Determination of Gerrard Rainbow Trout Productivity and Capacity in Defining Management Reference Points

Progress Report

July 2014

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Project No.-FF15-05

Prepared for

Fish and Wildlife Compensation Program – Columbia

and

Habitat Conservation Trust Foundation

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July 2014

This Project is partially funded by the Fish and Wildlife Compensation Program on behalf of its program partners BC Hydro, the Province of B.C. and Fisheries and Oceans Canada who work together to conserve and enhance fish and wildlife impacted by the construction of BC Hydro dams.

FISH AND WILDLIFE COMPENSATION PROGRAM

HABITAT CONSERVATION TRUST FOUNDATION

This project was primarily funded by the Habitat Conservation Trust Foundation. The Habitat Conservation Trust Foundation was created by an act of the legislature to preserve, restore and enhance key areas of habitat for fish and wildlife throughout British Columbia.
Anglers, hunters, trappers and guides contribute to the projects of the Foundation through licence surcharges. Tax deductible donations to assist in the work of the Foundation are also welcomed.

Cover Photo: 'Photo of the Lardeau River in the early spring March 2014.' Photograph taken in March 2014 by Greg Andrusak.

EXECUTIVE SUMMARY

Annual stock assessment of the juvenile Gerrard rainbow trout 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. This report summarizes recent survey work conducted in 2014 on the Lardeau and Duncan rivers combined with re-analyzed spring survey data from 2006-2014 in the Lardeau and Duncan rivers.

Sampling effort was slightly lower in 2014 compared to 2013 but well above sampling conducted in previous years' work (2006-2010). Beginning in 2011, the re-designed approach began to systematically assess >5% of 196 km of shoreline available in the Lardeau and Duncan rivers. Surveys conducted in the spring of 2014 covered approximately 11.2% Lardeau River and 8.1% of the Duncan River. A total of 9.6% of the mainstem shoreline and 18.3% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 11.6% of the mainstem shoreline were surveyed in the Duncan River. The goal of increasing effort was to improve the precision of the in-river juvenile abundance estimates by attaining a coefficient of variation of near 0.3.

A total of 1,764 juvenile rainbow trout were observed during the night time surveys conducted in the Lardeau and Duncan rivers in 2014. 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. Overall, the combined data provide 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 years' data (2006-2010) indicate the probable age structure from the 2014 fish observations. Spring age data suggests that fry are ≤ 100 mm, ranging from 25-90 mm, age 1 fish had a fork length between 100 and 150 mm and older juveniles of age-2+ and age 3+ fish had a fork length >150 mm.

Obtaining annual estimates of fish abundance using snorkel survey counts within the Lardeau and Duncan rivers relies on the ability to achieve unbiased and relatively precise estimates of snorkel efficiencies. Snorkel efficiency for age 1 (2006-2014) from mark-re-sight data was estimated to be 0.41 (95% CRI 0.36-0.45). However, based on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.17 (95% CRI 0.13-0.21). Results indicate substantial bias for snorkel efficiencies for age 1 when using mark-recapture methods

compared to standard count efficiencies. Consequently, snorkel efficiencies derived (2006-2010) were often over-estimated by 1.5-2x, leading to underestimated juvenile abundances by the same magnitude prior to 2011.

Based on improved modeling and the results, it appears that juvenile estimates for age 1 and parr are approximately 1.5-2.0x higher than previously reported (2006-2010). In 2014, age 1 was estimated to be 46,921 (95% CRI 35,559-60,918) in the Lardeau River and 16,060 (95% CRI 11,190-22,637) in the Lower Duncan River (LDR). Excluding 2006, the Lardeau River has averaged 88,578 (2006-2014) or approximately 75% of the standing stock estimates within both rivers since 2007. Likewise, the LDR contributes an average of 31,027 (2006-2014) age 1 or approximately 25% to the standing stock estimates within both rivers.

Utilization of a hierarchical Bayesian framework, improved survey design, increased sampling effort, improved habitat estimates using GIS and reduced bias in the mark recapture estimator suggest a rather large increase in precision compared to historic information reported for both fry and parr on the Lardeau River. While these estimates are preliminary and may vary annually due to changes in available habitat, particularly in the LDR, in most years age 1 estimates attained the desired level of precision with a coefficient of variation of 0.3.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Fish and Wildlife Compensation Program – Columbia (FWCP) and the Habitat Conservation Trust Foundation (HCTF). The FWCP-Columbia is a partnership between BC Hydro, the Province of B.C., First Nations and local community groups to conserve and enhance fish and wildlife affected by the construction (i.e. footprint) of BC Hydro dams in the Columbia region.

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. Joe Thorley, Jason Bowers, Gary Pavan, and Jimmy Robbins made up a great working team that made the work much easier than otherwise it could have been. As well, thanks to Gary for organizing all spatial data (GIS) and providing maps. Jeremy Baxter of Mountain Water Research is also acknowledged for use of the jet boat for the Duncan River surveys

Suggested Citation: Andrusak, G.F. 2014. Determination of Gerrard Rainbow Trout Productivity and Capacity in Defining Management Reference Points-2014. Prepared for the Fish and Wildlife Compensation Program – Columbia Basin, the Habitat Conservation Trust Foundation and the Ministry of Forests, Lands and Natural Resource Operations, Nelson, BC. August 2014. 19 pp+

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

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 then mortality imposed from the recreational fishery influences the status of these piscivorous rainbow trout on Kootenay Lake (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 a stock's reproductive capacity and productivity is essential for managing this highly exploited population (Hilborn 1992, Walters 2004). Assessment and estimations of the in-river juvenile abundance from the Lardeau and Duncan rivers, combined with Gerrard escapement information (Hagen et al. 2010), provides important information for developing the stock-recruitment relationship that is used to determine useable biological reference points for stock management. Understanding how fishing imposed mortality influences the status of this stock and determining whether the current rates of harvest are sustainable is considered to be a high priority for management (Andrusak 2005).

Despite the importance of defining biological reference points for the stock, development of a stock recruitment relationship relies on having or obtaining relatively precise indices of adult escapement and subsequent juvenile recruitment. Often, these biological relationships are based on relatively few and temporally auto-correlated data with substantive measurement errors that can lead to non-interpretative and indistinguishable information. An escapement index for Gerrard rainbow trout has been maintained since 1957 (Hartman 1969, 1970, Hartman and Galbraith 1970), providing a an excellent long-term time series. Recent information from telemetry work (Andrusak and Thorley 2013) has made substantial improvements into understanding how the escapement index translates into a total spawner abundance (Hagen et al. 2010). At the same time, in-river work has focused on obtaining estimates of juvenile Gerrard rainbow trout abundance in the Lardeau River (Decker and Hagen 2009, Andrusak 2010, 2013). Moreover, understanding juvenile distribution, habitat use, age structure and standing stock in relation to spawner abundance is required for effective conservation and management of this population.

To address potential problems associated with the development of stock-recruitment relationships, additional years of data are required for increasing the precision of the estimates. This report summarizes the 2014 spring survey conducted on the Lardeau and Duncan rivers utilizing nighttime snorkel methods to assess recruitment of Gerrard rainbow trout. The study was designed to obtain estimates of juvenile abundance, juvenile distribution, and habitat use by age class to be used in defining a stock recruitment relationship for management purposes.

Project objectives:

This project meets Goals 1 HCTF’s strategic plan, specifically Objective 1.2 (sustainability) and Goal 2, objective 2.1 (increase recreational use). The Lardeau River (44 km) represents the last major free flowing river system on Kootenay Lake, in which, the Gerard rainbow trout is entirely dependent upon for virtually all of its natural production (Irvine 1978, Redfish Consulting Ltd. 2002, Andrusak 2005).

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. Relate stock's compensatory capacity to current exploitation levels in the fishery

4. Determine river carrying capacity

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

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

BACKGROUND

Assessing and determining a stock's productivity is essential in managing exploited populations (Hilborn 1992, Walters 2004). Utility 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) is required to strengthen the stock-recruit relationship and improve on sampling shortcomings. Obtaining information on the reproductive performance of this stock is essential and is directly linked to the ongoing study to determine if current rates of exploitation are sustainable on Kootenay Lake (Andrusak and Thorley 2013). This compliment of data will provide much needed information for future management of these highly prized fish.

Data collected from the 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 studying 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 old 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 current survey work 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 of 162 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.

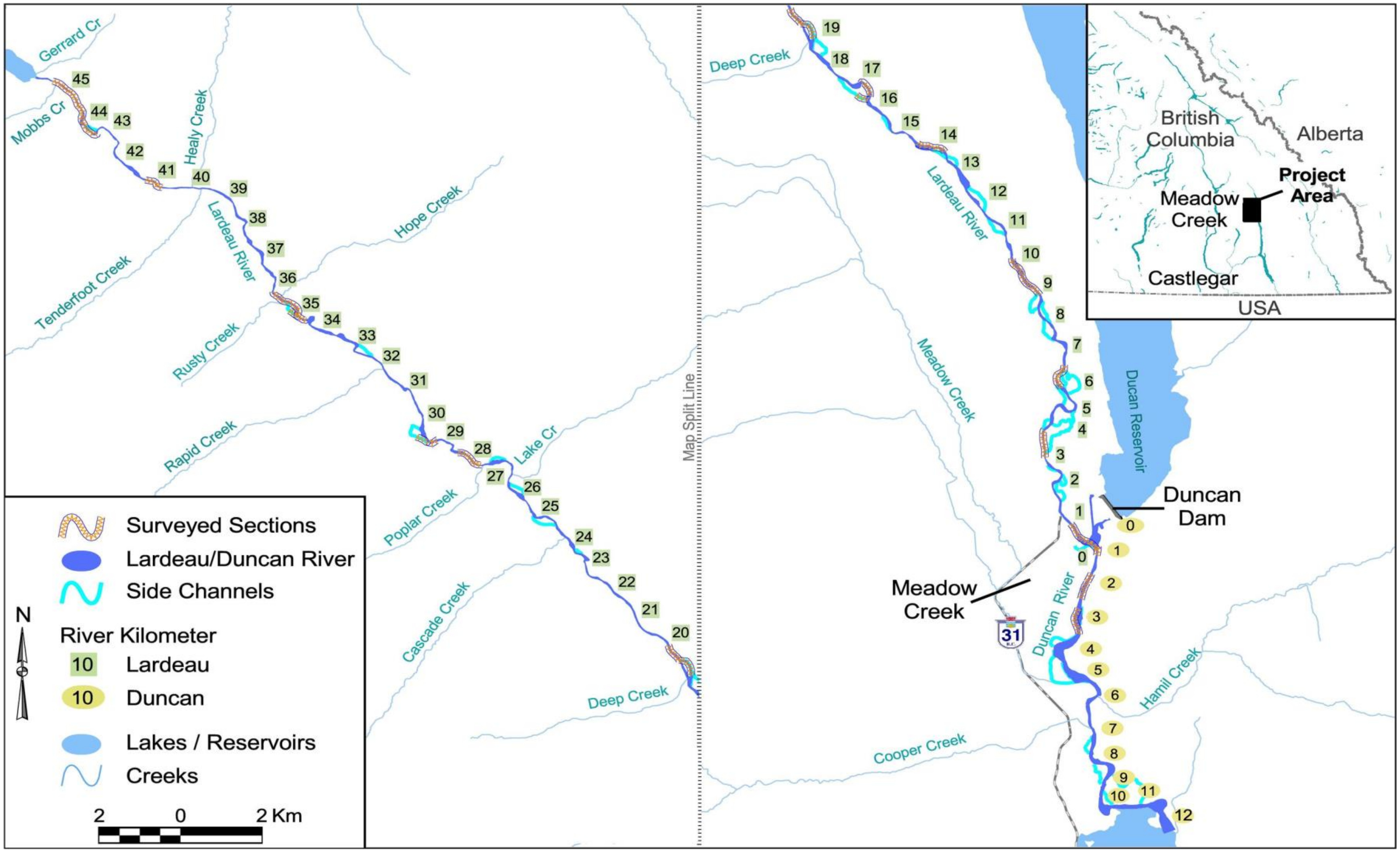

Figure 1. Location of Lardeau and Duncan rivers and length of study area (km)

METHODS

The original design and juvenile trout assessments were undertaken by John Hagen and Scott Decker beginning in 2006 (Decker and Hagen 2009). The design incorporated six important methods in an effort to obtain relatively precise and unbiased estimates of juvenile distribution, habitat use, age structure and abundance within the river. These methods are listed as follows but for further detail see Decker and Hagen (2009).

1. Stratification of sampling effort
2. Total amount of habitat based throughout the river (Lardeau and Duncan)
3. Nightime 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

However, based on the Decker and Hagen (2009) data plus two additional years for a total of five years (Andrusak 2010), the combined estimates demonstrated relatively high variability in juvenile densities within year and between years. To further reduce variability, bias and increase the precision of in river estimates by age class, the spring survey, beginning in 2011, increased the total sampling effort on the Lardeau and Duncan rivers. For example, to achieve a coefficient of variation of 0.3 in total river abundance estimates for age 1 spring parr (Korman et al. 2010), approximately 5% of the total useable shoreline length must be sampled in the Lardeau and Duncan rivers. Both systems combine to account for 196.2 lineal kilometers of shoreline habitat of which a minimum of 9.8 kilometers must be sampled. Therefore, the design required a minimum of 200 sites (> 50 m) to be surveyed using the combined methods. This equates into ~ 20 sites per day/night using the rapid assessment method developed for medium to large rivers (Mitro and Zale 2002, Hagen et al. 2005, Korman et al. 2010).

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.

Stratification of sampling effort

Shoreline surveys randomly selected sections of river, usually > 1000 m per section along the shoreline of the river. This design increased sampling effort, number of sites, site replication and made data comparable with previous data in Decker and Hagen (2009), which was based on discrete site lengths of 50 m. As well, this approach accounted for the potential effects of incremental changes along the length of the Lardeau River in abundance, stream discharge, and ecological conditions not available in previous designs. 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 in the surveys.

Further stratification of habitat will be done utilizing GIS mapping. 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. Analysis of data will determine if further stratification is necessary to obtain more precision in estimates.

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 2014 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 at night. 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. 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 identify and count. 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). 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 (Photo 1). 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.

Photo 1. Visible marks used for determining snorkel efficiency for juvenile rainbow trout on Lardeau and Duncan rivers in March 2014. Visible marks utilize a #16-18 fish hook with a small piece of florescent chenille attached to hooks.

Age determination

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

Analysis of Data

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.

A Hierarchical Bayesian Mixed model (HBM) was fitted to the data (count and mark-re-sight) using software packages R 2.15.3 (R Core Development Team 2013) and JAGS 3.3.0 (Plummer 2003) using Markov Chain Monte Carlo (MCMC) simulation (Appendix 3). 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 (Kery 2010, 2012) and is detailed in Appendix 3. Data analysis was conducted by Dr. Joe Thorley of Poisson Consulting Ltd.

The Bayesian model assumed that lineal density varied by river, year within river, site and useable width. Year within river and site were considered random effects. The expected number of fish present at a site on a given visit was assumed to be the lineal density multiplied by the site length. In order to account for possible differences in snorkeler behaviour at marked sites the observer efficiency was assumed to vary between marked and unmarked sites. The observer efficiency at marked sites was estimated from the number of marked fish re-sighted. The observer efficiency at unmarked sites was estimated from the difference in the expected count at that site in that year if marked fish had been present, i.e., counts at particular sites tended to be higher relative to other sites in years in which marked fish were present at that site versus years in which the site was not marked. The differences between marked and unmarked sites indicate potential bias in efficiencies.

The model, which is similar to that fitted by Wyatt (2003), makes the following key assumptions:

i. The logistic observer efficiency varies between site visits.

ii. The logistic observer efficiency is different when marked fish are present.

iii. The number of marked fish re-sighted is a binomially distributed function of the number of marked fish and the observer efficiency.

iv. The log lineal density (fish/m) varies with the width of useable habitat (from GIS photo-interpretation).

v. The log lineal density (fish/m) varies between the Lardeau and Lower Duncan Rivers.

vi. The log lineal density varies (fish/m) randomly by year within river and site.

vii. The abundance (fish) at a site in a given year is a Poisson-distributed function of the product of the lineal density (fish/m) and site length.

viii. The total number of fish observed at a site is a binomially distributed function of the abundance and the observer efficiency.

Density and Abundance Estimates

In summary, the model allows the mean fish density, assumed to be log-normally distributed, to vary with site and year. The total abundance at each index site was then calculated by multiplying the mean densities in each year by the lineal site length. Whole river estimates are derived in a similar manner based on lineal length of mainstem and side channel habitat available on Lardeau and Duncan rivers. Estimates are provided with Bayesian 95% credibility intervals (CRI). Analysis includes the 2011 to 2013 data as well as re-assessment of data from 2006-2010 (Decker and Hagen 2009, Andrusak 2010, 2013) to address uncertainty and bias in the original estimates.

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 1). Linear bank boundaries and river centerline, used to calculate 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 2). *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*.

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

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 (Andrusak 2013). 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 2014 due to limited observer efficiency information and model convergence.

Stream-wide habitat survey

The 2014 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 1). These estimates include both main and side channel habitat which exist 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 2014 covered approximately 11.2% Lardeau River and 8.1% of the Duncan River (Table 1). A total of 9.6% of the mainstem shoreline and 18.3% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 11.6% of the mainstem shoreline were surveyed in the Duncan River in 2014. As well, it should be noted that no side channel habitat was surveyed in the Duncan River in 2014 and that the Lardeau River side channel habitat is representative of similar habitat on the Duncan River (*see Discussion for further detail*).

Table 1. Estimated shoreline meters and estimated shoreline meters surveyed in the spring of 2014 on the Lardeau and Duncan rivers**.**

River	Channel	Surveyed (km)	Not Surveyed (km)	Total (km)	% Surveyed (km)
Lardeau	Main	11.0	103.9	114.9	9.6%
	Side	4.9	21.7	26.6	18.3%
Duncan	Main	4.4	33.4	37.8	11.6%
	Side	0	16.9	16.9	0%
Total		**20.3**	**175.98**	**196.2**	**Avg 13.2%**

Nightime snorkel surveys

A total of 1,764 juvenile rainbow trout were observed during the night time surveys conducted in the Lardeau and Duncan rivers in 2014. 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.

Overall, surveys 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, Andrusak 2010, 2013) indicate the probable age structure from the 2013 fish observations. Data suggests a separation in fork length between age-1 and older parr Gerrard rainbow trout and to a lesser extent between age-2 and age-3 juveniles (Figure 2). 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 (fry) 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 mm (Figure 2). Nonetheless, 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.

Snorkel efficiency

A total of 9 sites were used to obtain observer efficiency using mark-recapture methods in the spring of 2014 (Table 2). This builds on observer efficiency data collected from the previous years' studies (2006-2010) to obtain estimates of abundance age class (Decker and Hagen 2009, Andrusak 2010, 2013b). Efficiencies are provided by for age 1 only and assume closure at each site was met and that immigration and emigration was negligible. It is acknowledged that no assessment of tag loss was conducted which may also bias estimates.

Table 2. The estimated observer efficiencies obtained from 9 sites on the Lardeau River in 2014.

River	Year	Section	Mark	Observed	Count
Lardeau	2014	LAR04.8	17	4	282
Lardeau	2014	LAR14.05	15	7	113
Lardeau	2014	LAR19.45	14	3	52
Lardeau	2014	LAR22.7	14	2	94
Lardeau	2014	LAR41.7	5	0	13
Lardeau	2014	LAR18.94	14	2	154
Duncan	2014	LDR03	18	5	28
Duncan	2014	LDR05.9	23	11	97
Duncan	2014	LDR06.7	18	7	149

Age 1

Snorkel efficiency or probability of detection for age 1 (2006-2014) from mark-re-sight data was estimated to be 0.41 (95% CRI 0.36-0.45; Table 3; Figure 3). However, based on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.17 (95% CRI 0.13-0.21; Table 3; Figure 3). Results indicate substantial bias for snorkel efficiencies for age 1 when using mark-recapture methods compared to standard count efficiencies.

Table 3. Estimated snorkel efficiencies for age 1 and older parr in the Lardeau and Duncan rivers from 2006-2014

Season	Life Stage	Visit Type	Estimate	Lower 95% CRI	Upper 95% CRI
Spring	Age 1	Standard	0.17	0.13	0.21
Spring	Age 1	Marked	0.41	0.36	0.45

Density and Abundance Estimates

Age 1

To be consistent with previous work, the term “fry” is often used since the spring surveys occur before age 1 is achieved on June 1st. Nonetheless, these “fry” have survived through winter, the period of highest mortality, and often in the literature are referred to as parr. However, this year’s report displays fry as age 1 for most figures and tables.

With the exception of 2006, age 1 densities in the Lardeau River have averaged 1.0 fish/m from 2007-2014, substantially higher than previously reported (Table 4; Figure 4). The 2014 fry estimates of 0.53 fish/m (95% CRI 0.40-0.68) in the Lardeau River are substantially lower than the 0.72 fish/m (95% CRI 0.56-0.92) estimated in 2013 despite increasing escapement at Gerrard (*see Discussion*). While no age 1 estimates are available prior to 2006 using similar methods, data suggests a rather substantial change in age 1 density since 2006.

LDR age 1 densities were estimated to be 0.51 fish/m (95% CRI 0.35-0.72) in 2014 (Table 5; Figure 5). The LDR mean age 1 densities of 0.98 fish/m from 2006-2014 are slightly lower than densities observed in the Lardeau River for the same time period (Table 4; Figure 4).

Table 4. Estimated age 1 density (fish/m) in Lardeau and Duncan rivers from 2006-2014

Year	River	Estimate	Lower 95% CRI	Upper 95% CRI
2006	Lardeau	2.36	1.56	3.39
2007	Lardeau	0.91	0.59	1.32
2008	Lardeau	0.69	0.49	0.93
2009	Lardeau	0.73	0.51	1.02
2010	Lardeau	0.83	0.55	1.19
2011	Lardeau	1.16	0.89	1.51
2012	Lardeau	1.12	0.85	1.43
2013	Lardeau	0.72	0.56	0.92
2014	Lardeau	0.53	0.40	0.68
2006	Duncan	1.04	0.34	2.55
2007	Duncan	1.02	0.34	2.42
2008	Duncan	1.02	0.30	2.46
2009	Duncan	1.05	0.32	2.63
2010	Duncan	1.04	0.33	2.53
2011	Duncan	0.77	0.48	1.10
2012	Duncan	1.15	0.79	1.64
2013	Duncan	1.28	0.92	1.72
2014	Duncan	0.51	0.35	0.72

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

The 2014 Lardeau River age 1 abundance was estimated at 46,921 (95% CRI 35,559-60,918), substantially lower than 2013 estimate of 63,508 (95% CRI 49,520-81,211; Table 5). Age 1 abundance in the Lardeau River was highest in 2006 at 207,518 (95% CRI 138,902-301,812) over the eight year time period (Table 5; Figure 5). With the exception of 2006, Lardeau River age 1 abundance has averaged 88,578 (2006-2014), higher than that previously reported in Andrusak (2013; Table 5; Figure 4).

The 2014 LDR age 1 abundance was estimated at 16,060 (95% CRI 11,190-22,637), lower than 2013 estimate of 40,188 (95% CRI 29,113-54,577; Table 5). LDR age 1 abundance has averaged 31,027 (2006-2014) thus representing 25% of the stock in the rivers (Table 5; Figure 5). However, total age 1 abundance combined for the Lardeau and Duncan rivers of 62,981 is substantially lower than previous years (Table 5; Figure 5). With the exception of predicted recruitment of age 1 from 2006-2010 for the LDR, estimates are relatively precise with a coefficient of variation of 0.3 or less for both the Lardeau and Duncan rivers (Table 5), a substantial improvement from that reported in Decker and Hagen (2009) and Andrusak (2010). Precision (C.V.) was slightly lower for the LDR compared to the Lardeau for estimates for age 1 (Table 5).

Table 5. Estimated age 1 abundance in Lardeau and Duncan rivers from 2006-2014

Year	River	Estimate	Lower 95% CRI	Upper 95% CRI	CV
2006	Lardeau	207518	138903	301812	0.39
2007	Lardeau	79838	52329	115672	0.4
2008	Lardeau	60773	43704	81506	0.31
2009	Lardeau	64551	45638	90388	0.35
2010	Lardeau	73226	48399	104099	0.38
2011	Lardeau	102404	78997	132894	0.26
2012	Lardeau	98469	74788	126683	0.26
2013	Lardeau	63508	49520	81211	0.25
2014	Lardeau	46921	35599	60918	0.27
2006	Duncan	32618	10671	80371	1.07
2007	Duncan	32233	10680	77087	1.03
2008	Duncan	32075	9442	78995	1.08
2009	Duncan	33027	10412	80701	1.06
2010	Duncan	32608	10256	78387	1.04
2011	Duncan	24138	15528	34561	0.39
2012	Duncan	36293	24871	51946	0.37
2013	Duncan	40188	29114	54577	0.32
2014	Duncan	16060	11190	22637	0.36

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

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 for 2014 and demonstrate a considerable increase in total habitat, especially on the Duncan River (Table 1).

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 6). 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, Figure 7 demonstrates observed fish counts by size class on a restored side channel of the Lardeau River in 2014 (Andrusak 2013).

DISCUSSION

Determining a stock's reproductive capacity and productivity is essential for managing this highly exploited population (Hilborn 1992, Walters 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 management of this stock (Andrusak 2005). As recommended by the provincial stock assessment team and since most of the mortality occurs within the first year, the early spring time sampling is the most appropriate time for the snorkel surveys employed to assess the Gerrard juvenile population, despite fall surveys conducted in 2005 and 2006 (Decker and Hagen 2009). Obtaining precise and accurate data on the juvenile recruitment and their habitat requirements is vital to make informative management or conservation decisions related to the population.

Following the initial surveys on juvenile rainbow trout recruitment on the Lardeau and Duncan rivers (Decker and Hagen 2009, Andrusak 2010, 2013), a re-designed approach was undertaken to address the uncertainty and bias associated with juvenile assessments using snorkel methodology from previous work conducted. Most importantly, the re-designed objectives were aimed at providing more accurate and precise estimates of juvenile recruitment that would be informative for management purposes. Following the final year of the study in 2015, the data obtained will be used to develop stock recruitment relationship for defining management reference points for the Gerrard rainbow trout population.

An important criteria in reducing the uncertainty in juvenile abundance estimates is the ability to achieve a level of sampling effort or sampling coverage through increased site replication. To achieve coefficient of variation of 0.2 in total river abundance estimates for spring parr as suggested by Korman et al. (2010), approximately 5% of the total useable shoreline length must be sampled. Previous studies (Decker and Hagen 2009; Andrusak 2010), covered approximately 5.5 km and replicated 55 sites (~100 m) over the 140 km of lineal habitat available in the Lardeau River. The re-designed approach, commencing in 2011, increased sampling effort to attempt to over approximately 10% of the lineal habitat available in both rivers. The 2014 spring surveys covered approximately 11.2% of the Lardeau River and 8.1% of the Duncan River, exceeding the goal of 10% and well above the 5% recommended by Korman et al. (2010). It should be noted that no side channels were surveyed in the Duncan River in 2014, nonetheless, it is assumed that the Lardeau River side channels represents similar habitat to the Duncan River, of which, a total of 18.3% was surveyed.

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 efficiencies. Obtaining reliable estimates of fish abundance and species distribution requires the use of unbiased (statistical) estimators such as mark recapture or removal estimators (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 mark recapture over-estimated efficiencies, representing a substantial bias in juvenile abundances' reported in previous years (Decker and Hagen 2009, Andrusak 2010, 2013). Standard site visits (regular counts, no marked fish) indicated substantially lower efficiencies compared to mark recapture sites for both fry and parr, 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.

Based on improved modeling, survey design and quantified total habitat from GIS, it appears that juvenile estimates for age 1 and parr are approximately 1.5-2.0 x higher than previously reported by Decker and Hagen (2009) and Andrusak (2010). Excluding 2006, the Lardeau River as averaged 88,578 (2006-2014) age 1 juveniles representing 75% of the standing stock estimates within both rivers since 2007. Likewise, the LDR contributes an averaged 31,027 age 1 representing 25% of the standing stock estimates within both rivers. 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, similar to that suggested by Korman et al. (2010) for medium sized rivers. Older parr estimates were not obtained from the model in 2014 due to the high uncertainty in the estimates. Nonetheless, the improved study design indicates an increase in precision and reduction in bias compared to previous estimates derived in Decker and Hagen (2009) and Andrusak (2010) for juvenile rainbow trout. 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.)

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 (Kery 2010, 2012). 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. For example, GIS information in 2013 and 2014 indicated the LDR habitat was underestimated compared to previous years' reporting. As a result of the complex river morphology, 2013 and 2014 surveys increased sampling effort on the LDR to reduce the uncertainty in estimates for juvenile rainbow trout compared to previous years, hence, estimates on the Lardeau River are slightly more precise compared to the Duncan River.

The re-designed approach in assessing and obtaining juvenile abundance estimates in the Lardeau and Duncan rivers has been highly successful in addressing uncertainty and bias associated with survey methods. Moreover, the study appears to be meeting its primary objectives in providing more precise and accurate information on the juvenile recruitment required in defining a stock-recruitment relationship. Early indications suggest no appreciable increase in recruitment in the juvenile abundance since 2006 (Figure 8), despite a substantial increase in escapement at Gerrard over the same time period (Figure 9). The stock recruitment relationship suggests that the Gerrard rainbow trout population is near capacity within the river(Figure 8) and 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). Assuming no or a limited contribution from surplus fry that enter the lake (Irvine 1978) and due to the fact that over-winter mortality for fry is substantially high (Biro et al. 2004), the juvenile population in the river may be relatively small in comparison with other BC piscivores trout stocks (Andrusak 2005).

Understanding when juvenile Gerrard rainbow trout emigrate to the lake is a key component to the Gerrard population dynamics. Irvine (1978) suggested that most juveniles emigrated to the lake in their first spring. 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 the lacustrine environment of Kootenay Lake. Based on acoustic tagging information, 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 (Andrusak 2010). 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. Moreover, it will allow fisheries management to make informed decisions whether current regulations are appropriate especially in light of the popular fishery on the lake. Currently, a study is underway on Kootenay Lake to assess the natural and fishing mortality rates of this unique population (Andrusak and Thorley 2013). The information obtained from this exploitation study will compliment information collected from the work on the Lardeau River (spawner escapement and juvenile recruitment) to formulate biological reference points based on a stock recruitment relationship. In summary, the future of the study for 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.

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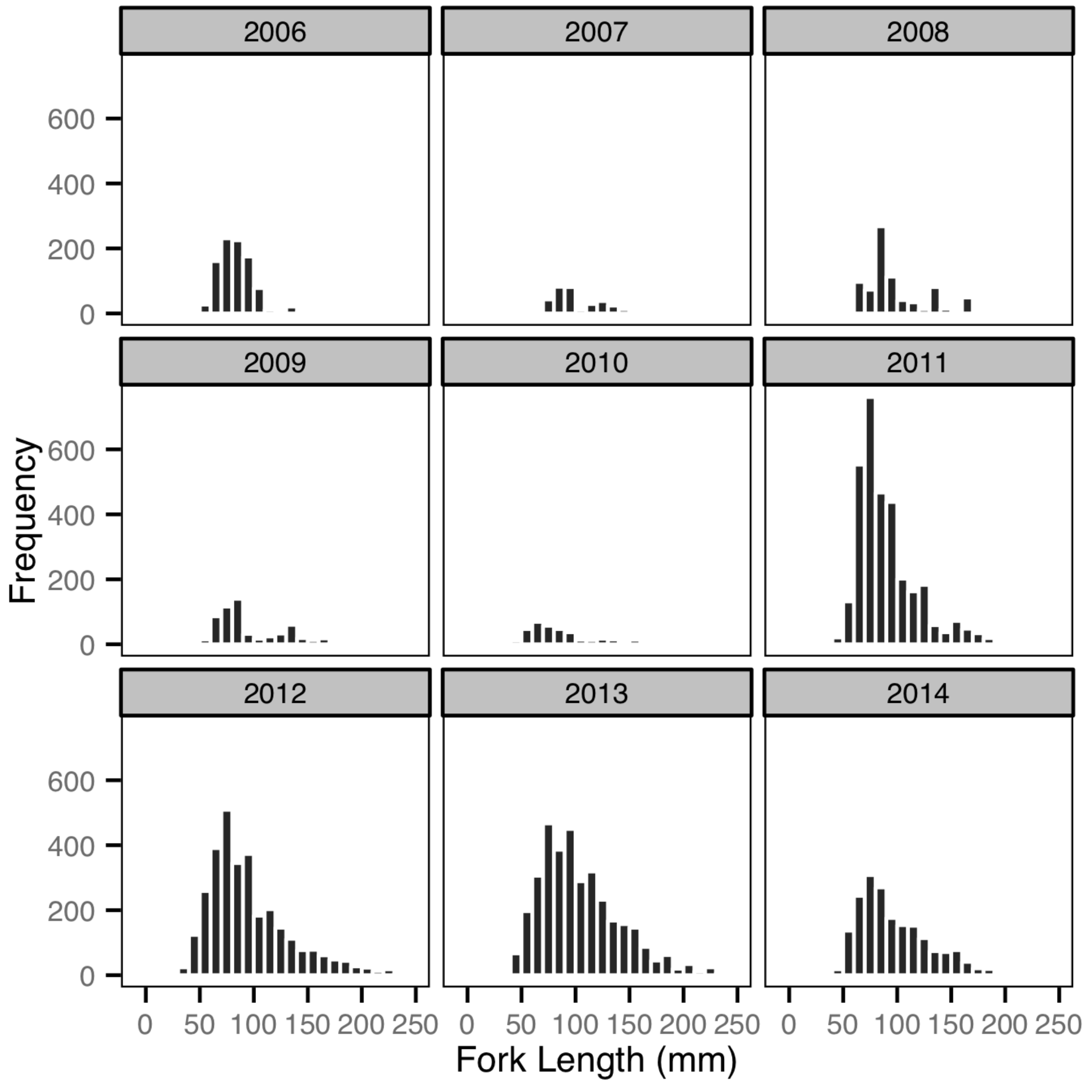


Figure 2. Length-frequency histogram of rainbow trout from the spring in the Lardeau River from 2006-2013. Age-0 fish had a fork length ≤ 100 mm, age-1 fish had a fork length between 100 and 150 mm and age-2+ fish had a fork length >150 mm.

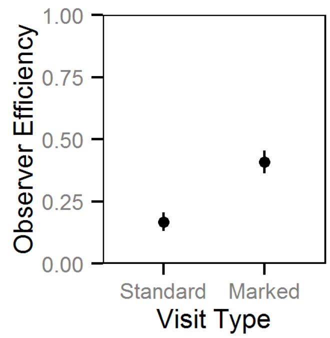


Figure 3. Estimated snorkel efficiency for age 1 obtained from standard count visits and mark-recaptures on Lardeau and Duncan rivers from 2006-2014.

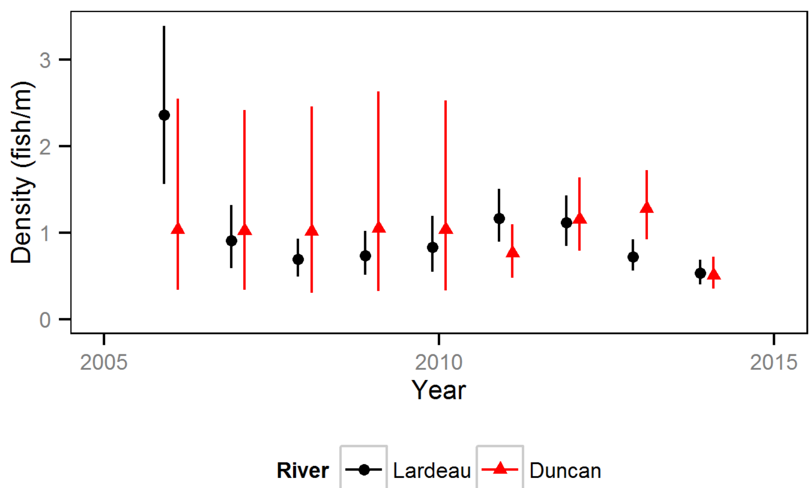


Figure 4. Estimated density (fish/m) of spring age 1 in Lardeau and Duncan rivers from 2006-2014

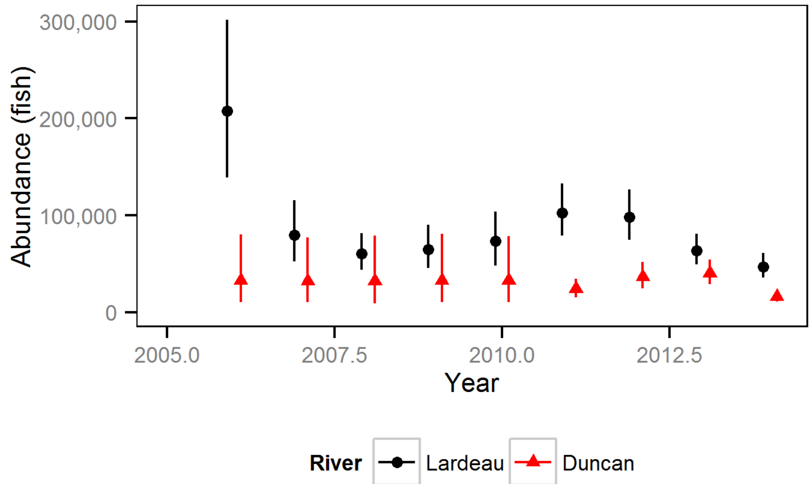


Figure 5. Estimated abundance of spring age 1 in Lardeau and Duncan rivers from 2006-2014.

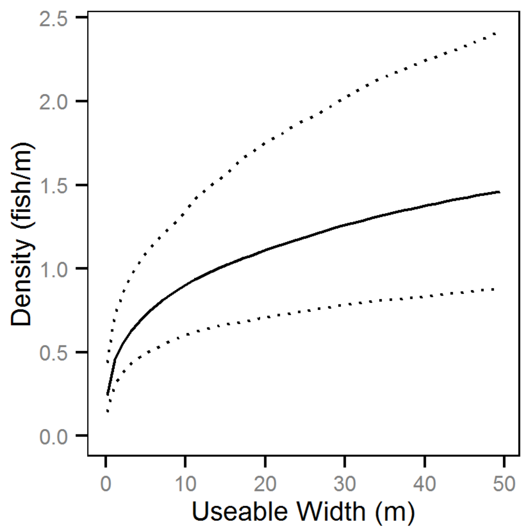


Figure 6. Relationship between useable widths and juvenile density for age 1 on the Lardeau and Duncan rivers.

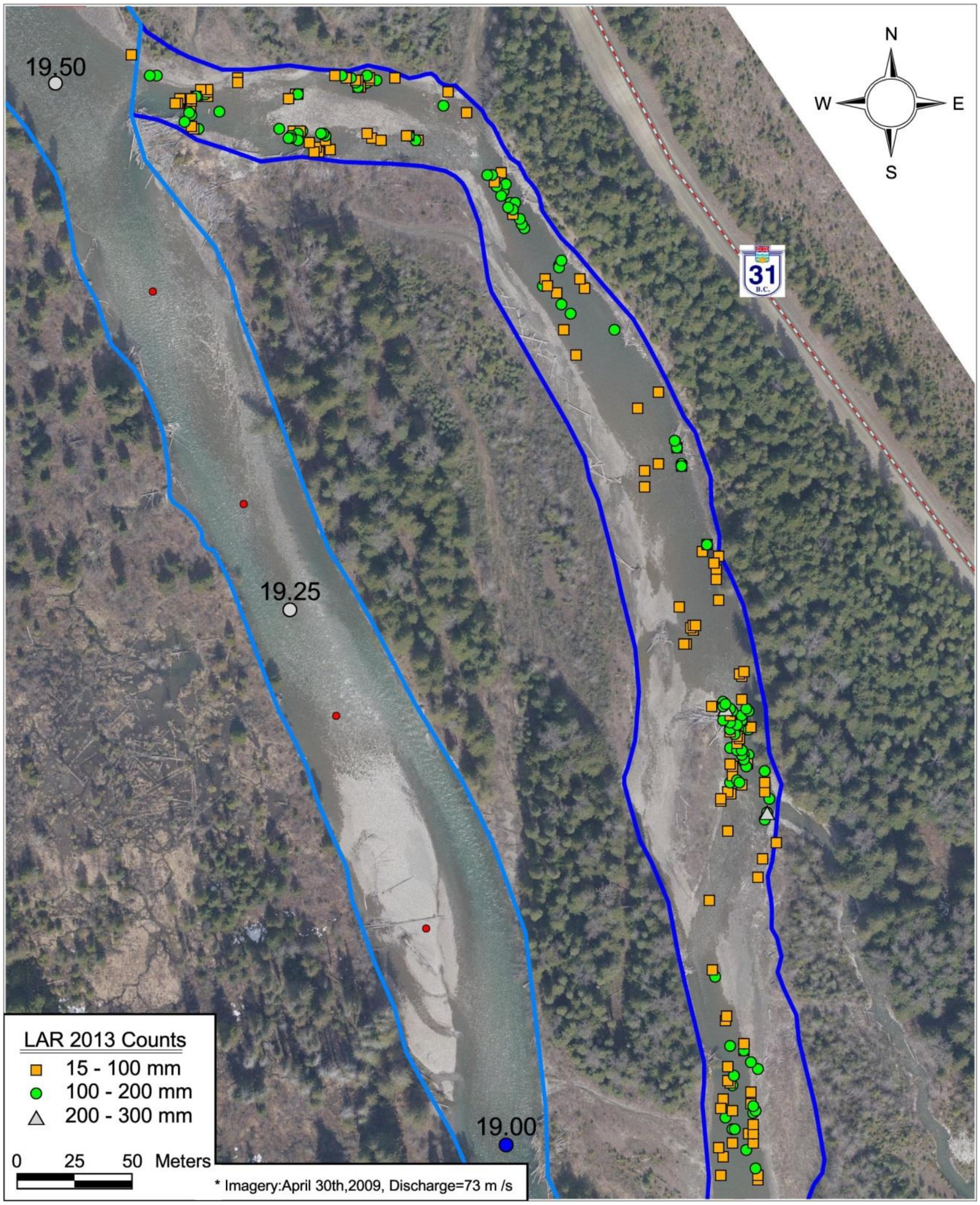


Figure 7. Geo-referenced fish counts by size category on a side-channel (19.25 km) of the Lardeau River in 2014.

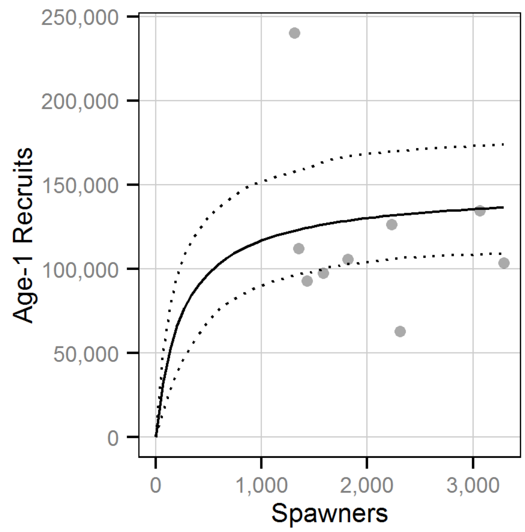


Figure 8. Preliminary stock-recruitment relationship for Gerrard rainbow trout

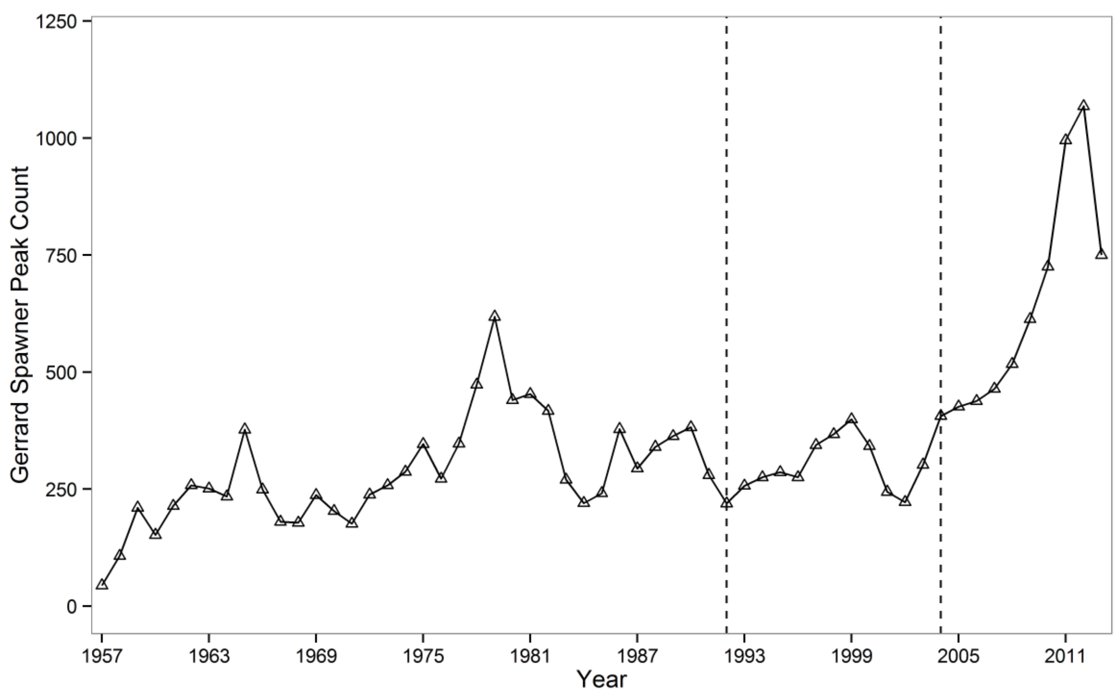
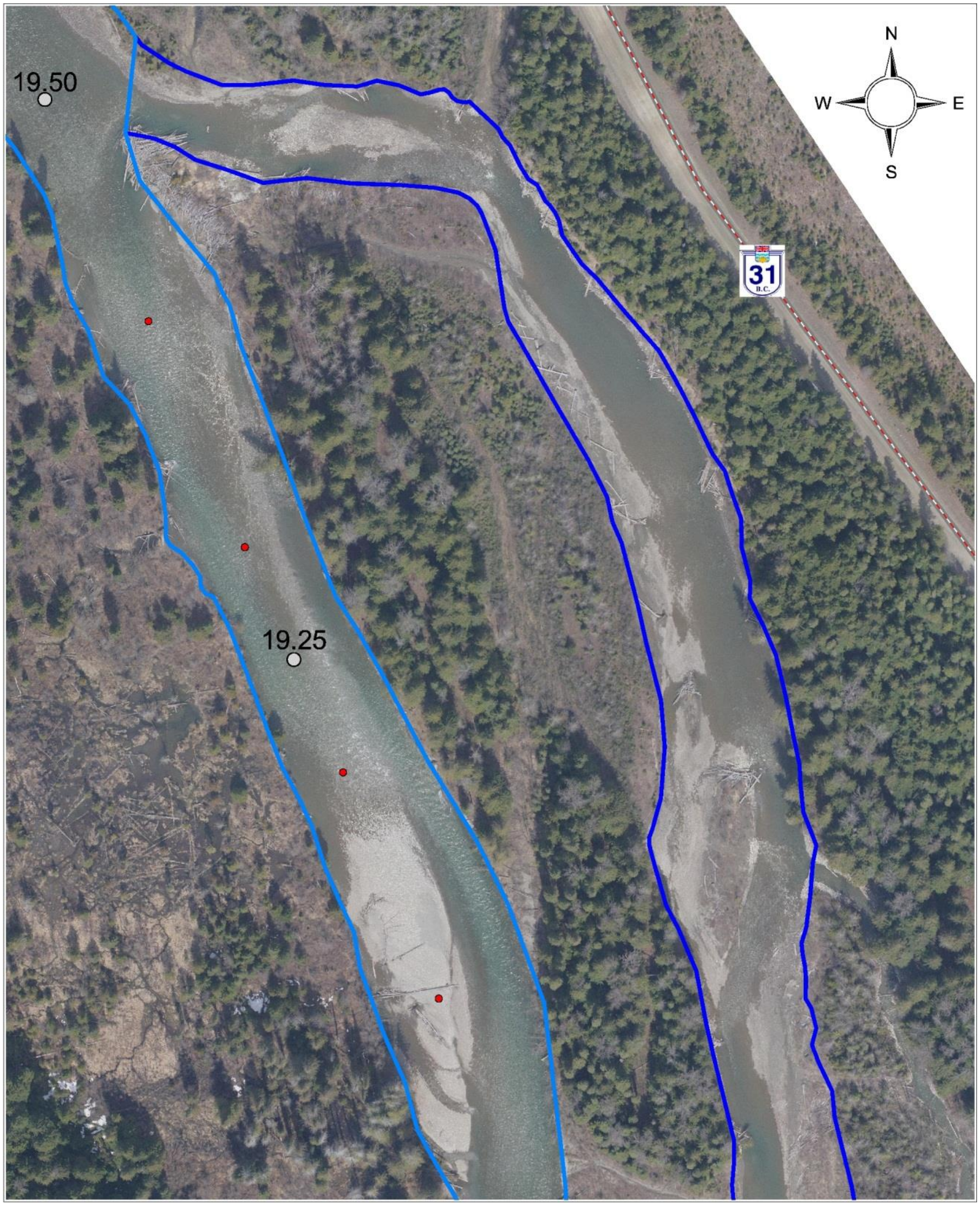
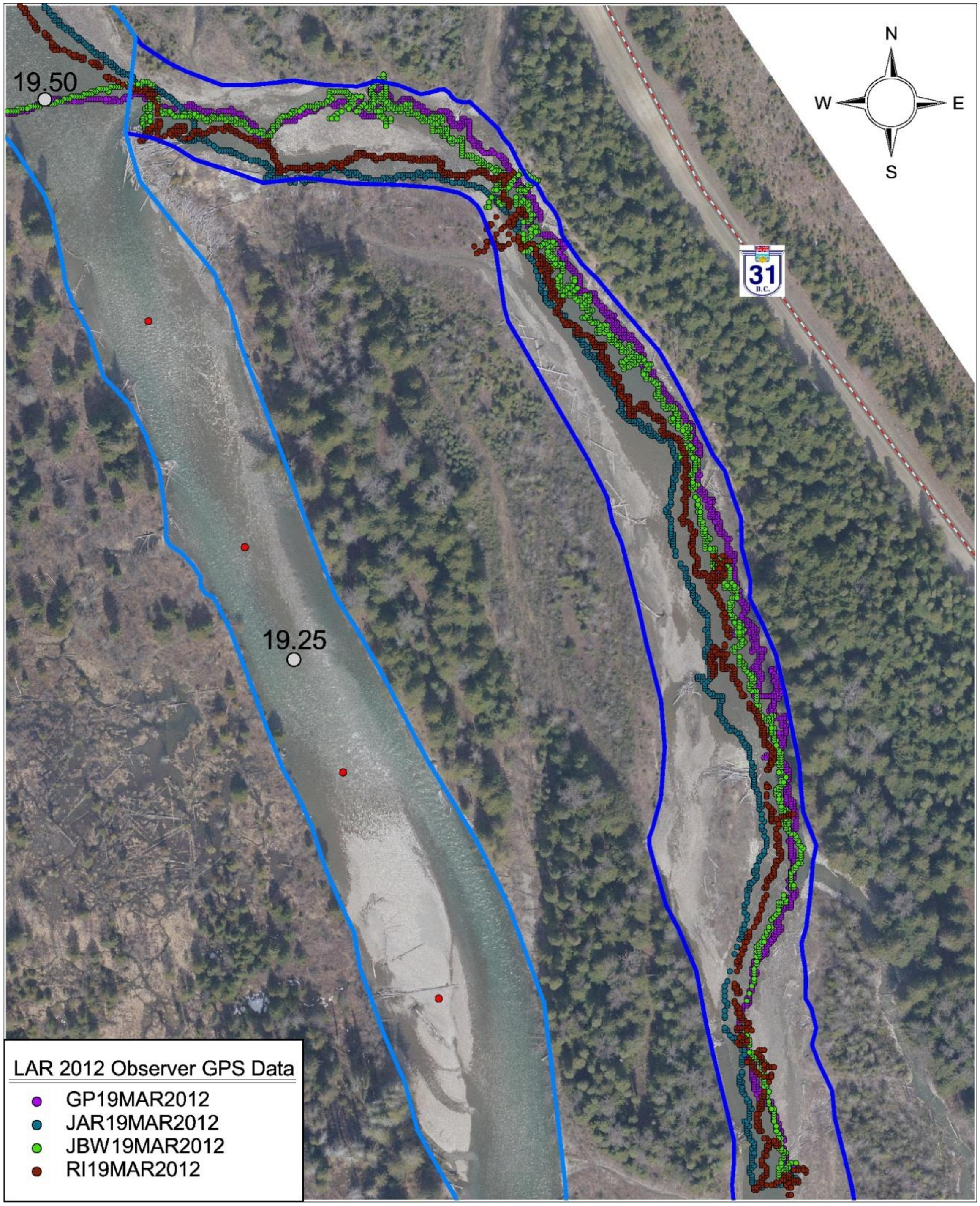


Figure 9. Gerrard rainbow trout spawner peak count from 1957-2013. Vertical lines represent the commencement of North Arm (1992) and South Arm (2004) nutrient addition (data from MNFLRO file data).

APPENDIX 1. Estimated lineal bank length using GIS



APPENDIX 2. GPS information from surveys in GIS



APPENDIX 3. Hierarchical Bayesian model details

Statistical Analysis

Hierarchical Bayesian models were fitted to the snorkel and stock-recruitment data using R version 3.1.0 (Team, 2013) and JAGS 3.4.0 (Plummer, 2012) which interfaced with each other via jaggernaut 1.8.2 (Thorley, 2014). For additional information on hierarchical Bayesian modelling in the BUGS language, of which JAGS uses a dialect, the reader is referred to Kery and Schaub (2011) pages 41-44.

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

The posterior distributions of the *fixed* (Kéry and Schaub, 2011, p. 75) 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, p. 37,42).

The results are displayed graphically by plotting the modeled 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, pp. 77-82). Plots were produced using the ggplot2 R package (Wickham, 2009).

Abundance

The abundance was estimated using a mark-resight-based binomial mixture model (Kéry and Schaub, 2011, pp. 134-136,384-388).

Key assumptions of the abundance model include:

- Lineal density (fish/m) varies with useable width.
- Lineal density (fish/m) varies randomly with year within river and site.
- Efficiency (probability of capture) varies by visit type (standard versus presence of marked fish).
- Marked and unmarked fish have the same probability of being counted.
- There is no tag loss, mortality or misidentification of fish.
- Sites are closed.

- The actual abundance at a site on a visit is described by an over-dispersed Poisson distribution- The number of marked and unmarked fish observed at a site are described by a binomial distributions.

Stock-Recruitment

The relationship between the number of spawners and the number of age-1 recruits the following spring was estimated using a Beverton-Holt stock-recruitment model.

Key assumptions of the stock-recruitment model include:

- The prior probability for the number of recruits per spawner at low density (`R0`) is normally distributed with a mean of 500 and a SD of 250.
- The residual variation in the number of age-1 recruits is log-normally distributed.

The mean prior probability of 500 for `R0` was 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.

Model Code

The JAGS model code, which uses a series of naming conventions, is presented below.

Abundance

Variable/Parameter	Description
`bDebsity0`	Intercept for `log(eDensity)`
`bDensityRiverYear`	Effect of `River` within `Year` on `log(eDensity)`
`bDensitySite`	Effect of `Site` on `log(eDensity)`
`bDensityWidth`	Exponent for effect of `Width` on `eDensity`
`bEfficiency0`	Intercept for `logit(eEfficiency)`
`bEfficiencyVisitType`	Effect of `VisitType` on `logit(eEfficiency)`
`eAbundance[ii]`	Expected abundance of fish at site of ii*th* visit
`eDensity[ii]`	Expected desnity on ii*th* visit
`eDispersion`	Overdispersion of `eTotal`
`eEfficiency[ii]`	Expected observer efficiency on the ii*th* visit
`eTotal[ii]`	Expected total number of fish at site of ii*th* visit
`Marked[ii]`	Number of fish marked prior to the ii*th* visit
`Resighted[ii]`	Number of marked fish resighted during ii*th* visit
`River[ii]`	River of ii*th* visit
`sDensityRiverYear`	SD of effect of `River` within `Year` on `log(eDensity)`
`sDensitySite`	SD of effect of `Site` on `log(eDensity)`
`sDispersion`	SD of overdispersion term
`Site[ii]`	Site of ii*th* visit

`SiteLength[ii]`	Length of site of ii*th* visit
`SurveyProportion[ii]`	Proportion of site surveyed during ii*th* visit
`Total[ii]`	Total number of fish observed during ii*th* visit
`VisitType[ii]`	Visit type of ii*th* visit
`Width[ii]`	Site width of ii*th* visit
`Year[ii]`	Year of ii*th* visit

Abundance - Model1

```
model {

  bEfficiency0 ~ dnorm(0, 2^-2)

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

  bDensity0 ~ dnorm(0, 5^-2)

  bDensityWidth ~ dnorm(0, 2^-2)

  sDensityRiverYear ~ dunif(0, 5)
  for (rv in 1:nRiver) {
    for (yr in 1:nYear) {
      bDensityRiverYear[rv, yr] ~ dnorm(0, sDensityRiverYear^-2)
    }
  }

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

  sDispersion ~ dunif(0, 5)

  for (ii in 1:length(Total)) {

    logit(eEfficiency[ii]) <- bEfficiency0
                            + bEfficiencyVisitType[VisitType[ii]]

    dEfficiencyMark[ii] <- min(eEfficiency[ii], Marked[ii])
    dMarked[ii] <- max(Marked[ii], 1)

    Resighted[ii] ~ dbin(dEfficiencyMark[ii], dMarked[ii])

    log(eDensity[ii]) <- bDensity0
```

```
                        + bDensityWidth * log(Width[ii])
                        + bDensityRiverYear[River[ii],Year[ii]]
                        + bDensitySite[Site[ii]]

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

    eDispersion[ii] ~ dgamma(1/sDispersion^2, 1/sDispersion^2)
    eTotal[ii] ~ dpois(eAbundance[ii] * eDispersion[ii])

    Total[ii] ~ dbin(eEfficiency[ii], eTotal[ii])
  }
}
```

Stock Recruitment

Variable/Parameter	Description
eRecruits	Expected number of age-1 recruits
k	Carrying capacity
R0	Recruits per spawner at low density
Recruits	Number of age-1 recruits
sRecruits	SD of log-normally distributed residual variation in Recruits
Stock	Number of spawners at Gerrard

Stock Recruitment - Model1

```
model {
  R0 ~ dnorm(8000 * 0.5^4, 250^-2) T(0,)
  k ~ dunif(5 * 10^4, 2.5 * 10^5)
  sRecruits ~ dunif(0, 5)

  for (ii in 1:length(Stock)) {
    eRecruits[ii] <- R0 * Stock[ii] / (1 + Stock[ii]*(R0-1)/k)

    Recruits[ii] ~ dlnorm(log(eRecruits[ii]), sRecruits^-2)
  }
}
```