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

Progress Report

March 2013

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

Progress Report

Project No.: FF13-04

Prepared for

Fish and Wildlife Compensation Program – Columbia Basin

and

Habitat Conservation Trust Foundation

Prepared by

Greg Andrusak, RPBio

Redfish Consulting Ltd.
Nelson, BC

March 2013

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.

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.

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 2011 and 2012 on the Lardeau and Duncan rivers combined with re-analyzed spring survey data from 2006-2010 in the Lardeau River.

Similar to 2011, sampling effort increased considerably in 2012 compared to previous years' work (2006-2010). Beginning in 2011, the re-designed approach began to systematically assess >5% of 143 km of shoreline available in the Lardeau and Duncan rivers. Surveys conducted in the spring of 2012 covered approximately 11.2% Lardeau River and near 10% of the Duncan River. A total of 10.5% of the mainstem shoreline and 14.4% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 9.8% of the mainstem shoreline and 10.9% of the side channel habitat 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 0.2.

A total of 6,456 juvenile rainbow trout were observed during the night time surveys conducted in the Lardeau and Duncan rivers. 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 year's data (2006-2010) indicate the probable age structure from the 2012 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 spring fry (2006-2012) from mark-re-sight data was estimated to be 0.42 (95% CRI 0.27-0.59). However, based

on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.24 (95% CRI 0.17-0.32), indicating substantial bias in the mark recapture estimator.. Snorkel efficiency for spring parr (2006-2012) from mark-re-sight data was estimated to be 0.27 (95% CRI 0.14-0.49). However, based on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.14 (95% CRI 0.08-0.25). Results indicate substantial bias for snorkel efficiencies for spring fry and parr when using mark-recapture methods. 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 spring fry and parr are approximately 1.5-2.0 fold higher than previously reported (2006-2010). In 2012, spring fry was estimated to be 51,717 (95% CRI 39,000-69,710) in the Lardeau River and 17,949 (95% CRI 12,142-27,830) in the Lower Duncan River. As well, in 2012, spring parr was estimated to be 18,917 (95% CRI 12,563-31,038) in the Lardeau River and 7,823 (95% CRI 4,450-13,933) in the Lower Duncan River. Spring fry estimates have averaged 53,000 within the Lardeau River since 2007 and spring parr estimates average 18,900 since 2007.

The improved modeling using a hierarchical Bayesian framework, further information on snorkel efficiency, and increased sampling effort 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 fry estimates attained the desired level of precision with a coefficient of variation of 0.2. Parr estimates were less precise but still attained a reasonable 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 Basin (FWCP) and the Habitat Conservation Trust Foundation (HCTF). The FWCP is a partnership of BC Hydro, the BC Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), BC Ministry of Environment, and Canada Department of Fisheries and Oceans.

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, Clint Tarala, Robyn Irvine, Jason Bowers, Gary Pavan, Jeremy Baxter 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.

Trevor Oussoren (FWCP) and Steve Arndt (FWCP) are acknowledged and thanked for their assistance with editing of this report.

Cover Photo: 'Photo of the Lardeau River during the spring freshet.' Photograph taken on the 15th of June 2012 by Greg Andrusak.

Suggested Citation: Andrusak, G.F. 2013. Determination of Gerrard Rainbow Trout Productivity and Capacity in Defining Management Reference Points-2012. 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. December 2012. 32 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*). This unique ecotype is highly sought after in the lakes' recreational fishery, often attaining a "trophy size" of > 7kg. The value of this unique stock has warranted a better understanding of how the population is regulated and how fishing from the recreational fishery influences the status of these piscivorous rainbow trout on Kootenay Lake (Andrusak and Thorley 2012). As well, conservation concern of this stock arises since most of their natural production (spawning and rearing) is dependent upon the Lardeau River (Irvine 1978; Redfish Consulting Ltd. 2002).

Assessing and determining a stock's reproductive capacity and productivity is essential for managing this highly exploited population (Walters and Martell 2004; Hilborn and Walters 1992). Assessment and estimations of the in-river juvenile abundance from the Lardeau and Duncan rivers provides important information for determining the stock-recruitment relationship that is used to determine useable biological reference points for stock management. Understanding how fishing influences the status this stock and determining whether the current rates of harvest are sustainable is considered to be a high priority for management (Andrusak 2005). Currently, a study is underway on Kootenay Lake to assess the natural and fishing mortality rates of this population (Andrusak and Thorley 2012). At the same time survey work has been underway on the Lardeau River to determine the stock's reproductive productivity, an essential piece of information when managing a highly exploited stock. Data obtained from the on-going exploitation study (Andrusak and Thorley 2012) will compliment information collected from the work on the Lardeau River (spawner escapement and juvenile recruitment) thus providing fisheries management with a sound foundation for future management of this highly prized rainbow trout population.

Utilization of a stock recruitment relationship relies on having or obtaining relatively precise indices of adult spawners and subsequent recruitment. Spawner counts have been conducted at the Gerrard spawning grounds and provide an excellent time series extending from 1961 to the present (Hartman 1969; Hartman and Galbraith 1970; Hagen et al. 2007). More recently, in-river work utilizing nightime snorkel methods have focused on obtaining estimates of juvenile Gerrard rainbow trout in the Lardeau River (Decker and Hagen 2009). 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. However, these biological relationships are often based on relatively few and temporally auto-correlated data with substantive measurement errors that can lead to non-interpretative and indistinguishable information. To overcome this potential problem additional years of data are required for increasing the precision of the measured variables in the stock-recruit relationship. This report summarizes the 2012 spring survey conducted on the Lardeau and Duncan rivers utilizing nightime 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 majority of the Gerrard rainbow trout natural production takes place (Irvine 1978; Redfish Consulting Ltd. 2002).

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 and Walters 1992; Walters and Martell 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 of previous work. 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 2012). 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 (AMEC 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 downstream of the Lardeau River confluence have been made (AMEC

2012; Decker and Hagen 2009). 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 positioned in a north-south axis between the Selkirk and Purcell mountain ranges in the southeast corner of British Columbia. The Duncan River, the major tributary entering the north end of the lake, receives the Lardeau River 10 km upstream of Kootenay Lake, at the town of Meadow Creek. The confluence is located approximately one kilometer downstream of the Duncan Dam, which is not operated to allow passage of adult rainbow trout. The Lardeau River, which is paralleled by Highway 31, originates at the outlet of Trout Lake, and flows approximately 45 km in a southeastern direction to its confluence with the regulated Duncan River. The Lardeau valley is quite narrow, often less than 2 km across the valley floor. After joining the Duncan the valley widens to about 4 km at the north end of Kootenay Lake at the Duncan River delta. The Lardeau River is a relatively low gradient system varying from <1% to 2%. Trout Lake serves as a settling basin, providing very clear water at the lake outlet. However, each tributary downstream from Trout Lake contributes substantial amounts of sediments to the Lardeau River during spring freshet and periods of heavy rainfall. As a result, the river is usually turbid from mid-May until early July. The system is fairly active geo-morphologically, with a broad floodplain, large wood accumulations (log jams), 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 143 km (Figure 1). However, the majority of the study area is located in the Lardeau River which constitutes 110 km of river bank from the total of 143 km.

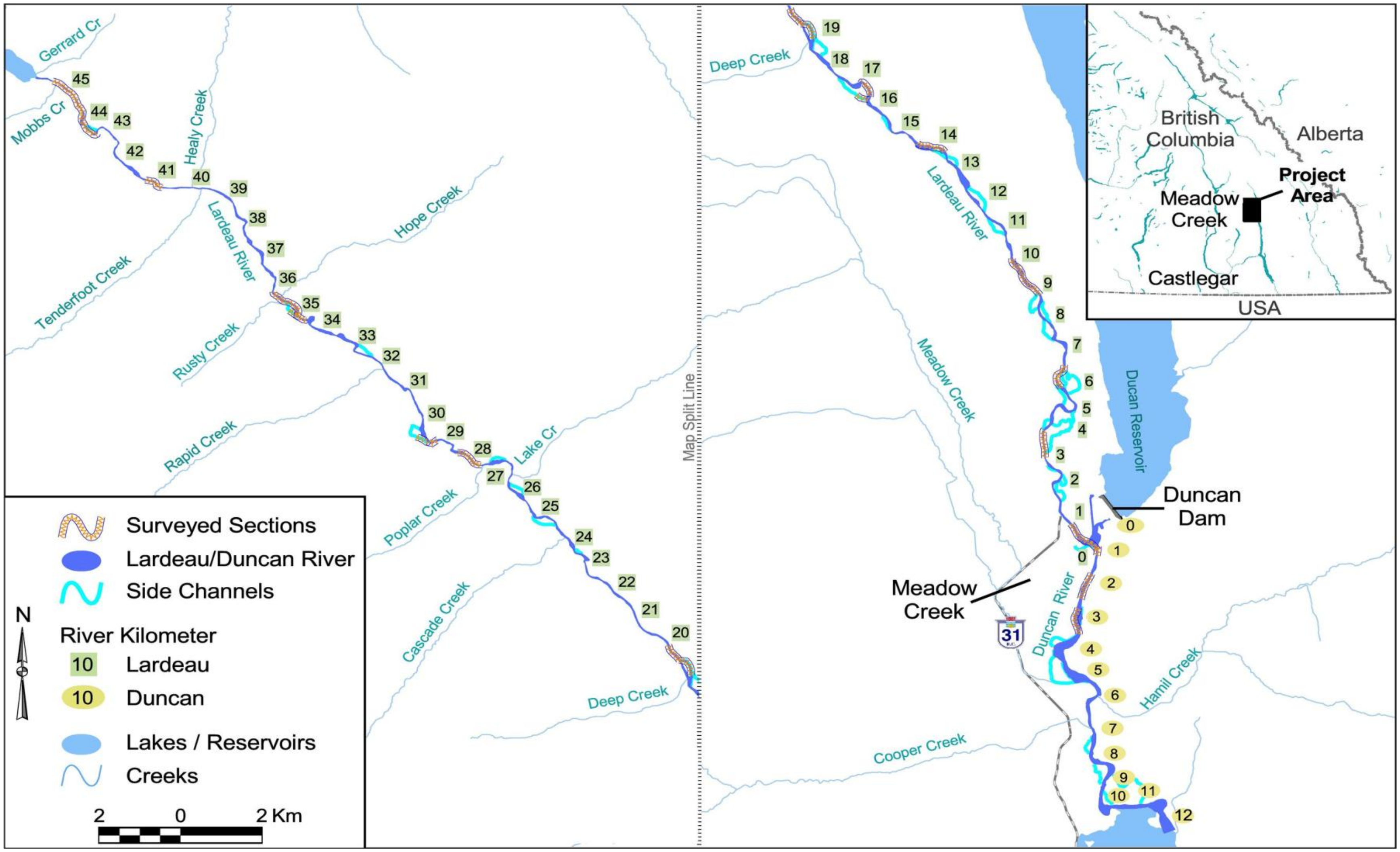


Figure 1. Location of Lardeau and Duncan rivers, length of study area (km), and location of surveyed sections in 2012.

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. In river estimates expanded based on total amount of habitat type 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 0.2 in total river abundance estimates for age 1 spring parr, approximately 5% of the total useable shoreline length must be sampled in the Lardeau and Duncan rivers. Both systems combine to account for 143 lineal kilometers of shoreline habitat of which a minimum of 7.15 kilometers must be sampled. Therefore, the design required a minimum of 150 sites (> 50 m) to be surveyed. This equates into ~ 20 sites per day/night using the rapid assessment method developed for medium to large rivers (Korman et al. 2010; Mitro and Zale 2002).

Stream-wide habitat survey

In order to convert an estimate of mean fish density to an estimate of standing stock for a particular sampling stratum, 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 orthophotography 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 orthophotography 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

Stratification of habitat for juvenile trout sampling in the Lardeau River defined three general habitat types by Decker and Hagen (2009) to derive estimates: 1) deep mainstem shoreline (average depth >40 cm within 2 m of the stream margin), 2) shallow mainstem shoreline (average depth <40 cm within 2 m of stream margin), and 3) side channels and braids. Based on analysis of data (Andrusak 2010), the re-design approach stratified habitat in to two general habitat types; 1) mainstem shoreline and 2) side channels and braids. However, the 2012 analysis did not incorporate the stratification of habitat into the analysis for this report.

In Decker and Hagen (2009), the sampling design implemented a systematic and random selection within each stratum. Sampling locations (access permitting) were selected systematically at uniform intervals (approximately every 2 km). Moreover, at each designated sampling location, habitat units of the appropriate type were selected randomly from those immediately available (i.e., in cases where several habitat units of the same type occurred at a designated sampling location). Whenever possible, mainstem and side channel/braid habitat units were sampled in their entirety, but sub-sampling was often employed in habitat units longer than 50 m. See Decker and Hagen (2009) for further detail.

The re-designed approach randomly selected sections of river, usually > 500 m per section (Figure 1). 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; Campbell and Neuner 1985) 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 2013 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; Campbell and Neuner 1985; Hillman et al. 1992) 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 in 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 2012. Visible marks utilize a #16-18 fish hook with a small piece of florescent chenille attached to hooks.

Age determination

Based on Decker and Hagen (2009) methods and results, fish with a fork length ≤ 100 mm were considered to be young of the year (age-0) while fish with a fork length (FL) between 101 and 150 mm were considered to be one year olds (age-1) and all other fish were classified as age-2+ where the + indicates three or more summers growth. To be consistent with Decker and Hagen (2009) protocols all trout were considered to be one year old (age 1) on the 1st of June - their theoretical emergence date.

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 (i.e., 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, observability by individual, site to site and year to year factors may also effect the variability in estimates.

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 and 2012 data as well as re-assessment of data from 2006-2010 (Decker and Hagen 2009; Andrusak 2010, 2011) 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

Hierarchical Bayesian Model

A Hierarchical Bayesian Mixed model (HBM) was fitted to the data (count and mark-re-sight) using software packages R 2.15.2 (R Development Core Team 2012) 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 (Kéry et al. 2005; Kéry and Shaub 2011) 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.

RESULTS

Stream-wide habitat survey

The 2012 survey involved both banks of the Lardeau River and Duncan River comprising a total of 110 km and 33 km of shoreline, respectively (Table 1). These estimates include both main and side channel habitat which exist within both systems. Mainstem habitat comprises ~92 km of shoreline, while side channels constitute ~18.4 km of habitat in the Lardeau River. Meanwhile, mainstem habitat comprises ~26.2 km of shoreline and side channel constitute ~7.3 km in the Duncan River.

Surveys conducted in the spring of 2012 covered approximately 11.2% Lardeau River and 10.1% of the Duncan River (Table 1). A total of 10.5% of the mainstem shoreline and 14.6% of the side channel habitat were surveyed in the Lardeau River. Similarly, a total of 9.8% of the mainstem shoreline and 10.9% of the side channel habitat were surveyed in the Duncan River.

Table 1. Estimated shoreline meters and estimated shoreline meters surveyed in the spring of 2012 on the Lardeau and Duncan rivers**.**

River	Channel	Surveyed (km)	Not Surveyed (km)	Total (km)	% Surveyed (km)
Lardeau	Main	9.7	82.3	92.0	10.5%
	Side	2.7	15.8	18.4	14.6%
Duncan	Main	2.6	23.7	26.2	9.8%
	Side	0.8	6.5	7.3	10.9%
Total		**15.7**	**128.2**	**143.9**	**10.9%**

Stratification of sampling effort

A total of 50 sections ~250 m in length were surveyed on the Lardeau River in the spring of 2012, equating into 12.5 km of habitat surveyed (Table 2). Similarly, 13 sections ~250 m in length were surveyed on the Duncan River in the spring of 2012. Based on the survey design and previous data (Andrusak 2010), the majority of effort (39 sections) were conducted on mainstem habitat, with remaining effort (11 sections) was dedicated to side channel habitat on the Lardeau River. Likewise on the Duncan, the majority of effort (10 sections) was conducted on mainstem habitat, with remaining effort (3 sections) dedicated to side channel habitat.

Further effort on the Duncan River was thwarted due to increased turbidity and decreased visibility to accurately conduct juvenile fish counts as a result of Duncan dam operations (i.e. higher flows that caused turbid conditions).

Table 2. Number of sections surveyed and not surveyed by habitat within the Lardeau and Duncan rivers in the spring of 2012.

River	Channel	Surveyed (#)	Not Surveyed (#)	Total (#)	% Surveyed (#)
Lardeau	Main	39	329	368	10.6%
	Side	11	63	74	14.9%
Duncan	Main	10	95	105	9.5%
	Side	3	26	29	10.3%
Total		**63**	**513**	**143.9**	**10.9%**

Nightime snorkel surveys

A total of 6,456 juvenile rainbow trout were observed during the night time surveys conducted in the Lardeau and Duncan rivers. 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 year’s data (Decker and Hagen 2009; Andrusak 2010) indicate the probable age structure from the 2012 fish observations. In general, the data from the previous study indicates a separation in fork length between age-0+ and age-1+ Gerrard rainbow trout and to a lesser extent between age-1+ and age-2+/3+ juveniles (Figure 2). In the latter case, information from scale-age analysis was needed to reliably separate age-1+ and 2+ parr (Decker and Hagen 2009; Andrusak 2010). Nevertheless, the data suggests that age 0 (fry) are ≤ 100 mm, ranging from 25-99 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 (Figure 2). Relatively few trout greater than 220 mm were observed during the study, however, there was an increase compared to 2011. It is uncertain if this is a limitation of snorkeler visibility or absence of larger trout.

Snorkel efficiency

A total of 4 sites were used to obtain observer efficiency using mark-recapture methods in the spring of 2012 (Table 3). This builds on observer efficiency data collected from the previous years' studies (2006-2010) to obtain estimates of abundance by age class (Andrusak 2010). As a result, efficiencies are provided by fry and parr separately and estimates 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 3. Mark recapture information used to estimate observer efficiencies obtained from 4 sites on the Lardeau River in 2012.

River	Year	Visit-type	Section	Mark-type	Sum of Count
Lardeau	2012	Count	18.77L	Resight	6
Lardeau	2012	Mark	18.77L	Marked	23
Lardeau	2012	Count	31.25	Resight	5
Lardeau	2012	Mark	31.25	Marked	16
Lardeau	2012	Count	40.5	Resight	2
Lardeau	2012	Mark	40.5	Marked	6
Lardeau	2012	Count	44.5	Resight	3
Lardeau	2012	Mark	44.5	Marked	7

Fry

Snorkel efficiency or probability of detection for spring fry (2006-2012) from mark-resight data was estimated to be 0.42 (95% CRI 0.27-0.59; Table 4; Figure 3). However, based on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.24 (95% CRI 0.17-0.32; Table 4; Figure 3). Results indicate substantial bias for snorkel efficiencies for spring fry when using mark-recapture methods compared to standard count efficiencies.

Table 4. Estimated snorkel efficiencies for fry and parr in the Lardeau and Duncan rivers from 2006-2012

Season	Life Stage	Visit Type	Estimate	Lower 95% CRI	Upper 95% CRI
Spring	Fry	Standard	0.24	0.17	0.32
Spring	Fry	Marked	0.42	0.27	0.59
Spring	Parr	Standard	0.14	0.08	0.25
Spring	Parr	Marked	0.27	0.14	0.49

Parr

Snorkel efficiency or probability of detection for spring parr (2006-2012) from mark-re-sight data was estimated to be 0.27 (95% CRI 0.14-0.49; Table 4; Figure 4). However, based on information from standard counts conducted at sites that did not contain marked fish, snorkel efficiencies were estimated to be 0.14 (95% CRI 0.08-0.25; Table 4; Figure 4). Once again results indicate a similar bias, snorkel efficiencies were substantially higher using mark-recapture methods compared to standard count efficiencies.

Density and Abundance Estimates

Fry

To be consistent with Decker and Hagen (2009) the term "fry" is 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. With the exception of 2006, spring fry densities in the Lardeau River have averaged 0.30 fish/m from 2007-2012 (Table 5; Figure 5). The 2012 fry estimates of 0.29 fish/m (95% CRI 0.22-0.39) are slightly lower than the 0.31 fish/m (95% CRI 0.24-0.42) estimated in 2011 despite increasing escapement at Gerrard (*see Discussion*). While no fry estimates are available prior to 2006 using similar methods, data suggests a rather substantial change in fry density in 2006 to 2007 in the Lardeau River. Lower Duncan River (LDR) spring fry densities are similar to Lardeau densities observed over the past six years averaging 0.30 fish/m from 2011-2012 (Table 5; Figure 5).

Table 5. Estimated spring fry density (fish/m) in Lardeau and Duncan rivers from 2006-2012.

River	Year	Estimate	Lower 95% CRI	Upper 95% CRI
Lardeau	2006	0.73	0.53	1.08
Lardeau	2007	0.32	0.22	0.50
Lardeau	2008	0.33	0.24	0.46
Lardeau	2009	0.29	0.19	0.45
Lardeau	2010	0.27	0.19	0.43
Lardeau	2011	0.31	0.24	0.42
Lardeau	2012	0.29	0.22	0.39
Lower Duncan	2011	0.31	0.21	0.50
Lower Duncan	2012	0.30	0.21	0.48

Spring fry abundance was highest in 2006 at 129,448 (95% CRI 93,677-185,887) and lowest in 2010 at 48,621 (95% CRI 33,320-74,711) over the seven year time period (Table 6; Figure 6). With the exception of 2006, spring fry abundance has averaged 53,000 (2007-2012 data) in the Lardeau River (Table 6; Figure 5). LDR spring fry abundance has averaged 18,000 (2011-2012 data) thus representing 25% of the stock in the rivers (Table 6; Figure 6). Total spring fry abundance in the Lardeau and Duncan rivers exceeded 69,000 in 2011 and 2012 (Table 6; Figure 6). Importantly, estimates are relatively precise with a coefficient of variation of 0.2 or slightly higher for both the Lardeau and Duncan rivers (Table 6). Nevertheless, precision was lower for the LDR compared to the Lardeau for estimates for fry (Table 6).

Table 6. Estimated spring fry abundance in Lardeau and Duncan rivers from 2006-2012

Year	River	Estimate	Lower 95% CRI	Upper 95% CRI	CV
2006	Lardeau	129,448	93,677	185,887	0.18
2007	Lardeau	57,652	38,205	86,370	0.21
2008	Lardeau	58,377	43,358	79,059	0.15
2009	Lardeau	50,470	34,082	78,922	0.22
2010	Lardeau	48,621	33,220	74,711	0.21
2011	Lardeau	54,898	42,590	74,401	0.14
2012	Lardeau	51,717	39,000	69,710	0.15
2011	Lower Duncan	18,570	12,680	28,352	0.21
2012	Lower Duncan	17,949	12,142	27,830	0.22

Parr

Spring parr in this report are age 1+ or older. Their densities in the Lardeau River have averaged 0.12 fish/m (2006-2012 data) as shown in Table 7 and Figure 7. In general, estimates are more variable compared to the fry estimates as a result of increased variation in observer efficiency for the larger size category. The 2012 parr estimates of 0.12 fish/m (95% CRI 0.08-0.21) is quite similar to the 0.11 fish/m (95% CRI 0.07-0.19) estimated in 2011 despite increased adult escapement at Gerrard (*see Discussion*). The two years of estimates for LDR spring parr densities are similar to Lardeau densities observed over the past six years averaging 0.11 fish/m (Table 7; Figure 7).

Table 7. Estimated spring parr density (fish/m) in Lardeau and Duncan rivers from 2006-2012

River	Year	Estimate	Lower 95% CRI	Upper 95% CRI
Lardeau	2006	0.10	0.06	0.19
Lardeau	2007	0.18	0.10	0.33
Lardeau	2008	0.08	0.05	0.14
Lardeau	2009	0.16	0.09	0.29
Lardeau	2010	0.11	0.06	0.22
Lardeau	2011	0.11	0.07	0.19
Lardeau	2012	0.12	0.08	0.21
Lower Duncan	2011	0.08	0.04	0.16
Lower Duncan	2012	0.14	0.08	0.26

Spring parr abundance was highest in 2007 at 26,925 (95% CRI 15,743-48,692) and lowest in 2011 at 16,806 (95% CRI 10,766-27,887) and track the cohort strength originating from the previous year as fry (Table 8; Figure 8). Spring parr abundance has averaged 18,900 from 2006-2012 in the Lardeau River (Table 8; Figure 8). LDR spring parr abundance has averaged 6,205 from 2011-2012, representing ~25% of the stock in the river (Table 8; Figure 8). Total spring parr abundance in the Lardeau and Duncan rivers exceeded 20,000 in 2011 and 2012 (Table 8; Figure 8). Parr estimates were less precise compared to fry estimates but still attained a reasonable level of precision with an average coefficient of variation of 0.29 for both rivers over the time period (Table 8). Nevertheless, precision was lower for the LDR compared to the Lardeau parr estimates (Table 8).

Table 8. Estimated spring parr abundance in Lardeau and Duncan rivers from 2006-2012

Year	River	Estimate	Lower 95% CRI	Upper 95% CRI	CV
2006	Lardeau	15,802	9,421	28,234	0.3
2007	Lardeau	26,925	15,743	48,692	0.31
2008	Lardeau	12,753	7,901	20,777	0.25
2009	Lardeau	23,975	14,125	43,328	0.3
2010	Lardeau	17,123	9,561	33,144	0.34
2011	Lardeau	16,806	10,766	27,887	0.25
2012	Lardeau	18,917	12,563	31,038	0.24
2011	Lower Duncan	4,586	2,538	8,477	0.32
2012	Lower Duncan	7,823	4,450	13,933	0.3

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. Integrating the spatial distribution data in the analysis demonstrated a positive relationship between useable widths and juvenile densities for both fry and parr on the rivers (Figure 9 and Figure 10). 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 11 demonstrates observed fish counts by size class on a restored side channel of the Lardeau River in 2012 (Andrusak 2011).

DISCUSSION

Kootenay Lake Gerrard rainbow trout represent a unique ecotype that provides an excellent year round fishery. This population is considered vulnerable primarily due to the fact that virtually all of their natural production (spawning and rearing) is dependent upon the Lardeau and lower Duncan rivers. From a fisheries management perspective assessing and determining a stock's reproductive capacity and productivity is essential for managing this exploited population. Obtaining precise and accurate data on the juvenile recruitment and habitat requirements are the primary objectives of this study. 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 stock management.

Subsequent to the initial surveys that assessed juvenile rainbow trout recruitment on the Lardeau and Duncan rivers (Decker and Hagen 2009; Andrusak 2010), a re-designed approach was undertaken to address the uncertainty and bias associated with juvenile assessments using snorkel methodology. 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. Ultimately the data obtained up to and including 2015 will be used to develop stock recruitment relationship for the Gerrard rainbow trout population. Experience to date suggests that despite fall surveys conducted in 2005 and 2006, the results clearly indicate that early spring time sampling is the best time for the snorkel surveys employed to assess the juvenile population.

An important criterion 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 110 km of lineal habitat available in the Lardeau River. The re-designed approach commencing in 2011 increased length of sampling effort twofold, covering 12.4 km and 3.4 km on the Lardeau and Duncan rivers, respectively. The spring 2012 surveys actually covered approximately 11.3% of the Lardeau River and 9.7% of the Duncan River, similar to that reported for 2011 (Andrusak 2011).

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). 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 applying lower efficiencies to the pre-2011 data indicates, juvenile trout estimates are 1.5-2x higher than previously reported in Decker and Hagen (2009) and Andrusak (2010) and more in line with the most recent estimates derived in 2011 and 2012.

Based on improved modeling and the results, it appears that juvenile estimates for spring fry and parr are approximately 1.5-2.0 fold higher than previously reported. Spring fry estimates average 53,000 within the Lardeau River since 2007 and spring parr estimates average 18,900 since 2007. Based on 2011 and 2012 results, the LDR contributed an additional ~18,000 spring fry and ~6,000 spring parr or 33% and 32% to the standing stock estimates within both rivers, respectively. While these estimates are preliminary and may vary annually due to changes in available habitat, particularly in the LDR, in most years instances the fry estimates attained the desired level of precision with a coefficient of variation of 0.2, as suggested by Korman et al. (2010). Parr estimates were less precise but still attained a reasonable level of precision with a coefficient of variation of 0.3.

The improved modeling, further information on observer efficiency from the most recent surveys (2011 and 2012), and increased sampling effort suggest a rather large increase in precision compared to previous abundance estimates reported in Decker and Hagen (2009) and Andrusak (2010) for both fry and parr (Table 9). Overestimated efficiencies from previous years' work have been corrected, leading to a substantial increase in abundance in annual in-river estimates than previously reported. Interestingly, the updated abundance estimates are very similar to those made by Slaney and Andrusak (2003) based on a habitat capability model.

The hierarchical framework used in this report allows for greater flexibility in partitioning variance among and within sites and years while accounting for similar effects associated with changes in the probability of detection (Kéry 2010; Kéry and Shaub 2011). In addition, estimates were more precise on the Lardeau compared to the Duncan for both fry and parr (Table 9); suggesting additional sampling effort should be allocated to the LDR in future. Moreover, GIS information also suggests that the LDR available habitat may be underestimated based on recent information due the complex river morphology and that increased sampling effort on the LDR may be required to reduce the uncertainty in estimates for both fry and parr (Gary Pavan pers. comm., GIS specialist).

Table 9. Estimated precision as coefficient of variation (C.V.) for recent and past analysis (Decker and Hagen 2009 and Andrusak 2010) for spring fry abundance in the Lardeau and Duncan rivers from 2006-2012.

		Fry		Parr	
Year	River	Recent	Past	Recent	Past
2006	Lardeau	0.18	0.35	0.30	0.59
2007	Lardeau	0.21	0.41	0.31	0.61
2008	Lardeau	0.15	0.30	0.25	0.50
2009	Lardeau	0.22	0.44	0.30	0.60
2010	Lardeau	0.21	0.42	0.34	0.68
2011	Lardeau	0.14	0.29	0.25	0.50
2012	Lardeau	0.15	0.29	0.32	0.64
2011	Lower Duncan	0.21	0.42	0.24	0.48
2012	Lower Duncan	0.22	0.43	0.30	0.60

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 despite a substantial increase in escapement at Gerrard over the same time period (Figure 12), suggesting the river maybe fully saturated or at its carry capacity.

Data from this current project also suggests that the Gerrard rainbow trout 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). 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 is 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 Gerard 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 2012). 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.

REFERENCES

AMEC Earth & Environmental Ltd. 2012. Lower Duncan River Habitat Use Monitoring (DDMMON-2). Report prepared for BC Hydro, Castlegar.

Andrusak, H. (2005). Kootenay Lake Gerrard Rainbow Trout Management Plan. Habitat Conservation Trust Fund, Victoria, BC. Redfish Consulting Ltd., Nelson, BC.

Andrusak G.F. (2010) Implementation of a Conservation Plan for Gerrard Rainbow Trout: Stock Assessment of Juvenile Gerrard Rainbow Trout in the Lardeau River.. A Redfish Consulting Ltd. Report prepared for the Habitat Conservation Trust Foundation.

Andrusak, G.F. 2011. Determination of Gerrard Rainbow Trout Productivity and Capacity in Defining Management Reference Points-2011. 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. December 2012. 17 pp+

Andrusak G.F. and Thorley J.L. 2012. Kootenay Lake Exploitation Study: Fishing and Natural Mortality of Large Rainbow Trout and Bull Trout. A Poisson Consulting Ltd. and Redfish Consulting Ltd. Report prepared for the Habitat Conservation Trust Foundation

Biro, P.A., A.E. Morton, J.R. Post and E.A. Parkinson. 2004. Overwinter lipid depletion and mortality of age-0 rainbow trout (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences 61:1513-1519.

Bradford, M. J. and P. S. Higgins. 2000. Habitat-, season, and size-specific variation in diel activity patterns of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss). Can. J. Fish. Aquat. Sci. 58:1-10.

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

Bonneau, J.L., R.F. Thurow, and D.L. Scarnecchia. 1995. Capture, marking and enumeration of juvenile bull trout and cutthroat trout in small, low conductivity streams. N. Amer. J. Fish. Manage. 15: 563-568.

Campbell, R. F. and J. H. Neuner. 1985. Seasonal and diurnal shifts in habitat utilized by resident rainbow trout (Salmo gairderi) observed in western Washington Cascade Mountain streams. Pages 39-49 in F. W. Olson, R. G. White, and R. H. Hamre, editors. Symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Engineering Section, Bethesda, Maryland.

Decker, S. and J. Hagen 2009. Juvenile Stock Assessment of Gerrard Rainbow Trout in the Lardeau/Duncan System: Feasibility Study 2005-2008. Habitat Conservation Trust Foundation, Victoria, BC, Ministry of Environment, Nelson, BC and BC Hydro, Castlegar, BC.

Edmundson, E. H., F. H. Everest, and D. W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish. Res. Bd. Can. 25:1453-1464.

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

Griffith, J. S. 1981. Estimation of the age-frequency distribution of stream-dwelling trout by underwater observation. Prog. Fish. Cult. 43:51-52.

Hagen, J., J. Baxter, J. Burrows and J. Bell. 2007. Rainbow trout (Oncorhynchus mykiss) spawner migration through the lower Duncan/Lardeau Rivers and residence at Gerrard, B.C., as estimated by radio telemetry 2004-2006.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Hartman, G. F. 1969. *Reproductive biology of the gerrard stock rainbow trout*. Symposium on salmon and trout in streams, University of British Columbia, Vancouver, B.C.

Hartman, G.F. and D.M. Galbraith. 1970. The Reproductive Environment of the Gerrard Stock Rainbow Trout. BC Fish and Wildlife Branch, Mngt. Publ. 15, 51p.

Hilborn, R. and Carl J. Walters 1992. Quantitative Fisheries Stock, Assessment Choice, Dynamics and Uncertainty. Chapman and Hall New York 570 p

Hillman, T. W., J. W. Mullan, and J. S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. N. Amer. J. Fish. Manage. 12:598-603.

Imre I, Grant JWA, Cunjak RA 2010. Density-dependent growth of young-of-the-year Atlantic salmon (Salmo salar) revisited. Ecol Freshw Fish 19:1–6

Irvine, J. R. 1978. The Gerrard rainbow trout of Kootenay Lake, British Columbia - a discussion of their life history with management, research and enhancement recommendations. Fisheries Management Report No. 72.

Keeley, E. R., E. A. Parkinson and E. B. Taylor (2007). The origins of ecotypic variation of rainbow trout: a test of environmental vs. genetically based differences in morphology. *Journal of Evolutionary Biology* 20: 725-736.

Kéry, M., J. A. Royle, and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications **15**:1450-1461.

Kéry, M.. 2010. Introduction to WinBUGS for ecologists: a Bayesian approach to regression, ANOVA, mixed models and related analysis. Marc Kéry 1st edition. Academic Press, Waltham, MA, USA.

Kery, M. and M. Schaub. 2011. Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press, Waltham, MA, USA.

Korman, J., Decker, A.S., Mossop, B., and J. Hagen. 2010. Comparison of electrofishing and snorkeling mark-recapture estimation of juvenile steelhead in a medium-sized river. North American Journal of Fisheries Management 30: 1280-1302.

Mitro, M.G. and A.V. Zale. 2002. Estimating abundances of age-0 rainbow trout by mark-recapture in a medium-sized river. N. Amer. J. Fish. Manage. 22:188-203

Myers, R. A. 2001. Stock and recruitment: generalizations about maximum reproductive rate, density dependence, and variability using meta-analytic approaches. – ICES Journal of Marine Science, 58: 937-951

Plummer, Martyn (2003). JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling, Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22, Vienna, Austria. ISSN 1609-395X.

Post, J. R., Parkinson, E. A. & Johnston, N. T. 1999. Density-dependent processes in structured fish populations: interaction strengths in whole-lake experiments. Ecological Monographs 69, 155–175

R Development Core Team. 2012. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Redfish Consulting Ltd. 2002. Quantitative Assessment of Gerrard Rainbow Trout Fry at Established Index Sites on the Lardeau River September 2002. Contract Report for the British Columbia Conservation Foundation.

Riley, S. C., and K. D. Fausch. 1992. Underestimation of trout population size by maximum likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768–776.

Slaney, P.A. and H. Andrusak. 2003. Lardeau River Fish Habitat Assessments (2002) and Preliminary Gerrard Rainbow Trout Production Capability Modeling. PSlaney Aquatic Science Ltd. Contract Report for the Ministry of Water, Land and Air Protection, Nelson BC.

Thurow, R. F., and D. J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate bull trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16:314–323.

Vincenzi S, Crivelli AJ, Giske J, Satterthwaite WH, Mangel M. 2011. Selective consequences of catastrophes for growth rates in a stream-dwelling salmonid. Oecologia. doi: 10.1007/s00442-011-2096-8

Walters, C.J. and S.J.D. Martell. 2004. Fisheries Ecology and Management. Princeton University Press, Princeton, New Jersey.

Ward, B.R., and P.A. Slaney. 1993. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead trout. Pages 209-217 *in* R.J. Gibson and R.E. Cutting [editors] Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publication Fisheries and Aquatic Sciences 118.

Wyatt, R.J. 2003. Mapping the abundance of riverine fish populations: integrating hierarchical Bayesian models with a geographic information system (GIS).

Canadian Journal of Fisheries and Aquatic Sciences 60: 997–1006. doi: 10.1139/f03-085.

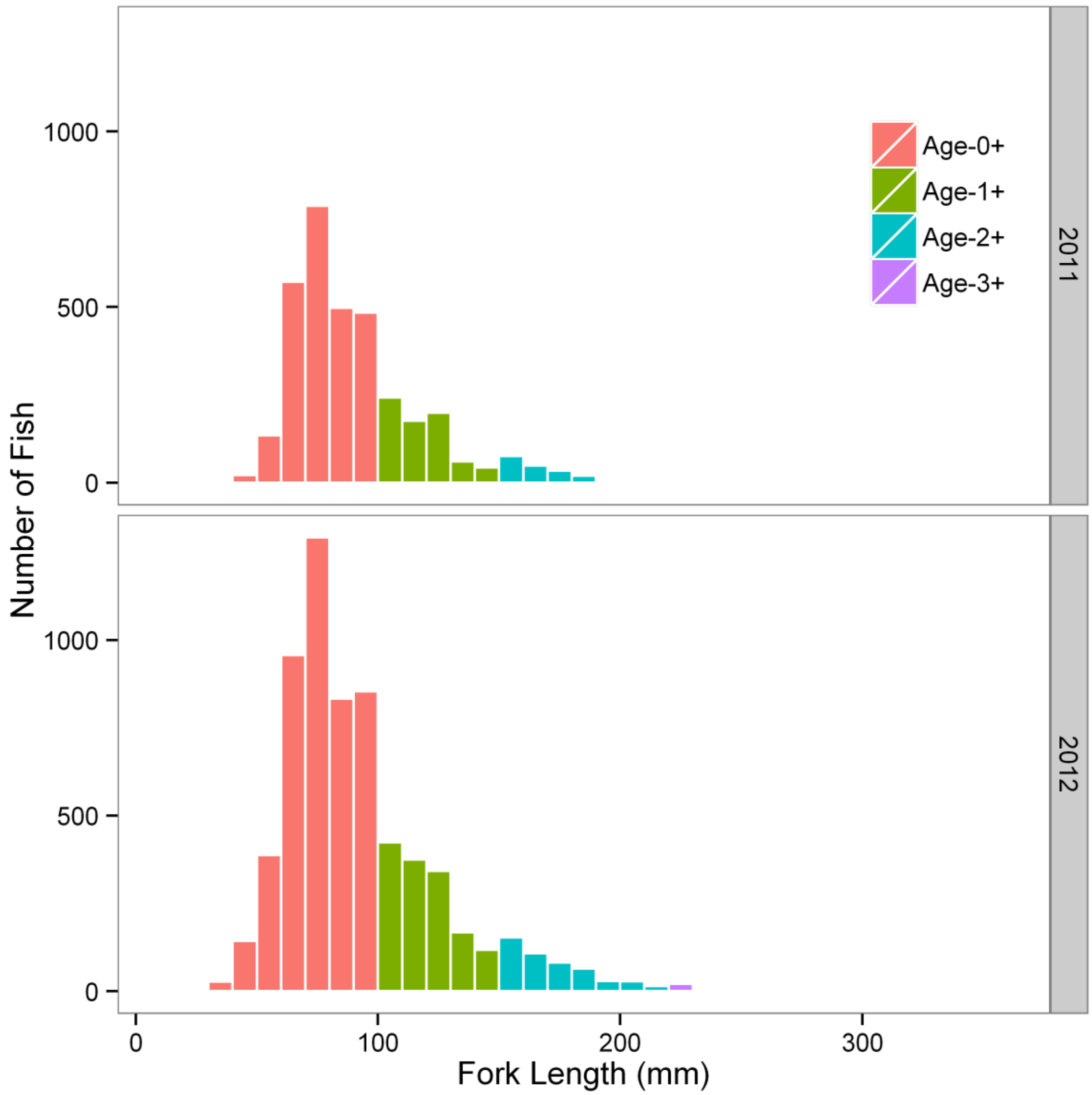


Figure 2. Length-frequency histogram for rainbow trout in the Lardeau River from the spring of 2011 and 2012. Age-0 fish were assumed to have a fork length ≤ 99 mm, age-1 fish between 100 and 150 mm and age-2+ fish >150 mm based on scale ages in a previous study (Decker and Hagen 2009; Andrusak 2010).

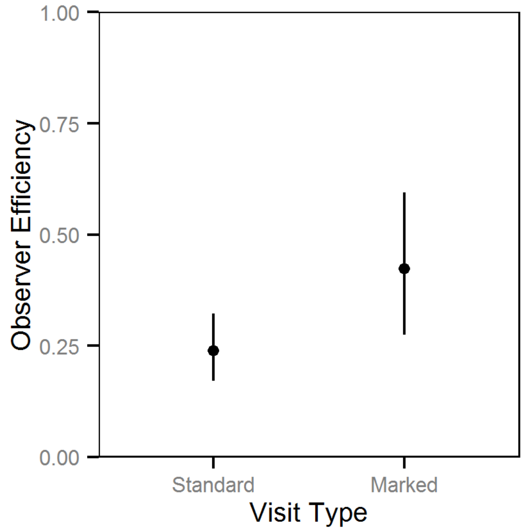


Figure 3. Estimated snorkel efficiency for fry obtained from standard count visits and mark-recaptures on Lardeau and Duncan rivers from 2006-2012.

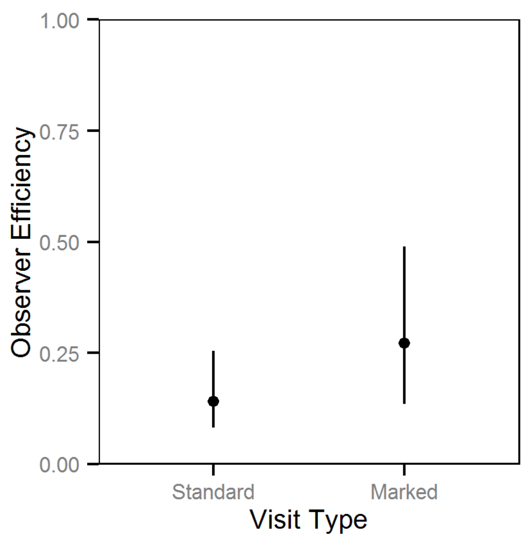


Figure 4. Estimated snorkel efficiency for parr obtained from standard count visits and mark-recaptures on Lardeau and Duncan rivers from 2006-2012.

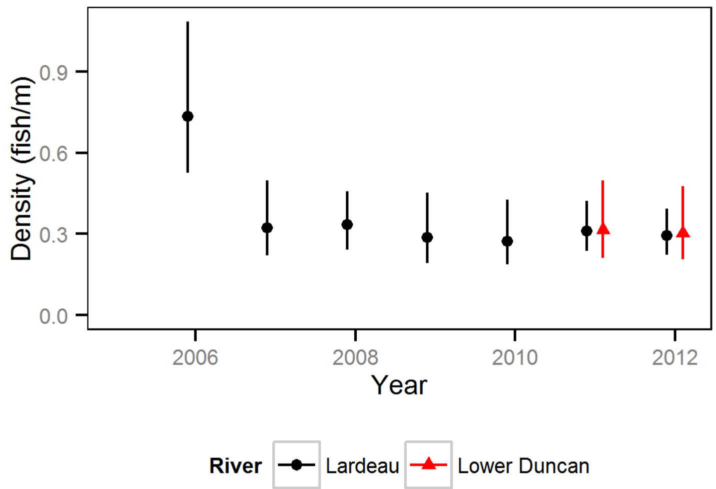


Figure 5. Estimated density (fish/m) of spring fry in Lardeau and Duncan rivers from 2006-2012

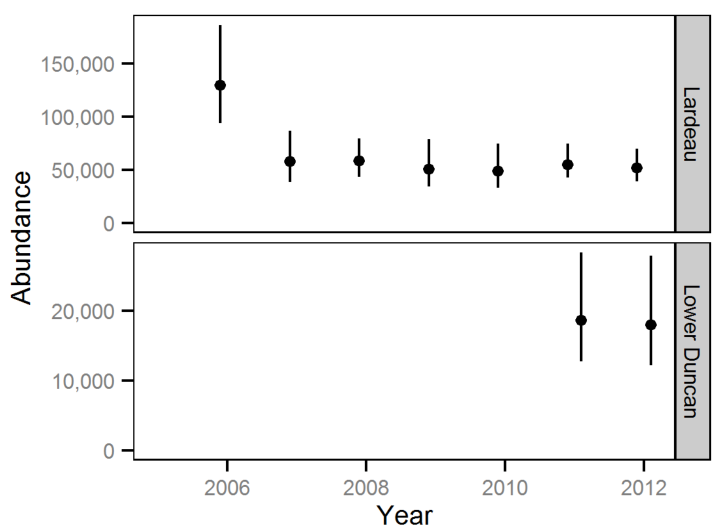


Figure 6. Estimated abundance of spring fry in Lardeau and Duncan rivers from 2006-2012.

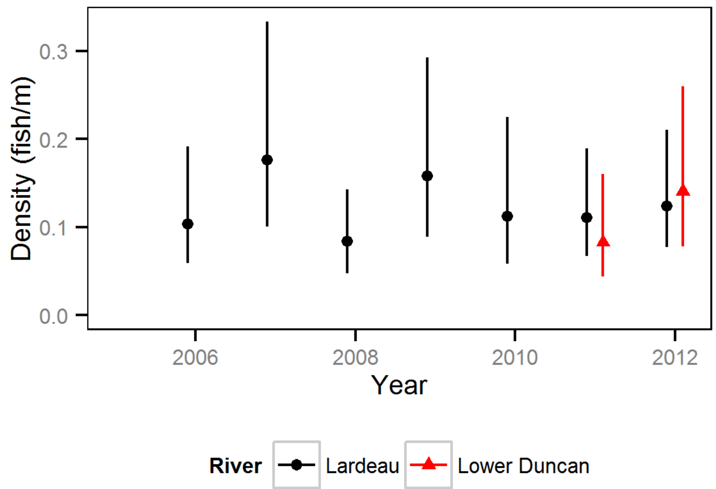


Figure 7. Estimated density (fish/m) of spring parr in Lardeau and Duncan rivers from 2006-2012

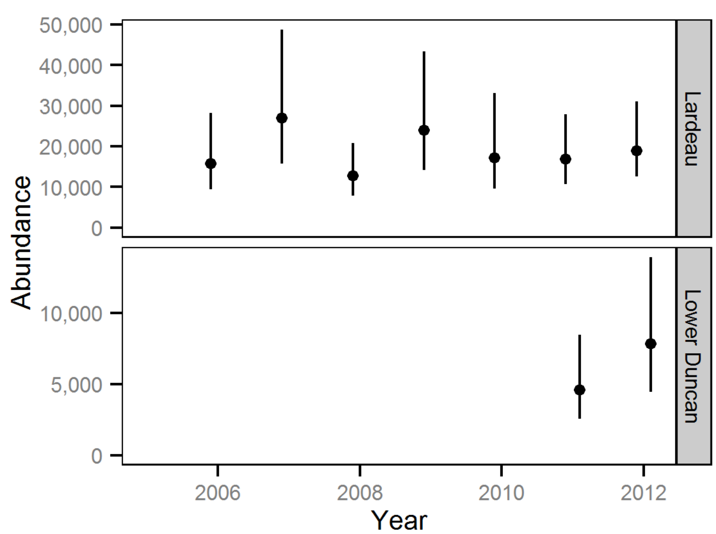


Figure 8. Estimated abundance of spring parr in Lardeau and Duncan rivers from 2006-2012.

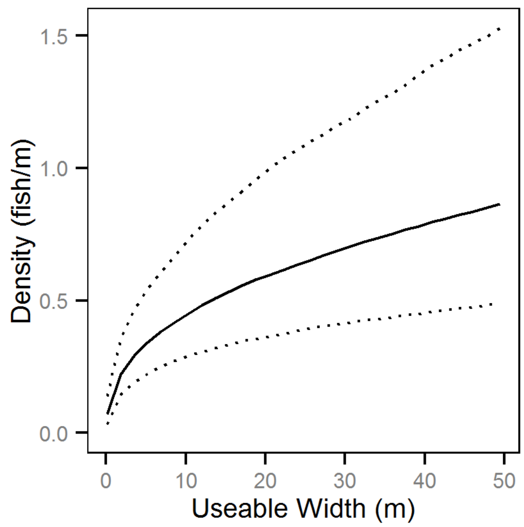


Figure 9. Relationship between useable widths and juvenile density for fry on the Lardeau and Duncan rivers.

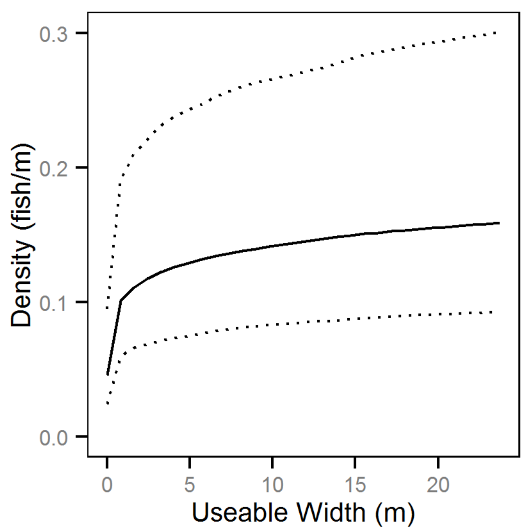


Figure 10. Relationship between useable widths and juvenile density for parr on the Lardeau and Duncan rivers

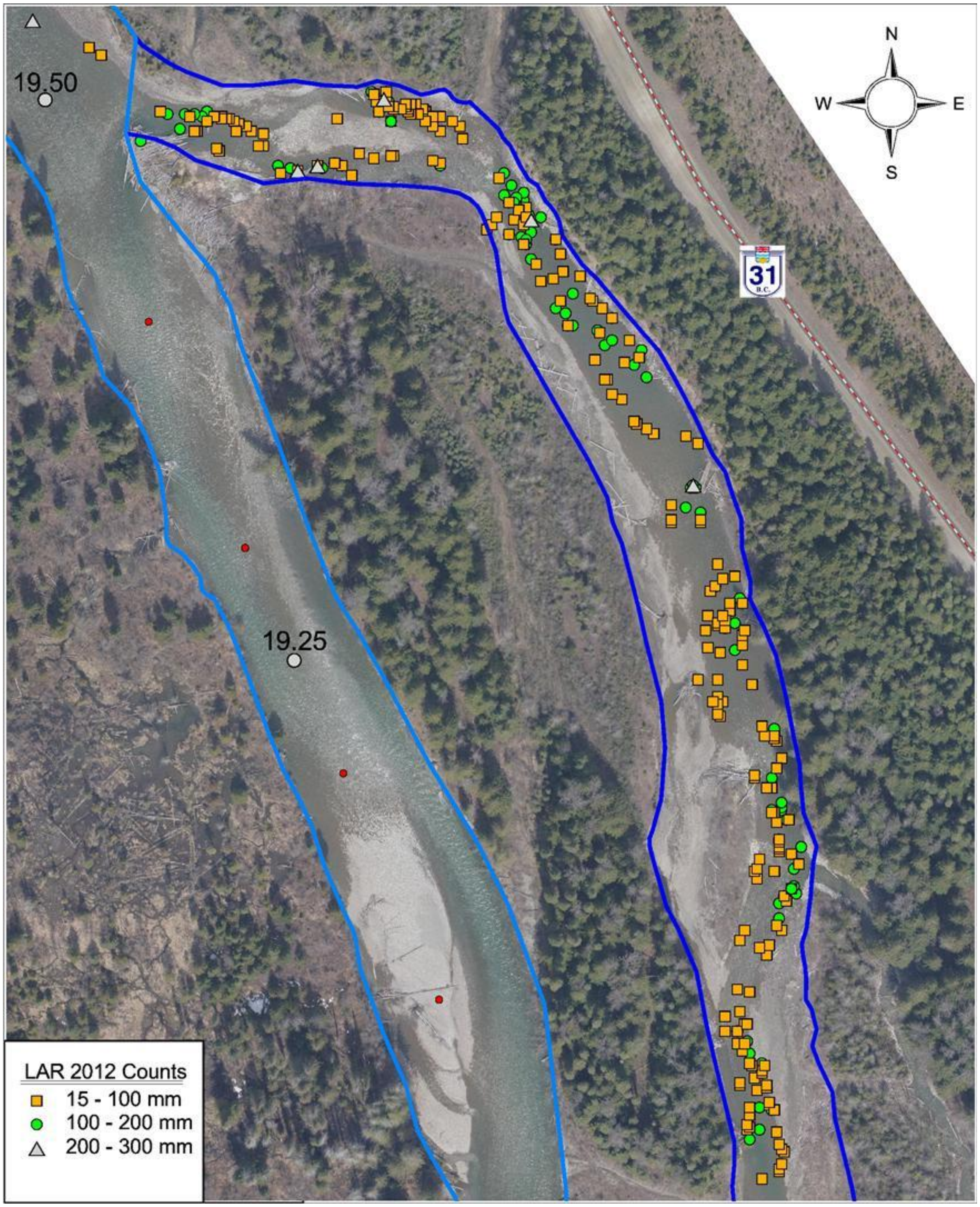


Figure 11. Geo-referenced fish counts by size category on a side-channel (19.25 km) of the Lardeau River in 2012.

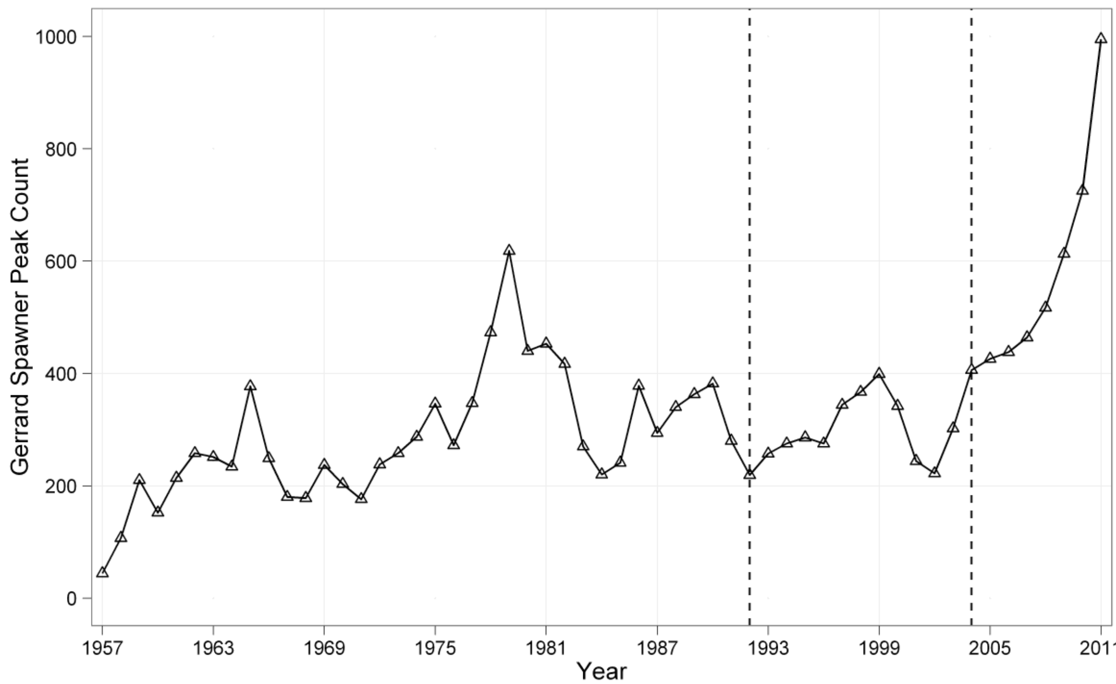
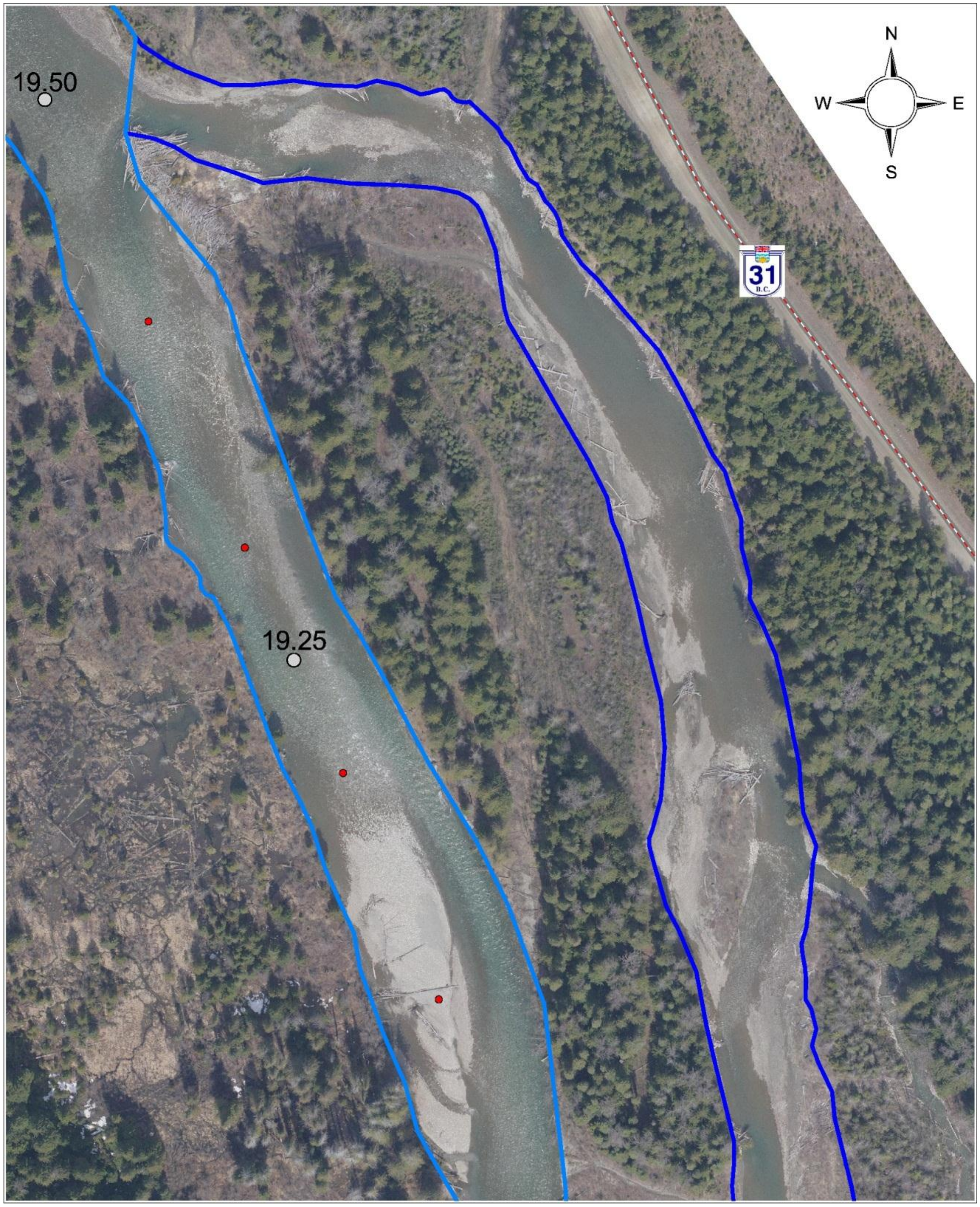
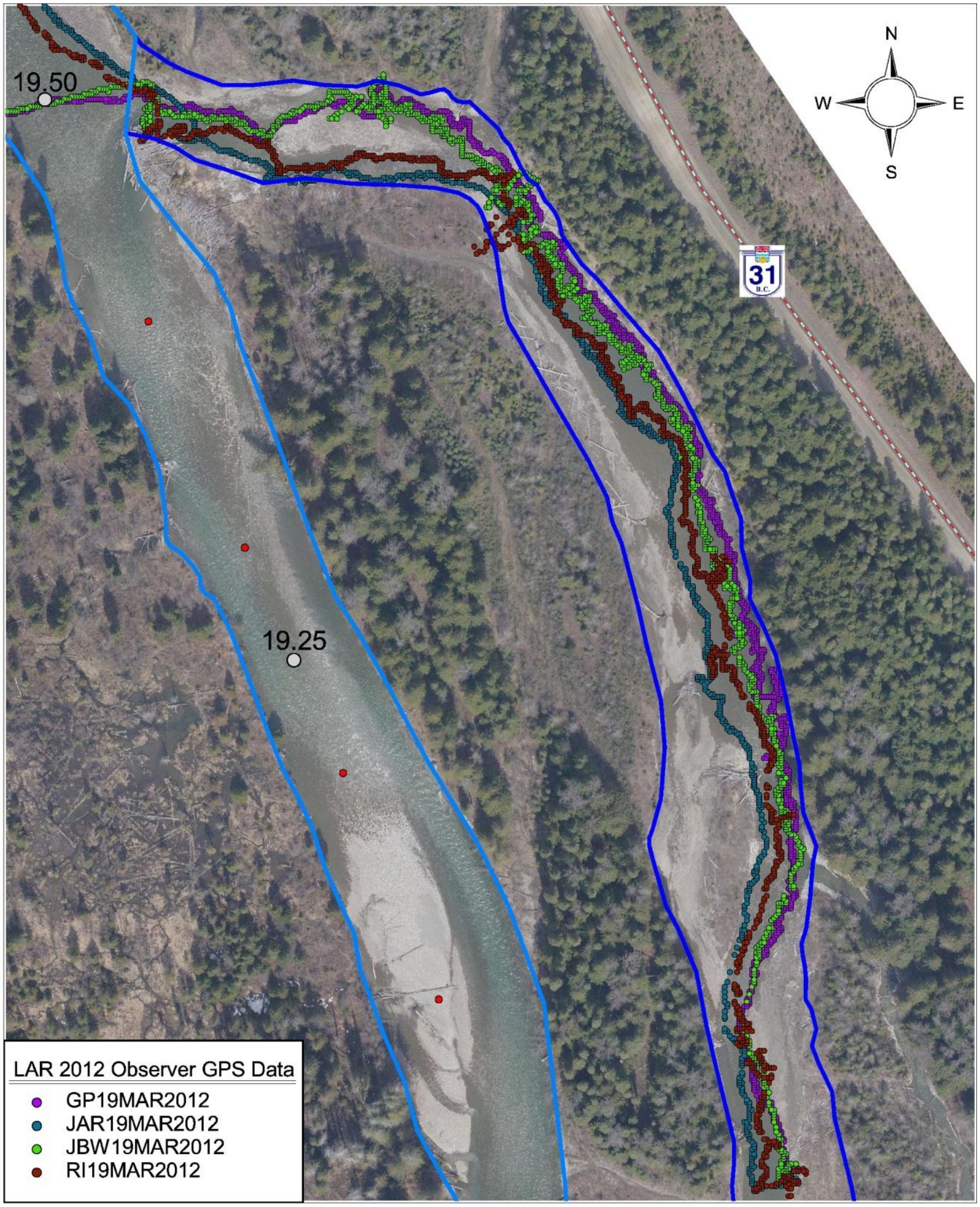


Figure 12. Gerrard rainbow trout spawner peak count from 1957-2011. Vertical lines represents commencement of North Arm (1992) and South Arm (2004) nutrient addition (data from MNFLRO file data).

APPENDIX 1. Estimated lineal bank length using GIS



APPENDIX 2. GPS information from surveys in GIS



APPENDIX 3. Hierarchical Bayesian model details

Hierarchical Bayesian Analysis

Joe Thorley Ph.D., R.P.Bio.
Poisson Consulting Ltd.

22 January 2013

1 General Approach

A Hierarchical Bayesian model was fitted to the count and mark-resight data for the Lardeau and Lower Duncan Rivers using the software packages R 2.15.2[6] and JAGS 3.3.0[4] which interfaced with each other via the rjags R package. The model assumed low information uniform or normal prior distributions. The posterior distributions were estimated from a minimum of 1,000 samples thinned from the second halves of three Gibbs sampling chains. Model convergence was confirmed by ensuring that R-hat (the Gelman-Rubin-Brooks potential scale reduction factor) was less than 1.1 for each of the parameters in the model[1, 3, 2].

Plots were produced using the ggplot2 R package [7].

2 JAGS Distributions, Functions and Operators

JAGS distributions, functions and operators are defined in the following two tables. For additional information on the JAGS language, which is a dialect of the BUGS language, see the JAGS User Manual[5].

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

JAGS Function or Operator	Description
<-	Deterministic relationship
~	Stochastic relationship
1:n	Vector of integers from 1 to n
for (i in 1:n) {...}	Repeat ... for 1 to n times incrementing i each time
log(x)	Logarithmic transform of x
logit(x)	Logisitic transform of x
max(x,y)	Maximum of x and y
min(x,y)	Minimum of x and y
x[1:n]	Subset of first n values in x
x^y	Power where x is raised to the power of y

i

3 JAGS Models

The following section provides the variable and parameter definitions and JAGS model code for the analysis.

3.1 Lineal Density

3.1.1 Variables and Parameters

Variable/Parameter	Description
bDensityRiver[rv]	Effect of rvth river on log density
bDensitySite[st]	Effect of stth site on log density
bEfficiencyVisitType[vt]	Effect of vtth visit type (standard vs marked) on logit observer efficiency
bDensityWidth	Effect of width on log density
bDensityRiverYear[rv, yr]	Effect of yrth year at rvth river on log density
eDensity[i]	Expected density at ith site visit
eEfficiency[i]	Expected observer efficiency on the ith site visit
SiteLength[i]	Length of site visited during ith site visit
bDensity0	Log density intercept
bEfficiency0	Logit observer efficiency intercept
Marked[i]	Number of fish marked prior to the ith site visit
Resighted[i]	Number of marked fish resighted during ith site visit
nrow	Number of site visits
SurveyProportion[i]	Proportion of site surveyed during ith site visit
sDensityRiverYear	SD of effect of river within year on log density
sDensitySite	SD of effect of site on log density
sEfficiencyVisit	SD of effect of site visit on logit observer efficiency
Total[i]	Total number of fish observed during ith site visit

3.1.2 Model Code

```
model {

  bEfficiency0 ~ dnorm(0, 2^-2)
  sEfficiencyVisit ~ dunif(0, 5)

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

  bDensity0 ~ dnorm(0, 5^-2)
  bDensityWidth ~ dnorm(0, 2^-2)

  bDensityRiver[1] <- 0
  for (rv in 2:nRiver) {
    bDensityRiver[rv] ~ dnorm(0, 5^-2)
  }

  sDensityRiverYear ~ dunif(0, 5)
  for (rv in 1:nRiver) {
```

ii

```
    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)
  }

  for (i in 1:nrow) {
    eLogitEfficiency[i] <- bEfficiency0
      + bEfficiencyVisitType[VisitType[i]]

    eLogitEfficiencyVisit[i] ~ dnorm(eLogitEfficiency[i], sEfficiencyVisit^-2)
    logit(eEfficiency[i])  <- eLogitEfficiencyVisit[i]

    dEfficiencyMark[i] <- min(eEfficiency[i], Marked[i])
    dMarked[i] <- max(Marked[i], 1)
    Resighted[i] ~ dbin(dEfficiencyMark[i], dMarked[i])

    log(eDensity[i]) <- bDensity0
      + bDensityWidth * log(Width[i])
      + bDensityRiver[River[i]]
      + bDensityRiverYear[River[i],Year[i]]
      + bDensitySite[Site[i]]
    eAbundance[i] <- eDensity[i] * SiteLength[i] * SurveyProportion[i]
    eTotal[i] ~ dpois(eAbundance[i])
    Total[i] ~ dbin(eEfficiency[i], eTotal[i])
  }
}
```

References

[1] S. Brooks and A. Gelman. Alternative methods for monitoring convergence of iterative simulations. *Journal of Computational and Graphical Statistics*, 7:434–455, 1998.

[2] A. Gelman, J. B. Carlin, H. S. Stern, and D. B. Rubin. *Bayesian Data Analysis*. CRC Press, Boca Raton, Florida, 2004.

[3] A. Gelman and D. Rubin. Inference from iterative simulation using multiple sequences. *Statistical Science*, 7:457–511, 1992.

[4] M. Plummer. Jags: A program for analysis of bayesian graphical models using gibbs sampling. In *Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003)*, Vienna, Austria, 2003.

[5] M. Plummer. *JAGS Version 3.1.0 User Manual*, 2011.

[6] R Development Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2012. ISBN 3-900051-07-0.

[7] H. Wickham. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag, New York, 2009.