Determination of Gerrard Rainbow Trout Stock Productivity at Low Abundance

Final Report

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FISH AND WILDLIFE
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Executive Summary

Annual stock assessment of the juvenile Gerrard Rainbow Trout (*Oncorhynchus mykiss*) population in the Lardeau and Duncan rivers is considered a management priority within the Kootenay Region. Assessing and determining the Gerrard rainbow trout stock's reproductive capacity and productivity is essential for managing this highly exploited population. Assessment of the in-river juvenile abundance in unison with adult escapement data provides important information for defining a stock-recruitment relationship used in determining useable biological reference points for management of this unique population. The recent unprecedented collapse of the lakes' Kokanee population has provided an ideal opportunity to obtain information on the population dynamics at low stock abundance, a key data piece required for determining stock status. This report summarizes spring 2016 survey work conducted on the Lardeau and Duncan rivers to assess juvenile recruitment at low stock abundance.

Snorkel surveys provide a proven method in obtaining juvenile abundance estimates on a medium to large size river in comparison to more labour intensive and more expensive methods such as electrofishing. This project has utilized night time snorkel methods since 2006 to assess Gerrard juvenile abundance on the Lardeau and Duncan rivers. Starting in 2011, increased sampling effort has improved precision thus reducing uncertainty in abundance estimates. Surveys conducted in the spring of 2016 covered approximately 10.4% Lardeau River and 6.6% of the Duncan River. A total of 8.7% of the mainstem shoreline and 17.7% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 7.6% of the mainstem shoreline and 0.7% of the side channel habitat were surveyed in the Duncan River in 2016.

In 2016, age 1 abundance for the Lardeau and Duncan rivers was estimated to be 43,570 (95% CRI 30,990-59,110) which is substantially lower than previous years. Spawner escapements at Gerrard using area under the curve (AUC) from daily counts have provided an index of abundance since 1961. The 2016 juvenile recruitment estimates are the progeny from the 2015 spawn of Gerrard Rainbow Trout which was estimated to be 301 AUC, well off the record high observed in 2012 of over 1,500 AUC.

Data analysis fitted a Beverton Holt stock-recruit (SR) curve for Gerrard Rainbow Trout based on river recruit and spawner data. Preliminary results of the stock-recruit relationship suggest no appreciable increase in recruitment in juvenile abundance as spawner abundance increased above 500 AUC. This relationship also suggests that most of the density dependent mortality in the early life stages occurs prior to age 1. Average annual recruitment is estimated to be approximately 85,000 age 1 juveniles. Based on the 2016 data, the SR also indicates that the maximum reproductive performance (recruits per spawner) has declined, indicating the population did not compensate in

survival at low abundance. It is uncertain whether the decline is a function of decreased egg production or an actual decline in overwinter mortality associated with limited or no Kokanee production in the rivers. Therefore, results should be used with caution until more information at low stock abundance can be obtained.

The recent collapse of Kootenay Lakes' Kokanee population has had a severe impact of the Gerrard Rainbow Trout population. The 2015 spawner numbers declined precipitously to a near historic low and their size and condition in the lake have also declined. This current status is an unfortunate circumstance for this population but provides a unique opportunity to assess the production of age 1 trout in the river at anticipated extremely low spawner numbers. Results of this project to date have provided estimates of the carrying capacity of the Lardeau-Duncan Rivers during high spawner years however to accurately assess stock productivity, several estimates of recruitment at very low stock abundances are required. It is recommended that future management of Gerrard Rainbow Trout population develop and adopt an abundance based framework utilizing reference points from indices of stock status to initiate management actions. Defining reference points for management requires a measure of carry capacity and stock productivity which can only be obtained at low stock levels. The expected decline in the Gerrard population over the next few years provides the opportunity to assess stock productivity, a critical parameter in the abundance based reference point framework.

Acknowledgements

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Field work related to this project was conducted under some very difficult and adverse weather conditions. Extraordinary effort by the snorkel survey crew is gratefully acknowledged. Stef Himmer, Kyle Mace, Kerry Reed, Gary Pavan, and Jillian Sanders formed a great working team that made the work much easier than otherwise it could have been. Joe Thorley is acknowledged for his data analysis and modeling. As well, thanks to Gary for organizing all spatial data (GIS) and providing maps.

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Introduction

Assessing and determining a stock's productivity, which can only be obtained when stock abundances decline to low levels, is essential in managing exploited populations (Myers et al. 1999). Estimates of stock productivity (i.e. maximum reproductive rate) and carry capacity are two of the most important parameters in population dynamics (Myers 2001), crucial for defining biological reference points for stock management (Johnston et al. 2002). Use of stock-recruitment (SR) relationships is extensively used to assess the stock's productivity and capacity for defining important biological reference points (BRP) for management. Moreover, assessment of the reproductive performance of a stock is essential in determining whether various levels of mortality are sustainable over time.

The recent unprecedented collapse of Kootenay Lakes' Kokanee (*Oncorhynchus nerka*) population has created serious problems for the predator populations on Kootenay Lake (MFLNRO 2016). The Gerrard Rainbow Trout (*Oncorhynchus mykiss*) population abundance has undergone a severe decline as a result of extremely low Kokanee abundance. The decline in the Rainbow Trout population provides a unique opportunity to obtain information on the population dynamics at low stock abundance, a crucial piece of information in stock assessment for the management of many fish stocks (Myers et al. 1999, Walters and Martell 2004).

This study focused on obtaining information on the recruitment of Gerrard Rainbow Trout under low stock abundance. Stock abundance (spawner numbers) is expected to be at or near record lows over the next 3-5 years, due to the near collapse in the Kokanee population on the lake (MFLNRO 2016). Obtaining estimates of juvenile production from the low abundance of spawners is expected to be highly informative in understanding the population dynamics of these unique trout population. Such information will provide necessary data in developing a SR relationship for this ecotype and assist fisheries managers in future using an abundance based management framework, similar to that for Steelhead in BC (MFLNRO 2015).

Project objectives:

Obtaining further estimates of juvenile production at contrasting escapements (high and low) is very important in defining a stock recruitment relationship and understanding the dynamics of this unique stock. When completed, this project is intended to achieve the following:

1. Estimate spring parr densities and estimate spring standing stock from Lardeau and Duncan rivers

2. Define a stock-recruitment relationship for Gerrard Rainbow Trout needed for management

3. Determine river carrying capacity at low stock abundance

4. Develop a hierarchical Bayesian Model to estimate abundance and uncertainty in abundance estimates

5. Obtain estimates on contrasting escapement information (high and low)

Background

The Gerrard Rainbow Trout that inhabit Kootenay Lake constitute a distinct population (Keeley et al. 2007) of large piscivorous rainbow trout (*Oncorhynchus mykiss*) and are an important sport species sought after in the intensive recreational fishery (Andrusak and Andrusak 2012). The value of this unique stock has warranted a better understanding of how the population is regulated and how mortality imposed from the recreational fishery influences the status of these piscivorous rainbow trout (Andrusak and Thorley 2013). As well, conservation concern of this stock arises since most of their natural production (spawning and rearing) is entirely dependent upon the Lardeau River (Irvine 1978, Redfish Consulting Ltd. 2002, Andrusak 2005)

Determining the long-term sustainability of exploited wild fish stocks in many recreational fisheries is an important goal for fisheries management in BC. Management actions are often initiated (i.e. harvest policy) by comparing stock status with specific biological reference points (BRP's) that set limits on mortality imposed on a fish population (Johnston et al. 2002). BRP's are targets derived from indices of stock status that are used to initiate management actions to meet particular management objectives (Johnston et al. 2000, 2002, Johnston 2013). The objectives of reference point management is to invoke actions when stock abundance exceeds critical thresholds, primarily where a population cannot sustain itself as a result of increasing levels of harvest mortality (Gabriel and Mace 1999, Williams and Shertzer 2003).

Assessing and determining a stock's productivity is essential in managing exploited populations (Hilborn and Walters 1992, Walters and Martell 2004). Use of the stock recruitment relationship provides the ability to assess the stock's productivity and define important biological reference points for management. The maximum annual reproductive rate is one of the most important parameters in population dynamics, and is critical for effective fisheries management (Myers 2001). Assessing the compensatory capacity of this stock is essential for understanding the effects of fishing on Kootenay Lake. Additional year's data to that obtained by Decker and Hagen (2009) was required to strengthen the stock-recruit relationship and improve on sampling shortcomings.

Obtaining information on the reproductive performance of this stock is essential and has been directly linked to a recent study to determine if current rates of exploitation are sustainable on Kootenay Lake (Andrusak and Thorley 2014).

Initial data collected from a juvenile study from 2005-2010 on the Lardeau River identified some important attributes of this stock (Decker and Hagen 2009). In general, their work achieved the main objectives; 1) feasibility of utilizing night snorkel survey methods for assessing juvenile trout in large rivers 2) provided relatively precise standing stock estimates of juvenile rainbow trout in the Lardeau River and 3) defined juvenile trout habitat use and preference. Overall, their study revealed that juvenile densities within the river were relatively low and estimates by age class (0-3 year old) were much lower than originally anticipated despite increasing escapements in recent years (MOE data on file). While their estimates were fairly precise for spring 1 year old parr, older age classes (> age 1) estimates were somewhat less informative for management purposes due to high variability. Despite this, the spring 1 year olds (herein referred to as parr) estimates did provide stable year over year (limited annual variability) estimates that, combined with spawner escapement data, could be used for defining a stock recruitment relationship. The survey results reported herein is intended to improve on the accuracy and precision of the earlier work of Decker and Hagen (2009) and Andrusak (2010).

Recently, rainbow trout spawning has also been observed in the tailrace of the dam in the Duncan River (Thorley et al. 2012). While the primary focus for this study is the Lardeau River, some previous assessments of juvenile rainbow trout that rear in the lower Duncan River (LDR) downstream of the Lardeau River confluence have been made (AMEC 2005, 2008, Decker and Hagen 2006). At the onset of the HCTF funded project the FWCP provided supplementary funding for parr assessments in the lower Duncan River.

Study Area

The Lardeau and Duncan rivers are located at the northern end of Kootenay Lake. Kootenay Lake is lies between the Selkirk and Purcell mountain ranges in the southeast corner of British Columbia and is located within the Interior Western Hemlock bio-geo-climatic zone. The Lardeau River forms at the outlet of Trout Lake and flows approximately 45 km in southeastern direction to its confluence with the regulated Duncan River near Meadow Creek, BC. The Lardeau valley is quite narrow, often less than 2 km across the valley floor. The unregulated Lardeau River is the largest tributary to the Duncan River and has the largest influence during freshet when it contributes approximately one third of the total discharge historically observed in the Duncan River. Much of the high inflows on the Lardeau River are a result of snowmelt during freshet from mid-May to late July. The Lardeau River has a mean annual discharge of 58 m^3/s and is monitored by an Environment Canada gauge (08N007) located above the confluence with the Duncan River.

The Duncan River is regulated by the Duncan Dam located approximately 1 km upstream with the confluence of the Lardeau River. The Duncan and Lardeau River confluence is located 10 km upstream of Kootenay Lake. The Duncan River has a relatively wide floodplain at the north end of Kootenay Lake at the Duncan River delta, where the valley widens to about 4 km. The Duncan River, regulated by the Duncan Dam, has a mean annual discharge of162 m^3/s and has target flows requirements (BC Hydro 2005). Discharge is monitored by an Environment Canada gauge (08N118) located below the confluence of the Duncan River.

Both the Lardeau and Duncan rivers are relatively low gradient systems varying from <1% to 2% and are active geo-morphologically, with meandering broad floodplains, large wood accumulations (log jams), alluvial bar development, and extensive bank erosion (Slaney and Andrusak 2003).

The study area includes the Lardeau and Duncan rivers with a total lineal length (both banks) of 196.2 km (Figure 1). However, the majority of the study area is located in the Lardeau River which constitutes 141.6 km of river bank from the total of 196.2 km.

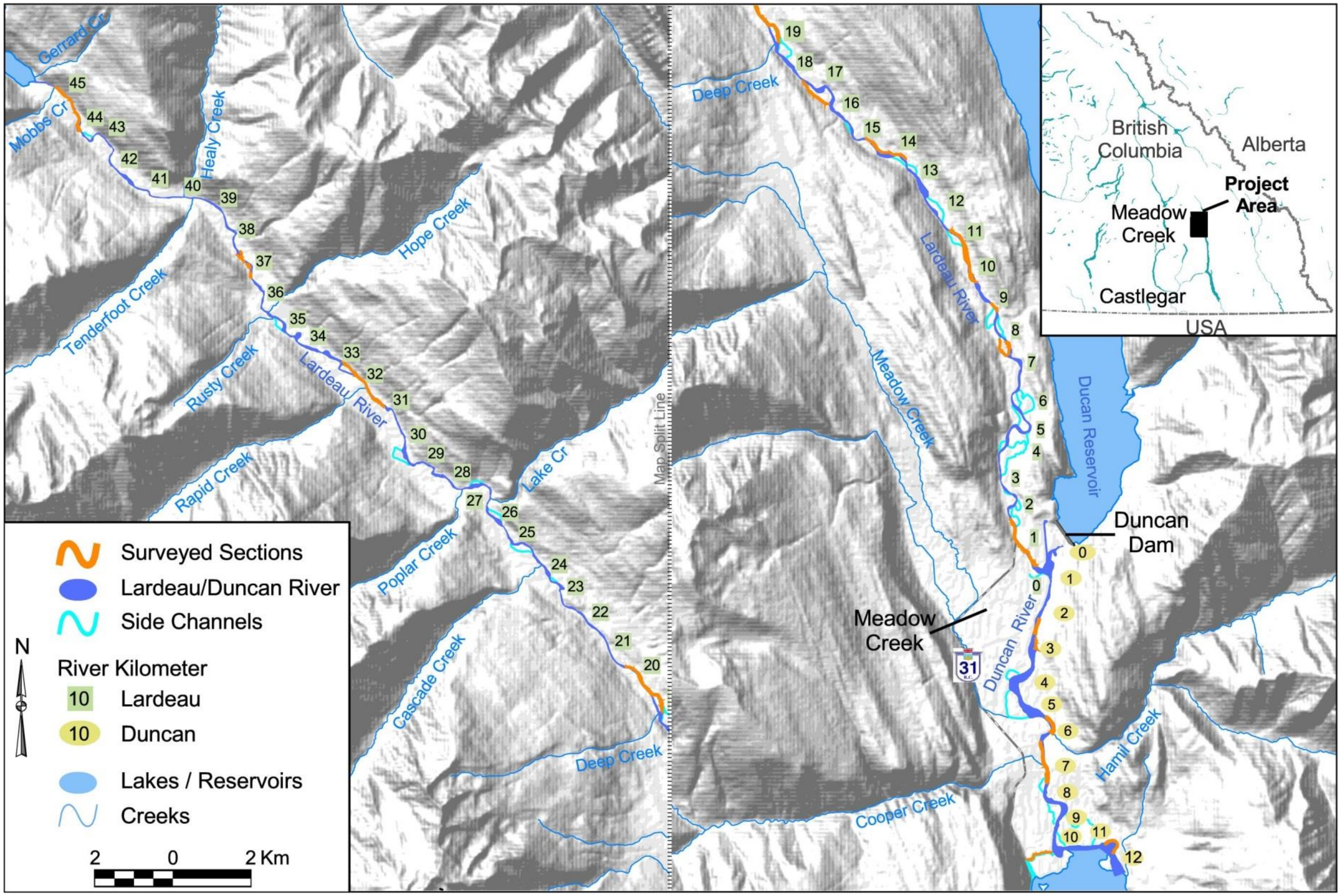

Figure 1. **Location of Lardeau and Duncan rivers and length of study area (km)**

Methods

Overview

Obtaining estimates of abundance of juvenile fish populations on medium to large rivers has proven to be a difficult task in fisheries investigations. The uncertainty in estimating abundance of a fish population occupying large streams or rivers is largely driven by spatial variability in abundance across sample sites rather than uncertainty in the estimates of abundance within sites (Hankin 1984). To overcome such issues, estimating population size at the whole river level requires the development of an assessment method that can effectively allocate sampling effort to improve the accuracy across sites which can sacrifice accuracy at the site level (Mitro and Zale 2000, Wyatt 2002, Thurow et al. 2006). “Rapid assessment’ using snorkel surveys and single pass electrofishing provide methods that reduce the uncertainty in estimating population size by increasing sampling effort within a large river system (Mitro and Zale 2000, Wyatt 2002, Korman et al. 2010a, Hagen et al. 2010).

Numerous investigations have determined that night time snorkel survey methods provide a unique way to effectively sample juvenile fish populations on medium to large rivers. This method efficiently allocates sampling effort over a larger proportion of the total river compared to more other labour intensive methods such as electrofishing (Wyatt 2002, Korman et al. 2010a) However, utilizing such methods also requires an understanding of some inherent limitations which can be dependent upon which life stage is sampled (Thurow and Schill 1996, Korman et al. 2010a). Using snorkel survey methods requires an understanding of observer efficiency or the proportion of fish observed within a given site (Mullner et al. 1998). Assessment of observer efficiency requires use of mark-recapture to determine probability of detection (Hagen et al. 2010).

Since 2011 this project has utilized night time snorkel methodology to obtain estimates of abundance for Gerrard Rainbow Trout rearing in the Lardeau and Duncan rivers, following a similar design detailed by Decker and Hagen (2009) during their work from 2005-2010. In general, the design incorporates six important variables required to obtain relatively precise and unbiased estimates of juvenile distribution and abundance within the river:

1. Total amount of habitat based throughout the river (Lardeau and Duncan)
2. Sampling effort (proportion of total habitat covered)
3. Nigh time snorkel surveys (fish counts)

4. Estimated observer efficiency using a mark recapture
5. Age structure (length at age)
6. Juvenile abundance estimates by age class

The time period of data in this report includes two distinct survey designs: 1) Decker and Hagen (2009) results from 2005-2010 termed the “Index” design and 2) since 2011, a more recent modified survey “GPS” design to address and account for concerns of relatively high variability and potential bias in juvenile estimates noted during the 2006-2010 surveys. Therefore since 2011 under the “GPS” design, total sampling effort on the Lardeau and Duncan rivers increased substantially in attempt to address these concerns. For example, to achieve a coefficient of variation of <0.2 in total river abundance estimates for age 1 spring parr (Korman et al. 2010a), approximately 5% of the total useable shoreline length must be sampled in the Lardeau and Duncan rivers. Since both systems combine to account for 196.2 lineal kilometers of shoreline habitat, based on Korman et al. (2010), a minimum of 9.8 kilometers must be sampled annually. Since 2011, the precision goal (C.V. <0.2) has been met each year under the “GPS” design (2011-2014).

Stream-wide habitat survey

In order to convert an estimate of mean fish density to an estimate of standing stock, an estimate of the total amount of habitat for that stratum was required. Lardeau and Duncan River distance calculations were derived in GIS using GEO BC 1:20,000 Freshwater atlas base data. River centerlines and linear bank boundaries were extracted in GIS and further refined to better represent the current conditions using digital ortho-photography and field ground truthing. Total river distance was calculated using both left and right bank linear boundaries (Appendix 1). It should be noted, the analysis did not incorporate the stratification of habitat into the analysis for this report.

River kilometer was generated along the river centerline every 0.01 km. Duncan River was calculated downstream from Duncan Dam to match historical river kilometers. Lardeau River was calculated from the confluence with Duncan River upstream. Section breaks were generated every 0.25km for left and right linear bank boundaries using river kilometer cross sections.

Side channels were mapped in GIS using ortho-photography and ground calibrated for accuracy for both the Lardeau and Duncan rivers (Appendix 1). BC Hydro also provided high resolution imagery conducted during the Water Use Plan (WUP) work on the Lower Duncan River (LDR). Side channel distances were calculated based on the points where they diverged from the river bank linear boundary. Importantly, estimates of habitat may alter from year to year as more analysis of high quality ortho-imagery becomes available.

Sampling effort

Randomly selected sites were obtained from GIS information on the Lardeau and Duncan rivers each year. Site lengths ranged from 1000 to 2000 meters and were surveyed by a 2 person crew at night. The approach accounted for the potential effects of incremental changes in fish density, stream discharge, and ecological conditions not available in previous designs along the length of the rivers. Similar to Decker and Hagen (2009), sites in side channel/braid habitat, snorkelers surveyed the entire wetted width. At sites in mainstem habitats, however, snorkelers surveyed only one shore. Shoreline habitat types often differed on opposite sides of the mainstem channel but the width of the river was too large at most locations to cross safely at night. Useable width, as detailed in Decker and Hagen (2009), was also determined at each site. The model assessed whether fish density was influenced by useable width at each site.

Further stratification of habitat could potentially be done utilizing GIS mapping which may improve the precision of the estimates. However, GIS mapping of the rivers was not complete at the time of reporting. Therefore analysis includes river wide abundance estimates from mainstem and side channel habitat combined in the Lardeau and Duncan rivers.

Nightime snorkel surveys

Calibrated night snorkeling methodology was utilized to obtain estimates of juvenile trout abundance in the Lardeau system (note: see following section re: estimated observer efficiency using mark recapture method). Besides being more visible at night compared to daytime, most salmonids in larger streams are also found closer to shore at night (Edmundson et al. 1968, Thurow and Schill 1996, Portt et al. 2006) and are less active (Bonneau et al. 1995), making them easier to count. Snorkel surveys commenced 0.5 hours after dusk, and did not exceed 4 hours in duration, based on Bradford and Higgins (2000).

During March 2016 fish counts by means of snorkel surveys were conducted by two-person crews. The snorkel crews used handheld dive lights to illuminate the sampling sites. In mainstem shoreline sites, snorkelers systematically surveyed one bank in an upstream direction and surveyed out as far as was physically possible from stream margin or until no fish were observed (generally < 2 m). In contrast, snorkelers surveyed the entire wetted width in the side channels and braid sites, with each snorkeler entering the site at its downstream end and systematically sweeping in an upstream direction the area between stream bank and the agreed upon mid-point of the site. Of particular importance at all mainstem, side channel and braid locations was the need for regular communication between snorkelers to ensure that duplication of counts did not occur, especially in the instances where fish were present in mid-channel areas. Previous years' experience found that snorkelers consistently could make observations well beyond the nighttime offshore distribution of juvenile trout.

Snorkel surveys have been reported to be ineffective for estimating the abundance of age-0+ salmonids (Griffith 1981, Hillman et al. 1992, Campbell and Neuner 1995) due to the fact that they occupy shallow (< 30 cm deep) nearshore habitats that are difficult for snorkelers to survey from an underwater offshore position. Korman et al. (2010) concluded a similar finding for juvenile steelhead on the Cheakamus River. Therefore, at shallow sites, one of the snorkelers systematically covered the shoreline on foot with a light to count fish in shallow water not observable by underwater snorkelers as detailed in Decker and Hagen (2009). They found that small fish in the shallow margins of the shoreline were easy identified and counted. For further detail see Decker and Hagen (2009).

Mark-recapture

Mark-recapture methods were implemented to estimate snorkeling efficiencies (the proportion of a fish population in a site that snorkelers detect), detailed in (Hagen et al. 2010). A sub-sample of the total number of sites surveyed was selected for the mark-recapture study. One night prior to the regular snorkeling survey, trout were captured and marked throughout the site. Snorkelers captured fish using a single diver equipped with one or two large aquarium nets affixed to handles. The snorkeler easily captured encountered fish during thorough searches at locations selected systematically throughout the site. The snorkeler captured fish in deeper water from an underwater, offshore position, while fish in shallow water were captured by dip net by a second crew member using a light while walking slowly along the stream margin. Minimizing site disturbance was a primary goal of the marking methodology. Captured fish were handed to the second crew member on the shore, who immediately measured the fish (fork length to nearest 5 mm), tagged it and returned it to the location where it was originally captured.

Fish were tagged using # 16 or 18 fish hooks (Hagen et al. 2010). The hooks had a visible piece of fluorescent chenille attached to the shank so the divers could readily observe them and with the counts used for estimating observer efficiency (Hagen et al. 2010).

Age determination

Fish with a fork length ≤ 100 mm (parr) were considered age 1 while fish with a fork length (FL) ≥ 101 were considered to be older parr (> age 2).

Analysis of Data

A Hierarchical Bayesian Mixed model (HBM) was fitted to the data using software packages R 3.2.4 (R Core Development Team 2013) and JAGS 4.2.0 (Plummer 2003) using Markov Chain Monte Carlo (MCMC) simulation. Convergence of the model was monitored using the Gelman and Rubin (1992) $\hat{R}$ as modified by Brooks and Gelman (1998). The binomial mixed model is described by two simple conditional probability statements: 1) state process and 2) observation process (Kéry 2010, Kéry and Schaub 2011) and is detailed in Appendix 1.

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

The posterior distributions of the *fixed* (Kéry and Schaub 2011) parameters are summarised in terms of a *point* estimate (mean), *lower* and *upper* 95% credible limits (2.5th and 97.5th percentiles), the standard deviation (*SD*), percent relative *error* (half the 95% credible interval as a percent of the point estimate) and *significance* (Kéry and Schaub 2011).

Variable selection was achieved by dropping *insignificant* (Kéry and Schaub 2011) fixed (Kéry and Schaub 2011) variables and *uninformative* random variables. A fixed variable was considered to be insignificant if its significance was ≥ 0.05 while a random variable was considered to be uninformative if its percent relative error was $\geq$ 80%. The Deviance Information Criterion (DIC) was not used because it is of questionable validity when applied to hierarchical models (Kéry and Schaub 2011).

The results are displayed graphically by plotting the modelled relationships between particular variables and the response with 95% credible intervals (CRIs) with the remaining variables held constant. In general, continuous and discrete fixed variables are held constant at their mean and first level values respectively while random variables are held constant at their typical values (expected values of the underlying hyperdistributions) (Kéry and Schaub 2011). Where informative the influence of particular variables is expressed in terms of the *effect size* (i.e., percent change in the response variable) with 95% CRIs (Bradford et al. 2005).

Snorkel Efficiency

Obtaining annual estimates of fish abundance using snorkel survey counts relies on the ability of surveyors to accurately observe fish numbers and size. It was assumed for estimating fish numbers that closure at each site was met and that immigration and emigration was negligible. Understanding snorkel efficiency is crucial in deriving estimated abundance and the uncertainty in fish counts at index sites using snorkel survey data given that $p < 1$ (detection probability). However, variable flows, visibility, habitat complexity (logs, debris, boulders), size of fish, observer efficiency by individual, site to site and year to year factors may also effect the variability in estimates.

Parameterization of the model is detailed in Table 1 and model code is available in Appendix 1. The observer efficiency for Age-1 fish was estimated using a mark-resight binomial model (Kéry and Schaub 2011).

Key assumptions of the observer efficiency model include:

- The observer probability varies with study design (Index and GPS).
- There is no tag loss.
- There is no emigration of marked fish.
- The number of marked fish that are re-sighted is described by a binomial distribution.

Table 1. Parameter distribution and description for Bayesian observer efficiency model.

Variable/Parameter	Description
bEfficiency	logit(eEfficiency) intercept
bEfficiencyStudyDesign[ii]	Effect of iith study design on logit(eEfficiency)
eEfficiency[ii]	Expected capture efficiency on iith visit
Marked[ii]	Number of marked fish prior to iith visit
Resighted[ii]	Number of marked fish resighted on iith visit
StudyDesign[ii]	Study design of iith visit

Density and Abundance Estimates

The abundance was estimated from the length bias-corrected observer count data using an over-dispersed Poisson model (Kéry and Schaub 2011). The annual abundance estimates represent the total number of fish in the study area.

Parameterization of the model is detailed in Table 2 and model code is available in Appendix 1. Key assumptions of the abundance model include:

- The lineal fish density varies with year, useable width and river kilometer as a polynomial, and randomly with site.
- The observer efficiency at marked sites was as estimated by the observer efficiency model (which varied by study design).
- The observer efficiency also varies with visit type (standard count versus presence of marked fish) within study design, and randomly with swimmer.
- The expected count at a site is the expected lineal density multiplied by the site length, the observer efficiency and the proportion of the site surveyed.
- The residual variation in the actual count, which is gamma-Poisson distributed, varies with the annual lineal fish density.

Table 2. Parameter distribution and description for Bayesian abundance model.

Variable/Parameter	Description
bDensityMarking	Effect of Marking on log(eDensity)
bDensityRkmX	Polynomial coefficients of effect of river kilometer on log(eDensity)
bDensitySite[ii]	Effect of iith site on log(eDensity)
bDensityWidth	Effect of site width on log(eDensity)
bDensityYear[yr]	Estimate of log(eDensity) for yrth year
bEfficiencySwimmer[ii]	Effect of iith swimmer on logit(eEfficiency)
bEfficiencyVisitStudy[ii, jj]	Effect of iith visit type within jjth study design on logit(eEfficiency)
bSDispersion0	Estimate of log(eSDispersion)
bSDispersion1	Effect of bDensityYear on log(eSDispersion)
eAbundance[ii]	Expected abundance of fish at site of iith visit
eCount[ii]	Expected total number of fish at site of iith visit
eDensity[ii]	Expected lineal density of fish at site of iith visit
eDispersion[ii]	Expected overdispersion of Count[ii]
eEfficiency[ii]	Expected observer efficiency on iith visit
eSDispersion[ii]	Expected SD of overdispersion of Count[ii]
logit(bEfficiencyStudy[ii])	Effect of iith study design on logit(eEfficiency)
Marking	Whether a site has been chosen as a marking site under the different study designs
Rkm[ii]	River kilometer of iith visit
sDensitySite	SD of effect of site on log(eDensity)
sEfficiencySwimmer	SD of effect of swimmer on logit(eEfficiency)
Site[ii]	Site of iith visit
SiteLength[ii]	Length of site of iith visit
StudyDesign[ii]	Study design of iith visit
SurveyProportion[ii]	Proportion of site surveyed on iith visit
Swimmer[ii]	Swimmer of iith visit
VisitType[ii]	Visit type of iith visit
Width[ii]	Site width of iith visit
Year[ii]	Year of iith visit

Stock-Recruitment

The relationship between the number of spawners in a given year (S) and the number of Age-1 recruits the following spring (R) was estimated using a Bayesian Beverton-Holt stock-recruitment model (Walters and Martell 2004):

$$R = \frac{a \cdot S}{1 + b \cdot S} \quad ,$$

where a is the maximum reproductive performance per spawner, and b determines the population size scaling.

Parameterization of the model is detailed in Table 3 and model code is available in Appendix 1. Key assumptions of the stock-recruitment model include:

- The prior probability a is normally distributed with a mean of 500 and a SD of 250; this mean is based on an average of 8,000 eggs per female spawner, a 50:50 sex ratio, 50% egg survival, 50% post-emergence fall survival and 50% overwintering survival.
- The residual variation in the number of recruits is log-normally distributed.

In addition, we may determine the maximum recruit population K that the environment can sustain indefinitely, the carrying capacity, by the relation:

$$K = \frac{a}{b} \quad .$$

Table 3. Parameter distribution and description for Bayesian stock recruitment model.

Variable/Parameter	Description
a	Maximum reproductive performance per spawner
b	Population size scaling parameter
eRecruits[i]	Expected number of recruits in i^{th} spawn year
Recruits[i]	Number of recruits in i^{th} spawn year
Spawners[i]	Number of spawners in i^{th} spawn year
sRecruits	Standard deviation of residual variation in log(eRecruits)

Distribution

Distribution of observed counts was also assessed using GIS layers and mapped according to size categories. A GIS meso-habitat layer[1] for the Lardeau and Duncan rivers, developed from BC Government LRDW 1:20,000, was used to assist with distribution (Appendix 3). Linear bank boundaries and river centerline, used to calculate

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[1] The entire GIS meso-habitat layer is available but too large to include in report

river kilometre (Rkm) for each system, were extracted from the Freshwater Atlas layers and corrected by an experienced photo interpreter using Orthos. Delineation of habitat and Rkm from each system, within the defined bank boundaries was then digitized to develop the initial pre-typing polygons representing the GIS habitats. Geo-referenced observations of individual fish during snorkel surveys from observed counts can be displayed spatially, demonstrating information on distribution and habitat use (Appendix 4). *However, it should be noted that Ortho-imagery used in the assessment of habitat within each of the systems was not current, with the exception of Duncan River, and may provide substantial error in assessing fish habitat relationship as a result of changes in river morphology over time*.

Results

It should be noted that estimates of fish density and abundance, total habitat, percentage of habitat surveyed have changed from prior reported results for both the Lardeau and Duncan rivers. Changes reflect improved GIS capability in estimating total habitat and stratification, improved estimates of observer efficiency and increased sampling effort.

No estimates are available for older parr (> age 2) for 2016 due to limited observer efficiency information and model convergence.

Stream-wide habitat survey

The 2016 survey involved inclusion of sites of both banks with the Lardeau River and Duncan River comprise a total of 141.6 km and 54.6 km of shoreline, respectively (Table 4). These estimates combined (196.2 km) include both main and side channel habitat within both systems. Mainstem habitat comprises 114.9 km of shoreline, while side channels constitute 26.6 km of habitat in the Lardeau River. Meanwhile, mainstem habitat comprises 37.8 km of shoreline and side channel constitute 16.9 km in the Duncan River.

Surveys conducted in the spring of 2016 covered approximately 10.4% Lardeau River and 6.6% of the Duncan River (Table 4). A total of 8.7% of the mainstem shoreline and 17.7% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 7.6% of the mainstem shoreline and 0.7% of the side channel habitat were surveyed in the Duncan River in 2016.

Table 4. **Estimated shoreline meters and estimated shoreline meters on the Lardeau and Duncan rivers.**

River	Channel	Surveyed (km)	Not Surveyed (km)	Total (km)	% Surveyed (km)
Lardeau	Main	10.1	104.8	114.9	8.7%
	Side	4.7	21.9	26.6	17.7%
Duncan	Main	2.9	34.9	37.8	7.6%
	Side	0.7	16.2	16.9	4.1%
Total		**18.4**	**177.8**	**196.2**	**Avg 9.53%**

Night-time snorkel surveys

A total of 842 juvenile rainbow trout were observed during the night time surveys conducted in the Lardeau and Duncan rivers in 2016. While the focus of the study was rainbow trout, juvenile and sub-adult whitefish (*Prosopium williamsoni*), bull trout (*Salvelinus confluentus*) and burbot (*Lota lota*) were also observed.

Survey data provided good and reliable insight into the age structure of juvenile rainbow trout rearing in the Lardeau and Duncan rivers. Length-frequency histograms and age data from previous year's data (Decker and Hagen 2009) indicate the probable age structure of the 2016 fish observations. Data suggests a separation in fork length between age-1 and older parr and to a lesser extent between age-2 and age-3 juveniles. In the latter case, information from scale-age analysis is needed to reliably separate older parr (Decker and Hagen 2009, Andrusak 2010, 2013). Nevertheless, the data suggests that age 1 (defined as parr) are ≤ 100 mm, ranging from 25-90 mm, age 2 fish had a fork length between 100 and 150 mm and older juveniles had a fork length >150. Relatively few trout greater than 200 mm have been observed during the study. It is uncertain if this is a limitation of snorkeler visibility or absence of larger trout.

Observer efficiency

A total of 3 sites were used to obtain observer efficiency using mark-recapture methods in the spring of 2016, further improving observer efficiency data collected from the previous years' studies to obtain estimates of age class abundance (Andrusak 2015). Efficiencies are provided for age 1 only and the assumption of closure at each site was met and that immigration and emigration was negligible based on assessment of movement of marked fish above and below sites. Information on movement of tagged fish above and below marked sites indicated emigration was less than <3.5% and similar to that reported in (Hagen et al. 2010). It is acknowledged that no assessment of tag loss was conducted which may also bias estimates.

The improved study design (GPS) since 2011 using night time snorkel survey method for the Lardeau and Duncan rivers suggested a diver observer efficiency of 32% (Table 5,

Figure 2). This estimate is substantially lower than the estimated 55% efficiency on the same rivers derived by Hagen and Decker (2009). The results from the improved design from 2011-2014, 2016) suggest that the previously reported estimate of observer efficiency by Decker and Hagen (2009) was too high thus likely underestimating the juvenile abundance by 1.5-3x. Posterior model predictions for parameters estimates are summarized in Appendix 5.

Table 5. **Predicted capture efficiency for Rainbow Trout age 1 by study design from 2006-2014 & 2016 (with 95% CRIs).**

Study Design	Estimate	Lower 95% CRI	Upper 95% CRI	SD
Index	0.55	0.47	0.63	0.039
GPS	0.32	0.26	0.37	0.028

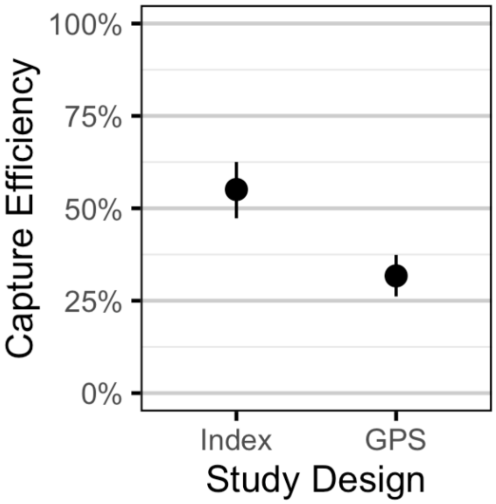

Figure 2. **Predicted capture efficiency for Rainbow Trout age 1 by study design from 2006-2014 & 2016 (with 95% CRIs).**

Further analysis of observer efficiency was derived between mark-recapture estimates conducted at select sites compared to counts conducted at regular selected sites for both study periods (Index vs GPS). This analysis suggested that age 1 estimates at the mark-recapture sites had substantially higher observer efficiencies compared to counts conducted at regular selected sites (Figure 3). This suggests a potential bias with mark-recapture methods that may be related to divers changing their behavior and/or search efficiency when marked fish are known in advance to be present.

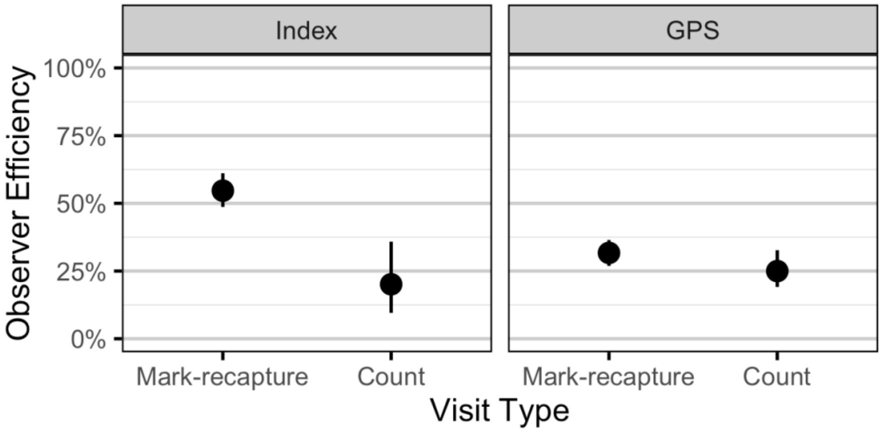

Figure 3. **Predicted observer efficiency for Rainbow Trout age 1 by visit type and study design from 2006-2014 & 2016 (with 95% CRIs).**

Density and Abundance Estimates

Annual age 1 density has averaged slightly greater than 1.1 fish per lineal meter for the study period (Table 5). It should be noted that the first year (2006) of the study yielded an age 1 density of 2.41 fish per lineal meter (95% CRI 1.21-4.76). However, this estimate is highly variable owing to emphasis on defining study methodology, lack of coverage and the initial survey (2006) result indicated more uncertainty compared to other years (Table 5). Nonetheless, over the study period there was an increasing, general improvement in the precision of the estimates with the coefficient of variation improving from 0.37 to 0.15.

Table 5. **Estimated age 1 density (fish/m) in Lardeau and Duncan rivers from 2006-2014 & 2016**

Year	Estimate	Lower 95% CRI	Upper 95% CRI	SD
2006	2.41	1.21	4.76	0.46
2007	1.00	0.45	1.96	0.19
2008	1.37	0.63	2.58	0.25
2009	1.04	0.48	1.94	0.20
2010	1.08	0.48	2.24	0.22
2011	1.04	0.72	1.48	0.10
2012	1.01	0.72	1.35	0.09
2013	0.71	0.52	0.97	0.06
2014	0.45	0.32	0.61	0.04
2016	0.18	0.12	0.24	0.02

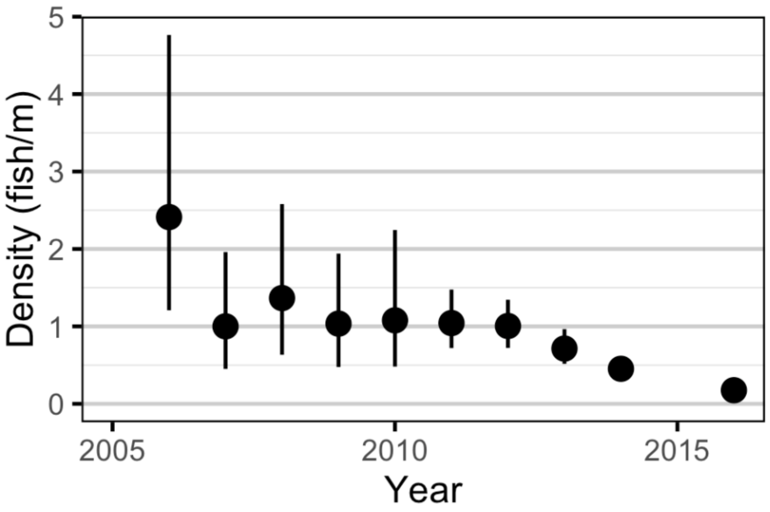

Figure 4. **Predicted lineal density of Rainbow Trout age 1 by year 2006-2014 & 2016 (with 95% CRIs).**

Useable width along the river shorelines of < 2m showed a positive relationship and were a predictor of juvenile density for age 1 on both the Lardeau and Duncan rivers (Figure 5). Juvenile fish density also displayed a decreasing gradient downstream towards the Duncan River and Kootenay Lake (Figure 6). While not explicitly displayed, juvenile density and abundance estimates were generally higher in the Lardeau River compared to the Duncan River over the entire study period.

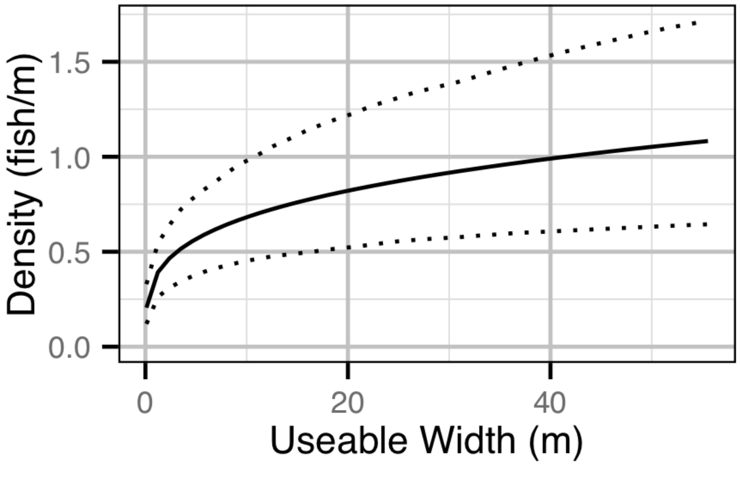

Figure 5. **Predicted lineal density (fish/m) of Rainbow Trout age 1 2006-2014 & 2016 by useable width (with 95% CRIs).**

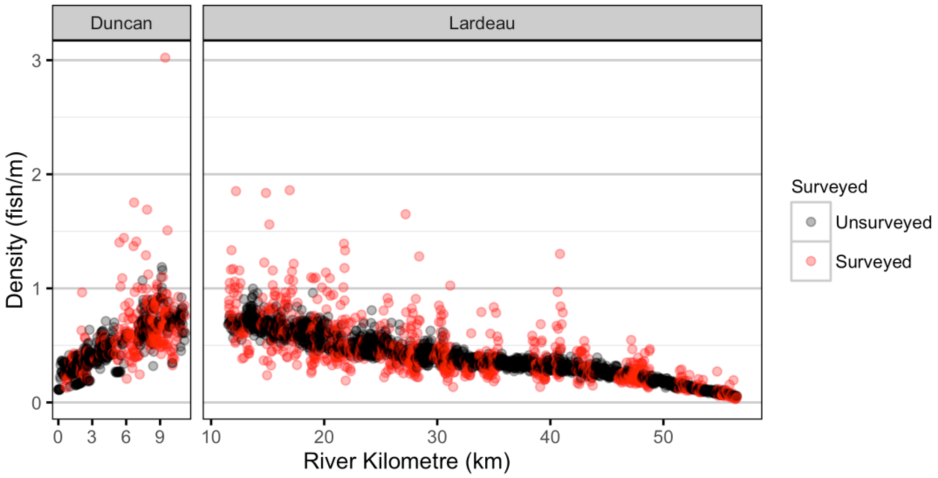

Figure 6. **Predicted lineal density of Rainbow Trout age 1 by river kilometer on Lardeau and Duncan rivers 2006-2014 & 2016 (with 95% CRIs).**

The 2016 Lardeau River age 1 abundance was estimated at 11,824 (95% CRI 8,273-15,932), substantially lower than 2014 estimate of 30,490 (95% CRI 21,640 -41,750; Table 6). The 2016 Lower Duncan River (LDR) age 1 abundance was estimated at 5,071 (95% CRI 3,412-7,105), considerably lower than 2014 estimate of 13,079 (95% CRI 9,095-18,078; 7). LDR age 1 abundance has averaged 29,669 thus representing approximately 25% of the stock in the rivers.

Table 6. **Estimated age 1 abundance in Lardeau and Duncan rivers from 2006-2014 & 2016**

Year	River	Estimate	Lower 95% CRI	Upper 95% CRI	SD
Duncan	2006	69,600	35,500	137,100	26,400
Duncan	2007	28,820	13,520	55,940	10,750
Duncan	2008	39,380	18,690	73,180	14,390
Duncan	2009	29,870	13,830	56,860	11,390
Duncan	2010	31,100	14,000	64,860	12,990
Duncan	2011	30,150	20,570	43,630	5,970
Duncan	2012	29,010	20,240	39,710	5,020
Duncan	2013	20,610	14,740	28,240	3,500
Duncan	2014	13,079	9,095	18,078	2,334
Duncan	2016	5,071	3,412	7,105	929
Lardeau	2006	162,300	83,200	317,400	60,900
Lardeau	2007	67,300	31,400	132,700	25,200
Lardeau	2008	91,900	43,300	176,400	33,200
Lardeau	2009	69,600	32,400	134,000	26,200
Lardeau	2010	72,500	33,100	149,400	29,700
Lardeau	2011	70,250	48,640	98,880	12,880
Lardeau	2012	67,710	48,970	91,190	11,300
Lardeau	2013	48,080	35,300	64,790	7,720
Lardeau	2014	30,490	21,640	41,750	5,090
Lardeau	2016	11,824	8,273	15,932	2,031

Note-LDR estimates from 2006 to 2010 are predicted estimates. No surveys were conducted.

The age 1 abundance for the Lardeau and Duncan rivers in 2016 is estimated to be 16,900 (95% CRI 11,800-22,930) which is substantially lower than previous years (Table 7; Figure 7). Age 1 abundance was highest in 2006 at 231,900, however, this data point is associated with high uncertainty and substantially leverages all other data points in the stock recruitment analysis and maybe unreliable (see SR next section). With the exception of 2006 data, the total age 1 abundance (both rivers) has averaged approximately 85,000. Posterior model predictions for parameters estimates are summarized in Appendix 5.

Table 7. Estimated age 1 abundance in Lardeau and Duncan rivers from 2006-2014 & 2016

Year	Estimate	Lower 95% CRI	Upper 95% CRI	SD
2006[1]	231,900	118,600	458,300	86,800
2007	96,100	45,500	186,900	35,700
2008	131,300	61,900	253,400	47,300
2009	99,500	46,700	189,500	37,300
2010	103,600	47,200	212,600	42,600
2011	100,400	70,000	141,270	18,500
2012	96,720	69,730	130,750	15,930
2013	68,690	50,590	92,770	10,940
2014	43,570	30,990	59,110	7,250
2016	16,900	11,800	22,930	2,900

[1] Note-estimate is considered an outlier and is not considered in SR relationship.

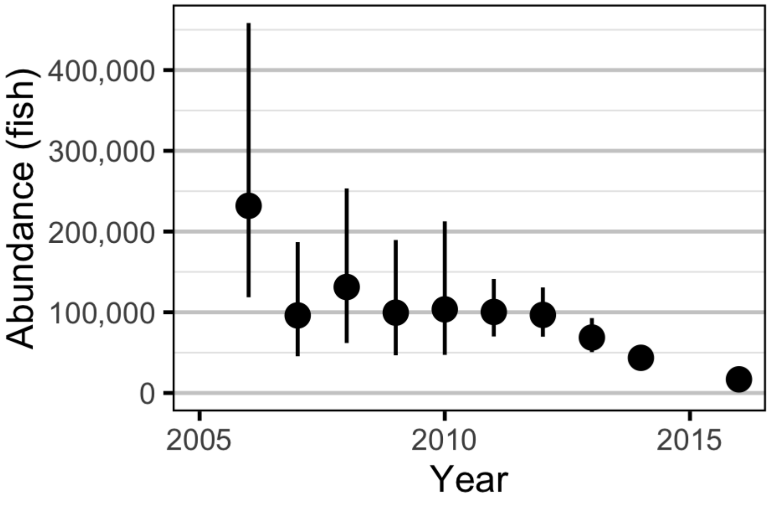

Figure 7. Predicted abundance of Rainbow Trout age 1 by year (with 95% CRIs) in Lardeau and Duncan rivers combined from 2006-2014 &2016. Note-2006 estimate is considered an outlier and is not considered in SR relationship

Spawner Abundance

Gerrard Rainbow Trout escapements using AUC methodology (Hagen et al. 2007) have varied widely in the past five decades, ranging from a low 283 in 1971 to a high of 1,532 in 2012 (Figure 8; Appendix 2). However, commencing in 2009, escapements began to increase substantially until they reached a historic high in 2012. Spawner estimates from 2009-2012 indicate escapements that are almost double the historic average which was approximately 500 spawners based on the time period 1961-2008.

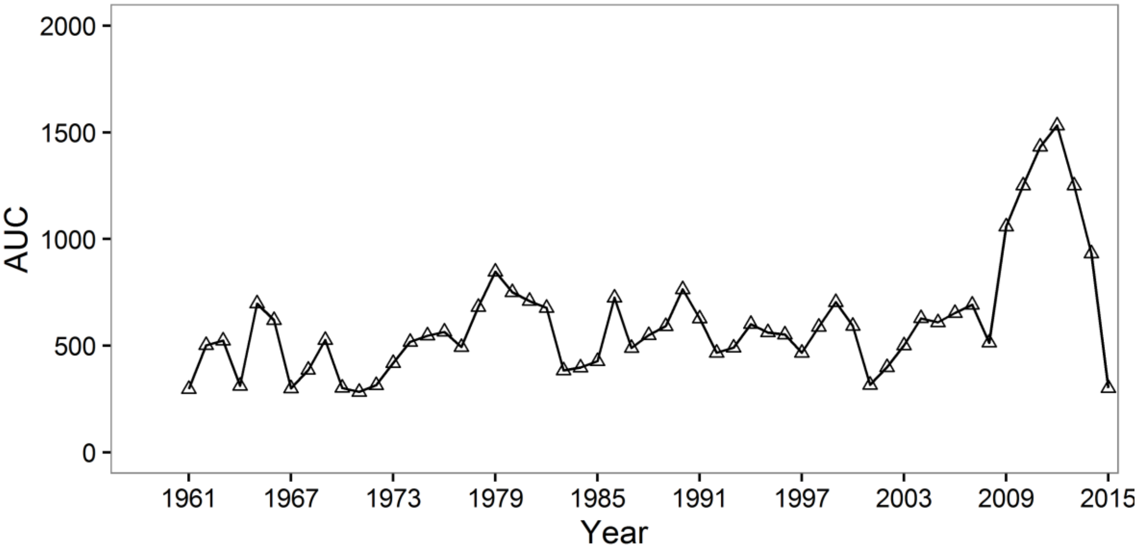

Figure 8. **Gerrard Rainbow Trout spawner escapement estimates from area-under the curve (AUC) at Gerrard from 1961-2015 (MFLNRO on file).**

Stock-Recruitment

A Beverton-Holt (Beverton and Holt 1957) stock recruitment curve was fitted to the Gerrard Rainbow Trout population using information from spawner numbers (AUC) and subsequent recruitment to age 1. In 2015, the substantial decline in spawner abundance (~300 AUC) was followed by a subsequent decline (>50%) in recruitment of spring age 1 juveniles (Figure 9). Additionally, preliminary results suggest no appreciable increase in recruitment in the juvenile abundance since 2006 at spawner abundances beyond 500 AUC, despite a substantial increase in escapement over the same time period (Figure 9). The SR relationship also suggests that most of the density dependent mortality in the early life stages occurs prior to age 1 with an average recruitment near 85,000 age 1 each spring when spawners are approximately 500 AUC. Posterior model predictions for parameters estimates are summarized in Appendix 5.

The 2006 recruitment data point has been removed from the SR analysis owing to its substantial uncertainty and high leveraging of all other points in the relationship. Furthermore, the 2006 data point was likely associated with considerable measurement error associated with the 1) first year of the study 2) emphasis on study methodology with no standardized method developed 3) non-random site selection 4) and limited coverage of river habitat (< 1% of total habitat). This is supported by the high variance and error associated with recruitment estimates derived in 2006. It is recommended weighting of data points be conducted to assess the influence of each point such that they are inversely proportional to variance, detailed in (Deriso et al. 2007).

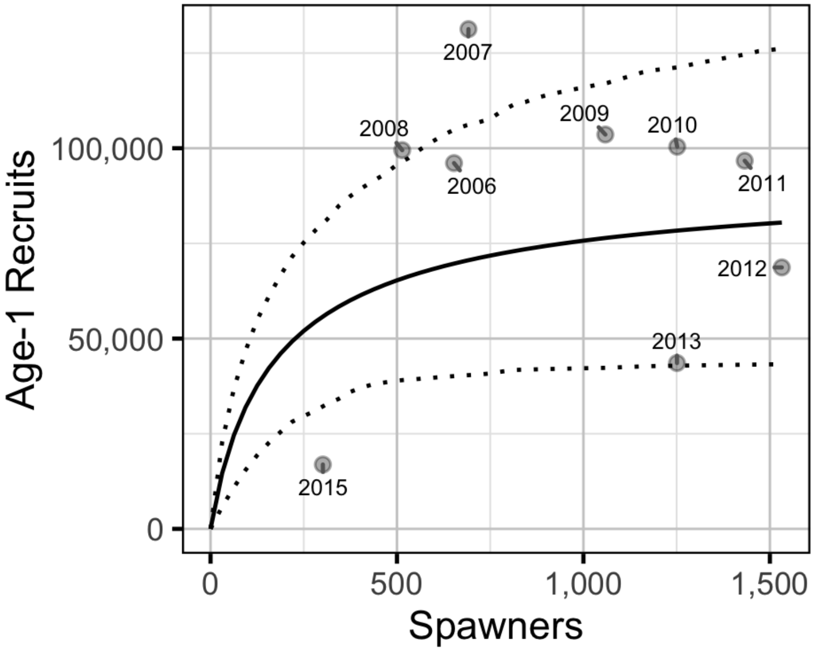

Figure 9. **Predicted Rainbow Trout stock-recruitment relationship (with 95% CRIs). Recruitment of spring age 1 and spawners based on AUC from Gerrard. Year is associated with brood year.**

Assessment of the recruits per spawner suggests that the maximum reproductive performance per spawner declines with increasing escapement (Figure 10). Maximum reproductive performance (*a*) was approximated to be 590 (95% CRI 198-1,026) recruits per spawner (Table 8). The carry capacity (K) that the riverine environment can sustain was estimated to be 92,500 (95% CRI 45,200-171,700) recruits (Table 8). The 2015-2016 data point also suggests limited compensation and a decline in reproductive success at lower stock abundance. It is speculated that this maybe a result of declining egg production owing to lower fecundity and smaller females since the Kokanee collapse on Kootenay Lake. In contrast, it is also speculated that survival decreased at low abundance associated with increased overwinter mortality associated with limited Kokanee abundance. Posterior model predictions for parameters estimates are summarized in Appendix 5. However, results should be used with caution until more information at low stock abundance can be obtained.

Table 8. **Posterior predictions from BH stock recruitment model**

Parameter	Estimate	Lower 95% CRI	Upper 95% CRI
a	589.8	197.5	1025.8
b	0.00743	0.00133	0.01734
K	92,500	45,200	171,700

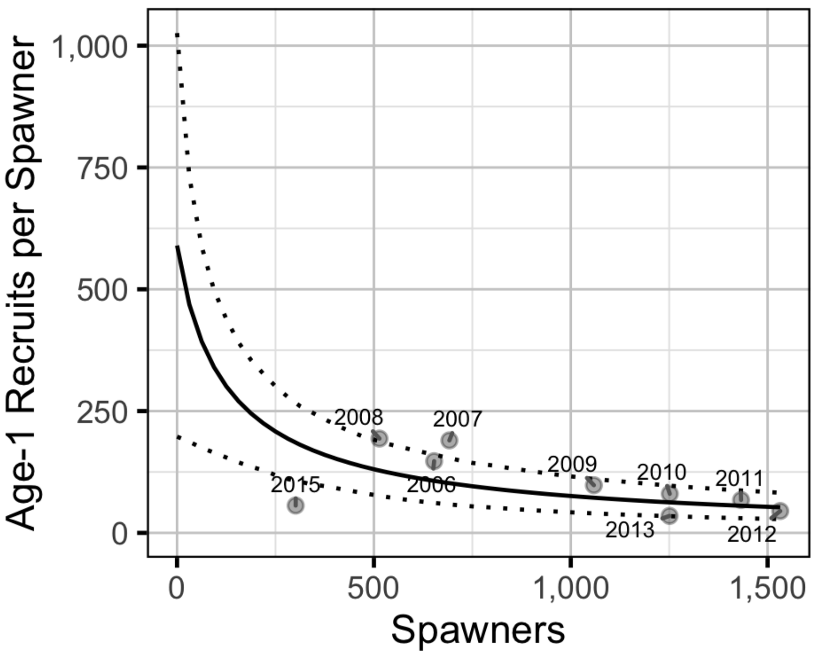

Figure 10. **Predicted recruit per spawner from Gerrard Rainbow Trout stock-recruitment relationship (with 95% CRIs). Recruitment of spring age 1 and spawners based on AUC from Gerrard. Year is associated with brood year.**

Distribution

Use of preliminary geo-referenced fish counts in assessing juvenile rainbow trout distribution and habitat use on the Lardeau and Duncan rivers is proving to be very informative. Estimates have improved since 2010 and demonstrate a considerable increase in total habitat, especially on the Duncan River (Table 4).

Integrating the spatial distribution data in the analysis demonstrated a positive relationship between useable widths and juvenile densities for age 1 on the rivers (Figure 5). Accurately quantifying the total amount of habitat is critical in order to obtain precise and unbiased estimates in juvenile abundance. Use of observed fish counts indicates important relationships by size class of fish and associated habitat use from information that can be acquired from GIS-ortho imagery data. As an example, Appendix 5. Posterior predictions

Observer efficiency

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	0.2055	-0.1089	0.5121	0.1565	150	0.1807
bEfficiencyStudyDesign[2]	-0.9755	-1.3770	-0.5923	0.2051	40	0.0010

Convergence	Iterations
1	5000

Abundance

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensityMarking[2]	0.39970	0.0605	0.71770	0.16650	82	0.0232
bDensityMarking[3]	0.28220	0.0804	0.49100	0.10640	73	0.0097
bDensityRkm1	-0.47620	-0.6462	-0.31540	0.08600	35	0.0010
bDensityRkm2	0.28750	0.0482	0.50670	0.11830	80	0.0155
bDensityRkm3	0.05130	-0.0258	0.13300	0.04090	160	0.2068
bDensityRkm4	-0.19750	-0.2750	-0.11640	0.04110	40	0.0010
bDensityWidth	0.19940	0.0923	0.29220	0.05150	50	0.0010
bDensityYear[1]	-0.20800	-0.8540	0.52800	0.34700	330	0.5392
bDensityYear[10]	-2.78120	-3.1332	-2.44960	0.18230	12	0.0010
bDensityYear[2]	-1.09200	-1.7830	-0.36700	0.36100	65	0.0020
bDensityYear[3]	-0.77700	-1.4610	-0.07000	0.34800	90	0.0310
bDensityYear[4]	-1.05900	-1.7700	-0.34100	0.36200	68	0.0020
bDensityYear[5]	-1.02900	-1.7700	-0.23700	0.39200	75	0.0097
bDensityYear[6]	-1.00100	-1.3650	-0.62590	0.18860	37	0.0010
bDensityYear[7]	-1.03520	-1.3712	-0.69060	0.17940	33	0.0010
bDensityYear[8]	-1.37640	-1.6902	-1.05010	0.16990	23	0.0010
bDensityYear[9]	-1.83290	-2.1605	-1.48350	0.17540	18	0.0010
bEfficiencyStudy[1]	0.54680	0.4866	0.61120	0.03260	11	0.0010
bEfficiencyStudy[2]	0.31698	0.2688	0.36487	0.02528	15	0.0010
bEfficiencyVisitStudy[2,1]	-1.61300	-2.4710	-0.78400	0.40800	52	0.0010
bEfficiencyVisitStudy[2,2]	-0.33710	-0.6132	-0.02040	0.15150	88	0.0387
bSDispersion0	0.03960	-0.1712	0.29640	0.11250	590	0.7208
bSDispersion1	0.16260	0.0140	0.34770	0.08210	100	0.0329
sDensitySite	0.59180	0.4957	0.68120	0.04600	16	0.0010
sEfficiencySwimmer	0.44080	0.2471	0.76430	0.13670	59	0.0010

Convergence	Iterations
1.05	20000

Stock recruitment

Parameter	Estimate	Lower	Upper	SD	Error	Significance
a	589.80000	197.50000	1025.80000	224.10000	70	0.001
b	0.00743	0.00133	0.01734	0.00456	110	0.001
sRecruits	0.69340	0.39710	1.28490	0.25010	64	0.001

Convergence	Iterations
1	5e+05

Appendix 6 illustrates observed fish counts in 2016 by size class on a restored side channel of the Lardeau River (Andrusak 2013).

Discussion

Determining a stock's reproductive capacity and productivity is essential for managing this highly exploited population (Hilborn and Walters 1992, Walters and Martell 2004). Obtaining estimates of the in-river Gerrard juvenile abundance from the Lardeau and Duncan rivers provides a critical component for developing a stock-recruitment relationship used to assess the population dynamics and defining biological useable reference points for stock management (Andrusak 2005). The recent unprecedented collapse of the lakes’ Kokanee population (MFLNRO 2016) has provided a unique opportunity to obtain information on the population dynamics at low stock abundance.

Snorkel surveys provide a proven method for obtaining juvenile abundance estimates on a medium to large size river in comparison to more labour intensive and more expensive methods such as electrofishing (Mullner et al. 1998, Korman et al. 2010a). This project has utilized night time snorkel methods since 2006 to assess Gerrard juvenile abundance in the Lardeau and Duncan rivers, similar to that used for stock assessment methods used for Steelhead in BC (Hagen et al. 2010). Starting in 2011, increased sampling effort (>5%), as detailed in Korman et al. (2010b), has improved precision thus reducing uncertainty in abundance estimates. For example, to achieve coefficient of variation of 0.2 in total river abundance estimates for spring parr approximately 5% of the total useable shoreline length must be sampled.

Obtaining juvenile abundance estimates within the Lardeau and Duncan rivers, utilizing nighttime snorkel surveys relies on the ability to achieve unbiased and relatively precise estimates of snorkel survey observer efficiencies. Obtaining reliable estimates of fish abundance and species distribution requires the use of unbiased estimators using mark recapture or removal methods (Hankin and Reeves 1988, Riley and Fausch 1992, Thurow and Schill 1996, Thompson 2003, Peterson et al. 2004). Analysis and model results indicate snorkel efficiencies derived from earlier mark recapture work over estimated efficiencies thus underestimating abundance, representing a substantial bias in juvenile abundances’ reported in previous years (Decker and Hagen 2009). Standard site visits (regular counts, no marked fish) indicated substantially lower efficiencies compared to mark recapture sites, demonstrating that crews spent more time and were more efficient when they knew marked fish present in the site. Consequently, the estimator for observer efficiency was negatively biased pre-2011 data and subsequently underestimated the in-river juvenile population by 1.5-2x.

The extent of uncertainty in stock productivity and carrying capacity varies and depended on the amount of information on parr production at low and high spawning stock size, respectively (Walters and Martell 2004). The 2016 surveys indicate a substantial reduction in recruitment in concert with the decline in the Gerrard stock abundance most likely a result of the recent collapse of the Kokanee population since 2012 (MFLNRO 2016). The stock recruitment information collected in 2016 suggests that the maximum reproductive performance has declined, indicating there was no compensation in survival at low abundance. It is speculated that this maybe a result of declining trout egg production due to lower fecundity and smaller females since the Kokanee collapse on Kootenay Lake (MFLNRO 2016). A recent growth and condition study supports the notion that egg production has been reduced and is likely the contributing factor (Andrusak and Andrusak 2015). However, it is also speculated that a decline in parr survival at low abundance may be related to an increase in overwinter mortality associated with the lack of Kokanee eggs and fry, a potential annual major food source within the river. In addition, SR information results also indicates no appreciable increase in recruitment in the juvenile abundance with increased escapement above 500 AUC, suggesting the river was near capacity from 2006-2014. These factors also indicate that the population is likely regulated by density dependent factors similar to most riverine salmonid populations (Ward and Slaney 1993, Imre et al. 2010, Vincenzi et al. 2011).

Improved modeling, survey design and quantified total habitat from GIS, indicate juvenile abundances that are approximately 1.5-2.0 x higher than previously reported by Decker and Hagen (2009) and Andrusak (2010). Excluding the outlier 2006 data, the Lardeau River averages approximately 69,000 age 1 juveniles representing 70% of the standing stock estimates. Likewise, the LDR contributes an averaged 29,000 age 1 representing 30% of the standing stock estimates. While these estimates are still preliminary, in most years instances the age 1 estimates attained the desired level of precision with a coefficient of variation of less than 0.3, suggesting reliable estimates of production can be obtained for a medium sized river such as the Lardeau and Duncan rivers. Older parr (> 170 mm) estimates were not obtained from the model in 2016 due to the high uncertainty in the estimates and the inability to accurately assess and detect these size classes. Interestingly, the updated abundance estimates are very similar to those made by Slaney and Andrusak (2003) based on a habitat capability model and habitat model designed by Ron Ptolemy (Rivers Biologist/Instream Flow Specialist, MOE, pers. comm.) and estimates derived by Irvine (1978).

The analysis utilizing a Bayesian hierarchical framework allows for greater flexibility in partitioning variance while accounting for similar effects associated with changes in the probability of detection (Kéry 2010, Kéry and Schaub 2011). Improved estimates (CV) on both rivers are a result of increased sampling effort, reduced bias in the mark recapture estimator, and improved estimates of total habitat using GIS. For example, GIS information indicated the LDR habitat was underestimated in previous years' (pre 2011) reporting compared to more recent information (post 2011). In recognition of more the complex river morphology, the surveys since 2011 have increased sampling effort on the

LDR to reduce the uncertainty in estimates for juvenile rainbow trout. As a result, the re-designed approach (GPS) has been quite successful in addressing uncertainty and bias associated with survey methods and appears to be meeting its primary objectives of providing relatively precise and accurate information on the juvenile recruitment, needed to define a stock-recruitment relationship (Myers and Barrowman 1996).

Understanding when juvenile Gerrard Rainbow Trout emigrate to the lake is a key unknown component of the Gerrard population life history. Irvine (1978) suggested that most juveniles emigrated to the lake in their first spring as age 1s. However, following the theory of size dependent mortality (Post et al. 1999), there may be a minimum size threshold rather than age specificity which is optimal for survival before entering Kootenay Lake. Based on some very limited acoustic tagging information (Andrusak 2010), the majority of older parr (1-2 year olds), which are believed to contribute to the adult population, migrated from the river during the spring with some holding off into the fall, possibly after kokanee spawning is complete. Microchemistry analysis of juvenile trout from the river and adult trout obtained in the fishery may provide some insight into when the majority of juvenile population migrate to the lake (Matt Neufeld, Fisheries Biologist MFLNRO pers. comm.).

The importance of obtaining more accurate and precise juvenile trout data on the Gerrard Rainbow Trout population is fundamental to effective stock assessment and management for this unique ecotype. Reducing the uncertainty in estimates will help define informative BRPs for management and allow fisheries management to make informed decisions whether current regulations are appropriate especially in light of the popular fishery on the lake. The information obtained from the exploitation study (Andrusak and Thorley 2014) will compliment information collected from the work on the Lardeau River (spawner escapement and juvenile recruitment) to formulate abundance based reference points based on a stock recruitment relationship.

In summary, this study over the next three years aims to improve on current estimates by reducing uncertainty related to total available habitat through improved mapping in GIS on both rivers and minimizing biases associated with observer efficiencies related to mark-recapture methodologies. The expected low spawner numbers in the near future also provides an opportunity to determine recruits at low abundance thus improving the stock recruitment relationship for this ecotype.

References

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Appendix 1. Hierarchical Bayesian model code

Capture Efficiency - Model1

```
model{

 bEfficiency ~ dnorm(0, 5^-2)

 bEfficiencyStudyDesign[1] <- 0
 for (ii in 2:nStudyDesign) {
   bEfficiencyStudyDesign[ii] ~ dnorm(0, 2^-2)
 }

 for(ii in 1:length(Marked)){
   logit(eEfficiency[ii]) <- bEfficiency
                     + bEfficiencyStudyDesign[StudyDesign[ii]]

   Resighted[ii] ~ dbin(eEfficiency[ii], Marked[ii])
 }
}
```

Abundance - Model1

```
model{
   for(yr in 1:nYear){
   bDensityYear[yr] ~ dnorm(0, 5^-2)
 }

   bDensityWidth ~ dnorm(0, 2^-2)

   sDensitySite ~ dunif(0, 5)
 for(st in 1:nSite){
   bDensitySite[st] ~ dnorm(-sDensitySite^2 / 2, sDensitySite^-2)
 }

 bDensityMarking[1] <- 0
 for(mk in 2:nMarking) {
   bDensityMarking[mk] ~ dnorm(0, 5^-2)
 }

   sEfficiencySwimmer ~ dunif(0, 5)
 for(sw in 1:nSwimmer){
   bEfficiencySwimmer[sw] ~ dnorm(0, sEfficiencySwimmer^-2)
 }

   bDensityRkm1 ~ dnorm(0, 2^-2)
 bDensityRkm2 ~ dnorm(0, 2^-2)
 bDensityRkm3 ~ dnorm(0, 2^-2)
 bDensityRkm4 ~ dnorm(0, 2^-2)

   for(sd in 1:nStudyDesign){
   bEfficiencyStudy[sd] ~ dnorm(Efficiency[sd], Efficiency.sd[sd]^-2) T(Efficiency.lower[sd], Efficiency.upper
[sd])
```

```
 }

   for(sd in 1:nStudyDesign){
   bEfficiencyVisitStudy[1, sd] <- 0
   for(vt in 2:nVisitType){
     bEfficiencyVisitStudy[vt, sd] ~ dnorm(0, 2^-2)
   }
 }

   bSDispersion0 ~ dnorm(0, 2^-2)
 bSDispersion1 ~ dnorm(0, 2^-2)

   for(ii in 1:length(Count)){
   log(eDensity[ii]) <- bDensityYear[Year[ii]]
                 + bDensityWidth * log(Width[ii])
                 + bDensitySite[Site[ii]]
                 + bDensityRkm1 * Rkm[ii]
                 + bDensityRkm2 * Rkm[ii]^2
                 + bDensityRkm3 * Rkm[ii]^3
                 + bDensityRkm4 * Rkm[ii]^4
                 + bDensityMarking[Marking[ii]]

   eAbundance[ii] <- eDensity[ii] * SiteLength[ii]

   logit(eEfficiency[ii]) <- logit(bEfficiencyStudy[StudyDesign[ii]])
                     + bEfficiencyVisitStudy[VisitType[ii], StudyDesign[ii]]
                     + bEfficiencySwimmer[Swimmer[ii]]

   eCount[ii] <- eAbundance[ii] * eEfficiency[ii] * SurveyProportion[ii]

   log(eSDispersion[ii]) <- bSDispersion0 + bSDispersion1 * bDensityYear[Year[ii]]

   eDispersion[ii] ~ dgamma(1/eSDispersion[ii]^2, 1/eSDispersion[ii]^2)

   Count[ii] ~ dpois(eCount[ii] * eDispersion[ii])
 }
}
```

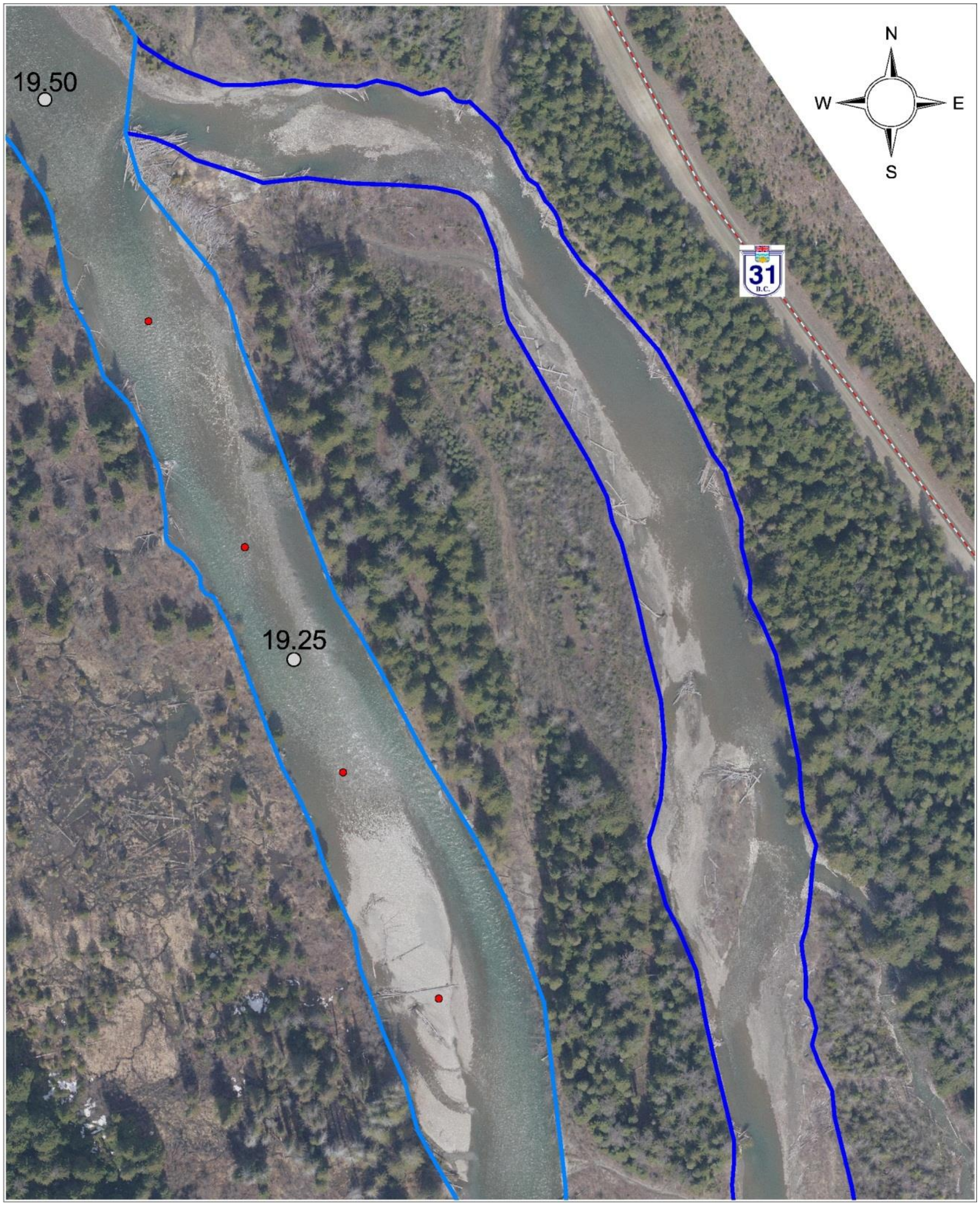
Stock-Recruitment - Model1

```
model {

 a ~ dnorm(8000 * 0.5^4, 250^-2) T(0, )
 b ~ dunif(0, 0.1)

 sRecruits ~ dunif(0, 5)

 for(i in 1:length(Spawners)){
   eRecruits[i] <- a * Spawners[i] / (1 + Spawners[i] * b)
   Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
 }
}
```

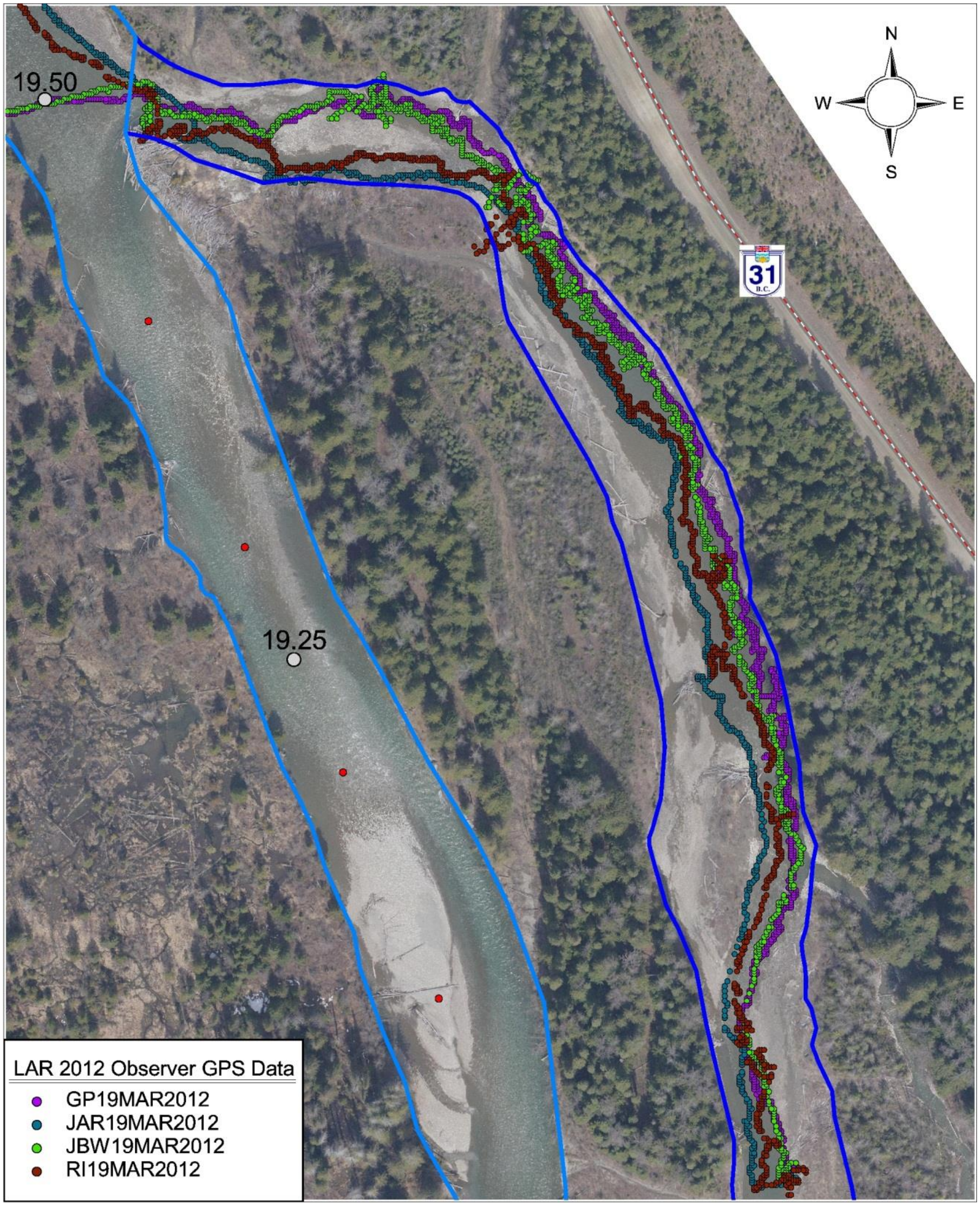
Appendix 2. Gerrard spawner escapement 1961-2015

Year	Peak Count	Peak X 3.08	AUC (fish*days)	*AUC (N)*
2015	188	579	3398	301
2014	711	2190	11091	932
2013	750	2310	14886	1251
2012	1068	3289	18231	1532
2011	995	3065	17047	1432
2010	725	2233	14893	1251
2009	589	1814	12599	1059
2008	514	1583	6117	514
2007	464	1429	8231	692
2006	438	1349	7770	653
2005	426	1312	7242	609
2004	406	1250	7478	628
2003	303	933	5964	501
2002	227	699	4748	399
2001	244	752	3762	316
2000	340	1047	7061	593
1999	399	1229	8382	704
1998	367	1130	6997	588
1997	344	1060	5551	466
1996	275	847	6564	552
1995	286	881	6684	562
1994	275	847	7149	601
1993	257	792	5841	491
1992	219	675	5544	466
1991	280	862	7460	627
1990	382	1177	9091	764
1989	363	1118	7028	591
1988	340	1047	6531	549
1987	294	906	5821	489
1986	378	1164	8623	725
1985	241	742	5077	427
1984	220	678	4721	397
1983	270	832	4564	384
1982	417	1284	8051	677
1981	453	1395	8435	709
1980	440	1355	8933	751
1979	618	1903	10076	847
1978	473	1457	8099	681
1977	347	1069	5878	494
1976	272	838	6726	565
1975	346	1066	6505	547
1974	287	884	6168	518
1973	258	795	4979	418
1972	238	733	3747	315
1971	176	542	3371	283
1970	203	625	3599	302
1969	237	730	6275	527
1968	178	548	4597	386
1967	180	554	3575	300
1966	249	767	7380	620
1965	377	1161	8297	697
1964	234	721	3715	312
1963	251	773	6234	524
1962	258	795	5977	502
1961	214	659	3534	297

Appendix 3. Estimated lineal bank length using GIS



Appendix 4. GPS information from surveys in GIS



Appendix 5. Posterior predictions

Observer efficiency

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bEfficiency	0.2055	-0.1089	0.5121	0.1565	150	0.1807
bEfficiencyStudyDesign[2]	-0.9755	-1.3770	-0.5923	0.2051	40	0.0010

Convergence	Iterations
1	5000

Abundance

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bDensityMarking[2]	0.39970	0.0605	0.71770	0.16650	82	0.0232
bDensityMarking[3]	0.28220	0.0804	0.49100	0.10640	73	0.0097
bDensityRkm1	-0.47620	-0.6462	-0.31540	0.08600	35	0.0010
bDensityRkm2	0.28750	0.0482	0.50670	0.11830	80	0.0155
bDensityRkm3	0.05130	-0.0258	0.13300	0.04090	160	0.2068
bDensityRkm4	-0.19750	-0.2750	-0.11640	0.04110	40	0.0010
bDensityWidth	0.19940	0.0923	0.29220	0.05150	50	0.0010
bDensityYear[1]	-0.20800	-0.8540	0.52800	0.34700	330	0.5392
bDensityYear[10]	-2.78120	-3.1332	-2.44960	0.18230	12	0.0010
bDensityYear[2]	-1.09200	-1.7830	-0.36700	0.36100	65	0.0020
bDensityYear[3]	-0.77700	-1.4610	-0.07000	0.34800	90	0.0310
bDensityYear[4]	-1.05900	-1.7700	-0.34100	0.36200	68	0.0020
bDensityYear[5]	-1.02900	-1.7700	-0.23700	0.39200	75	0.0097
bDensityYear[6]	-1.00100	-1.3650	-0.62590	0.18860	37	0.0010
bDensityYear[7]	-1.03520	-1.3712	-0.69060	0.17940	33	0.0010
bDensityYear[8]	-1.37640	-1.6902	-1.05010	0.16990	23	0.0010
bDensityYear[9]	-1.83290	-2.1605	-1.48350	0.17540	18	0.0010
bEfficiencyStudy[1]	0.54680	0.4866	0.61120	0.03260	11	0.0010
bEfficiencyStudy[2]	0.31698	0.2688	0.36487	0.02528	15	0.0010
bEfficiencyVisitStudy[2,1]	-1.61300	-2.4710	-0.78400	0.40800	52	0.0010
bEfficiencyVisitStudy[2,2]	-0.33710	-0.6132	-0.02040	0.15150	88	0.0387
bSDispersion0	0.03960	-0.1712	0.29640	0.11250	590	0.7208
bSDispersion1	0.16260	0.0140	0.34770	0.08210	100	0.0329
sDensitySite	0.59180	0.4957	0.68120	0.04600	16	0.0010
sEfficiencySwimmer	0.44080	0.2471	0.76430	0.13670	59	0.0010

Convergence	Iterations
1.05	20000

Stock recruitment

Parameter	Estimate	Lower	Upper	SD	Error	Significance
a	589.80000	197.50000	1025.80000	224.10000	70	0.001
b	0.00743	0.00133	0.01734	0.00456	110	0.001
sRecruits	0.69340	0.39710	1.28490	0.25010	64	0.001

Convergence	Iterations
1	5e+05

Appendix 6. GPS referenced count data