Capture & Life History Sampling

Catch rates were substantially higher for boat electrofishing than for angling, though the CPUE for angling increased from 0.85 in 2010/2011 to 1.28 in 2011/2012 likely due to learning fish preferences and fish aggregation locations from the first year of angling (Table 4-2, Thorley et al. 2011a). Similar to 2010/2011, capture rates increased until peak spawning and then sharply decreased afterwards (Table 4-2).

Table 4-2: Catch per unit effort (CPUE) comparisons for boat electrofishing and angling used to capture MW in the LDR, 2011/2012.

Method	CPUE (fish/hr)
Boat Electrofishing (overall)	27.74
Session 1 (Sept 2, 2011)	33.8
Session 2 (Nov 15, 2011)	38.1
Session 3 (Nov 21, 2011)	122.0
Session 4 (Dec 12, 2011)	4.91
Angling (overall)	1.28

During the 2011/2012 field season, a total of 78 fish were caught by boat electrofishing, while 77 fish were captured by angling. Of the 155 MW captured in total during the 2011/2012 field season, 12 were immature fish, 137 were mature fish in spawning condition and 6 fish were mature, but not in spawning condition. Of the 12 immature fish, 8 were female and 4 were male for a sex ratio of 2:1, which was opposite of findings in 2010/2011 (5 females and 10 males for a sex ratio of 0.5:1; Thorley et al. 2011). As described in the methods, the low number of immature fish captured was largely intentional since fish in good condition that were smaller than 230 mm were released in 2011/2012. The sex ratio observed for mature fish in 2010/2011 was 1.58:1 (30 females: 19 males), whereas in 2011/2012 the ratio was 1.18:1 (74 females and 63 males). Of the mature fish not in spawning condition, 5 were female and 1 was male and all were greater than 300 mm so were within the size range for mature fish given the length-frequency information from the previous year's study (Thorley et al. 2011). The non-spawners comprised 4.2% of the mature mountain whitefish sample. Length frequency by sex for immature and mature fish is illustrated in Figure 4-11 and Figure 4-12, respectively.

At peak spawning, tubercles were consistently noted on ripe males, but were not always perceptible on ripe females. At least for the 2011/2012 sample year, it does not appear that tubercles can be used as a reliable, non-lethal indicator of spawning readiness for both sexes, but could be used for identifying ripe males. This is not of much assistance or additional benefit since ripe males may be identified by expressing milt and very ripe females by expressing eggs through squeezing on the body.

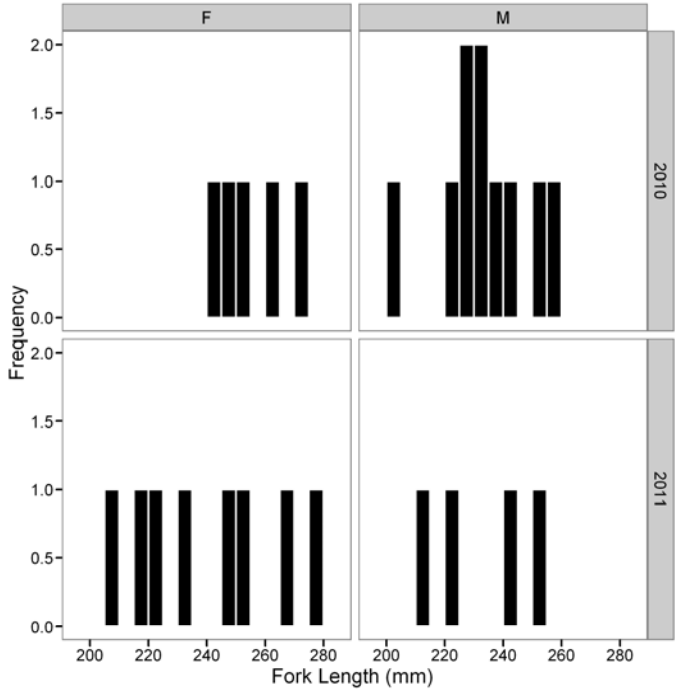

Figure 4-11: Length frequency by sex and spawn year for immature mountain whitefish, 2010 and 2011.

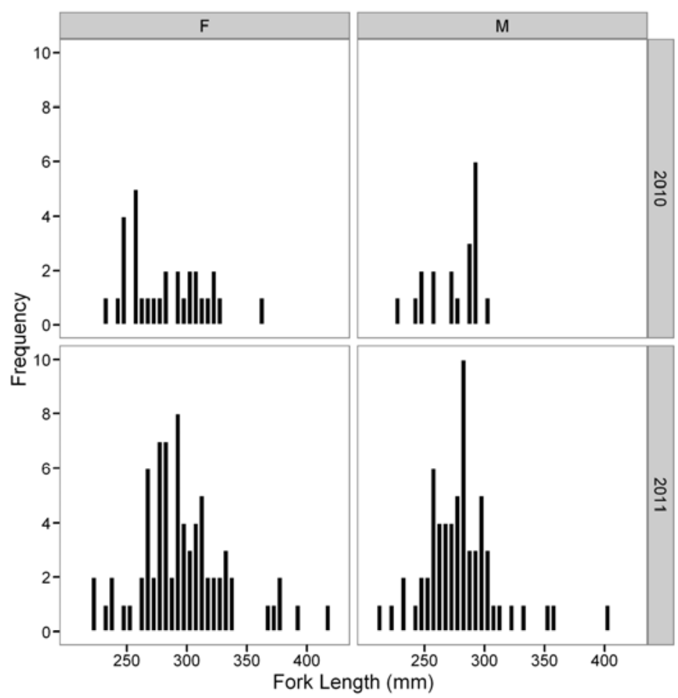

Figure 4-12: Length frequency by sex and spawn year for mature mountain whitefish, 2010 and 2011.

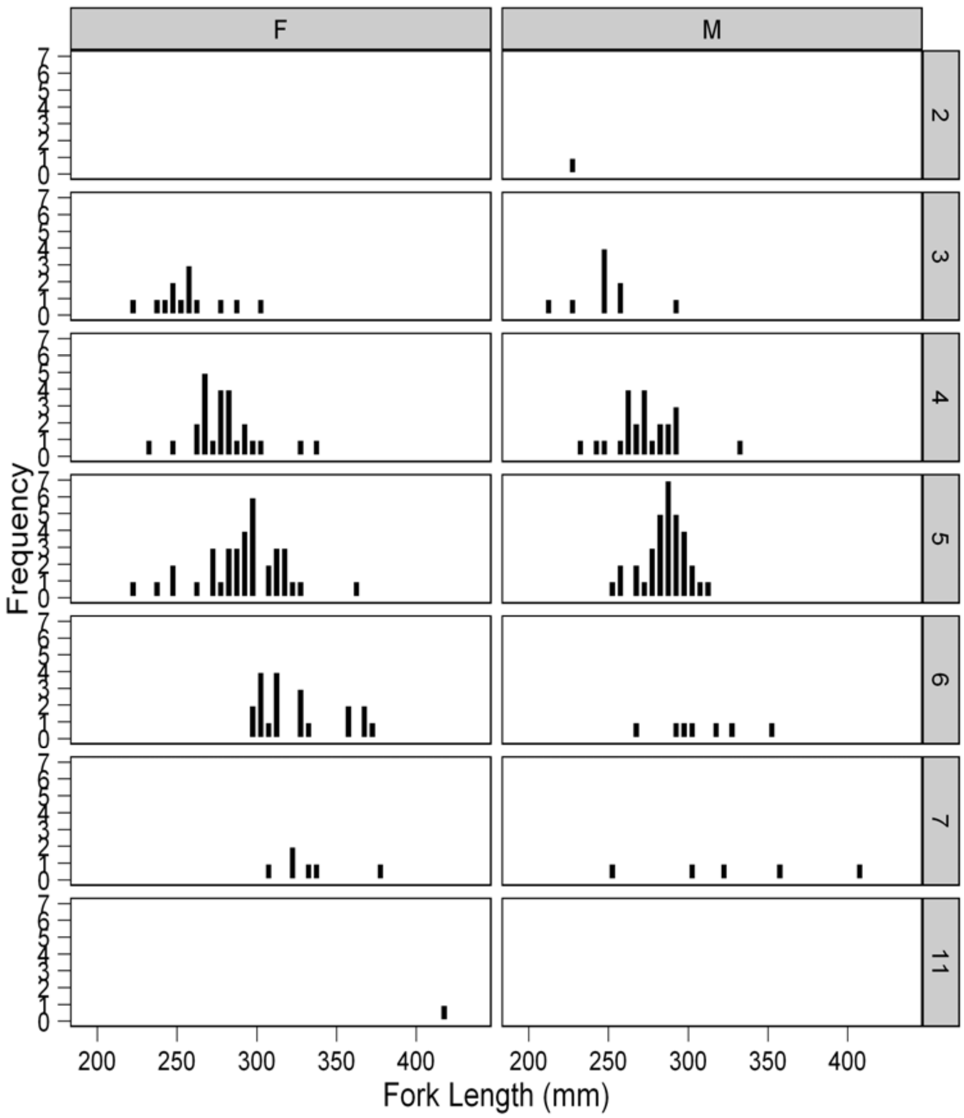

Figure 4-13: Length frequency by sex and age for sexually mature mountain whitefish, 2010 and 2011.

4.3.2.4 Life History Observations

During the pre-spawn period (early to mid-September), groups of mountain whitefish were observed in areas of rapid velocity alongside large woody debris jams, or in pool areas with deep water or boulder cover. Fish distribution was generally clumped as observed during boat electrofishing surveys conducted on September 2, 2010 and 2011. Aggregations of MW were also seen during snorkel surveys conducted in September 2010 (Section 5) along cobble bars, in pool tailouts and alongside the riprap on the left bank at approximately

Km 1.2. These fish appeared to be staging and engaging in pre-spawning aggregation behaviour.

During the spawning season, MW developed secondary sex characteristics that were visible to observers from the boat deck or when handling the fish after capture by angling or electrofishing. A rosy hue, particularly on the scales above the lateral line and the pectoral fins as well as distinctive tubercles were observed on several fish (Figures 4-14 and 4-15). Darkened lateral stripes were also seen during the spawning season during night spotlighting sessions. In Utah populations of MW, these lateral lines were prominent on fish that were currently spawning (Stalnaker and Gresswell 1974). These rosy-orange colourations have been observed in round whitefish (*Prosopium cynlindraceum)* (Normandeau 1969). Tubercles appear in some populations on both sexes of fish and in other populations are found on males only (Stalnaker and Gresswell 1974). Mountain whitefish observed early in the season were somewhat evasive if the light during spotlighting surveys was directly focused, but as the spawning season commenced in earnest, they were less responsive to the direct light and were often observed in pairs, trios or small groups holding station over clean cobble or large gravel and they would not move away from the light. Although this species is not known for preparing the substrate for spawning or for making nests, it appeared that simply the presence and movement of the aggregation might have cleaned the substrate of silt and periphyton to the degree that it was evident to observers. Mountain whitefish were also observed rolling on their side when they were in pairs and aggregations, which may be reflective of spawning or courting behaviour.

The stomachs of all MW that were captured were assessed during dissection and in early spawn and peak spawn, the contents were predominantly small caddisflies (Tricopteran) in rectangular, dark brown cases. Once spawning activity began, mountain whitefish eggs were found in high proportion in the stomachs of the dissected MW and near the end of the spawning season, the stomachs were largely empty.

By early December in both years, mountain whitefish were notably absent from the banks adjacent to swiftly flowing water and the riffles and pool tailouts where they had been observed and captured earlier during the spawning season. Large aggregations of all ages of MW, though with a bias towards smaller fish, were noted in the spillway channel of the LDR by early December and in side channels with silt or fine substrate and low flow or slack conditions. Ice formation was observed below the spillway channel prior to the conclusion of the MW field season each year and in 2010/2011 it was noted that ice was used as winter cover for the MW during daylight observations.

Figure 4-14: Tubercles and rosy hued scales on a ripe male MW captured by boat electrofishing in LDR, November 14, 2011.

Figure 4-15: Rosy hued female MW captured by angling in the LDR, October 14, 2011.

4.3.3 Emergence Timing

Mean emergence timing ranged from early February at the warmer side channel at 2.7R, to late March at 2.4R in the 2010 spawn year (Figure 4-16). The earliest emergence may have occurred in early December at S2.7L, whereas the latest emergence may have occurred in early May 2010 at 2.4R. Emergence timing estimates were tighter for the 2011 spawn year due to larger sample sizes obtained for GSI measurements, but ranged from mid-December for earliest emergence to early May for latest emergence and showed a generally similar timing to the 2010 data (Figure 4-16).

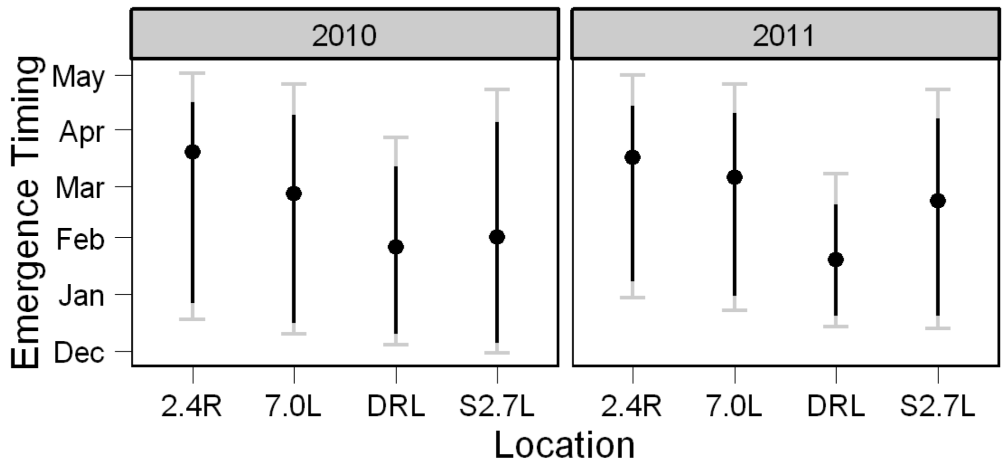

Figure 4-16: Emergence estimates for mountain whitefish based on temperature data measured at 2.4R, 7.0L, the DRL WSC gauge at Km 2.1R, and in side channel at 2.7L, 2010 and 2011. Points represent expected peak emergence date for 400ºC-days; black lines are the 95% credibility intervals for 400ºC-days; and, grey lines are the 95% credibility intervals for 365ºC-days and 495ºC-days.

4.3.4 Habitat Use Curves

It must be emphasized that habitat use curves derived for MW represent the conditions where fish were observed, which may be limited by accessibility and by what habitat was available to MW at that time based on flows from DDM, the Lardeau River and other tributaries. In no way does it connote habitat preference or signify that the habitats represented by these depths and velocities are optimal for mountain whitefish.

4.3.4.1 Water Velocity

Mean column water velocity at locations where aggregations of MW were observed ranged from 0 to 1.48 m/s with peak values at 0.68 m/s (Figure 4-17).

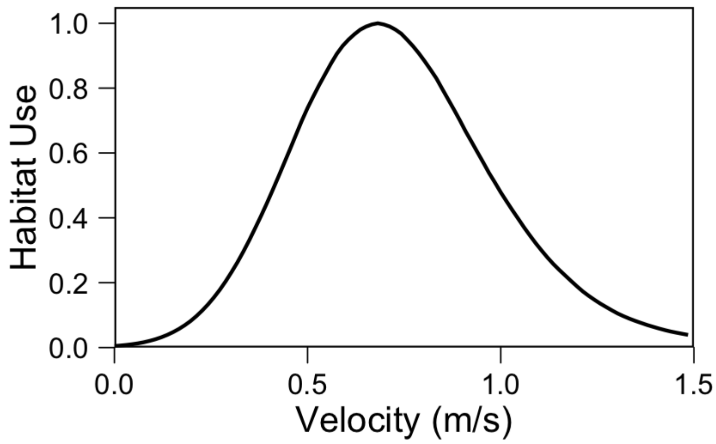

Figure 4-17: Habitat use curve for mean column velocity at sites where spawning MW were observed in the LDR, 2011.

4.3.4.2 Depth

Mean depth ranged from 0 to 2 m with peak values at 0.88 m (Figure 4-18).

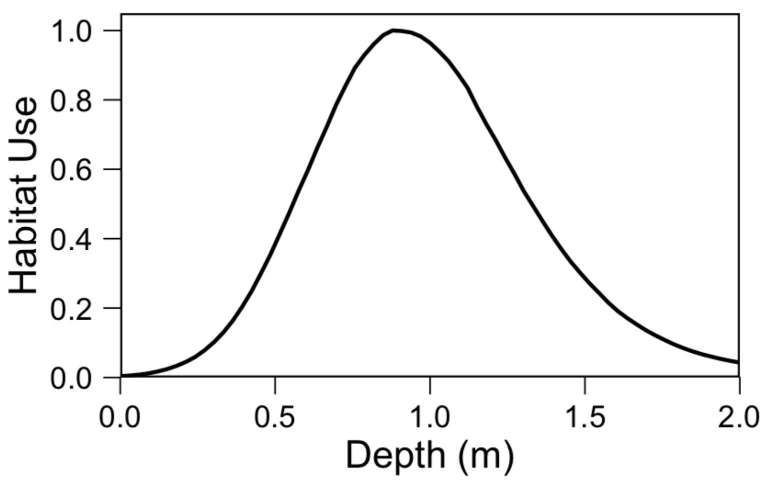

Figure 4-18: Habitat use curve for mean depth at sites where spawning MW were observed in the 2011 spawn year.

4.3.4.3 Substrate

The range of substrates available in the LDR was not fully assessed due to the log jam blockage at Km 4.1. However, of the sites surveyed, over 66% of the MW spawners were observed in areas dominated by gravel, 32% were observed over cobble substrate and 1%

were observed over fines. Size ranges for these substrate classes are provided in the methods.

4.3.4.4 Proximity to Wood

Of the sites surveyed where MW spawners were observed, 20% were within 2 m of large woody debris (LWD), with the other 80% not within 2 m of LWD.

4.4 Discussion

Mountain whitefish have been identified as a species sensitive to changes due to impoundment (Paragamian 2002). Recently, declining populations of MW in the states of Idaho and Colorado have prompted additional research on the mechanisms driving population dynamics of this species and the effects of altered flow regimes, habitat changes, disease and non-native species introductions and other factors on MW populations (Idaho Department of Fish and Game 2007; Schisler 2010).

Changes downstream of Duncan Dam (DDM) relative to historical flow regimes may have altered access to, and quality and quantity of MW spawning habitat (DVH Consulting 2001). Prior to the initiation of the DDMMON-2 MW study, the state of understanding about MW spawning in the LDR was that it ranged from October 21 to December 21 and that the incubation period was from October 21 to May 31 (BC Hydro 2005b). The performance measure defined for adult mountain whitefish through the Consultative Committee process was the number of hectares of effective whitefish mainstem habitat lost over spawning and incubation periods (Irvine and Porto 2010, BC Hydro 2005b). The key management questions for the adult mountain whitefish study component of DDMMON-2 are outlined in detail in Section 1.1 and the following discussion is structured in terms of those questions.

4.4.1 Management Question 1

The first management question asks for the typical life history timing, abundance, and relevant environmental cues for mountain whitefish spawners using the Duncan River mainstem.

4.4.1.1 Life History Timing

In general, mountain whitefish gather in the LDR in September to stage, commence spawning in late October and complete spawning by mid-December. The timing estimates were tightened significantly with two years of GSI data and with the model that incorporated the different mechanisms of spawning observed for male and female mountain whitefish. In the 2010 spawning year, peak spawning was predicted to range from November 13 to 21 with the peak estimated around November 17. This assumes that spawning is 2.5% complete by October 22 and 97.5% complete by December 11. The additional samples obtained in the 2011 spawning year increased the accuracy of the spawn timing estimates with peak spawning predicted to range from November 17 to 22 and a probable peak date of November 20th. As above, this assumes that spawning is 2.5% complete by October 27th and 97.5% complete by December 14th. These estimates confirm the dates outlined in the TOR and tighten the date ranges determined from egg mat studies (Baxter 2007; Thorley et al. 2011).

The previous estimated spawning window (Thorley et al. 2011) based on 4 years of egg mat data was considerably wider than the range estimated with two years of GSI data (Thorley et al. 2011). The wider confidence intervals may have resulted because egg mat methods may have been biased by re-flotation of eggs when flows increased or it could be representative of inter-annual variability in spawn timing that has not been captured by the two years of field study for DDMMON-2. Egg staging completed for the MW eggs captured on mats in the lower Columbia River demonstrated that a minimum of 12% of the eggs captured by mats were from the drift (Hildebrand 2011a). Advantages of the egg mat method are that it is non-lethal and non-invasive for spawning fish. Disadvantages are that: 1) eggs may disperse after the initial spawning event and may be captured by the mats at any time they are moving in the river thereby providing misleading estimates of timing unless egg staging is done; 2) they collect low densities of eggs in the LDR due to the dispersed nature and lower numbers of mountain whitefish relative to the Columbia River; and 3) they are labour intensive and and mats can move when flows increase.

If spawn timing had been estimated solely by night spotlighting surveys within the index reach, the estimated date of peak spawning would be November 15th. For relatively little effort and almost no impact on the fish this date is quite close to that estimated by the GSI methods and could be employed in future years to better determine the range of inter-annual variability in spawn timing for mountain whitefish as well as relative abundance of spawning adults in the index reach as an indicator.

Mountain whitefish do not prepare redds for their spawning, but broadcast spawn over the substrate (Northcote and Ennis 1994) after coming into aggregations with small groupings of both sexes of fish within the aggregation (Brown 1952). After spawning, the eggs may drift a short or substantial distance before coming to rest in the area where they will incubate and from which they will emerge. Mountain whitefish egg incubation generally occurs in the LDR from mid-October until early May, depending on location, water temperature and discharge volatility. Peak emergence is dependent upon where in the river the eggs have been deposited, but ranged from the first week of February for the warmer left downstream bank side channel habitat at S2.7L, to the first week of March for 7.0L. The latest emergence was estimated around the third week of March, which was associated with the influence of the Lardeau River along the right bank of the LDR (2.4R). Mean emergence timing estimated during this program varied by one to two weeks between years. The range of ATUs required for MW egg incubation to emergence is quite wide spanning from 365 to 495°C-days (Brown, 1952; Rajgopal 1979; Brinkman and Viera 2009). In order to narrow down this ATU range, egg incubation studies or larval sampling would be required. The increased refinement in spawn timing resulting from the analysis of two years of GSI data also allowed a more accurate estimate of emergence timing and the overlap of the DDMMON-2 study program with the DDMMON-7 program provided excellent crossover temperature data from throughout the extent of the LDR. Sites with temperature loggers were selected that covered the range of temperatures that could be encountered by a MW egg.

4.4.1.2 Frequency Distribution (Abundance)

Relative spawner abundance within the index site peaked at ~340 fish on November 14th, during the 2011 spawn year. Comparable estimates are not available for the 2010 spawn year though the trial night spotlighting survey on November 19th, 2010 enumerated 299 mountain whitefish within the index site (Thorley et al. 2011). Night spotlighting surveys in the 2011 spawn year were planned to survey an index site and then additional random sites stratified by habitat throughout the LDR to determine the relative abundance through time and across habitats. Relative abundance is defined as where we know how many of an organism there are in a location from year to year, but it is not an absolute count or estimate of all fish in the population, but rather a statistical sample that is indicative of the population size. The log jam at Km 4.1 was a severe impediment and forced the study program to focus only on the top 4 km of river. The relative abundance of spawners in the index site was plotted through time to provide a corroborative line of evidence for spawn timing, but this site and method could also be used in future years to assess the relative abundance of MW spawning. This requires several assumptions to be made including that the site is representative of the habitat available in the LDR at the time of spawning and that the spawner numbers in that location are indicative of the abundance of spawners in the LDR in general. It could be useful for determining whether spawning by mountain whitefish in the LDR has cycles with strong year classes or is relatively consistent through time.

4.4.1.3 Environmental Cues

Spawning for mountain whitefish is cued by both internal (endogenous) and external (exogenous) factors that drive the onset and synchronization of spawn timing (Wang et al. 2010). The exogenous cues are similar to other salmonids and include water temperature, photoperiod, and changes in water level or velocity, with water temperature and photoperiod as the main cues (Northcote and Ennis 1994; McPhail 2007; Wang et al. 2010). Of those factors, photoperiod is the factor that has the strongest influence on coregonid initiation of spawning with water temperature as the secondary factor that modulates the metabolic processes of gametogenesis (Gillet 1991b, Wang et al. 2010). Less is known about the influence of discharge or velocity though there may be physical or behavioural upper limits to both of these variables above which spawning behaviours would be impeded. The use of external environmental factors to refine spawn timing allows adjustment of reproductive timing to optimize survival in the offspring (Wang et al. 2010). As photoperiod is unaffected by the operation of DDM, it will not be discussed further.

Water Temperature

Mountain whitefish usually spawn below water temperatures of 10^{o}C and peak at temperatures of 6^{o}C (Northcote and Ennis 1994). In the LDR in the 2010 spawn year the water temperatures reached 10^{o}C on October 7 on the right bank and between October 11 and 16 on the left bank. In the 2011 spawn year both banks of the river reached 10^{o}C between October 11 and 13. The GSI model predicted that spawning was 2.5% complete approximately 2 weeks after this temperature was reached in each of the spawn years. The LDR did not reach 6^{o}C until November 21 to December 5, 2010 and November 16 to December 2, 2011. Peak spawning estimated for MW in the LDR did not coincide with the 6^{o}C temperature threshold though recent reviews on salmonids have demonstrated that temperature does not appear to synchronise spawning and that in general, salmonids do not rely on external cues once they have reached the final stages of the reproductive cycle (Wang et al. 2010).

Water temperature and oxygenation levels are key variables for incubation and emergence timing (Brown 1952; Rajagopal 1979) and broadcast spawned eggs will be less buffered by groundwater temperatures than eggs of other nest-building salmonids. Water temperature needs to be within a relatively tight range for successful incubation of mountain whitefish eggs with optimal incubation temperatures (based on hatching success percentages) estimated to be between 4ºC and 6ºC (Rajagopal 1979). Egg mortality rates progressively increased at temperatures above this optimum range with mortality of about 50% at 8ºC (Brinkman and Vieira 2009), 97.8-100% mortality at 11ºC, and 100% egg mortality at 12-15ºC (Rajagopal 1979). Mountain whitefish that spawn in the LDR prior to the late November period may encounter substantial egg mortality due to warmer water temperatures observed and the proportion of spawners' eggs affected would vary from year to year. During the 2010 spawn year, the LDR had temperatures above 6ºC for longer compared to the 2011 spawn year. Mountain whitefish that spawn at peak or after peak spawning may have a competitive advantage because they may experience better egg survival due to cooler water temperatures observed in the LDR at this time.

Discharge

It was thought that the increase in discharge from DDM on December 22nd each year could negatively affect late MW spawners (Thorley et al., 2011), but the refinement of the timing window indicated that the majority of the spawning is complete by mid-December. The increase in flow in the LDR at the end of December most likely affects MW eggs rather than spawners who appear to move into areas of slack flow after spawning is completed. It remains uncertain whether the discharge values of 76 m^3/s from October 1 to 21 and 110 m^3/s from October 22 to December 21 are optimal for spawning MW in the LDR.

Velocity and Stage

The literature on velocity or water level preferences of spawning mountain whitefish is minimal. These variables in an unregulated riverine system in the interior of BC would generally show increased water volume in early fall due to the autumnal precipitation cycle with decreased volume in winter as air temperatures drop below freezing and precipitation is held as snow and ice. The decrease in water volume, velocity and depth would be collinear with early winter declining temperatures and photoperiod. Although the hydrograph of the LDR is fundamentally altered by DDM operations, habitat use curves for spawning MW show a wide range of velocity and depth at which spawning can occur. For example, velocities ranged from almost still water to over 1 m/s (Lewis and Healey 2009; Figure 4-17) and water column depths ranged from 0 to 2 m (Lewis and Healey 2009; Figure 4-18). Velocity and stage are more likely to affect MW egg incubation and emergence timing as is discussed in Section 4.4.3.

4.4.2 Management Question 2

The second management question is concerned with the habitats and habitat preferences associated with the mountain whitefish spawning period.

4.4.2.1 Habitats

Habitat use curves generated for depth and velocity show that mountain whitefish can utilise a wide range of mean column velocities with a peak use velocity of 0.68 m/s and a range from 0 to 1.48 m/s. Velocity was faster than that predicted by the Lewis and Healey (2009) analysis from the USFWS data on mountain whitefish, which had an upper mean column velocity limit of 1 m/s. Depths used by spawning mountain whitefish in the LDR ranged from 0.03 to 2 m and this range was very similar to the depth habitat suitability curve (HSI) curve estimated by Lewis and Healey (2009) and is substantially shallower than depths at which mountain whitefish were observed spawning in the lower Columbia River (Hildebrand 2011). This tight range of depths is likely more reflective of the habitat available in the LDR during the spawning period than the actual habitat preference of the species or their optimal depth range.

4.4.3 Management Question 3

The third management question is concerned with what operations would minimize habitat dewatering and reduce the impact on species life histories within the constraints of the DDM WUP.

4.4.3.1 Habitat Dewatering

The flow regime outlined in the WUP operating orders significantly increases flow during the later portion of the MW spawning period. Inundation and egg scour out of the areas where eggs have been deposited is more realistic than habitat dewatering for this life history stage during the early part of the incubation period with dewatering more likely later in the incubation period when flows drop to the annual minimum. Current incubation flows for the latter half of emergence near the annual minimum of 73 m^3/s and the river stage as measured at DRL changed by up to 80 cm from peak flows during spawning (October to December) to minimum flows during the incubation period (October to May). Any eggs that are still incubating when this flow level is reached that have been deposited in shallow portions of the river may be dewatered unless they drifted to deeper parts of the river after release. As discussed in Porto et al. 2009, the operating regime at DDM is dictated in part by the Columbia River Treaty, while the DDM WUP also specified operating targets that are designed to achieve tradeoffs in the flow benefits to competing resources. Dewatering of significant numbers of MW eggs is considered unlikely due to the hydrograph during the incubation period, but could occur if eggs are redistributed into the shallows at higher flows in December and January and then when discharge levels are again reduced in February or January, the eggs could be stranded and desiccated or predated upon. If this scenario occurred, it is very unlikely that any eggs re-deposited in such a manner would remain viable.

BC Hydro has recently identified an increased risk of stranding newly emerged whitefish and kokanee in the spring prior to the onset of freshet (Alf Leake, BC Hydro, Burnaby, pers. comm., 2010), so this life stage may be of most concern for habitat dewatering. The focus on the DDMMON-2 mountain whitefish component was on refining the spawn timing for adults. A separate study on the eggs, larvae and fry or an increased focus on whitefish in programs such as DDMMON-16 would be required to assess the stranding risk of MW eggs, larvae, fry and juveniles in the LDR.

4.4.3.2 Potential Operational Impacts on Mountain Whitefish

Autumn spawning fish and coregonids in particular have been determined to be a species group that may be sensitive to increases in water temperature (Cingi et al. 2010) due to climate change or other alterations such as impoundments that increase water temperature at the time of spawning, fertilization, and incubation. Coregonids, including mountain whitefish, show cumulative increases in egg mortality and embryo defects with increases in water temperature outside of a narrow range (Rajagopal 1979, Brinkman and Vieira 2009, Cingi et al. 2010). Mountain whitefish may be especially vulnerable to water temperature effects on egg viability, fertilization, and successful incubation since they are broadcast spawners and the eggs are not buffered by groundwater temperatures as much as a species that constructs redds and buries its eggs. Water temperatures in the LDR prior to the construction of DDM are not available (Lynne Campo, Water Survey Canada, pers. comm., 2010), so it is uncertain what conditions this population evolved under. The Lardeau River temperatures fall below 10°C by the end of September and are at 6°C by approximately mid-late October (DDMMON-7, AMEC and Poisson 2012). However, the estimated spawn timing window in the LDR and the water temperature data collected as part of DDMMON-7 predicted that egg mortality levels of MW in the LDR could be high (ranging from 50% -100% egg mortality depending on water temperature induced mortality experienced in a particular year (Rajgopal 1979, Brinkman and Viera 2009) for the 50% of spawning fish who spawn prior to the estimated peak when water temperatures are overly high for optimal egg survival. Additionally, the advent of winter high flows on December 22nd may cause eggs to re-enter the water column after they are fertilized, which could cause mortality since they are in a critically sensitive stage during development (Rajgopal 1979).

MW fry are small (16-20 mm Total Length) and upon emergence usually drift downstream before moving into low velocity margins, side channels, and backwaters (McPhail 2007). A challenging part of their life history in the LDR with dammed conditions and high mid-winter flows may be that fry that emerge prior to April 9th, when flows are reduced from 250 m^3/s to 110 m^3/s, may be emerging into high flow conditions with limited marginal and low velocity habitat and cold temperatures. There may also be competition amongst kokanee, rainbow trout, and cyprinid species for shallow, rearing habitats at times of the year when flows minimize such habitat. MW young-of-the-year are associated with water less than 50 cm in depth with quiet velocities and over finer (sand and silt) substrates (McPhail 2007). The drop to minimum flows prior to the end of the emergence period could also be an operational impact because deposited eggs in the shallows may become stranded. Operational opportunities to keep eggs inundated could be explored within treaty and other constraints.

Some coregonids have been shown to emerge after large discharge increases in spring in order to utilise the descending limb of the water pulse to drift to appropriate rearing habitats (Naesje et al. 1995). A mechanical cue of jostling can shorten the incubation period by as much as 26% (92-128°C-days earlier) for whitefish of the species *Coregonus lavaretus* and *C. albula* (Naesje et al. 1995). Sudden increases in temperature can also induce hatching in advanced stage embryos of mountain whitefish (Schisler 2010), so a stable, slowly increasing trend of temperature and velocity during the later stages of incubation are critical to prevent early emergence and a hydrograph that increases naturally as would occur in spring may be important to cue emergence at the appropriate time for MW fry.

4.5 Considerations for Future Water Management Planning for the Lower Duncan River Mountain Whitefish

- The spawning window for adult mountain whitefish should be extended so that it ranges from October 15 to December 21 based on modelled GSI data
- Incubation of mountain whitefish eggs generally occurs from mid-October to early May which narrows the emergence window in the spring from the WUP predicted incubation period. The number of ATUs for emergence of LDR MW is unknown at this time and could be affected by sudden changes in discharge such as the increase in flows on December 22nd. Egg incubation experiments or drift netting or seining for emerging mountain whitefish may help narrow this window if further refinement is required.
- Water temperatures at the start of the spawning period were approximately 8-11ºC (depending upon location and year) and maintained an average temperature higher than the optimum of 6ºC until late November or early December. These temperatures are warmer than is optimal for egg incubation.
- The drop to minimum flows prior to the end of the emergence period could also be an operational impact because deposited eggs in the shallows may become stranded. Operational opportunities to keep eggs inundated could be explored within treaty and other constraints. Knowledge of the MW egg distribution is not necessary to optimize egg incubation; a certain proportion of the bankfull width of the LDR could be kept wetted regardless of egg deposition patterns to encompass the majority of locations where MW eggs would be.
- Operational alterations to the way flow is released over the winter months should be assessed to see if operational objectives can still be met while maximizing the rearing habitat for MW and other species. If higher flows were maintained throughout the spawning period, then the flow levels would not have to rise so much in December and early emerging MW may have more low velocity habitat in the mainstem LDR.

5.0 JUVENILE RAINBOW TROUT AND MOUNTAIN WHITEFISH REARING HABITAT USE

5.1 Introduction

An overall goal of the Duncan Dam Water Use Plan (DDM WUP) is to maximize fish productivity in the lower Duncan River (LDR) within the operating potential of the Duncan Dam (BC Hydro 2008). The Duncan-Lardeau system, which consists of the 45 km of the Lardeau River from Trout Lake to its confluence with the lower Duncan River and the 12.5 km of the lower Duncan River from the Duncan Dam to Kootenay Lake (Figure 1-1), provides rearing habitat for Kootenay Lake Gerrard rainbow trout and mountain whitefish.

As discussed in the rainbow trout spawning component (Section 3), the Gerrard rainbow trout of Kootenay Lake, which support an economically and socially important recreational fishery, spawn exclusively in the Duncan-Lardeau system. After emerging in June and July the juveniles then rear in the mainstem and side channels of the Lardeau and Lower Duncan Rivers for up to 3 years (Hagen and Decker 2006, Decker and Hagen 2009) before outmigrating to Kootenay Lake. Adult mountain whitefish spawn in the Lower Duncan River from mid-October to the end of December period and the eggs hatch sometime between February and May (Section 3). Low winter snorkel counts (AMEC 2005) suggest that juvenile mountain whitefish experience extremely high overwintering mortality and/or overwinter in the Lardeau River or Kootenay Lake.

The current component of the DDMMON-2 estimated the habitat use and abundance of juvenile rainbow trout and mountain whitefish during fall 2009 and 2010 and in spring 2012 as part of a separate program. Some of the uncertainties concerning the influence of dam operations on juvenile rainbow trout and mountain whitefish productivity due to habitat dewatering are also discussed. Key management questions for the juvenile component of DDMMON-2 are outlined in Section 1.1. In addition, two supplementary snorkel swims were undertaken during winter 2011/2012 to partially and qualitatively answer the following questions:

1. Do juvenile mountain whitefish appear to overwinter in the LDR?
2. Do overwintering juvenile rainbow trout (and mountain whitefish) appear to be primarily associated with side channel or mainstem habitat?
3. Does the increase in flow from 110 to 250 m^3/s appear to be associated with increased use of side channel habitat?

The snorkel crew also opportunistically recorded observations in an attempt to partially and qualitatively answer the question:

4. Do overwintering juvenile rainbow trout (and mountain whitefish) appear to use slower and deeper water than in the fall?

5.2 Methods

5.2.1 Study Area

The study area encompassed approximately 11.0 km of main channel and 9.6 km of side and secondary channels of the Lower Duncan River from its confluence with the Lardeau River to Kootenay Lake.

During the first year of study (Thorley et al. 2011), habitats were mapped using an output of the River2D hydraulic model (Steffler and Blackburn 2002) produced by DDMMON-3 (NHC 2010). For site selection and analysis purposes the main channel was considered to be the primary channel (i.e., that with the greatest discharge), while side channels were considered to be secondary channels separated from the mainstem by vegetated bars as opposed to braids, which were secondary channels that were separated from the mainstem by un-vegetated bars (Decker and Hagen 2009).

In 2012, habitat was mapped from the BC 1:20,000 Freshwater Atlas and fine scale orthomosaic imagery (see Section 5.2.3.2 below). Based on bankfull channel widths (high water mark), the Lower Duncan River was divided into main versus side channel habitat each of which was then further subdivided into primary, secondary and tertiary channels. For comparative purposes the major channels in the lower Duncan River are listed together with their classifications for both years of study.

Table 5-1: Major channels in the lower Duncan River with length and classification used in 2009 and 2012.

Channel	Length (m)	2009	2012
1.1R	910	Wetted Side	Dry Side
1.8L	195	Wetted Braid	Wetted Main Secondary
2.7L	431	Wetted Side	Wetted Main Secondary
3.5R	958	Wetted Side	Wetted Side
4.1R	1,404	Wetted Side	Wetted Side
4.4R	510	Wetted Side	Wetted Main Secondary
6.9R	570	Dry Side	Dry Main Secondary
7.6R	649	Wetted Side	Wetted Side
8.2L	1,592	Wetted Side	Dry Side
8.8L	355	Wetted Side	Wetted Side
9.6R	1,693	Wetted Side	Wetted Side

5.2.2 Juvenile Microhabitat Use

5.2.2.1 Microhabitat Use Study Period

Snorkel surveys used to quantify juvenile microhabitat were conducted from October 18 to 21, 2009 when the discharge at DRL was at approximately 77 m^3/s (Figure 5-1).

5.2.2.2 Microhabitat Use Site Classification

Sites were classified according to channel type (mainstem or side channel), mean depth (shallow versus deep) and mean velocity (slack versus flowing) within the useable area. For additional information on the mesohabitat classes see Thorley et al (2011).

5.2.2.3 Microhabitat Use Site Selection

Specific sites were chosen by dividing the river into mainstem sections and side channels (braids were not sampled as they were assumed to be identical to side channels) and then within each section or side channel, selecting one or two sites from each strata. The location of each site within a sampling section/side channel was pseudo-randomly determined in the field by allowing the boat operator to choose a particular bank location and then randomly choosing between the two closest sites of each strata by tossing a coin. All the sites were 10 m in length with the exception of H6, which was 20 m (Thorley et al. 2011).

5.2.2.4 Microhabitat Use Snorkel Surveys

Surveyed sites were snorkeled at night. The surveys began approximately 0.5 hour after dusk and were completed within the four hour window during which juvenile salmonids are most visible (Bonneau et al. 1995, Bradford and Higgins 2001).

Each site was swum in an upstream direction by an experienced snorkeler carrying a handheld waterproof dive light. The snorkeler placed numbered metal tags to mark the location of each juvenile salmonid. When a fish location was marked, the snorkeler called out the species, tag number and a visual estimate of fork length (to the nearest 5 or 10 mm) that was recorded by a second crew member on shore. After the snorkeler had finished searching the immediate area, depth and mean column velocity measurements were taken at the location of each tag by a third crew member. As snorkeling could not be conducted in water <15 cm deep, fish were observed in these shallow locations by carefully walking through the area while spotlighting the fish from above.

5.2.2.5 Microhabitat Use Analysis

Rainbow trout with a fork length <100 mm were classified as fry (age-0), while all other rainbow trout were classified as parr (age-1 and older) (Irvine 1978, Decker and Hagen 2009). Mountain whitefish were classified as fry or parr (age-1 and older) based on a length cut-off of 110 mm that was estimated from a visual examination of the distribution of modes in the length-frequency histogram. Habitat use curves were estimated from the depth and velocity data using Bayesian analysis as described in Section 5.2.3.5 and Appendix B.

5.2.3 Juvenile Abundance

5.2.3.1 Abundance Study Period

The main part of the juvenile abundance study was conducted from September 15 to 19, 2010 (fall) when discharge at DRL, which averaged 220 m^3/s, had been stable for eight days (Figure 5-1). In order to estimate overwintering densities, two additional supplementary surveys were conducted in channel 2.7L on December 12, 2011 and January 3, 2012 (winter) at 102 m^3/s and 244 m^3/s, respectively (Figure 5-1). Selected sections of the LDR were also snorkelled from March 18 to 20, 2012 (spring) when the discharge was approximately 95 m^3/s as part of the Habitat Conservation Trust Foundation's ongoing stock-assessment of juvenile rainbow trout in the Duncan-Lardeau River (Andrusak 2010). There was substantial overlap between the crew members on the various surveys.

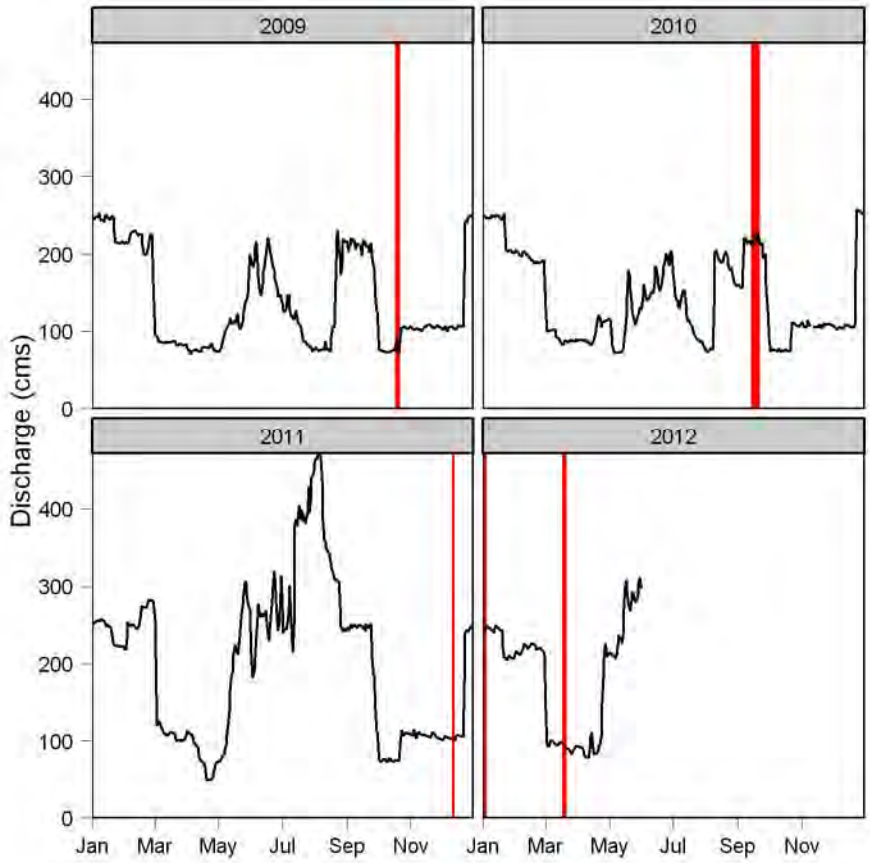

Figure 5-1: ***Mean daily discharge at DRL, 2009 to 2012. The vertical red lines indicate snorkel surveys. As the fall 2009 snorkel survey was conducted for the juvenile microhabitat use study the snorkel counts are not considered comparable to those collected during the later surveys and are therefore not included in the juvenile abundance study.***

5.2.3.2 Abundance Habitat Mapping

As mentioned above, fish habitats in the Lower Duncan River were mapped in 2010 based on an output of the River2D hydraulic model that predicted the depths and velocities at discrete nodes in the river channel when the discharge at DRL was 225 m^3/s (Thorley et al. 2011). The nodes were used to map depth and velocity contours, which were then used to identify fish habitat (depth >0 m and velocity ≤0.5 m/s). For sampling and analytic purposes the areas of fish habitat were broken into sites with an average length of approximately 50 m.

In 2012, an aquatic habitat map for the Lower Duncan River and its side channels was developed from BC Government Data Catalogue (DataBC) 1:20,000 Freshwater Atlas (http://www.data.gov.bc.ca) and fine scale (1:2,500) orthomosaic imagery collected by Terrasaurus Aerial Photography Ltd on April 30, 2009 when the discharge at DRL was 73 m^3/s. Linear bank boundaries and the river centerline were extracted from the Freshwater

Atlas layers and corrected using the orthophotos by an experienced photo interpreter. Physical habitat boundaries such as depth and velocity contours were then delineated within the defined bank boundaries and digitized to produce the initial pre-typing polygons, which were refined using GPS field data and knowledge gained from multiple field visits. The physical habitat layers were combined to produce fish habitat layers where fry habitat was defined to be that with a depth between ≤0.15 m and velocity ≤0.5 m/s and parr habitat was that with a depth >0.15 m and a velocity ≤0.5 m/s. Although fry were observed using water deeper than 0.6 m, 0.15 m was chosen as the edge of the fry habitat as it was the only depth contour that could be reliably identified from the orthophotos. For the purposes of analysing fish counts by site, the lower Duncan River was first subdivided by breaking main and side channels into sectors of approximately 50 m perpendicular to the channel's centerline. Next, the sectors were further subdivided based on the presence of dry (depth <0 m) or fast (velocity >0.5 m/s) areas to produce left and right bank sites and in the case of multichannel sections secondary and even tertiary left and right bank sites. Finally, the LDR was broken into sections based on similar habitats with each side channel being considered a separate section (Figure 5-2).

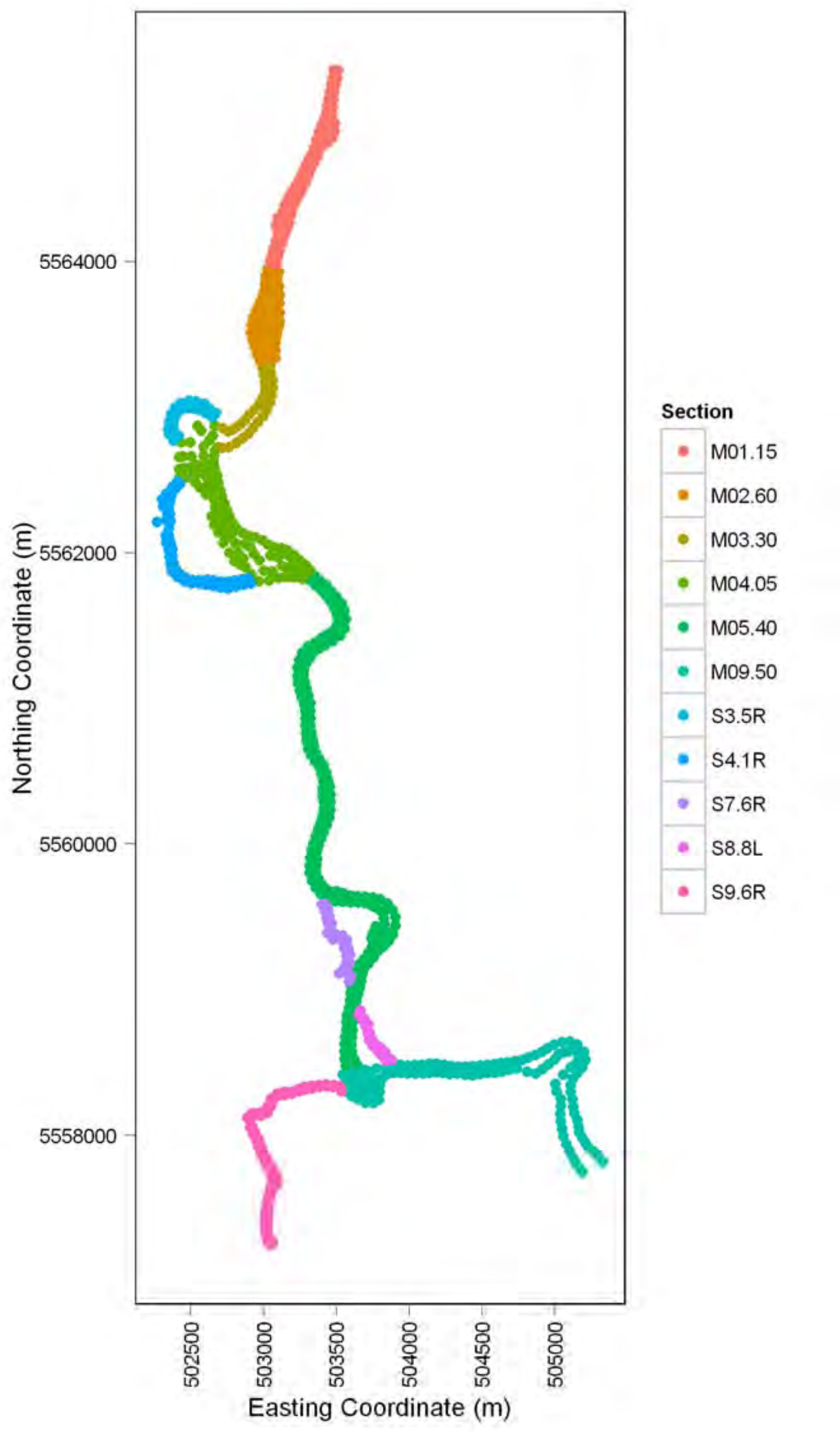

Figure 5-2: Lower Duncan River from its confluence with the Lardeau River in the North to where it meets Kootenay Lake in the South. Channels 6.9R and 8.2L are not shown because they were dry at the time the ortho-based habitat maps were constructed.

5.2.3.3 Abundance Site Selection

In 2010, a subset of the River2D sites were selected using a stratified random procedure to ensure a relatively uniform distribution of sites by reach, side channel, and mesohabitat class. The few sites that were deemed unsafe to snorkel due to fast current associated with large woody debris accumulations were excluded.

In 2011 and 2012, segments of river between 250 and 1,500 m were selected for snorkelling based on visibility, accessibility, safety, available resources and professional judgement.

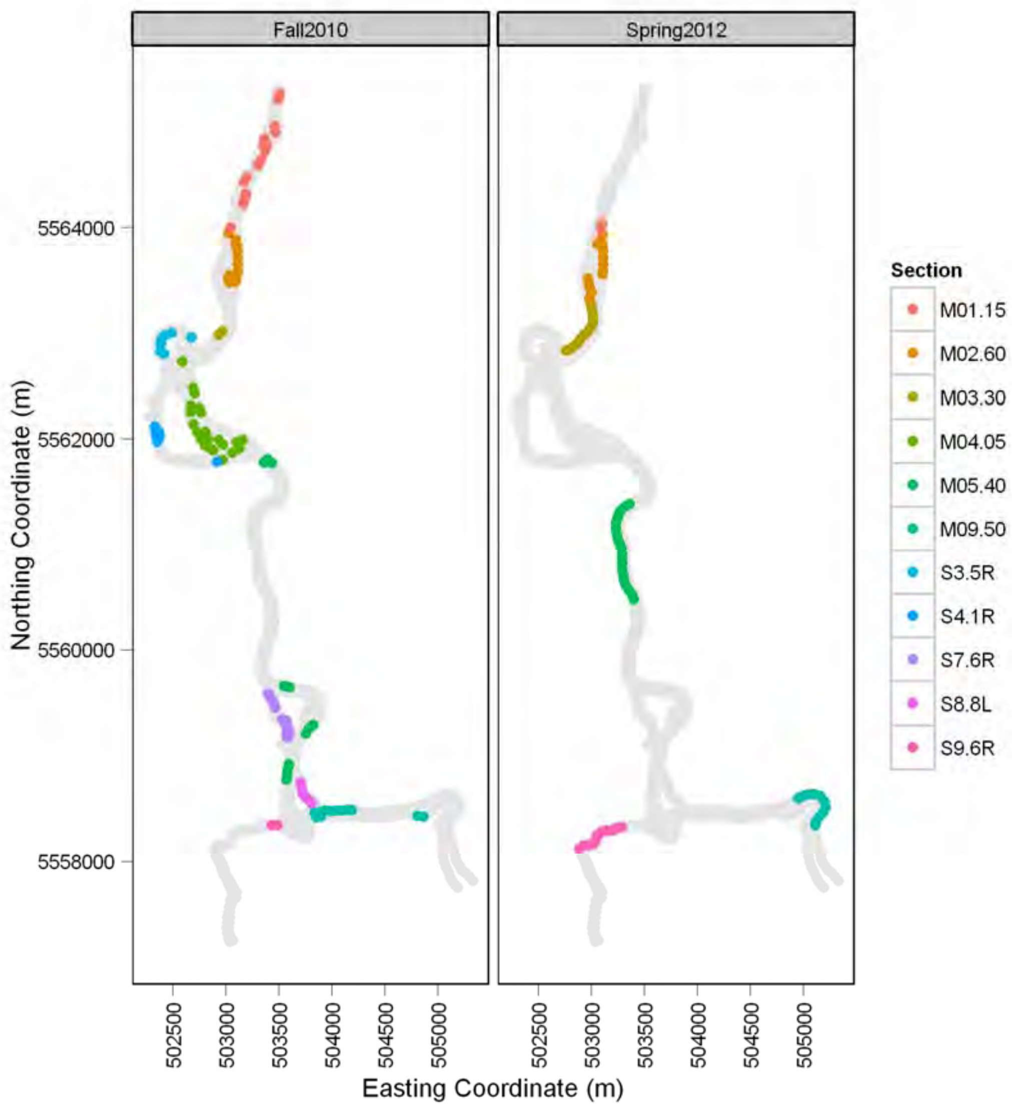

Figure 5-3: Snorkel sites surveyed during Fall 2010 (Thorley et al. 2011) and Spring 2012.

5.2.3.4 Abundance Snorkel Surveys

In 2010, the selected sites were snorkeled using the methods of Decker and Hagen (2009) and Hagen et al. (2010b). The swims were conducted at night by teams of two snorkelers at each site, whom surveyed sites in an upstream direction and coordinated manner while estimating fish length and species observed; information was recorded in waterproof notebooks. In depths less than 15 cm, fish were enumerated by slowly walking through the area while spotlighting the fish from above. Whether or not an individual was marked was also recorded. Underwater visibility was measured each night with the snorkeler moving away from an 8 cm Secchi disk until it was no longer possible to discern the pattern on the disk. The secchi disk was drawn on a page of standard-sized (4.6 x 7.0 inches) white field book using black permanent marker.

In 2010 known numbers of fish were marked at six sites in order to estimate observer efficiencies (Thorley et al. 2011). Consistent with the methods of Decker and Hagen (2009) and Hagen et al. (2010b), fish were caught at night using handnets. The fish were then marked by holding in a solution of 30 mg/l Bismarck brown for 20 minutes (Ewing et al. 1990). The sites were snorkeled the following night by a different crew. Six sites adjacent to the marking sites were also surveyed for marked fish to evaluate the assumption of closure (Thorley et al. 2011).

In 2011 and 2012, river segments were surveyed using the same methods as above with two main modifications: 1) the location of each fish was georeferenced using a handheld GPS unit (Figure 5-4) and 2) one member of each two person crew remained on the bank spotlighting and recording fish observations for both crew members. Mark recapture was not conducted.

5.2.3.5 Abundance Analysis

For the fall and winter surveys, rainbow trout with a fork length less than 100 mm and mountain whitefish with a fork length less than 110 mm were considered to be young-of-the-year (Figure 5-5). For the spring surveys, the cutoff was 110 mm for rainbow trout and 130 mm for mountain whitefish. Individuals with a fork length greater than 200 mm were not considered to be juveniles.

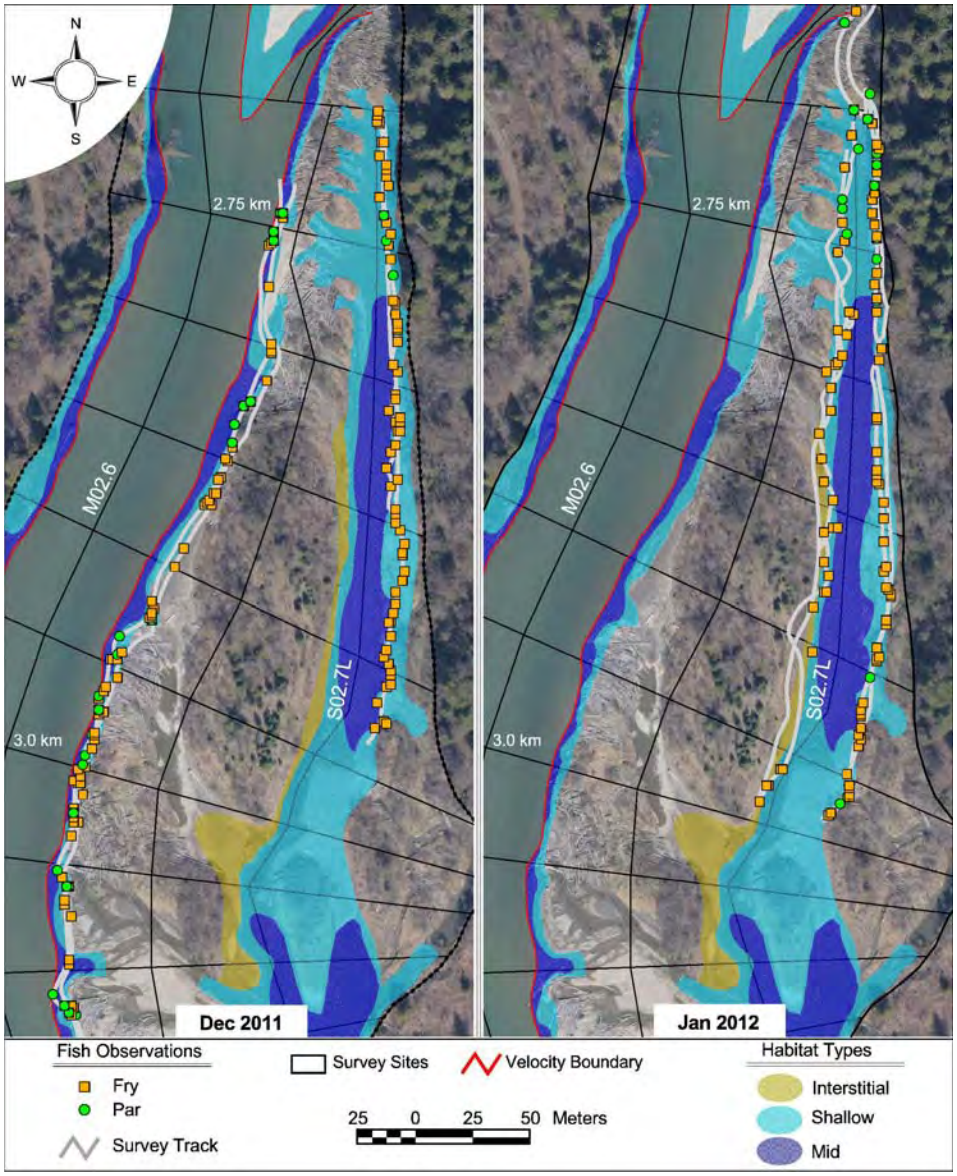

Figure 5-4: ***The locations of georeferenced rainbow trout fry and parr in channel 2.7L and the adjacent primary main channel, December 12, 2011 and January 3, 2012. The areas surveyed which varied between visits is indicated by the grey survey track line.***

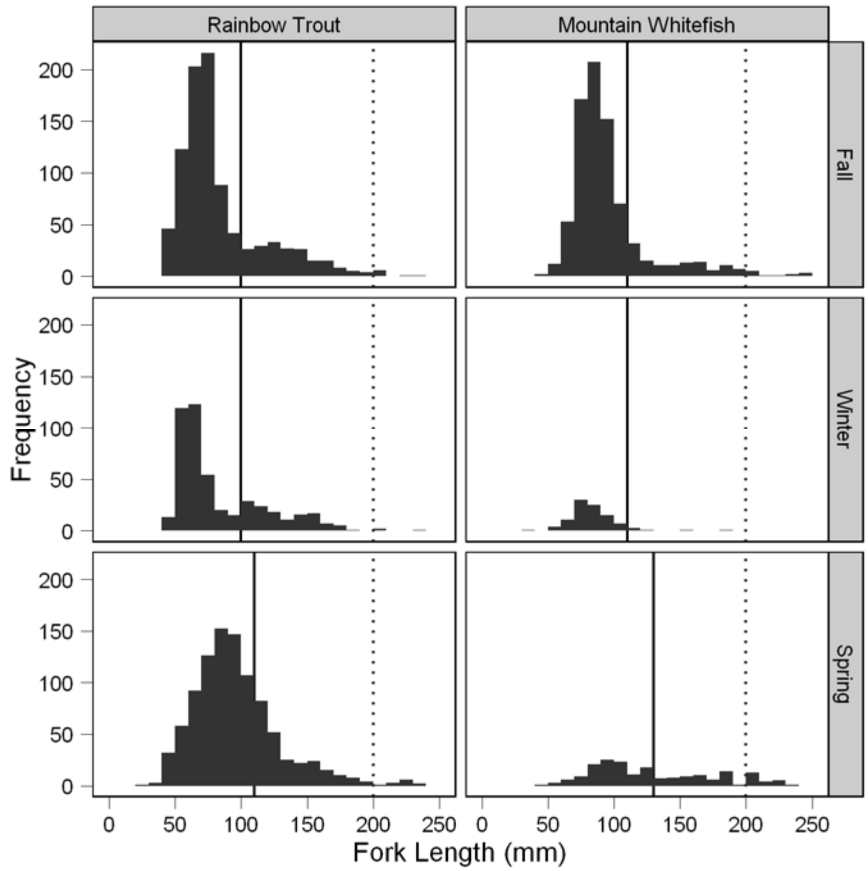

Figure 5-5: ***Length-frequency histograms for rainbow trout and mountain whitefish observed during snorkel surveys. The solid vertical lines indicates the assumed fry-parr length cut-offs while the dotted vertical line indicates the juvenile-subadult cutoff.***

Following Wyatt (2002, 2003) and Korman et al. (2010), juvenile abundances were estimated from the site counts using a hierarchical Bayesian model, which assumed that the number of fish at each site were drawn from a Poisson distribution with a mean density drawn from a log-normal distribution. As the juveniles were primarily restricted to the near-shore margins, fish densities were modeled as the number of individuals per lineal distance. The observed counts were in turn assumed to be drawn from a binomial distribution where *n* was the predicted number of fish at the site and *p* was the observer efficiency. The prior distributions for the observer efficiencies were assumed to be similar to those estimated in the hierarchical Bayesian reanalysis of Decker and Hagen's (2009) juvenile rainbow trout snorkel counts on the Lardeau River (Andrusak 2010). More specifically the log odds site-level rainbow trout fry observer efficiencies were assumed to be drawn from a normal distribution with a mean of -0.53 and a standard deviation of 0.68 (which equates to an observer efficiency of 0.37 with lower and upper 95% quantiles of 0.14 and 0.71). In the case of rainbow trout parr, the log-odds observer efficiency was assumed to be constant at -0.89 (observer efficiency of 0.29). In the absence of any information, the observer efficiencies for juvenile mountain whitefish were assumed to be the same as those for the equivalent life stage in rainbow trout.

Preliminary analysis of the data indicated that there was insufficient information to model the counts if an overdispersion parameter was included (Kéry 2010). Consequently, the final models were simpler than those used by Wyatt (2002, 2003) and Korman et al. (2010) in that they did not allow extra-Poisson variation. Preliminary analysis also indicated that there was insufficient information to include habitat width as an explanatory variable or treat section as a random effect except when considering rainbow trout fry in the LDR. For additional information on the hierarchical Bayesian juvenile abundance models see Appendix B.

5.3 Results

5.3.1 Juvenile Microhabitat Use

The depth habitat use curves indicate that rainbow trout fry tend to be found in shallower water than mountain whitefish fry, which tend to be found in shallower water than parr of either species (Figure 5-6).

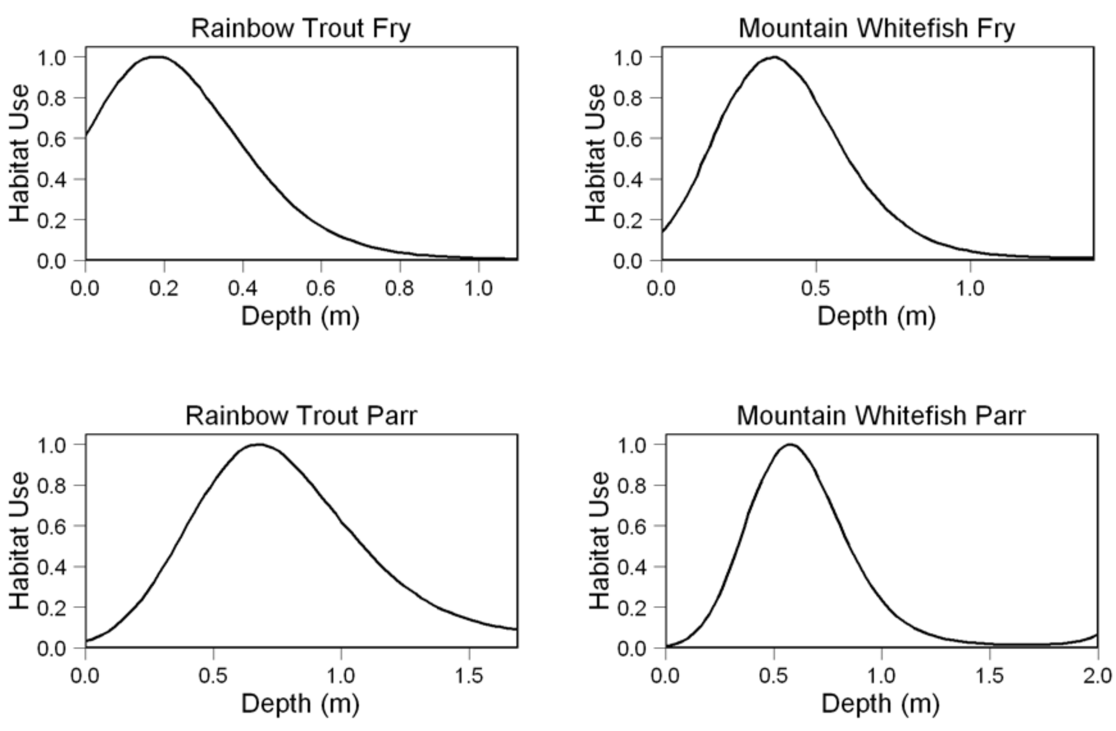

Figure 5-6: Rainbow trout and mountain whitefish fry and parr depth habitat use curves as estimated by the Bayesian habitat use model.

The velocity habitat use curves indicate that rainbow trout tend to be found in slower water than mountain whitefish, while within each species the fry tend to be found in slower water than the parr (Figure 5-7).

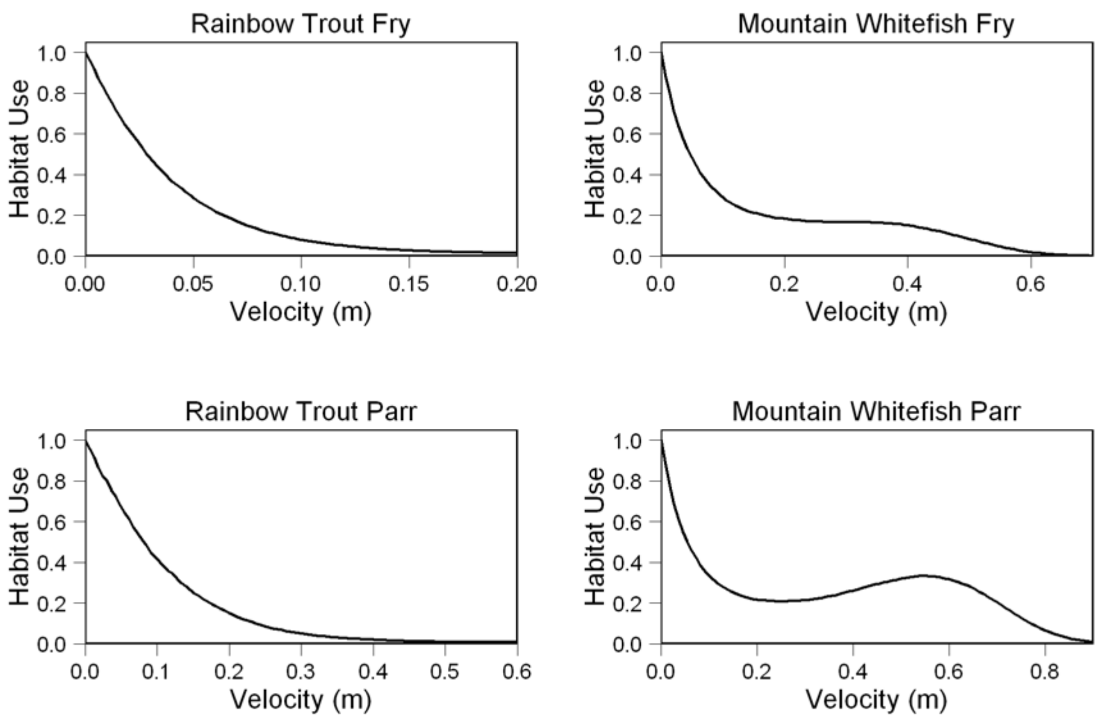

Figure 5-7: Rainbow trout and mountain whitefish fry and parr velocity habitat use curves as estimated by the Bayesian habitat use model.

5.3.2 Juvenile Abundance

The mark recapture estimates for parr, which were based on the marking of just five rainbow trout parr and two mountain whitefish parr respectively were too uncertain to have any utility (Thorley et al. 2011). The estimates for fry suggest that rainbow trout observer efficiencies may be marginally higher in the LDR than the Lardeau River while snorkelers may be less efficient at observering mountain whitefish fry than assumed (Thorley et al. 2011). However, as discussed below, both these results have to be interpreted with caution.

The juvenile abundance model estimated that there was between 29,000 and 64,000 rainbow trout fry (age-0 individuals) in the LDR downstream of the confluence with the Lardeau River during Fall 2010 compared to less than 17,000 age-1 individuals during Spring 2012 (Figure 5-8). Its important to note that because the comparison is separated by more than a year any decline is only ‘apparent’ in the sense that it is not for the same cohort of fish. Even bigger apparent drops were observed for mountain whitefish fry, which the model estimated to fall from more than 28,000 individuals to less than 126. In comparison, rainbow trout parr numbers were relatively stable apparently falling just 24% from 5,500 to

4,200. The estimates for mountain whitefish parr were too uncertain to have any utility (not shown).

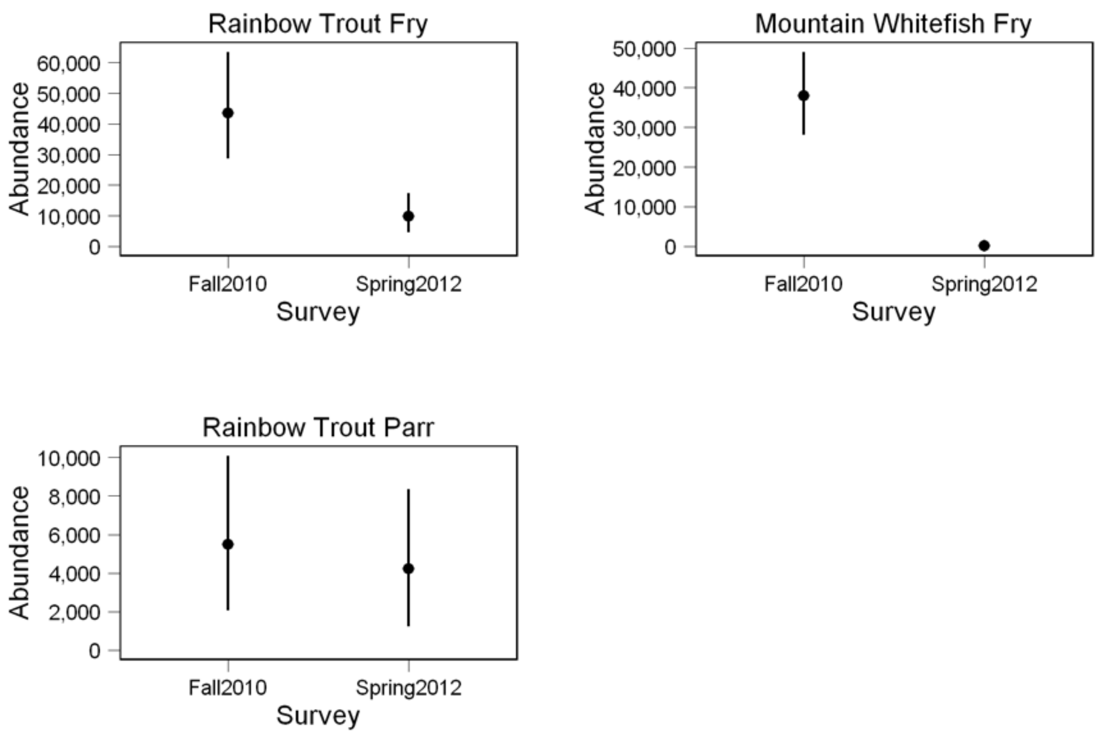

Figure 5-8: ***Rainbow trout and mountain whitefish fry and parr abundance estimates (with 95% credibility intervals) for the LDR downstream of the confluence with the Lardeau River.***

The lineal density estimates by section indicate that rainbow trout are relatively uniformly distributed throughout the LDR with the exception of sections M03.30 and M04.05 (Figure 5-3), which had exceptionally high and low lineal densities, respectively (Figure 5-9). Densities in side channels did not systematically differ from those in the main channel.

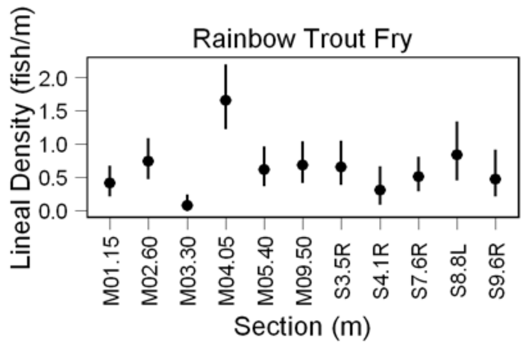

Figure 5-9: ***Rainbow trout fry lineal density estimates (with 95% credibility intervals) for the sections of the LDR downstream of the confluence with the Lardeau River.***

The abundance model estimated that rainbow trout fry densities increased with habitat width with the strongest effect at widths less than 5 m.

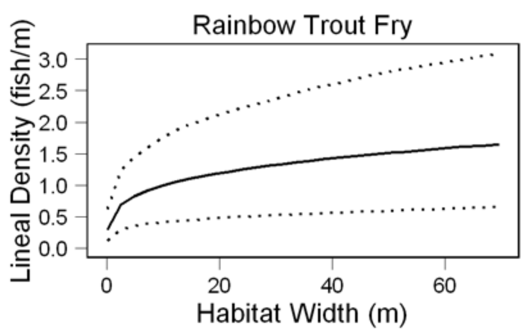

Figure 5-10: ***The estimated relationship between habitat width and lineal density (with 95% credibility intervals) for rainbow trout fry in the LDR downstream of the confluence with the Lardeau River.***

For channel 2.7L, the abundance model estimated that during winter 2011/2012 the number of rainbow trout fry fell from 2,700 in December to 1,100 in January to less than 500 in March (Figure 5-11). Over the same time period the number of mountain whitefish fry initially remained stable before dropping dramatically between January and March, while the number of rainbow trout parr increased 8-fold between the December and January surveys before settling at an intermediate level. The mountain whitefish parr abundance estimates, which were based on just two fish were too uncertain to have any utility (not shown).

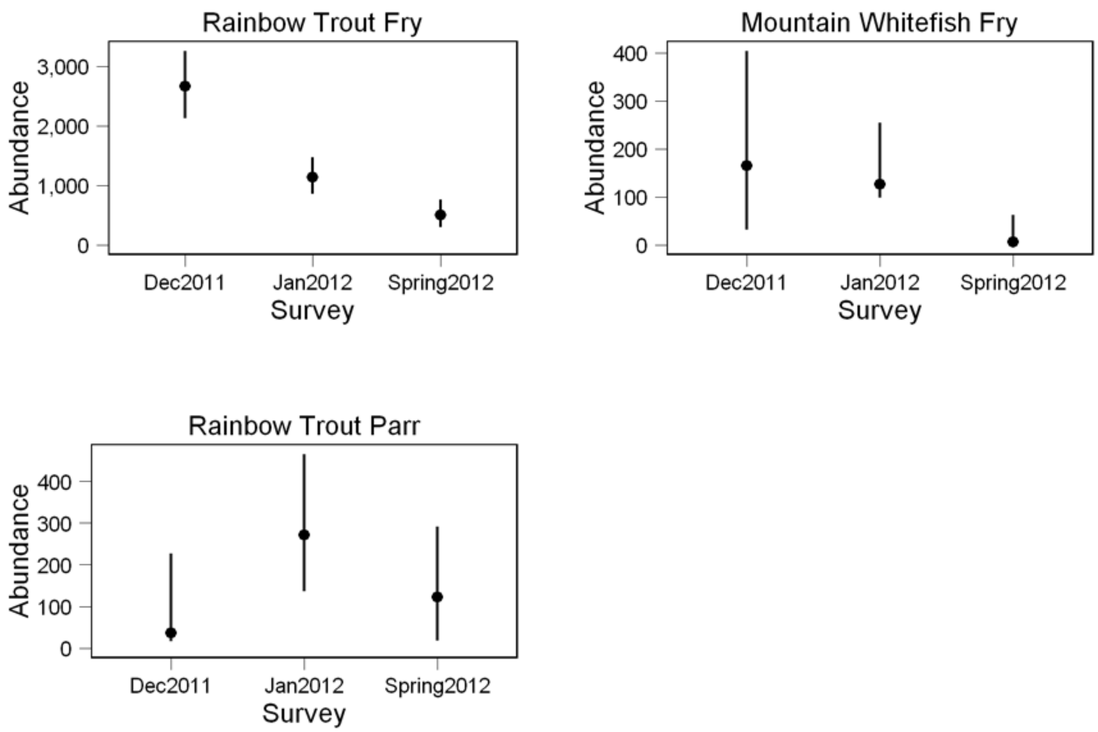

Figure 5-11: Rainbow trout and mountain whitefish fry and parr abundance estimates (with 95% credibility intervals) for channel 2.7L.

5.4 Discussion

The following discussion is structured in terms of the three management questions and their sub-questions.

5.4.1 Management Question 1

The first management question asks for the life history timing, environmental cues and abundance through space and time associated with juvenile rainbow trout and mountain whitefish rearing in the lower Duncan River.

5.4.1.1 Life history timing

The WUP assumed that juvenile rainbow reared in the LDR from April to October. However, the results of this and previous studies (Hagen and Decker 2006, Decker and Hagen 2009) indicate that juvenile rainbow trout rear in the LDR year-round although the abundance of particular age-classes changes throughout the year.

Assuming that rainbow trout eggs survive in the tailout area (see Section 3), the fry would enter the lower Duncan River from late May until the end of June as they emerge from the gravels (based on analysis of spawn timing and ATU data). Later in the summer, they are joined by fry that emerged at Gerrard or other spawning locations in the Lardeau River. For example, it was estimated that in 1966, 100,000 rainbow trout fry entered the LDR from the Lardeau River between July and August (Acara 1969).

The most recent river wide abundance estimates suggest that during their first winter the number of rainbow trout fry in the LDR declines by approximately 75% although it is important to note that the decline is only apparent in the sense that it was not calculated for the same cohort of fish. Nonetheless the decline is within the range estimated by Decker and Hagen (2009) for three cohorts of rainbow trout fry in the Lardeau River (65% - 77%). Furthermore although the comparison assumes identical observer efficiencies, Decker and Hagen (2009) estimated that observer efficiencies were higher in the spring which suggests that the apparent decline in the LDR is conservative. Finally, it is also important to be aware that the decline may also only be apparent in the sense that it is currently unknown whether any of the missing fish outmigrate to Kootenay Lake and experience sufficient survival to eventually contribute to the fishery (Rosenau 1991; Hayes 1995; Graynoth 1999).

Seasonal changes in abundance estimates for the Lardeau River suggest that substantial numbers of age-1 fish then outmigrate in the spring with most of the remaining individuals leaving the river sometime between the late fall and early spring although some fish may remain in the river until they are two or three years of age (Decker and Hagen 2009). With regard to the timing of the spring outmigration, acoustic tagging of larger (>140 mm fork length) rainbow trout parr suggests that it occurs from late May to early June (Andrusak 2010).

The WUP did not explicitly consider the timing of mountain whitefish rearing (BC Hydro 2008). Nonetheless the mountain whitefish spawning component of the current program has estimated that mountain whitefish eggs in the LDR hatch sometime between February and May, depending on location within the study area and which ATU values from the literature are applied (Section 4). Although mountain whitefish numbers are high in the fall they apparently decline precipitously during the winter. For example, during the Fall 2010 snorkel surveys over 1,500 fry were observed in 3.1 km of bank compared to just 56 individuals in 3.4 km of bank during Spring 2012 and during Winter 2011/2012, the number of mountain whitefish fry in channel 2.7L fell 10 fold. AMEC (2005) also observed much lower numbers of juvenile mountain whitefish when snorkeling in the LDR during February compared to May, August, October or November. It is currently unclear to what extent the apparent decline is influenced by seasonal difference in observer efficiencies and whether or not the missing individuals are overwintering in other areas such as the Lardeau River or Kootenay Lake. Anecdotal late winter observations made during the rainbow trout spawning component of the current program suggest that a proportion of the juvenile and adult mountain whitefish populations overwinter in the Spillway area, which presumably offers preferable velocities and/or temperatures compared to the Lower Duncan River.

5.4.1.2 Frequency Distribution (Abundance)

The hierarchical Bayesian analyses of the snorkel count data estimated that there were 44,000 rainbow trout fry, 5,500 rainbow trout parr and 38,000 mountain whitefish fry in the LDR below the confluence with the Lardeau River during Fall 2010. The same analyses estimated that during Spring 2012 there were 10,000 rainbow trout fry, 4,200 rainbow trout parr and 126 mountain whitefish fry.

Comparison of the fall LDR rainbow trout fry numbers with those of the Lardeau River (Andrusak 2010) suggests that pre-winter the two rivers may contain approximately comparable numbers of rainbow trout fry (Thorley et al. 2011) although the lineal habitat in the LDR is a third to a quarter that in the Lardeau River (Thorley et al. 2011). During winter months, rainbow trout fry numbers in the LDR apparently fell by approximately 75%, while the cross-study comparison tentatively suggests that overwintering mortality in rainbow trout parr is around 25%. In contrast the number of mountain whitefish fry apparently declined by between 90 and 99%.

A key assumption of the snorkel count comparison was that the distributions of observer efficiencies were similar to those previously estimated for rainbow trout fry in the Lardeau River. As most of the snorkelers used during these surveys also snorkeled during the Lardeau River surveys, inter-snorkeler variation in observer efficiency can largely be excluded. Nevertheless, salmonid snorkeling efficiency is affected by species, location, habitat, and fish body size as well as water clarity (Hagen et al. 2010b and references therein). The fact that the abundance models were unable to incorporate extra-Poisson variation was at least partly attributed to a lack of site-specific observer efficiency estimates. As part of the HCTF's ongoing stock assessment an integrated analysis of all the rainbow trout snorkel count and mark-resighting data for the Duncan-Lardeau system is planned (G. Andrusak, Biologist, Redfish Consulting Ltd., pers. comm., 2012). This analysis should help resolve some of the uncertainties regarding observer efficiency for rainbow trout. Until the analysis is completed, programs such as the LDR fish stranding impact study (DDMMON-16), which are dependent on the absolute abundance estimates, should allow for the possibility of a halving or doubling of the abundance estimates presented in the current report.

5.4.1.3 Environmental Cues

Environmental cues that trigger the outmigration of juvenile rainbow trout and mountain whitefish are unknown, but likely involve photoperiod, temperature and discharge (Zydlewski et al. 2005). In order to determine the relative importance of the possible environmental cues, outmigration timings of juvenile rainbow trout and mountain whitefish would have to be monitored for multiple years under contrasting discharge and temperature regimes. Environmental cues may also influence habitat selection and feeding or concealment behaviours but there is currently little data available to understand how they might act in the LDR.

5.4.2 Management Question 2

The second management question is concerned with the habitats and habitat preferences associated with juvenile rearing. The implications of the findings for the assessment of the relationships between discharge and juvenile rearing habitat is discussed in Section 5.4.3.

5.4.2.1 Habitats

Preliminary data analysis indicated that, in general, juvenile rainbow trout and mountain whitefish do not exhibit a significant preference for main or side channel habitat with one exception: during high overwinter flows the number of rainbow trout parr in side channel 2.7L increased. Whether or not the densities of rainbow trout and mountain whitefish fry also increased in side channel habitats is unclear as any patterns are confounded by the large apparent changes in overall abundance of this age class during this period, as described previously.

5.4.2.2 Habitat Preferences

The depth habitat use curves indicated that rainbow trout fry used shallower water than mountain whitefish fry, which in turn preferred shallower water than the parr of either species.

The velocity curves suggest that, with the possible exception of mountain whitefish parr, juveniles on the LDR almost exclusively utilize water slower than 0.5 m/s (Figure 5-7). Nevertheless, the hump in the velocity habitat suitability curves (HSC) for mountain whitefish parr at 0.55 m/s may be an artefact of the low sample size and should be interpreted with caution.

Interestingly, the velocity HSCs for rainbow trout fry and parr are quite different to the suitability curves presented by NHC (2010) for rainbow trout and steelhead, which indicate a preference for faster water. This result is consistent with Slaney and Andrusak's (2002, 2003) conclusion that the meso-habitat associations for juvenile steelhead on the Keogh River are not applicable on the Duncan-Lardeau system.

5.4.3 Management Question 3

The third management question is concerned with minimizing habitat dewatering through changes to operations within the constraints of the DDM WUP. In order to answer this question, it is necessary to discuss the assumptions made by the DDM WUP Consultative Committee (CC) in determining minimum flows of 73 m^3/s.

In order to define rainbow trout Effective Rearing Habitat (ERH), the DDM WUP CC assumed that juvenile rainbow trout: 1) rear in the LDR mainstem and side channels between 1 April and 31 October; 2) only utilize habitats that have been wetted for at least 10 days; and, 3) experience all available (wetted) habitat as equally suitable. Then when the resultant definition of ERH was factored into the various tradeoffs and constraints of the WUP process the CC selected a year round minimum discharge at DRL of 73 m^3/s.

Key findings of this and other programs include the presence of significant numbers of juvenile rainbow trout in the LDR year-round; the almost complete absence of juvenile mountain whitefish in late winter; the almost exclusive use of slower, shallower, margin habitat; and the absence of a significant difference in the lineal densities of juveniles in main versus side channel habitats (except perhaps during high discharge). Finally although not tested, the assumption that habitats must be wetted for at least 10 days in order to be utilized is consistent with a study on brown trout in the Selwyn River, New Zealand (Davey and Kelly 2007) although recolonization of a side channel that has been completely dewatered might take longer.

5.4.4 Supplementary Questions

During Winter 2011/2012, two supplementary snorkel swims were undertaken to partially and qualitatively answer four additional questions as indicated below.

1. Do juvenile mountain whitefish appear to overwinter in the LDR?

The data from this and previous studies (AMEC 2005) suggest that in late winter the juvenile mountain whitefish population experiences high mortality and/or migrates into the Lardeau River, Kootenay Lake or refugia in the LDR such as the spillway although the possibility that the low counts are due to low observer efficiencies cannot be currently excluded.

2. Do overwintering juvenile rainbow trout (and mountain whitefish) appear to be primarily associated with side channel or mainstem habitat?

No, although during high discharge densities may increase in side channel habitat (see question 4).

3. Does the increase in flow from 110 to 250 m^3/s appear to be associated with increased use of side channel habitat?

Although rainbow trout parr use of channel 2.7L increased during high flows, interpretation of the changes in fry abundance was confounded by the overwintering declines.

4. Do overwintering juvenile rainbow trout (and mountain whitefish) appear to use slower and deeper water than in the fall?

Although only qualitative and therefore subject to possible observer error or bias the professional opinion of the snorkelers was that winter and spring depth and velocity habitat use was sufficiently similar to that of the fall to justify the use of the same curves.

5.4.4.1 Maximizing Juvenile Productivity

In order to reliably predict changes in fish productivity from changes in operations the periods during the populations' life-cycle when habitat is limiting must also be identified as well as other flow related factors such as temperature, food availability and channel morphology (Annear et al. 2004).

For example, the results of the current study suggest that rainbow trout fry experience an overwinter mortality of approximately 75%. If the overwintering mortality is density-dependent then the availability of fall fry habitat would have little to no consequences for the abundance of older age-classes and therefore overall fish productivity (Huusko et al. 2007). This in turn would suggest that the mortality of fall fry from for instance stranding due to reduction events at DDM (Hildebrand 2011b) might have little to no consequences for the productivity of the rainbow trout population. However, the fact that rainbow trout fry could potentially outmigrate to Kootenay Lake and contribute to the fishery currently confounds identification of the critical period(s) when riverine habitat is likely to be limiting (Rosenau 1991, Hayes 1995). A similar argument applies to mountain whitefish.

5.5 Recommendations for Juvenile Habitat Use

The following are recommendations to further our knowledge about juvenile rainbow trout and mountain whitefish in the LDR to aid in operations management:

1. Conduct more extensive mark-resighting experiments to reduce the uncertainty surrounding the observer efficiency estimates for both rainbow trout and mountain whitefish.
2. Estimate how many days it takes for previously dewatered side channels to be repopulated by juvenile rainbow trout and mountain whitefish.
3. Conduct otolith analyses on adult rainbow trout and mountain whitefish to see if the ages at which they outmigrated from the LDR can be determined (Hayes 1995).

5.6 Considerations for Future Water Management Planning for the Lower Duncan River

- Rainbow trout in the LDR and Lardeau River support an important recreational fishery on Kootenay Lake and should therefore be considered a priority for water management decisions.
- A substantial proportion of the juvenile rainbow trout population in the Lardeau-Duncan system utilizes the LDR.
- Juvenile rainbow trout utilize the LDR year-round while juvenile mountain whitefish numbers appear to decline precipitously during the late winter although the extent to which the low MW counts are due to high mortality versus outmigration versus low observer efficiency is currently unclear.
- Juvenile rainbow trout and mountain whitefish almost exclusively used the slower, shallower, margin habitat.
- Lineal densities of juvenile rainbow trout and mountain whitefish did not differ significantly between main or side channel habitats except during high flow events when rainbow trout parr at least may use secondary channels as refugia.
- Due to uncertainties associated with the outmigration of juvenile rainbow trout and mountain whitefish to Kootenay Lake it is currently unclear at which stage(s) in the life-cycle habitat in the Lower Duncan River is likely to be limiting.

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Appendix A
Bayesian Analyses

Bayesian Analyses

Poisson Consulting Ltd.
Joe Thorley PhD, RPBio

5 July 2012

1 General Approach

Bayesian models were fitted to the data using the software packages R 2.15.0[9] and JAGS 3.2.0[7] which interfaced with each other via the rjags R package. In general the models assumed low information uniform or normal distributions. The posterior distributions were estimated from a minimum of 1,000 samples thinned from the second halves of three Gibbs sampling chains. Model convergence was confirmed by ensuring that R-hat (the Gelman-Rubin-Brooks potential scale reduction factor) was less than 1.1 for each of the parameters in the model[3, 5, 4]. Where relevant, the statistical significance of particular parameters was calculated using two-sided Bayesian p-values[1, 6].

Following Bradford et al. (2005)[2], the influence of particular variables was, where informative, expressed in terms of the effect size (i.e., percent change in the response variable) with 95% credibility intervals. When the variable was considered a random effect, the percent change in the response was quantified with respect to the typical value, i.e., the expected value of the underlying distribution from which the observed values represent random draws. Plots were produced using the ggplot2 R package [10].

2 JAGS Distributions, Functions and Operators

JAGS distributions, functions and operators are defined in the following two tables. For additional information on the JAGS language, which is a dialect of the BUGS language, see the JAGS User Manual[8].

JAGS Distribution	Description
dbern(p)	Bernoulli distribution
dbin(p, n)	Binomial distribution
dlnorm(mu, sd^-2)	Log-normal distribution
dnorm(mu, sd^-2)	Normal distribution
dpois(lambda)	Poisson distribution
dunif(a, b)	Uniform distribution

JAGS Function or Operator	Description
1:n	Vector of integers from 1 to n
<-	Deterministic relationship
T(L,U)	Truncate a distribution so that it lies between L and U
exp(x)	Exponential of x
for (i in 1:n) {...}	Repeat ... for 1 to n times incrementing i each time
log(x)	Natural logarithm of x
logit(x)	Log-odds of x
max(x, y)	Greater of x or y
phi(x)	Standard normal cumulative distribution function
sum(x)	Sum of values in x
x[1:n]	Subset of first n values in x
x^y	Power where x is raised to the power of y
~	Stochastic relationship

3 JAGS Models

The following sections provide the JAGS model code and variable and parameter definitions for each of the analyses.

3.1 Habitat Use

3.1.1 Variables and Parameters

Variable/Parameter	Description
Use	Observed relative use
bHabitat0	Intercept for log relative use
bHabitat1	Effect of habitat on log relative use
bHabitat2	Effect of second-order habitat polynomial on log relative use
bHabitat3	Effect of third-order habitat polynomial on log relative use
eLogUse	Expected log relative use
nrow	Number of habitat bins
sUse	Standard deviation of the residual log relative use

3.1.2 Model Code

```
model {
    sUse ~ dunif(0, 5)

    bHabitat0 ~ dnorm(0, 5^-2)
    bHabitat1 ~ dnorm(0, 5^-2)
    bHabitat2 ~ dnorm(0, 5^-2)
    bHabitat3 ~ dnorm(0, 5^-2)

    for (i in 1:nrow) {
      eLogUse[i] <- bHabitat0 + bHabitat1 * Habitat[i]
+ bHabitat2 * Habitat[i]^2 + bHabitat3 * Habitat[i]^3
      Use[i] ~ dlnorm(eLogUse[i],sUse^-2)
```

```
    }
  }
```

3.2 Rainbow Trout Spawn Timing

3.2.1 Variables and Parameters

Variable/Parameter	Description
Dayte[i]	Day of the year on the ith survey
Redds[i]	Cumulative redd count on the ith survey
bPeakIntercept	Intercept for the peak spawn timing
bPeakYear[yr]	Effect of the yrth year on the peak spawning timing
bReddsIntercept	Intercept for the total redd count
bReddsYear[yr]	Effect of the yrth year on the total redd count
bRedds[yr]	Expected total number of redds in the yrth year
ePeak[i]	Expected peak timing for the ith survey
eRedds[i]	Expected cumulative redd count on the ith survey
nYear	Number of years
nrow	Number of surveys (across all years)
sPeakYear	Standard deviation of the annual variation in peak spawn timing
sRedds	Standard deviation of the residual cumulative redd count
sReddsYear	Standard deviation of the annual variation in the total redd count
sTiming	Standard deviation of the duration of spawning

3.2.2 Model Code

```
model {
    sTiming ~ dunif(0, 14)
    sPeakYear ~ dunif(0, 21)
    sReddsYear ~ dunif(0, 200)
    sRedds ~ dunif (0, 10)

    bReddsIntercept ~ dunif(10, 250)
    bPeakIntercept ~ dunif(90, 120)

    for (yr in 1:nYear) {
      bPeakYear[yr] ~ dnorm (0, sPeakYear^-2)
      bReddsYear[yr] ~ dnorm (0, sReddsYear^-2)
      bRedds[yr] <- bReddsIntercept + bReddsYear[yr]
    }

    for (i in 1:nrow) {
      ePeak[i] <- bPeakIntercept + bPeakYear[Year[i]]
      eRedds[i] <- phi((Dayte[i] - ePeak[i])/sTiming) * bReddsYear[Year[i]]
      Redds[i] ~ dnorm (eRedds[i], sRedds^-2)
    }
  }
```

3.3 Stage Height

3.3.1 Variables and Parameters

Variable/Parameter	Description
Stage[i]	Recorded stage height in the ith period
Time[i]	Number of hours since the start of the time series of the ith period
bCor	Autocorrelation coefficient
bDDM	Effect of Duncan Dam discharge on the stage
bDDM.bLAR	Effect of interactions between discharge on the stage
bDDM.bLAR2-bDDM2.bLAR2	Effect of interactions between second-order discharge polynomials
bDDM2-LAR3	Effect of discharge polynomials on the stage
bIntercept	Intercept for the stage
bLAR	Effect of Lardeau River discharge on the stage
eCorStage[i]	Expected stage in the ith period corrected for autocorrelation
eStage[i]	Expected stage in the ith period
nrow	Number of recorded stage heights
sStage	Standard deviation of the residual stage

3.3.2 Model Code

```
model {
    sStage ~ dunif(0, 2)

    bCor <- 0.4

    bIntercept ~ dnorm(0, 2^-2)

    bDDM ~ dnorm(0, 2^-2)
    bLAR ~ dnorm(0, 2^-2)
    bDDM.LAR ~ dnorm(0, 2^-2)

    bDDM2 ~ dnorm(0, 2^-2)
    bDDM3 ~ dnorm(0, 2^-2)
    bLAR2 ~ dnorm(0, 2^-2)
    bLAR3 ~ dnorm(0, 2^-2)

    bDDM.LAR2 ~ dnorm(0, 2^-2)
    bDDM2.LAR ~ dnorm(0, 2^-2)
    bDDM2.LAR2 ~ dnorm(0, 2^-2)

    eCorStage[1] <- eStage[1]
    for(i in 2:nrow) {
      eCorStage[i] <- eStage[i] + bCor^(Time[i] - Time[i-1])
* (Stage[i-1] - eStage[i-1])
    }

    for (i in 1:nrow) {
      eStage[i] <- bIntercept + bDDM * DDM[i] + bLAR * LAR[i] + bDDM2 * DDM[i]^2
+ bLAR2 * LAR[i]^2 + bDDM3 * DDM[i]^3 + bLAR3 * LAR[i]^3
+ bDDM.LAR * DDM[i] * LAR[i] + bDDM2.LAR * DDM[i]^2 * LAR[i]
```

```
+ bDDM.LAR2 * DDM[i] * LAR[i]^2 + bDDM2.LAR2 * DDM[i]^2 * LAR[i]^2
      Stage[i] ~ dnorm(eCorStage[i], sStage^-2)
    }
  }
```

3.4 Mountain Whitefish Spawn Timing

3.4.1 Variables and Parameters

Variable/Parameter	Description
DayteFemale[fm]	Day of the year the fmth female was encountered
DayteMale[ma]	Day of the year the math male was encountered
GSI[ma]	Measured GSI of the math male
Spent[fm]	Whether or not the fmth female was spent
YearFemale[fm]	Year the fmth female was encountered
YearMale[ma]	Year the math male was encountered
bPeakIntercept	Intercept for the peak spawn timing
bPeakYear[yr]	Effect of the yrth year on the peak spawning timing
bPeak[yr]	Expected peak spawn timing in the yrth year
bPostGSI	Intercept for the post-spawning male GSI
bPreGSI	Intercept for the pre-spawning male GSI
eGSI[ma]	Expected GSI of the math male
ePhi[ma]	Expected proportion of math male's milt remaining
eSpent[fm]	Expected probability that the fmth female was spent
nFemale	Number of females
nMale	Number of males
nYear	Number of years
sGSI	Standard deviation of the residual variation in male GSI
sTiming	Standard deviation of the duration of spawning

3.4.2 Model Code

```
model {
    sTiming ~ dunif(0, 21)
    sGSI ~ dunif(0, 5)

    bPreGSI ~ dunif (0, 10)
    bPostGSI ~ dunif (0, 10)
    bPeakIntercept ~ dunif (275, 365)

    bPeakYear[1] <- 0
    for (yr in 2:nYear) {
      bPeakYear[yr] ~ dnorm(0, 7^-2)
    }

    for (yr in 1:nYear) {
      bPeak[yr] <- bPeakIntercept + bPeakYear[yr]
    }

    for (fm in 1:nFemale) {
      eSpent[fm] <- phi((DayteFemale[fm] - bPeak[YearFemale[fm]])/sTiming)
```

```
        Spent[fm] ~ dbern(eSpent[fm])
    }

    for (ma in 1:nMale) {
      ePhi[ma] <- phi((DayteMale[ma] - bPeak[YearMale[ma]])/sTiming)
      eGSI[ma] <- ePhi[ma] * bPostGSI + (1 - ePhi[ma]) * bPreGSI
      GSI[ma] ~ dnorm(eGSI[ma], sGSI^-2)
    }
  }
```

3.5 Juvenile Abundance

3.5.1 Variables and Parameters

Variable/Parameter	Description
Count[st, sr]	Number of fish observed at stth site in srth survey
Length[st, sr]	Length of the stth site in the srth survey
LogWidth[st, sr]	Log useable habitat width of the stth site in the srth survey
MinFish[st, sr]	Number of fish observed at stth site in srth survey
Surveyed[st, sr]	Proportion of the stth site surveyed in the srth survey
bEfficiency	Intercept for log odds observer efficiency
bFish[st, sr]	Expected fish at the stth site in the srth survey
bSection[sc]	Effect of the scth section on log lineal density
bSurvey[sr]	Intercept for log lineal density in the srth survey
bWidth	Effect of log useable width on log density
eDensity[st, sr]	Expected lineal density at the stth site in the srth survey
eEfficiency[st, sr]	Expected observer efficiency at the stth site in the srth survey
eLogitEfficiency[st, sr]	Expected log odds of observer efficiency at the stth site in the srth survey
nSection	Number of sections
nSite	Number of sites
nSurvey	Number of surveys
sEfficiency	SD of site within survey variation in log odds observer efficiency
sSection	Standard deviation of the effect of section on log lineal density

3.5.2 Model Code

```
model {

  sSection ~ dunif(0, 5)

  for (sc in 1:nSection) {
    bSection[sc] ~ dnorm(0, sSection^-2)
  }

  for (sr in 1:nSurvey) {
    bSurvey[sr] ~ dnorm(0, 5^-2)
  }

  bWidth ~ dnorm(0, 5^-2)

  for (st in 1:nSite) {
```

```
    for (sr in 1:nSurvey) {
      eLogitEfficiency[st,sr] ~ dnorm(bEfficiency, sEfficiency^-2)
      logit(eEfficiency[st,sr]) <- eLogitEfficiency[st,sr]

      log(eDensity[st,sr]) <- bSurvey[sr] + bWidth * LogWidth[st, sr]
 + bSection[Section[st,sr]]
      bFish[st,sr] ~ dpois(eDensity[st,sr] * Length[st,sr]) T(MinFish[st,sr],)
      Count[st,sr] ~ dbin(eEfficiency[st,sr] * Surveyed[st,sr], bFish[st,sr])
    }
  }
}
```

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Appendix B
Adult Mountain Whitefish Night Spotlighting Maps

Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads

- Paved
- Unpaved
- Named Sidechannel
- Streams

Density

- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

Disclaimer

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PROJECT:
DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on October 13, 2011.

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

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Legend

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Scale:1:6,000

0 50 100 200

Metres

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Scale:1:6,000

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Legend

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Scale:1:6,000

0 50 100 200

Metres

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Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on October 13, 2011.

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads

- Paved
- Unpaved
- Named Sidechannel
- Streams

Density

- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

Disclaimer

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PROJECT:
DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 6, 2011.

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads
- Paved
- Unpaved
- Named Sidechannel
- Streams

Density
- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

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Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 6, 2011.

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Legend

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- Kilometre Line
- Boat launch
- Communities
- Dam

Roads

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- Unpaved
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- Streams

Density

- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

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PROJECT:

DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 14, 2011.

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

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads

- Paved
- Unpaved
- Named Sidechannel
- Streams

Density

- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

Ortho Date: April 30, 2009
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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 14, 2011.

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GIS FILE: MW_study_v2_111114.mxd	REVISION DATE: 2011/01/28	
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Legend

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- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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Juvenile Habitat Survey: Poisson Consulting

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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 14, 2011.

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
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Roads

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- Streams

Density

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Scale:1:6,000

0 50 100 200

Metres

Reference

Ortho Date: April 30, 2009
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Juvenile Habitat Survey: Poisson Consulting

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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 6, 2011.

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

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads
- Paved
- Unpaved
- Named Sidechannel
- Streams

Density
- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 21, 2011.

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

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
- Communities
- Dam

Roads
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- Streams

Density
- 0.00 - 15.00
- 15.01 - 50.00
- 50.01 - 100.00
- 100.01 - 200.00
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Scale:1:6,000

0 50 100 200

Metres

Reference

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

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PROJECT:
DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 21, 2011.

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

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
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Roads
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Scale:1:6,000

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Metres

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Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 28, 2011.

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UTM Zone 11	NAD83	BB	LP	LP

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
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- Dam

Roads

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Density

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- 200.01 - 1656.00

Scale:1:6,000

0 50 100 200

Metres

Reference

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

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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 28, 2011.

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Legend

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PROJECT: DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 28, 2011.

JOB No: VE51873	COMPILATION DATE: 2011/01/28	Page 3 of 3
GIS FILE: MW_study_v2_111128.mxd	REVISION DATE: 2011/01/28	
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Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on November 21, 2011.

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Legend

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DDMMON-2 Lower Duncan River Habitat Use Monitoring

Relative mountain whitefish densities along left bank of LDR as assessed with spotlighting on December 4, 2011.

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

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Legend

- Start and End Point
- Kilometre Mark
- Kilometre Line
- Boat launch
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- Dam

Roads

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Density

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GIS FILE: MW_study_v2_111204.mxd	REVISION DATE: 2011/01/28	
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Legend

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