Columbia River Water Use Plan

Lower Columbia River Fish Management Plan

Implementation Year 7
Reference: CLBMON-46

Lower Columbia River Rainbow Trout Spawning Assessment

Study Period: January to July 2014

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Prepared for:
BC Hydro
Castlegar, BC

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February 4, 2015

WLR Monitoring Study

LOWER COLUMBIA RIVER RAINBOW TROUT SPAWNING ASSESSMENT 2014

CLBMON-46 (Year 7)

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February 4, 2015 – Final Report

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Cover Photos: Lower Columbia River Rainbow Trout Spawning Assessments (shallow redds, helicopter survey crew, and aerial view of the Norn's Fan spawning area).

Suggested Citation:

Irvine, R.L., J.T.A. Baxter and J.L. Thorley (2014). WLR Monitoring Study No. CLBMON-46 (Year 7) Lower Columbia River Rainbow Trout Spawning Assessment. *Columbia River Water Use Plan*. BC Hydro, Castlegar. A Mountain Water Research and Poisson Consulting Ltd. Final Report.

EXECUTIVE SUMMARY

Each spring in the Lower Columbia River (LCR) below Hugh L. Keenleyside Dam (HLK) and in the Lower Kootenay River (LKR) below Brilliant Dam, thousands of Rainbow Trout (*Oncorhynchus mykiss*) spawn. Since 1992, BC Hydro has stabilized the spring discharge releases from HLK to protect Rainbow Trout redds from dewatering. Prior to the 1992 implementation of the spring operational regime (April 1-June 30) of stable or increasing flows known as the Rainbow Trout Spawning Protection Flows (RTSPF), the discharge from HLK Dam decreased during the March to May period. This resulted in Rainbow Trout redds being dewatered and possible population level effects. The current Rainbow Trout spawning assessment monitoring program, which commenced in 2008, was implemented to better understand the links between the spring flow regime and the abundance of the Rainbow Trout population and to assess population trends in this ecologically and recreationally important species.

The current knowledge relative to the defined management questions of CLBMON-46 is summarized in the table below and addressed in detail in this report. The remaining uncertainties now require a more experimental and adaptive approach going forward with the program to assess the effects of altering the timing and magnitude of the RTSPF. In order to manage this population, the two management questions that are as yet unanswered should be addressed with well-designed scientific studies.

Objectives	Management Questions	Year 7 (2014) Status
Assess changes in the relative abundance, distribution and spawn timing of Rainbow Trout in the lower Columbia River	1. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the relative abundance of Rainbow Trout spawning in the LCR downstream of HLK?	The number of Rainbow Trout spawners and redds has increased about 10-fold since 1999. RTSPF may or not be responsible for this increase. Proposed experimental flow manipulations may clarify the role of the hydrograph in influencing the Rainbow Trout abundance.
	2. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the spatial distribution of locations (and associated habitat area) that Rainbow Trout use for spawning in the LCR downstream of HLK?	The number of locations and the spatial distribution of Rainbow Trout spawning have increased since 1996. This may be related to an increase in the number of Rainbow Trout spawners but since the effects of the RTSPF on Rainbow Trout abundance are still unclear, this management question cannot be answered currently (Thorley and Baxter 2011; Appendix C).
	3. Does the implementation of RTSPF over the course of the monitoring period protect the majority of Rainbow Trout redds (as estimated from spawning timing) from being dewatered in the LCR downstream of HLK?	Yes. Over all years of analysed data, the mean stranding rate of redds has been 0.75%, as compared to the estimated 50-75% stranding rate noted in shallow water habitat on Norn's Fan in 1990 and 1991 prior to implementation of RTSPF.

ACKNOWLEDGEMENTS

A number of people dedicated their time and efforts to ensure the successful completion of this project. Their help is greatly appreciated.

BC Hydro
Philip Bradshaw, Guy Martel, and James Baxter

Dam Helicopters
Duncan Wassick

Additional Technical Support
Clint Tarala, Gary Pavan, and Jason Bowers

ABBREVIATIONS

Abbreviations used throughout the report:

Abbreviation	Full Name
2D	Two Dimensional
ALH	Arrow Lakes Hydro unit
ALR	Arrow Lakes Reservoir
AUC	Area-Under-the-Curve
BCH	BC Hydro
BRX	Brilliant Expansion Project
BIR	Birchbank Gauging Station
BRD	Brilliant Dam
HLK	Hugh L. Keenleyside Dam
KHz	Kilohertz Frequency
LCR	Lower Columbia River
LDR	Lower Duncan River
LKR	Lower Kootenay River
MAF	Million Acre Feet
MFLNRO	Ministry of Forest Lands & Natural Resource Operations
PIT	Passive Integrated Transponder
RB	Rainbow Trout
RTSPF	Rainbow Trout Spawning Protection Flows
TOR	Terms of Reference
WLR	Water Licence Requirements
WUP	Water Use Plan

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1.0 INTRODUCTION

The Rainbow Trout (*Oncorhynchus mykiss*) population in the Lower Columbia River (LCR) between Hugh L. Keenleyside (HLK) dam and the U.S. border and in the Lower Kootenay River (LKR) below Brilliant Dam (BRD) has been studied extensively since the early 1990s. Studies have focused on the assessment of effects of hydro-electric dam operations on various life history parameters, genetics, spawn timing, habitat use, and population trends and dynamics. (Heaton and Hildebrand 1997a, 1997b, Arndt 2000, Taylor 2002, Arndt and Klassen 2004, Ford and Hildebrand 2007, Baxter 2011). A brief summary of the previous studies on this single genetic population of Rainbow Trout can be found in Irvine et al. (2014).

Prior to 1992, the discharge from HLK typically decreased from March to May resulting in substantial Rainbow Trout redd dewatering with potential effects on the abundance of the adult population (Hildebrand and McKenzie 1995, Thorley and Baxter 2011). BC Hydro therefore altered the spring HLK operations to keep river levels stable or increasing from April 1 to June 30 and agreed to consult with the government agencies regarding the timing and rampdown method from the Mountain Whitefish protection flows to Rainbow Trout protection flows at the beginning of April (BC Hydro 2005, Ford et al. 2008). The Rainbow Trout Spawning Protection Flows (RTSPF) have occurred annually since 1992 (BC Hydro 2007). The ecological productivity study in the Lower Columbia River found that cumulative elevational drops during the pre-RTSPF period (1984-1991) were significantly higher than during the period when the protection flows were implemented (1992-2014) (Larratt et al. 2013). The mean stranding rate of redds over all years of analysed data was 0.75% as compared to the only data from pre-RTSPF flows where the stranding was estimated at 50-75% in shallow water habitat on Norn's Fan in 1990 and 1991 (Hildebrand and McKenzie 1995, Irvine et al. 2014).

The implementation of the RTSPF requires ~1 million acre-feet of retained storage in Arrow Lakes Reservoir (ALR) which is then released in summer. This represents a significant trade off for other operational soft constraints (BC Hydro 2005). Minimizing the volume of water stored in ALR, delaying the onset of storage and quickly releasing the additional storage could improve vegetation survival and increase littoral productivity and wildlife habitat (BC Hydro 2007). Consequently, the primary objective of the present program is to monitor the status of the Rainbow Trout population in order to better understand the link between flow management strategy and population abundance and to propose and monitor testing of alternative flow strategies (BC Hydro 2007).

Commencing in 1999, various forms of the spawner assessment program have occurred in each year. The program annually monitors spawn timing, location and spawner abundance in order to address the primary objective of the program which "*is to continue the collection of annual Rainbow Trout monitoring data to qualitatively and quantitatively assess changes in the relative abundance, distribution and spawn timing of Rainbow Trout in the lower Columbia River*" (BC Hydro 2007 p.3) and to address the specific management questions outlined below.

Long term monitoring of the LCR RB population continues to be of vital importance due to ongoing change in the river's natural and operationally altered environment. Current questions of relevance to the health and sustainability of the RB population in the LCR include, but are not limited to, the impact of the invasive species such as Northern Pike (*Esox lucius*), the influence of the very prevalent Didymo (*Didymosphenia geminata*) mats that now exist in the river, and the influence of thousands of hatchery released White Sturgeon (*Acipenser transmontanus*) as they grow into adults. While the long term fish indexing study on the LCR provides key data on a number of important parameters including growth rate, body condition, and spatial distribution of Rainbow Trout, Walleye and Mountain Whitefish fish in this section of the river, the low recapture rates may be limiting the program's ability to detect population trends (Ford et al. 2013). In this regard, the RB spawning monitoring program is a more robust program for determining adult Rainbow Trout trends as the proportion of the population observed is higher.

Since 1992 BC Hydro has monitored RB redds in shallow water areas to identify those at risk of dewatering. From 1999-2012, dewatered redds were excavated and the salvaged eggs were transferred to suitable, wetted gravels (Baxter 2010a, 2010b, 2011). In 2013, the Department of Fisheries and Oceans (DFO) and the Ministry of Forests, Lands, Natural Resources and Operations (MFLNRO) granted BC Hydro permission to dewater up to 111 redds which was 1% of the estimated annual redd abundance from 1999-2011. Since 77 redds were dewatered in 2014, no salvage was required.

The following management questions are the focus of the LCR RB spawning assessment program:

1) Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the relative abundance of Rainbow Trout spawning in the LCR downstream of HLK?
2) Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the spatial distribution of locations (and associated habitat area) that Rainbow Trout use for spawning in the LCR downstream of HLK?
3) Does the implementation of RTSPF over the course of the monitoring period protect the majority of Rainbow Trout redds (as estimated from spawning timing) from being dewatered in the LCR downstream of HLK?

The TOR state that these three management questions will be answered by testing three key hypotheses:

H_{01}: The relative abundance of Rainbow Trout spawners or redds in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of RTSPF.

H_{02}: The spatial distribution of locations and the associated habitat area that Rainbow Trout spawners use in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF.

H_{03}: The proportion of redds dewatered relative to the total redd production for Rainbow Trout spawning in the Columbia River mainstem does not increase between the baseline period (1999 to 2006) and the WUP monitoring period associated with the continued implementation of the RTSPF.

In order to achieve the program's primary objective, the population's response to alternative discharge regimes also needs to be understood since the annual studies on this population have mainly been conducted with the same flow regime in each year. Discussions are ongoing (Baxter 2012) to implement an alternate spring flow regime in the future and assess the impacts on the Rainbow Trout population. This experimental approach has been successful at teasing apart mechanisms behind population trends in other systems such as the Colorado (Korman et al. 2011).

2.0 METHODS

2.1 Mainstem Spawner and Redd Surveys

The mainstem portions of the Canadian LCR below HLK and the LKR below BRD (Figure 1) have been surveyed from helicopter approximately once a week during the spawning season since 1999 and the numbers of redds and spawners recorded by location. Prior to commencing helicopter surveys, 2-3 boat surveys are done to ensure spawning has begun.

The major gravel areas on the LCR and in the LKR are known by name and river kilometer, and all areas are surveyed during the flights. In 2014, the section of river with the lowest density of spawners (from Genelle to the U.S. border) was not surveyed in order to save flight budget. Because of minimal numbers of spawners and redds in all years of survey, this section of river was excluded from all analyses. The helicopter surveys are supplemented by the use of boat surveys, which cover the main spawning areas from Norn's Creek Fan to the lower island at Genelle. The boat surveys allow the identification of redds that are questionable from the air, the marking of redds in less than 1.0 m of water to monitor the risk of dewatering and the confirmation of possible new spawning areas seen from the air (Baxter 2011).

In 2014, nine aerial surveys were completed in a twin engine helicopter and each aerial survey was followed by a boat survey (Table 1). As in previous surveys the spawners and redds were enumerated by two experienced observers situated on the same side of the helicopter with one person responsible for counting redds and the other for counting spawners. Boat surveys without aerial surveys were conducted to assess the shallow redds and the onset of spawning on January 22, February 9, February 22, and March 1 (Table 1). The number of days between helicopter surveys during the 2014 field season ranged from 5 to 12 with the mean time between surveys of 8.75 days. During the final survey on May 16, 2014, the visibility was noted as average in the upper section and poor in the lower sections so no further helicopter surveys were completed after that date.

Table 1. Helicopter and boat based redd survey schedule for 2014.

Date	Survey Type(s)
January 22	Shallow Water Redd Boat Survey
February 9	Shallow Water Redd and Dewatering Boat Survey
February 22	Shallow Water Redd Boat Survey and VR2W Install
March 1	Shallow Water Redd Boat Survey
March 7	Twin engine helicopter, Boat survey
March 15	Twin engine helicopter, Boat survey
March 24	Twin engine helicopter, Boat survey
April 2	Twin engine helicopter, Boat survey
April 11	Twin engine helicopter, Boat survey
April 16	Twin engine helicopter, Boat survey
April 28	Twin engine helicopter, Boat survey
May 7	Twin engine helicopter, Boat survey
May 16	Twin engine helicopter, Boat survey

2.2 Norn's Creek Spawner and Redd Surveys

When time, resources and conditions permit, spawner and redd surveys are conducted in Norn's Creek – a major spawning tributary of the LCR and a significant contributor for Rainbow Trout recruitment in the LCR. The index section surveyed on May 7, 2014 in Norns Creek was from the point below the falls where flows were swimmable at river kilometer 1.93 to the confluence with the LCR (see Appendix A: Figure A12). The surveys were conducted during daylight hours by a pair of snorkelers who counted spawners and a bank observer moving downstream who counted redds. The three-person crew was sufficient to cover the entire width of the creek that was usable by spawning trout. The snorkelers divided the mean usable width of the creek into approximately two 5 m lanes with the bank observer walking on the left bank. Frequent stops occurred where required to discuss any potential duplication in counts and record the results. If a snorkeler observed a redd in deep water which might have been missed by the bank observer it was discussed and counted. In years prior to 2011, the spawner and redd counts were recorded by river section. The methodology since 2011 has been for the crew to georeference all spawners and redds using a handheld Garmin GPS. Underwater visibility was recorded during each snorkeling survey, usually at the beginning and completion of the survey by measuring the distance at which a white 10 cm by 18 cm dive notebook page was no longer distinctly identifiable by the snorkelers. In addition, in 2014 two VR2W receivers were deployed at the bridge and adjacent to the Norn's Creek campground to determine residence time and record the timing of passage for any tagged fish.

2.3 Redd Dewatering Surveys

Redd dewatering surveys in the past were implemented as part of a separate project, but in conjunction with the boat surveys of the current program. In 2014, locations of shallow water redds with the potential to dewater were determined during the boat surveys. These data have been entered into the database including location and depth to allow future data exploration.

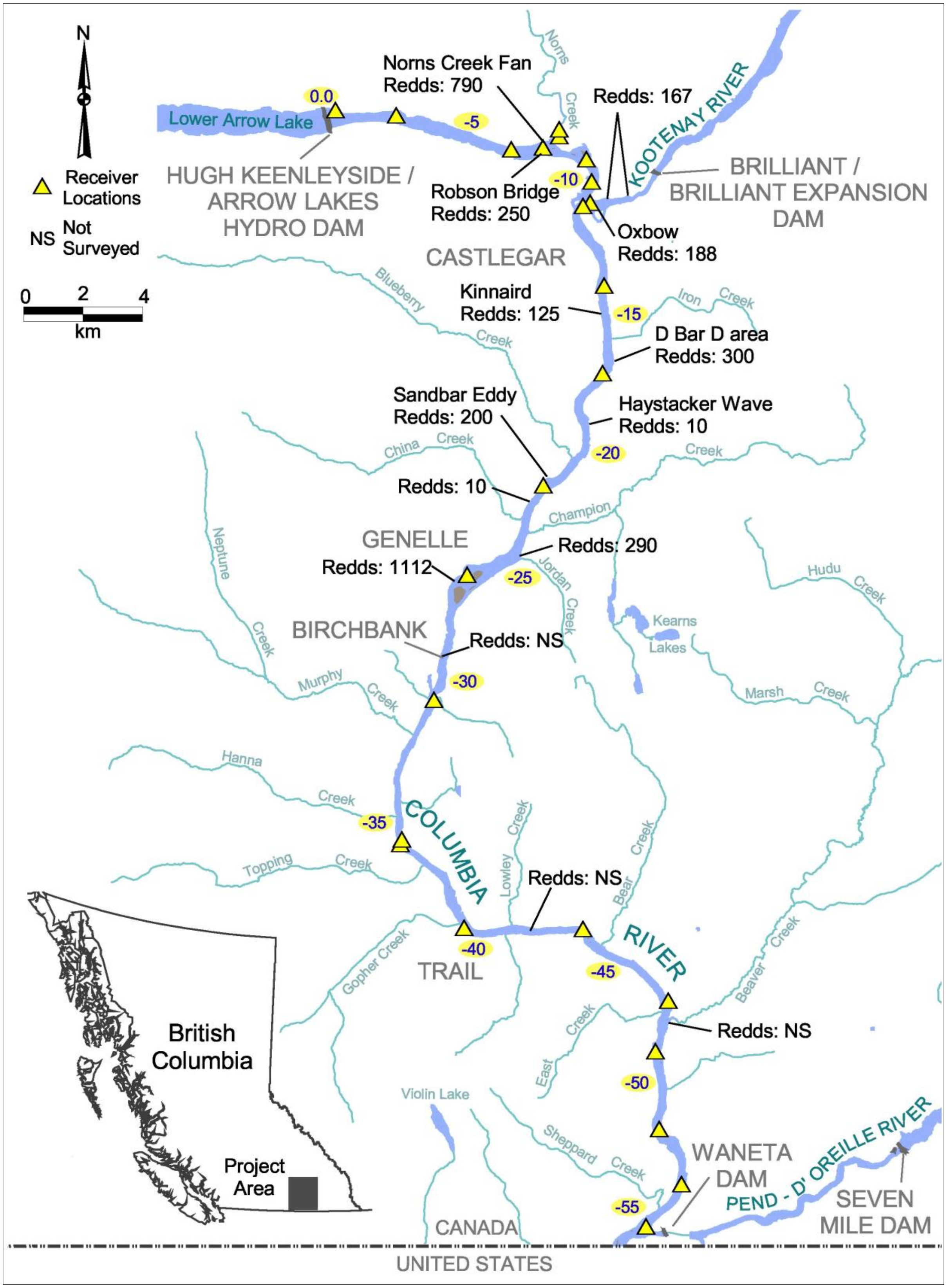

Figure 1. **Study area for the Rainbow Trout spawning assessment program within the Lower Columbia and Lower Kootenay Rivers. The yellow numbers indicate river kilometre downstream of HLK dam, and the yellow triangles indicate acoustic receiver locations. NS refers to areas that were not surveyed.**

2.4 Spawner and Redd Abundance and Spawn Timing

2.4.1 Data Preparation

The Rainbow Trout fish and redd aerial count data for the LCR and LKR were collected by Mountain Water Research and databased by G. Pavan. Golder Associates provided the age-1 Rainbow Trout abundance data from the LCR Fish Population Indexing Program (CLBMON-45) database.

The study area was divided into three sections: the LCR above the LKR, the LKR and the LCR below the LKR. Redd and spawner counts upstream of Norns Creek Fan and downstream of Genelle were excluded from the section totals because they constitute less than 0.1% of the total count and were not surveyed every year. The redd and spawner counts for the Right Upstream Bank above Robson Bridge were also excluded as they appear to be primarily driven by viewing conditions (and constitute less than 2.5% of the total). Simultaneous declines in both spawners and redds for a particular section were inferred to be caused by poor viewing conditions (turbidity) and the affected spawner and redd section counts were excluded from any subsequent analyses.

2.4.2 Data Analysis

In order to estimate spawner and redd abundance as well as spawn timing of Rainbow Trout in the LCR throughout the spawning period over all years with applicable data, hierarchical Bayesian Area-Under-the-Curve (AUC) models were fitted to the aerial spawner and redd counts combined. For the purposes of the analyses the abundance was estimated for each of the three sections (the LKR below BRD, the LCR above the LKR, the LCR below the LKR).

The models' variables, parameters, distributions and assumptions are fully described online at http://www.poissonconsulting.ca/f/1157179155.

Key assumptions of the AUC model include:

- Abundance varies by section.
- Abundance varies randomly by year and section within year.
- Spawner observer efficiency is between 0.9 and 1.1 (where values greater than 1 indicate overcounting).
- Redd observer efficiency is 1.0.
- Mean spawner residence time is between 14 and 21 days.
- Redd residence time is 35 days based on redd fading experiments done in the lower Duncan River (Thorley et al. 2010).
- The number of redds per spawner is a fixed constant.
- Spawner and redd arrival and departure are normally distributed.
- The duration of spawning is constant across years.
- Peak spawn timing varies randomly by year.
- The residual variation in the spawner and redd counts is described by overdispersed Poisson distributions (Poisson-gamma distributions).

2.5 Spatial Distribution of Spawners

The proportions of spawners at each site were used to calculate the Shannon Index, an information-theoretic measure of the diversity in the abundance distribution of a resource (Krebs, 1999). In the current context, the Shannon Index takes into account both the number of spawning sites and how the spawning activity is distributed amongst these. A higher index value indicates spawners more equally spread amongst more sites.

The Shannon Index (H) is given by:

$$H = -\sum p_i log(p_i)$$

Where, p_i is the proportion of the spawning activity at the i^{th} location.

2.6 Acoustic Telemetry

To collect information on Rainbow Trout spawn timing and residence time, 16 adult Rainbow Trout were tagged in the fall of 2010 and in the summer and fall of 2012. The sixteen Rainbow Trout acoustically tagged in 2010 were boat electrofished for capture and then had Vemco V13-1x-A69-1303 69 KHz tags inserted internally by Golder Associates Ltd. as part of the Lower Columbia River Fish Population Indexing program (Ford et al. 2011). The twenty fish tagged in 2012 were captured through angling and were tagged by a Mountain Water Research/Poisson Consulting Ltd. field crew. The same tag type and frequency of tag were utilized to continue to make use of the existing array of acoustic receivers maintained by BC Hydro in the mainstem of the LCR to detect tagged White Sturgeon (*Acipenser transmontanus*). The locations of the 28 acoustic receivers are mapped in Figure 1.

The biometric and capture data for the fish tagged in 2012 are summarized in Irvine et al. (2013) and the equivalent data for fish tagged in 2010 can be found in Thorley and Baxter (2012). All fish with an acoustic tag inserted in their body cavity also had a Passive Integrated Transponder (PIT) tag inserted on the left side of the dorsal fin to provide permanent identification after the battery on the Vemco tags expires. In order to minimize interference with White Sturgeon during their spawning season, the pulse rate of the Rainbow Trout tags is reduced to almost nothing between May 31 and the end of September. Movements detected between June and September are not considered reliable. The battery of each tag is estimated to last 1701 days (4.6 years).

Vemco VR2W receivers have been deployed in the Norn's Creek Fan area since 2011 to detect the tagged fish at this key spawning location (Table 2). In the 2014 field season the main VR2W receiver was located adjacent to Norn's Fan where previous range testing had shown the best reception to occur for a single receiver in the fan area (Irvine et al. 2013). Two additional VR2W receivers were deployed in Norn's Creek adjacent to the Norn's Creek Bridge and the Norn's Creek Campground in the 2014 season (Table 2) in order to detect the timing of fish entering Norn's Creek to spawn and departing Norn's Creek to get more accurate residence timing for these fish. DNA samples (caudal fin clips) were taken at the time of capture and will be processed in 2015 to sex the tagged fish in order to refine residence time estimates and assess if they differ between males and females.

Table 2. Vemco VR2W receiver deployment information by year. The receivers deployed in Norn's Creek in 2014 are denoted by NC.

Year	Number of Receivers	Date Deployed	Date Retrieved
2011	3	April 8	May 31
2012	1	February 9	June 2
2013	1	March 4	May 30
2014	1	February 22	May 30
2014	2	March 29(NC)	May 30

2.7 Fry Emergence Timing

The expected annual emergence timing was calculated from the estimated spawn timing and the surface water temperature at Norn's Creek Fan under the assumption that Rainbow Trout embryos require 480 accumulated thermal units (ATUs) to reach the emergence stage. Water temperature data have been collected at the gauging station on Norn's Creek Fan since 1999 and consistently throughout the year since 2000 though in some years there are missing data. In 2009, temperature loggers were buried in the gravels at depths of 0.15 m and 0.30 m from May to August at the Norn's Creek Fan site. Comparison of these two hyporheic temperatures with the surface water temperature suggested that surface water temperatures approximate the ATUs experienced by the developing embryos.

2.8 Stock-Recruitment Relationship

There are three main sources of data for Rainbow Trout stock recruitment in the LCR: the spawner counts, the redd counts (e.g., Irvine et al. 2013) and the boat electrofishing captures (Ford et al. 2012). All three data types have historically been sampled over the LCR from HLK dam to the U.S. Border and in the ~1.8 km of the lower Kootenay River below Brilliant Dam. Previous genetic work shows that the fish in the Kootenay and the Columbia interbreed readily so they are considered the same population for the purposes of assessment (Taylor 2002).

In order to examine the relationship between spawners and recruits, the indexing program's mark-recapture-based estimates of age-1 Rainbow Trout abundance (Ford et al. 2012) were plotted against the previous year's AUC-based spawner abundance estimates and the relationship was assessed using a Beverton-Holt stock-recruitment model.

Key assumptions of the stock-recruitment model include:

- The prior probability distribution for the maximum number of recruits per spawner (R0) is normally distributed with a mean of 90 and a SD of 50.
- The residual variation in the number of age-1 recruits is log-normally distributed.
- The prior probability distribution mean of 90 for R0 was based on an average of 2,900 eggs per female spawner, a 50:50 sex ratio, 50% egg survival, 50% post-emergence fall survival, 50% overwintering survival and 50% summer survival(Allen and Sanger 1960, Hildebrand and McKenzie 1995, Thorley 2009).

3.0 RESULTS

3.1 Mainstem LCR and LKR Spawner and Redd Abundance and Spawn Timing

The spawner and redd counts from the nine aerial surveys conducted in 2014 were combined in this year's analysis to produce abundance estimates by year and annual spawn timing estimates (Figure 3). The estimated abundance of Rainbow Trout for 2014 was 13,137 fish (95% CI 8,996 – 19,509). This is a continued increase of approximately 3,000 fish from the 2013 estimated abundance and continues the upward trend in spawner numbers that has occurred since 2011. (Figure 2).

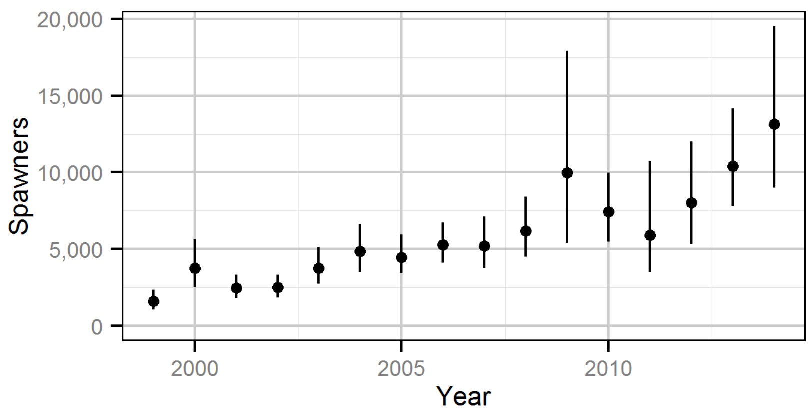

Figure 2. **Annual estimates of abundance of Rainbow Trout spawners in the LCR below HLK dam and the LKR below Brilliant Dam from 1999-2013 with 95% credible intervals.**

The spawn timing for three stages of spawning within the spawning period were estimated with 95% credibility intervals for each period (start, peak, end) from spawner and redd surveys for 2014. The start of spawning was estimated to be on March 19 (95% CI March 14-March 25), the peak spawning had an estimated mean date of May 21 (95% CI May 15 – May 29), and the end of spawning had an estimated mean date of July 24 (95% CI July 15- August 3) (Figure 3). The spawner and redd counts for 2014 are mapped in Appendix A. The spawner and redd counts for the study area's three sections, their AUC estimates and viewing conditions are plotted in Appendix B.

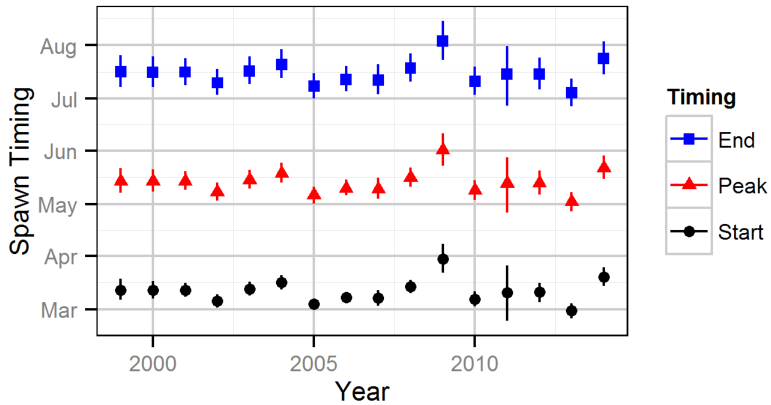

Figure 3. **Annual estimates of peak, start and end of spawn timing of Rainbow Trout in the LCR below HLK dam and the LKR below Brilliant Dam from 1999-2014 with 95% credible intervals plotted for each timing category.**

The number of spawners per redd was estimated to be 0.77 which suggests that each female is estimated to be building 1.54 redds, based on the current modeling assumptions outlined in the statistical methods sections.

3.2 Norn's Spawner and Redd Abundance and Spawn Timing

The total observed peak spawner count for Norn's Creek was 2,392 in 2014 (Figure 4). Observed counts by river section are shown in Figure A12 (Appendix A). This is the highest number of spawners observed in Norn's Creek over the surveyed years. The lowest peak number of fish was in 1983 with 81 fish and the previous high value was 1,486 fish in 2009. The increase in the LCR is mirrored in the trend in Norn's Creek.

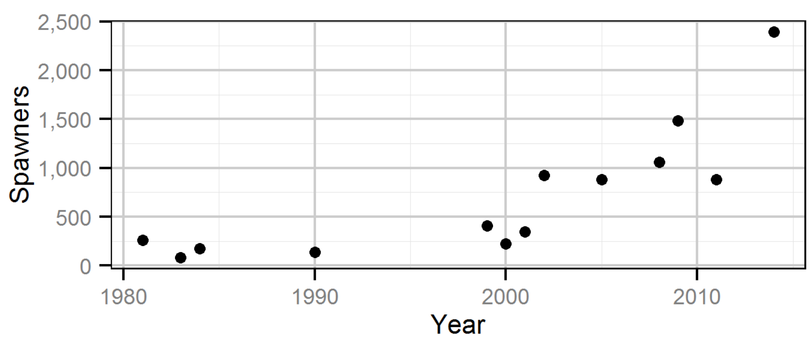

Figure 4. **Annual peak observed counts of Rainbow Trout redds in Norn's Creek from 500m below the falls at 2.2km to the confluence with the LCR. The estimates are derived from the redd and spawner counts.**

The spatial distribution of spawners in Norn's Creek was compared between 2011 and 2014 (Figure 5). The same areas of the river showed peaks in spawner numbers in 2011 and 2014 though the modes were more distinct in the 2014 survey due to more fish observed overall (Figure 5).

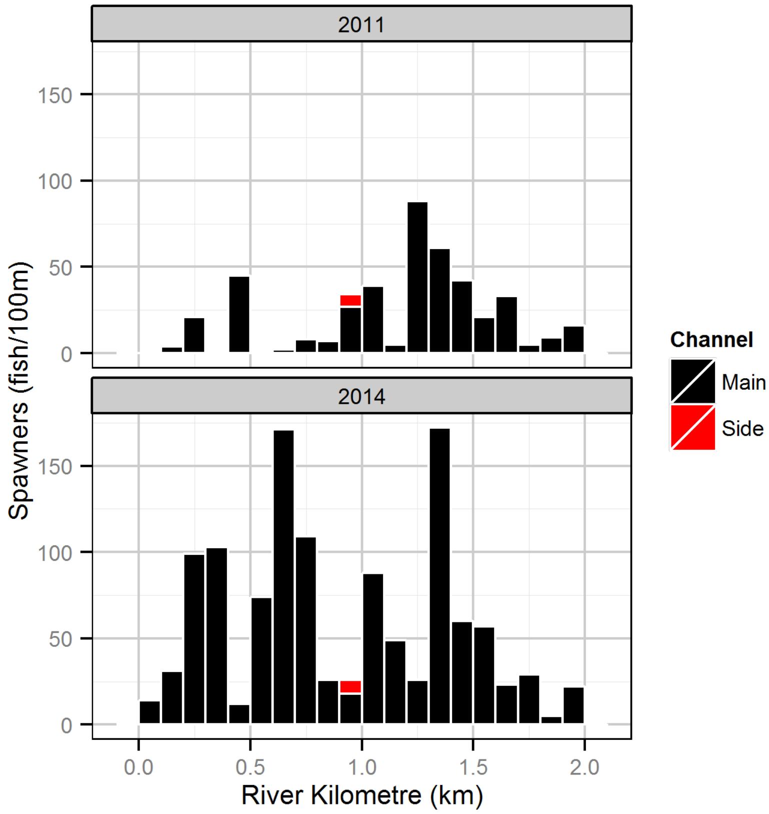

Figure 5. **Spatial distribution of Rainbow Trout spawners in Norn's Creek for 2011 and 2014 snorkel surveys.**

3.3 Redd Dewatering

During 2014 no redds were salvaged, but redds were surveyed to determine the number and percentage that were in shallow water habitat and either dewatered or at risk of dewatering if a reduction event should happen. The biologists at MFLNRO and DFO decided not to excavate and salvage redds until 1% of the mean annual redd abundance from 1999-2011 was reached. In total, 77 redds were dewatered in the 2014 spawn year which was estimated to be 0.78% when the number of redds was divided into the model's estimate of total redds for the year. When the annual dewatering rate for each year was averaged over the fifteen years for which there were data, the mean percentage of redds that dewatered was 0.75% and ranged from near zero to 2% (Figure 6).

Each year the vast majority of redd dewatering occurs during the early spawning period (beginning of January to the end of March). It was a remaining data gap to determine whether the early spawners are genetically unique from the peak spawners which may entail alternative management approaches if there are genetically unique groups. The Castlegar BCH office arranged for DNA collection from early spawners in the Lower Columbia River, Lower Kootenay River, and Norn's Creek to determine if these fish are genetically different from peak mainstem spawners. DNA collection was conducted by Mountain Water Research from January to March (mainstem early spawners) and again in mid-May (Norn's Creek spawners) with help from BCH and MFLNRO staff. The DNA results will indicate whether or not early constructed redds (which dewater) provide genetic variance to the population and will help determine if eggs from early dewatered redds require salvaging. At the time of this report the DNA results of the early spawners were not available.

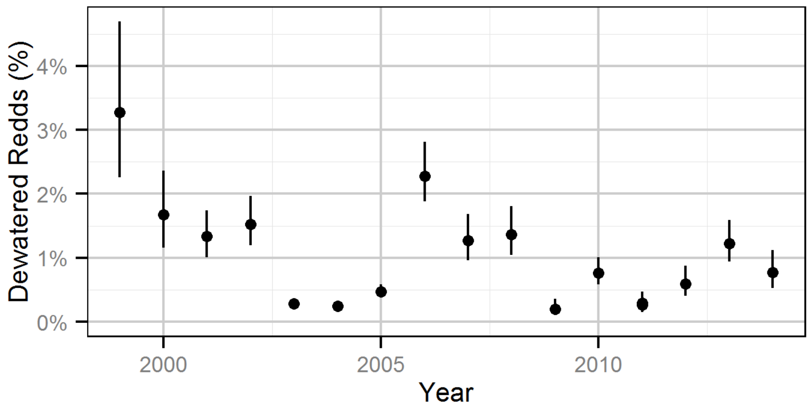

Figure 6. **Percentage of redds dewatered in the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam by year from 1999 to 2014. The bars represent 95% credible intervals.**

3.4 Acoustic Telemetry

Of the 16 Rainbow Trout acoustically tagged in 2010, six were detected by the receivers on Norn's Creek Fan in 2011, three in 2012, one in 2013 and none in 2014. Of the 20 fish tagged in the summer and fall of 2012, 12 were detected in 2013 and six were detected in 2014 (Figure 7). Of the six recorded in 2014, one had not been recorded in previous years. For the purposes of displaying photoperiod, day was considered to be the period between 06:00 and 18:00 hours. It was assumed that the period of time the fish was detected by the receiver was representative of the residence time on the spawning beds. The calculated residence times did not require the fish to be detected in consecutive days but instead represent the total of number of days during which fish were detected at least once during the spawning period.

When residence was defined as detection once per 24h period, the average residence time in 2014 was 28.8 days. When residence was defined by detection during daylight hours in a 24h period, the average residence time in 2014 was 24.3 days (Figure 8). The residence time as defined as detection once per 24h period is approximately double the residence time recorded in 2013 (Figure 8). Over all years, the average residence time was 19.1 days when fish were detected once in a 24h period and 16.8 days when they were detected only during daylight.

The receivers placed at the bridge and near the campground in Norn's Creek detected three fish, but only one of the fish was detected multiple times. This may have been due to a fish moving through moving water (causing noise) quickly enough to avoid detection with the pulse interval. All three fish were also detected on the main fan area by the mainstem receiver (Figure 9).

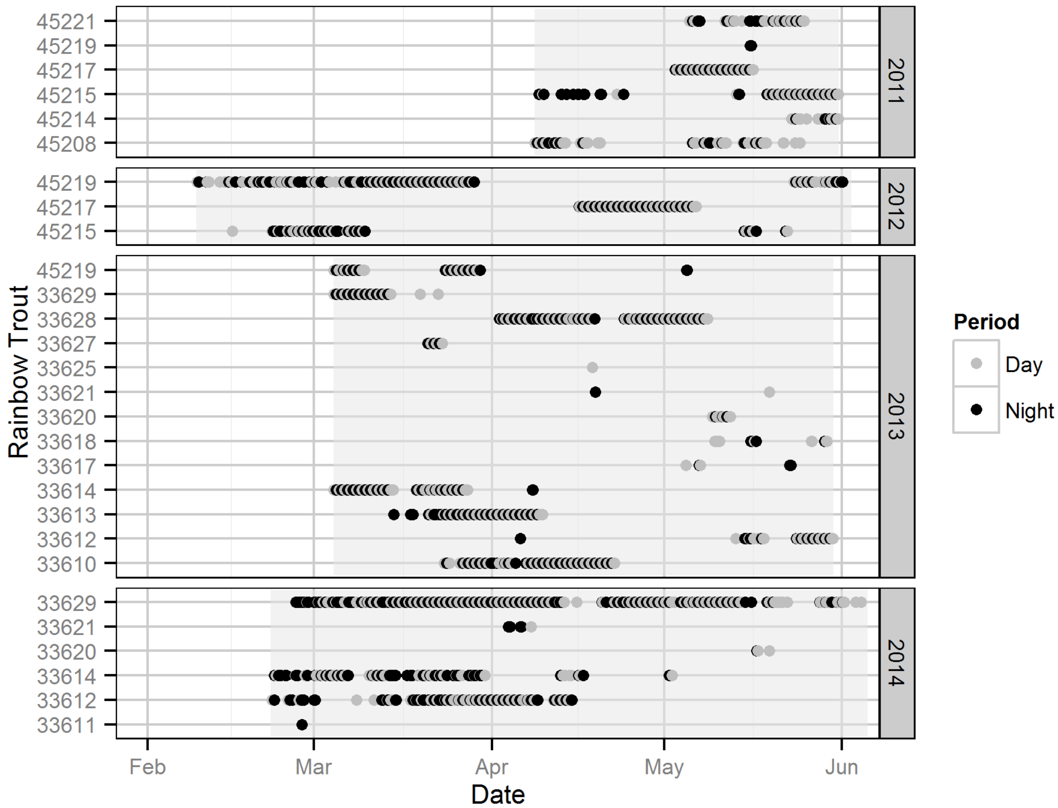

Figure 7. **Norn's Creek Fan Rainbow Trout acoustic tag detections. The period of receiver deployment is indicated by the grey area. The Rainbow Trout numbers correspond to acoustic tag codes.**

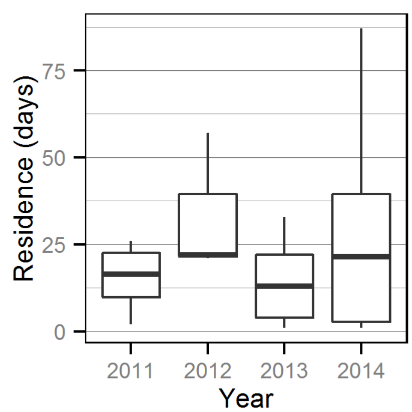

Figure 8. **Norn's Creek Fan Rainbow Trout residence times by year where residence is considered any detection within a 24h period.**

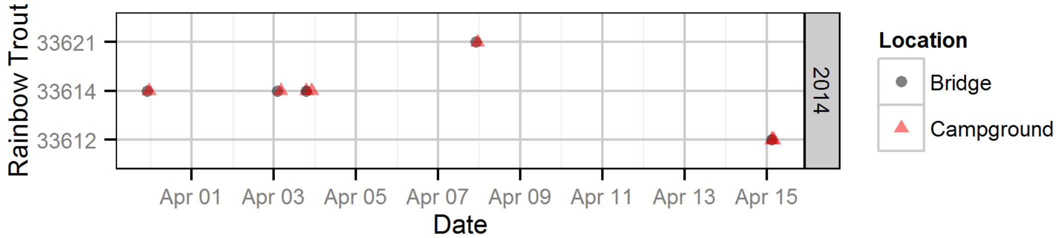

Figure 9. **Norn's Creek bridge and campground Rainbow Trout acoustic tag detections. The receiver was deployed from March 29 until May 30. The Rainbow Trout numbers correspond to acoustic tag codes.**

3.5 *Fry Emergence Timing*

The fry emergence timing estimates use the results of the spawn timing model (Section 3.1) and water temperatures recorded at Norn's Creek Fan for the calculation of the ATUs. There is general agreement between the water temperature at Birchbank and Norn's with the biggest differences seen in June when Birchbank temperatures tend to be higher on average (Irvine et al. 2013). The Norn's temperature data was used since there are data for the study's entire duration and Birchbank water temperature data only commenced in 2005. Norn's water temperature data were plotted with mean and range of temperatures throughout the spawning and emergence periods to describe trends and the earliest predicted date for spawning and emergence (from both redd and fish data) and the latest predicted date are plotted on the temperature plot as well (Figure 10). The water temperature reaches 5°C in mid-April at Norn's Creek Fan, a temperature associated with the advent of spawning in other systems (Thorley et al. 2012) and reaches 17°C in early July, a temperature associated with increased embryonic mortality (Humpesch 1985) (Figure 10).

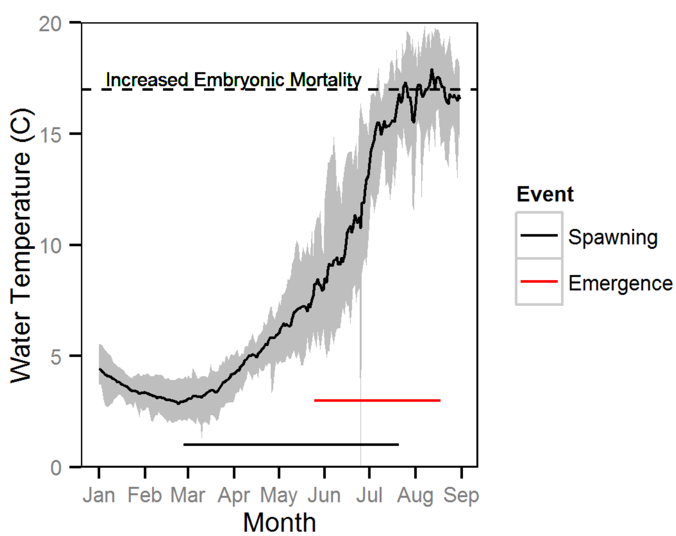

Figure 10. **Mean daily surface water temperature at Norn's Creek Fan from January to September for the years 2000 to 2013 with the range of spawning and emergence dates demarcated. The black line indicates the average temperature, while the grey band indicates the range.**

When predicting emergence timing, a similar approach was used as for determining the spawning timing where three periods of spawning (start, peak, end) were delineated and estimates and 95% credibility intervals were derived for each period. The mean estimate of peak fry emergence for the 2014 spawn year was July 3 (95% CI June 30 – July 7) (Figure 11). The mean estimate for the start of fry emergence was June 7 for 2014 (95% CI June 6- June 9). The end period of fry emergence mean estimate and the lower and upper credibility intervals could not be determined for some years due to missing temperature data. It is important to note that the last fry may not emerge until late-August (Figure 11, Irvine et al. 2014).

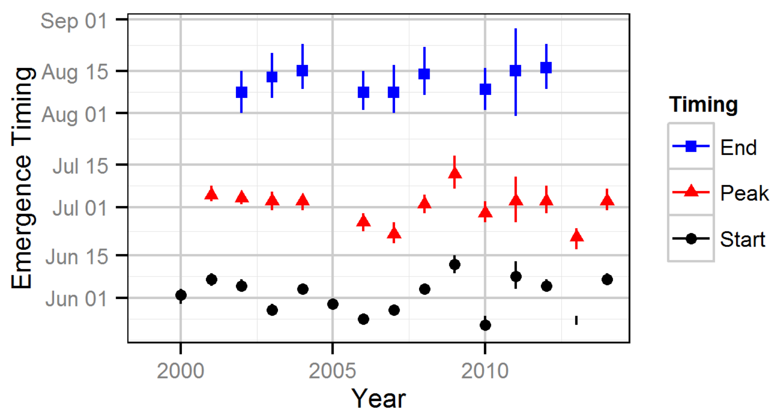

Figure 11. **Annual estimates of the timing of emergence of Rainbow Trout fry from 2000 to 2014 in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam. The bars indicate the 95% credibility intervals for each estimated timing point. The estimates are derived from the spawner and redd counts and surface water temperature at Norn's Creek Fan.**

3.6 Stock-Recruitment Relationship

The Beverton-Holt stock recruitment model fitted to age-1 RB abundance vs. spawner abundance shows clear patterns of density dependent stock-recruitment dynamics (Figure 12). The abundance of age-1 Rainbow Trout at the index sites in the Lower Columbia River and Lower Kootenay River as estimated by the indexing program (Ford et al. 2013) is highest in the 2000, 2001, 2006 and 2010 spawn years. Those first two years in which both types of data were collected had the lowest combined redd / spawner abundance observed over the course of the study. This relationship between the age-1 fish and the spawner abundance is consistent with the density dependent curve. Also consistent with density dependence is the fact that the roughly quadrupled number of redds over the years where there are data for all indices (1999-2012) are not strongly reflected in the numbers of age-1 recruits.

Although there are no data pertaining to the slope of the line through the origin at low densities of spawners, the slope of the initial portion of the curve was informed based on the known biology of the species including information on the number of eggs, survival of eggs and survival of 1 year old fish. If the estimates of the slope are correct, then the shape of the curve and the density dependence are robust estimates. The relationship between age-1 RB and spawners suggests that recruitment of age-1 RB is unaffected (i.e., the curve does not drop off substantially) as long as a minimum of approximately 1,500 spawners are present in the system but the abundance has not fallen below that level to empirically test the minimum levels required.

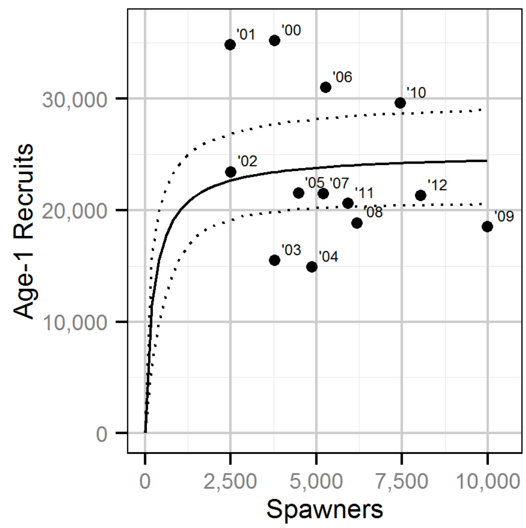

Figure 12. **Beverton-Holt stock recruitment curve including prior information for estimating the starting slope of the curve for Rainbow Trout in the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam for the spawn years from 1999 to 2012.**

The last two strong peak abundance levels in Age-1 fish are 4 years apart (2006, 2010) with another peak in 2000 and 2001. The abundance of Age-1 recruits has been relatively steady around the 20,000 point since 2002 (Figure 13).

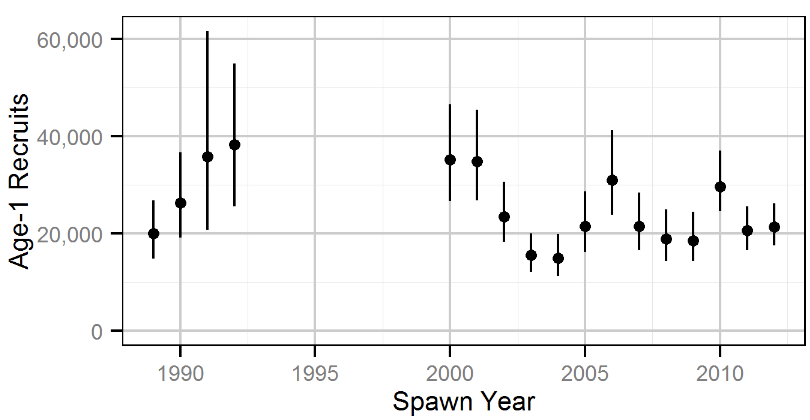

Figure 13. **Number of age-1 Rainbow Trout vs. the spawn year for the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012. The vertical and horizontal bars represent 95% credible intervals.**

4.0 DISCUSSION

The majority of the conclusions and discussion of results in relation to the management questions are drawn from the LCR Rainbow Trout Spawning Assessment program itself. However, there are two other WUP programs that directly inquire into the status, life history needs and environmental correlates that may drive population dynamics of Rainbow Trout in the Lower Columbia River: CLBMON-45 LCR Fish Population Indexing Surveys and CLBMON-44 LCR Physical Habitat and Ecological Productivity Monitoring. Both of these reports were reviewed in the context of the management questions for this study program.

4.1 Management Question 1

The first management question asks whether RTSPF are linked to an increase in the number of spawners. The AUC-based estimates showed ~13000 spawners in 2014 in comparison to ~1600 in 1999 which is an almost 10-fold increase of RB in the Lower Columbia and Lower Kootenay Rivers since the study program commenced. However, it is unknown whether this increase is due to the RTSPF, as a number of environmental and biological factors have also changed including the opening of 26 km of Blueberry Creek for Rainbow Trout spawners (Arndt and Klassen 2004), and the fertilization programs in Kootenay Lake and Arrow Lakes Reservoir.

The accuracy and magnitude of the abundance estimates depend on the extent to which the assumptions of the model are met. Spawner residence time was described by a uniform distribution from 14 to 21 days and redd residence time was assumed to be 35 days. Redd and spawner residence times were based on assessments conducted in the Lower Duncan River combined with professional judgement. These residence time distributions will be refined in the 2015 study year with the telemetry data that has been obtained over the last few years of the LCR study. If these assumed residence times are too high, they will result in an underestimate of the spawner and redd abundance and if they are too low, they will result in an overestimate. It is a similar situation for the assumed observer efficiencies of 0.9 to 1.1 for spawners and redds; if they are too high an underestimate will result, and the opposite if they are too low.

It is also important to be aware that the AUC-based estimates exclude fish spawning in tributaries (other than the Lower Kootenay River below Brilliant Dam), at deep-water sites, downstream of Genelle including below the US Border and upstream of Norn's Creek fan. The current state of knowledge with regard to the numbers of fish spawning in tributaries, deepwater sites and in the US is summarized in Thorley and Baxter (2011, 2012). In brief, tributaries to the LCR may provide habitat for over 3,000 spawners, fish are likely spawning unrecorded in the deeper parts of the Lower Columbia and Lower Kootenay Rivers (based on deep water observations on an exceptionally clear viewing day in 2010) and Rainbow Trout in the U.S. spawning locations may contribute to the LCR Canadian population. As part of their early 1990s Lower Columbia River fisheries inventory Hildebrand et al. (1995) radio-tagged 34 Rainbow Trout, 15 (44%) of which moved downstream into the US and acoustically tagged fish have been observed to undertake 50 km spawning migrations.

The density of Rainbow Trout in the lower Columbia River has changed very little over the course of the indexing program according to mark-recapture analyses with a small and gradual increase in abundance during the period of study (Ford et al. 2013). This trend is quite markedly different from the trend in spawning RB in the LCR over the same span of years where an almost 10-fold increase has been observed. This may be due to a number of reasons: 1) fish may migrate into the study reach for spawning and then leave before fall, therefore not being captured by either the fall tagging data from the spawning program or by the indexing study's data, 2) fish may move offshore into deeper water that is not sampled by boat electrofishing methodologies during fall when they are in the river at higher densities therefore masking any increase, 3) the low recapture efficiencies of the indexing program may be limited its ability to detect the increase, 4) the indexing program initially selected sites of known high abundance – it is possible that the additional Rainbow Trout occupied the previously low abundance sites and were not detected by the program, and 5) Rainbow Trout spawners may migrate upstream from sites in the United States in the spring season, but then return to their usual feeding areas by the fall when the indexing program commences.

The LCR fish indexing program studies Rainbow Trout as one of its focal species and over the years of the program (2001-present) has assessed the effects of variation in flow regimes on abundance, growth rates, survival, body condition and spatial distribution of the focal species. Abundance is a challenge given the inherently low recapture rates associated with large river or marine work.

Rainbow Trout survival for the subadult life stage as estimated from the LCR indexing program ranges between 45-60% and declined sharply to 32% in 2012 (Ford et al. 2013) which was postulated to be due to the extremely high water year. For adult RB, survival was 30% on average, climbing to 56% in 2011 and declining in 2012 to 28%. Interestingly, the decline did not correspond with a decline in density or with the number of spawners estimated from visual surveys in that year.

The absolute density of subadult RB was negatively correlated with mean discharge in November and December and with variation in discharge in January and February (Ford et al. 2013). This was interpreted to mean that flow variation in the overwintering period could be affecting subadult RB survival (Ford et al. 2013). Length at age was also negatively correlated with mean autumn (Sept/Oct) discharge and growth was negatively correlated with variation in discharge in January and February (Ford et al. 2013). There was no significant correlation between the biometric measures and water temperatures. There is some evidence for density dependent growth rates as indicated by the higher rates of growth and greater length at age of fry and subadult RB in the early 2000s when density of subadult fish was lower.

4.2 Management Question 2

The second management question concerns the spatial distribution and associated habitat area of spawning Rainbow Trout within the study area. As discussed by Thorley & Baxter (2011) the spawner and redd count data indicate that the spatial distribution and habitat area of spawning have increased slightly over the last decade. As the RTSPF have been implemented since 1992 it is unclear why they would be responsible for this increase. One possible explanation is that as spawner abundance has increased, particular areas have become saturated and as a result fish have begun to utilize additional locations. Field crews have noted over the years of monitoring that the locations available for spawning Rainbow Trout vary considerably with the river stage and the discharge levels provided from HLK and BRD. Rainbow Trout spawning in the LCR and LKR select habitats where velocities range from 0 to 1.4 m/s with peak spawning activity at a velocity of ~0.6 m/s and depth ranges from 1 to 1.5 m with peak habitat suitability curve values at ~1.1 m (Thorley and Baxter 2012). Therefore, although there are some spawning areas that are used every year, there are locations and habitats that are used sporadically depending on their suitability. In the 2013 spawn year, the spawning season commenced early and reached high numbers and stayed there for a protracted period of time. The density of redds in known, annually used spawning locations was higher than in previous years and significant superimposition was probable.

As Rainbow Trout move into additional habitats within the LCR and LKR or spawn in increasing densities in existing habitats, they may be using areas that are less optimal or at risk of operational effects on flow or water temperature. The range of emergence timing predicted from the modeling indicates that some redds with developing eggs may be dewatered or reach lethal water temperatures at the end of their development window. The discharge from HLK dam increases or stays flat throughout the summer months, but the discharge from BRD decreases over 1000 m^3/s from mid-late June until early August. It is unknown whether all Rainbow fry have emerged by that time and the emergence dates predicted from the model over all years include late-August. This may put Rainbow Trout redds in the LKR at risk of dewatering. Approximately 15% of the spawning Rainbow Trout in the study area use the LKR.

Habitats within the study area that experience sudden changes in water temperature or water warm enough to cause embryonic mortality prior to emergence may be sub-optimal habitat for the survival of Rainbow Trout from egg to age-1. Some spawning locations throughout the study area may be more affected by temperature increases at the end of the predicted emergence period depending on the discharge and temperature of the released water from BRD and HLK dams. The relationship between water temperatures and operations was one of the foci of the ecological productivity study (CLBMON-44). The investigation of the influence of various operational and environmental factors on LCR water temperatures found that the influence of flow was low compared to other predictors such as air temperature, reservoir temperature and reservoir elevation (Larratt et al. 2013). Flow did still have an influence on water temperature but the effects were found to vary and were highly dependent upon season (Larratt et al. 2013). Based on their analyses, the null hypothesis that the implementation of the protection flows does not alter water temperature regimes of the LCR was preliminarily accepted. The report rejected all null hypotheses stating that flows did not affect seasonal water levels, river level differences between maximum peak spawning MW flows and minimum incubation flows, or constant water level elevations at Norn's between April 1 and June 30. It was inferred that the stable flows during the MW protection flow period may help the Didymo to establish in the LCR and that RBTSPF have stabilized the invertebrate community due to the decreases in dewatering events. It was concluded that the protection flow management has caused changes in the LCR benthic community. The fluctuating flows in the fall period in the LCR were considered to likely have the same detrimental effect on periphyton and benthic invertebrates as seen in the MCR due to repeated dewatering. This could potentially directly affect the overwinter survival of RB young-of-year who depend upon these resources to attain size before winter. The dissolved oxygen levels have been adequate for all salmonid life stages throughout the productivity and habitat study as per the provincial guidelines although Norn's measured DO of 9.0-13.2 mg/L so was at the threshold (9 mg/L) of the guidelines in August due to low, warm flows (Larratt et al. 2013).

4.3 Management Question 3

The third and final management question asks whether RTSPF protect the majority of redds from dewatering. This management question can be answered positively with the current flow regime. In 2014, 77 Rainbow Trout redds dewatered during the spawning season. Using the redd dewatering estimates from the hierarchical model, the calculations suggest that the mean dewatering rate is 1.02% with the current flow regime and was 0.77% in 2014. In 2013 with a very early onset of spawning it was higher than average with 1.23% dewatered. There are no good data on the level of redd dewatering from prior to the protection flows, but in a study done in 1990-1991 between 50-75% of the redds observed during field surveys were exposed by ensuing flow reductions (Hildebrand and McKenzie 1995).

4.4 Recommendations

The primary purpose of the program is '*to better understand the link between flow management strategy and population abundance'* (BC Hydro 2007, p.2). In order to experimentally test the effect, if any, of the RTSPF on trout abundance in the study area to address the first management question, it is still proposed that alternative flow scenarios be tested (Baxter 2012). One proposed study plan which will be discussed at the interim review stage of the WLR programs next year in 2015 is to maintain 35 kcfs until mid-April or until a large number of redds have been constructed and then drop flows to 15 or 20 kcfs to dewater approximately 25% of Rainbow Trout redds within the study area. Results from the current analysis suggest that 50% of the redds could be dewatered without a population effect, but to be conservative while still potentially observing an effect, 25% was selected. The proposed alternate flow regime that would dewater 25% of the RB redds should generate data to help confirm or deny the compensatory egg model that was supported more highly than the density independent model in previous analyses (Thorley 2009). It is proposed that any selected alternative flow scenario be implemented for three years occurring in alternate years (i.e., three redd dewatering events over 6 years) to ensure the observation of any effect in the abundance estimates from this study program or in recruitment to the Large River Indexing program. Alternate year sampling is suggested to conservatively assess any effect on the Rainbow Trout population while controlling for any sustained population decline due to the incursion of Northern Pike (*Esox lucius*) into the Lower Columbia River.

Further research is recommended for the Lower Kootenay River due to drops in discharge from BRD during the incubation period for Rainbow Trout in the spawning location where 15% of the estimated spawning population choose to make their redds. Research would include: 1) obtaining accurate and precise stage data from a levellogger/barologger combination to determine what drops actually dewater usable and utilised habitat, 2) reliable water temperature data for the LKR during the incubation period to refine the timing of when habitats need to remain watered in order to protect fry, and 3) monitoring of egg stages and egg mortality or fry emergence during the summer months would address this data gap.

5.0 CONCLUSIONS

To date, the program has conclusively answered the last of the three management questions. The first two management questions have been partially answered by the documenting of the increasing trends in RB abundance and spatial distribution (Table 3). However, these increases cannot be attributed to the RTSPF without further research. The primary objective of the program is to better understand the link between flow management strategy and LCR RB population abundance and it remains unanswered at this point. The strong data and extensive time series in place at this point in the program will allow the testing of specific questions and the monitoring and testing of alternative flow strategies. The study's results and the above recommendations have pointed out where and what type of additional research appears to be needed at this time to advance the understanding of the primary objective. The proposed experimental manipulations in the spring hydrograph commencing in 2015 would be a step towards improving the answers to these management questions (Baxter 2012) and a final decision on whether this experimental approach is taken will be confirmed after the interim review of the WLR studies on the LCR.

Table 3. Status of Objectives, Management Questions and Hypotheses after Year 6

Objectives	Management Questions	Year 6 (2013) Status
Assess changes in the relative abundance, distribution and spawn timing of Rainbow Trout in the lower Columbia River	1. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the relative abundance of Rainbow Trout spawning in the LCR downstream of HLK?	The number of Rainbow Trout spawners and redds has increased about 10-fold since 1999. RTSPF may or not be responsible for this increase. Proposed experimental flow manipulations may clarify the role of the hydrograph in influencing the Rainbow Trout abundance.
	2. Does the implementation of RTSPF over the course of the monitoring period lead to an increase in the spatial distribution of locations (and associated habitat area) that Rainbow Trout use for spawning in the LCR downstream of HLK?	The number of locations and the spatial distribution of Rainbow Trout spawning have increased since 1996. This may be related to an increase in the number of Rainbow Trout spawners (Thorley and Baxter 2011; Appendix C).
	3. Does the implementation of RTSPF over the course of the monitoring period protect the majority of Rainbow Trout redds (as estimated from spawning timing) from being dewatered in the LCR downstream of HLK?	Yes. Over all years of analysed data, the mean stranding rate of redds has been 0.75%, as compared to the estimated 50-75% stranding rate noted in shallow water habitat on Norn's Fan in 1990 and 1991 prior to implementation of RTSPF.

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APPENDIX A

2014 Spawner and Redd Count Maps

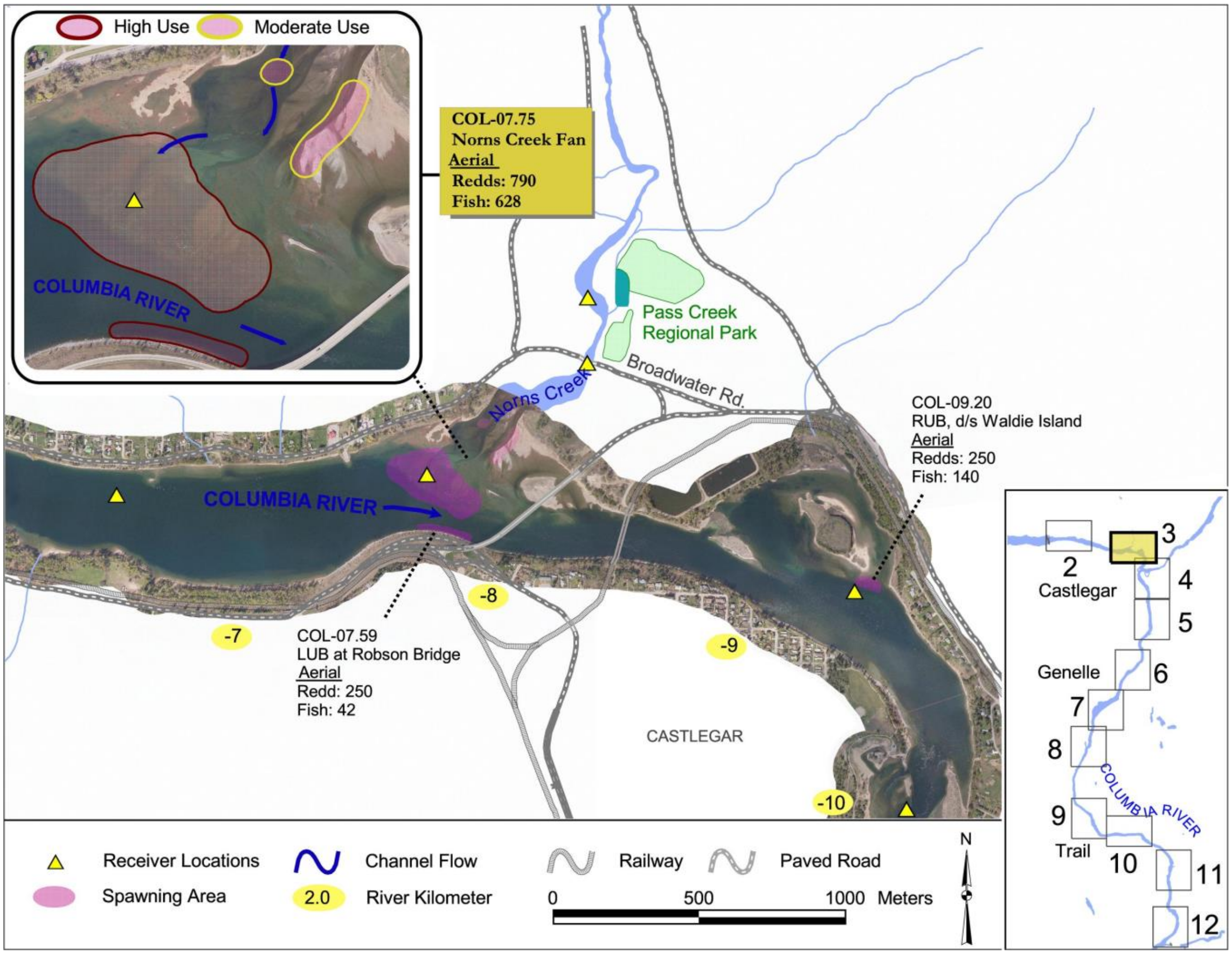

Figure A1. **Spawner and redd counts in Norn's Fan Area in 2014.**

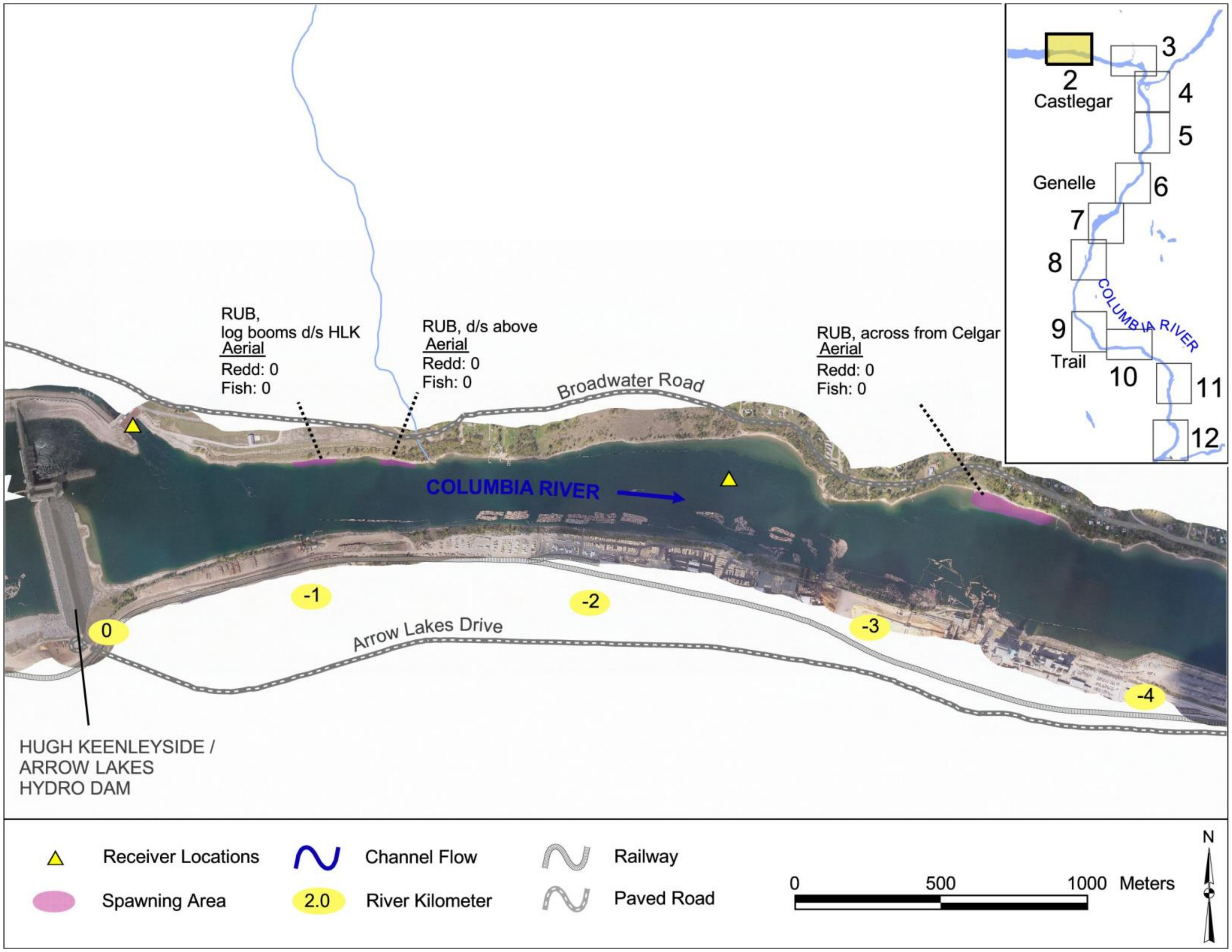

Figure A2. **Spawner and redd counts by location in the HLK Dam area in 2014.**

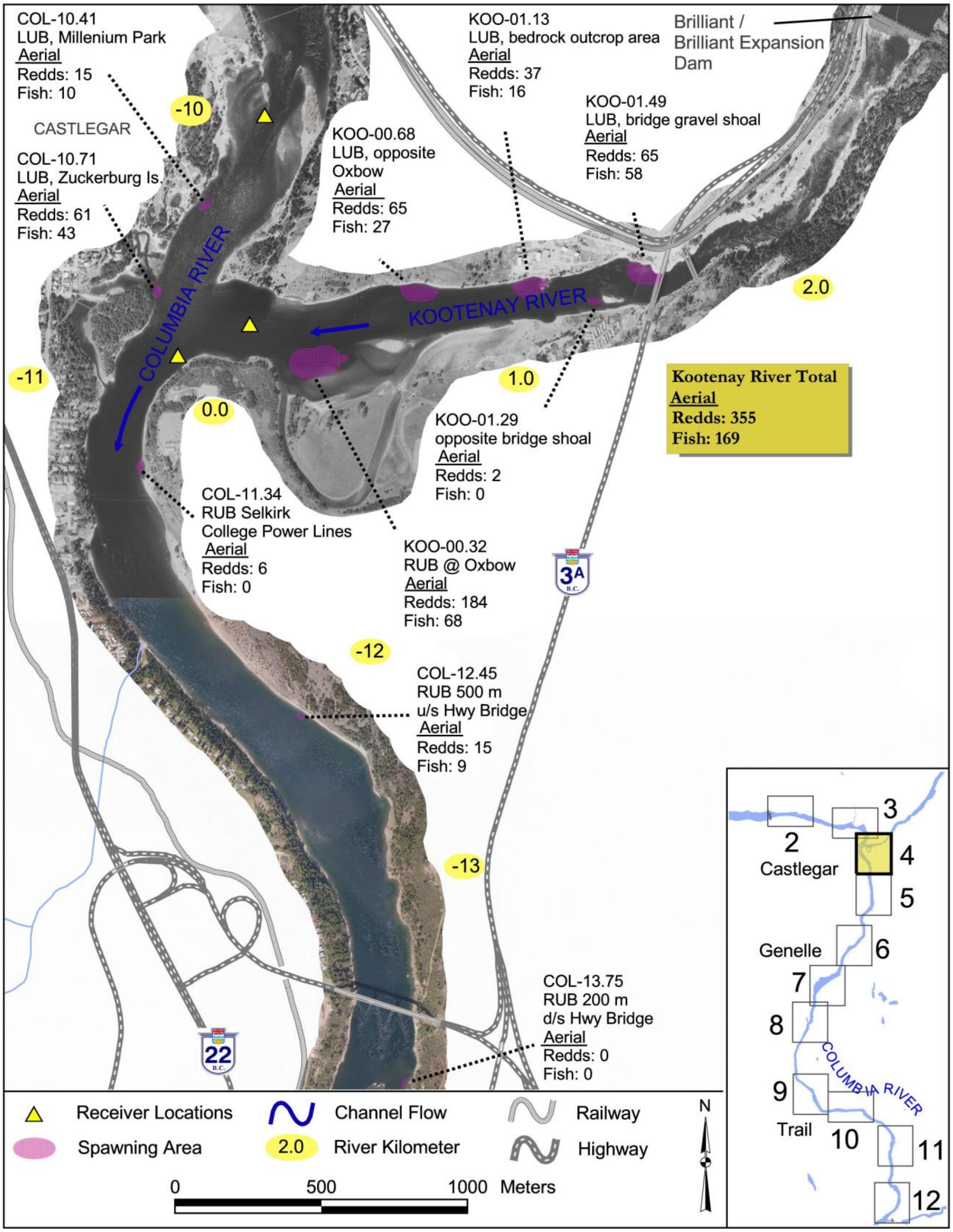

Figure A3. **Spawner and redd counts by location in the Kootenay-Columbia confluence area in 2014.**

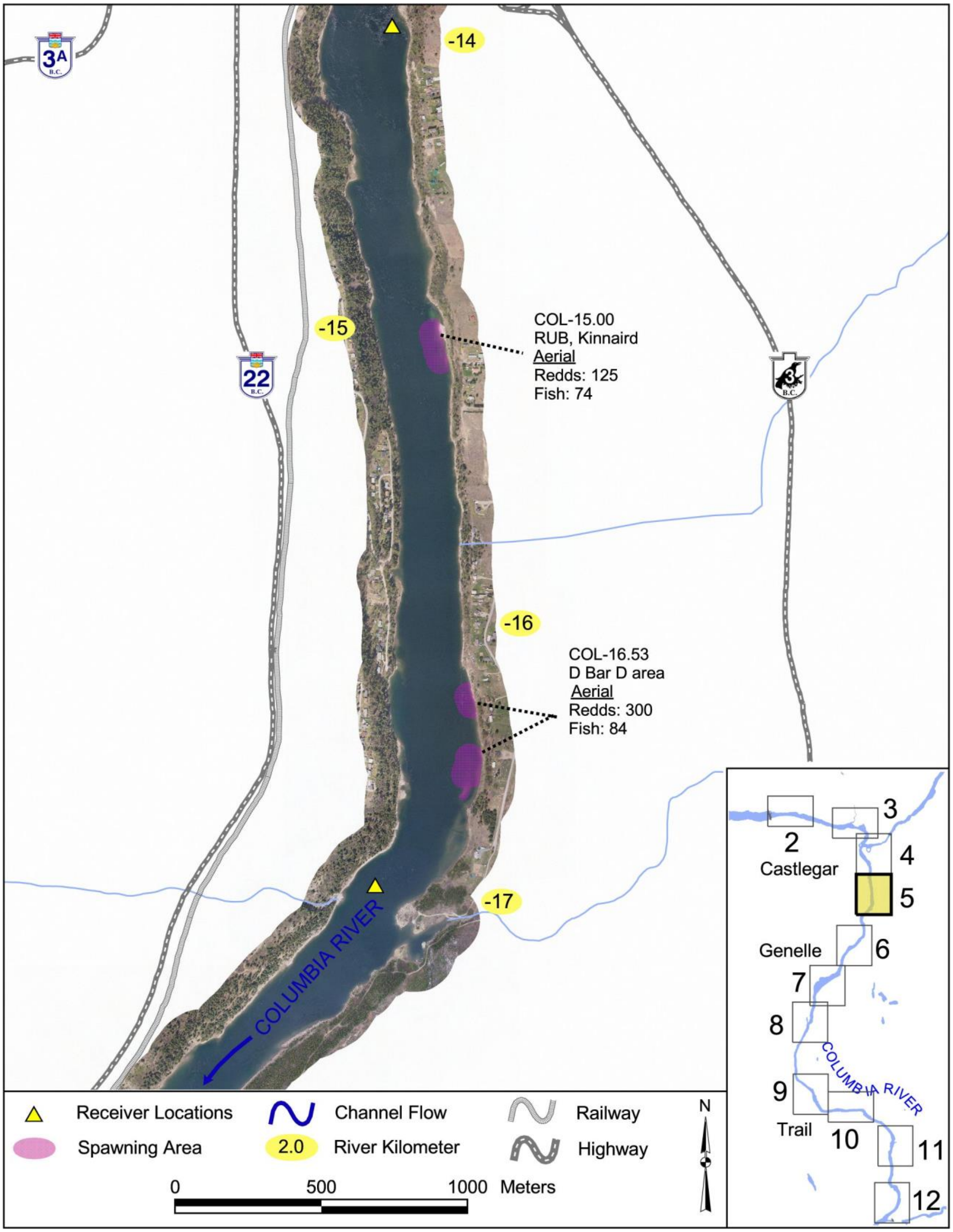

Figure A4. **Spawner and redd counts by location in the D-Bar-D area in 2014.**

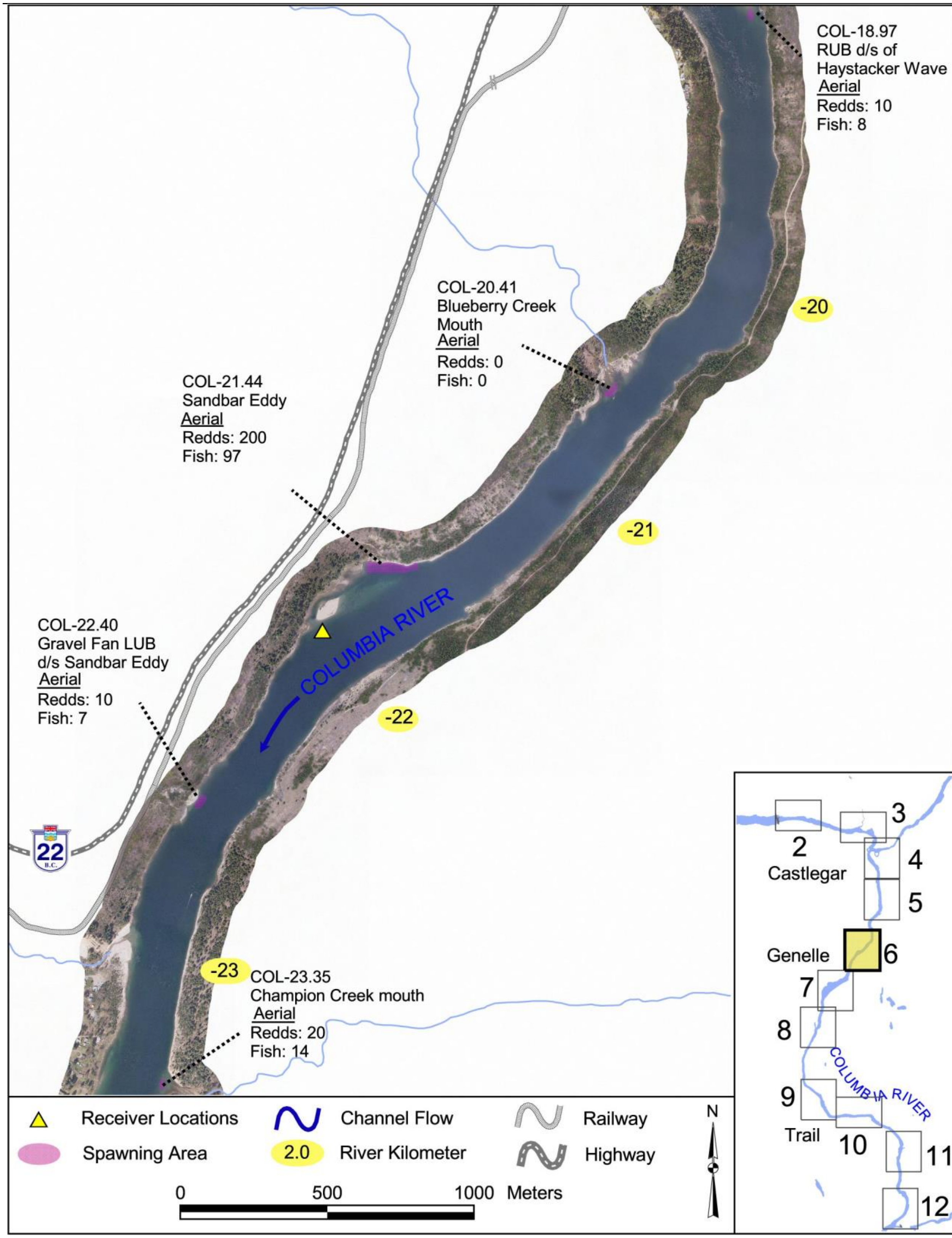

Figure A5. **Spawner and redd counts by location in the Sandbar Eddy area in 2014.**

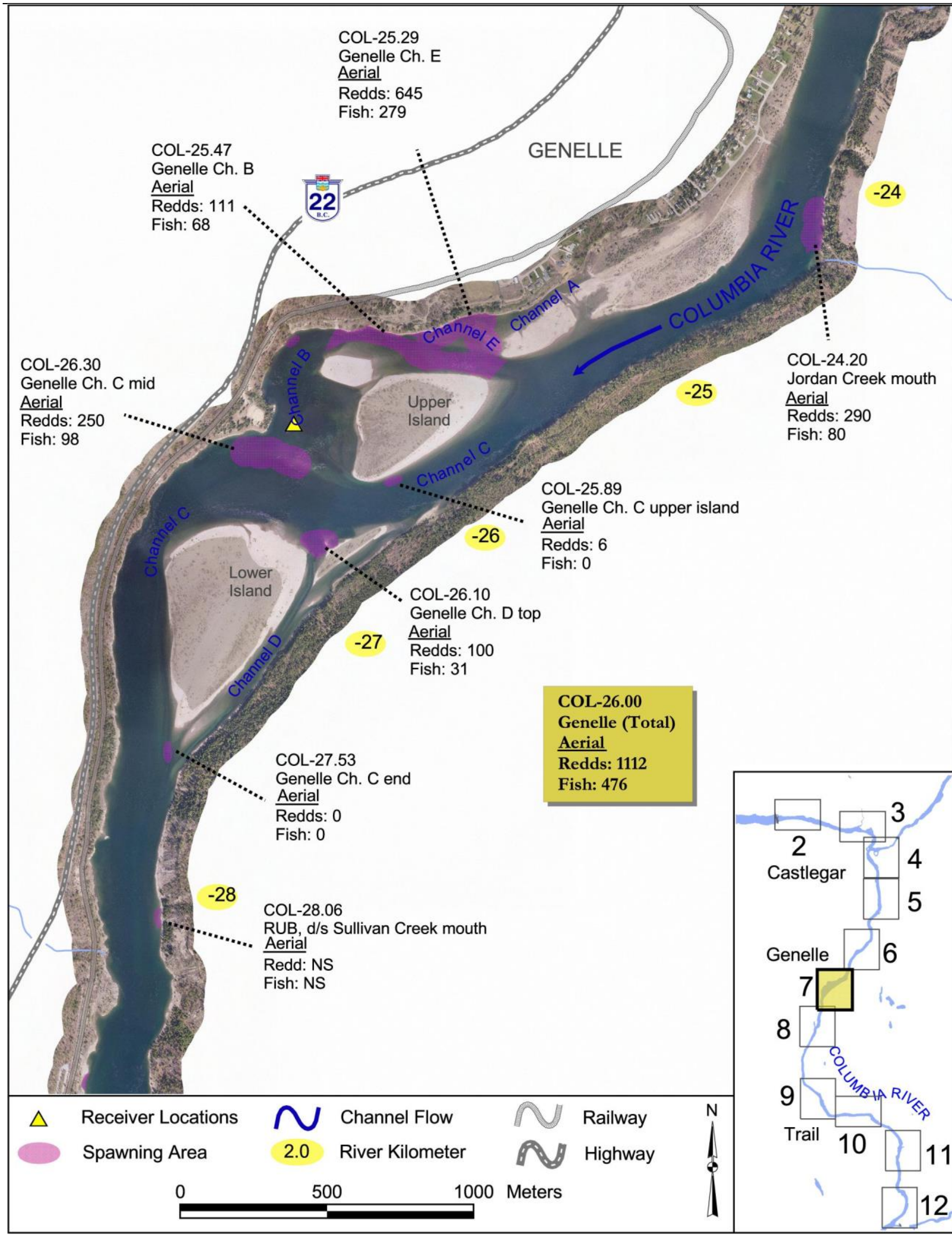

Figure A6. **Spawner and redd counts by location in the Genelle area in 2014 (NS=Not Surveyed).**

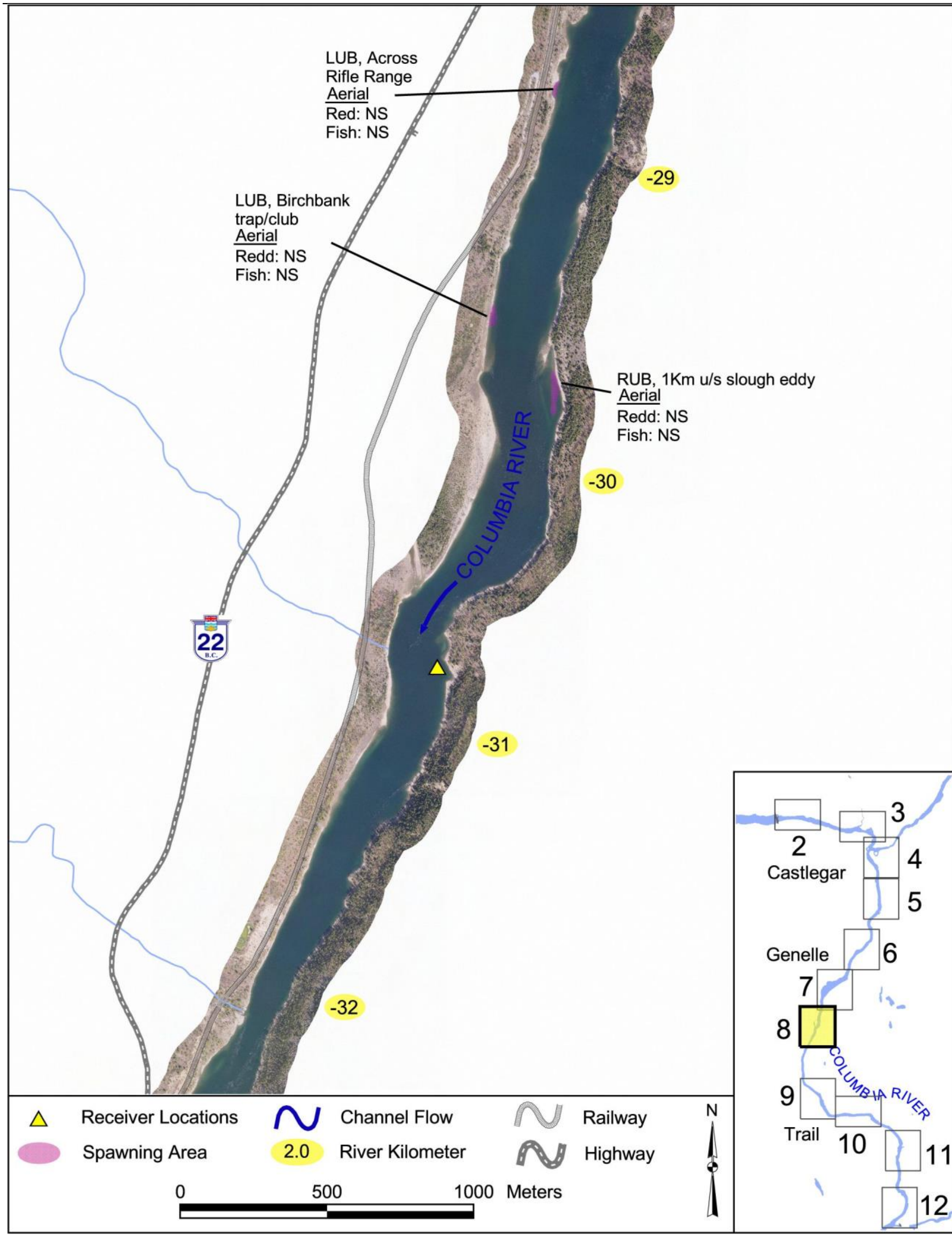

Figure A7. **Spawner and redd counts by location in the Birchbank area in 2014 (NS=Not Surveyed).**

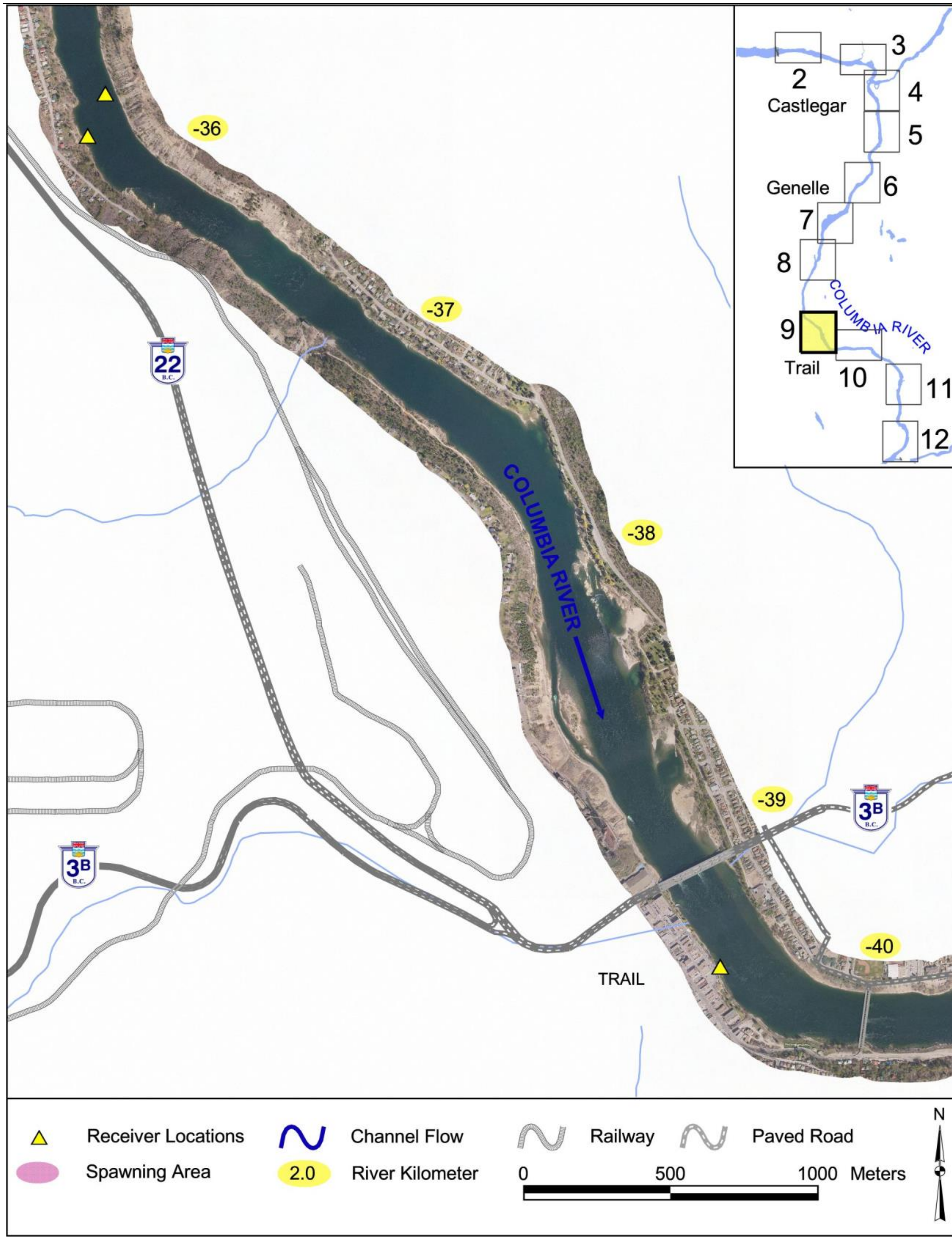

Figure A8. **Spawner and redd counts by location in the Trail area in 2014.**

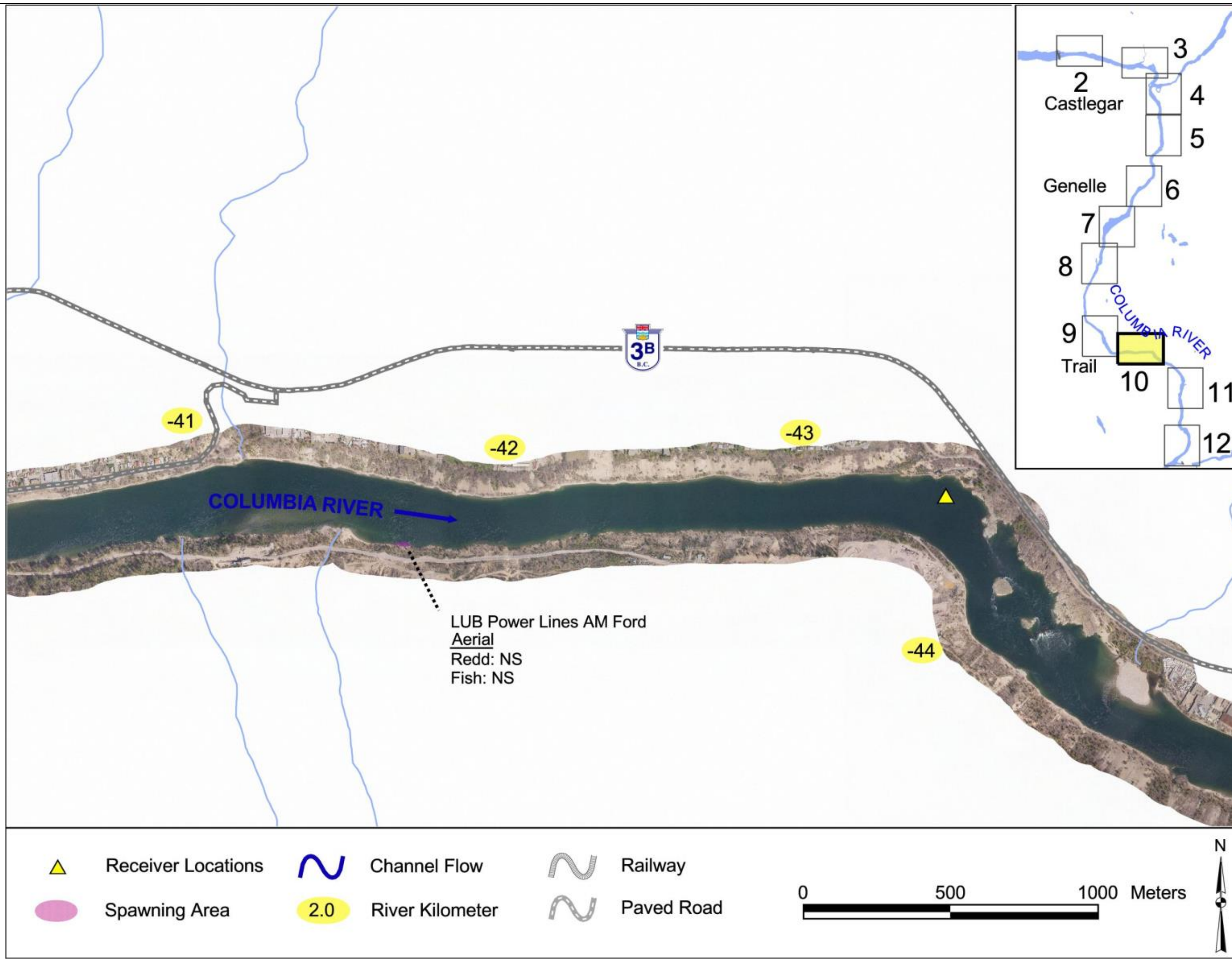

Figure A9. **Spawner and redd counts by location in the Trail AM Ford area in 2014 (NS=Not Surveyed).**

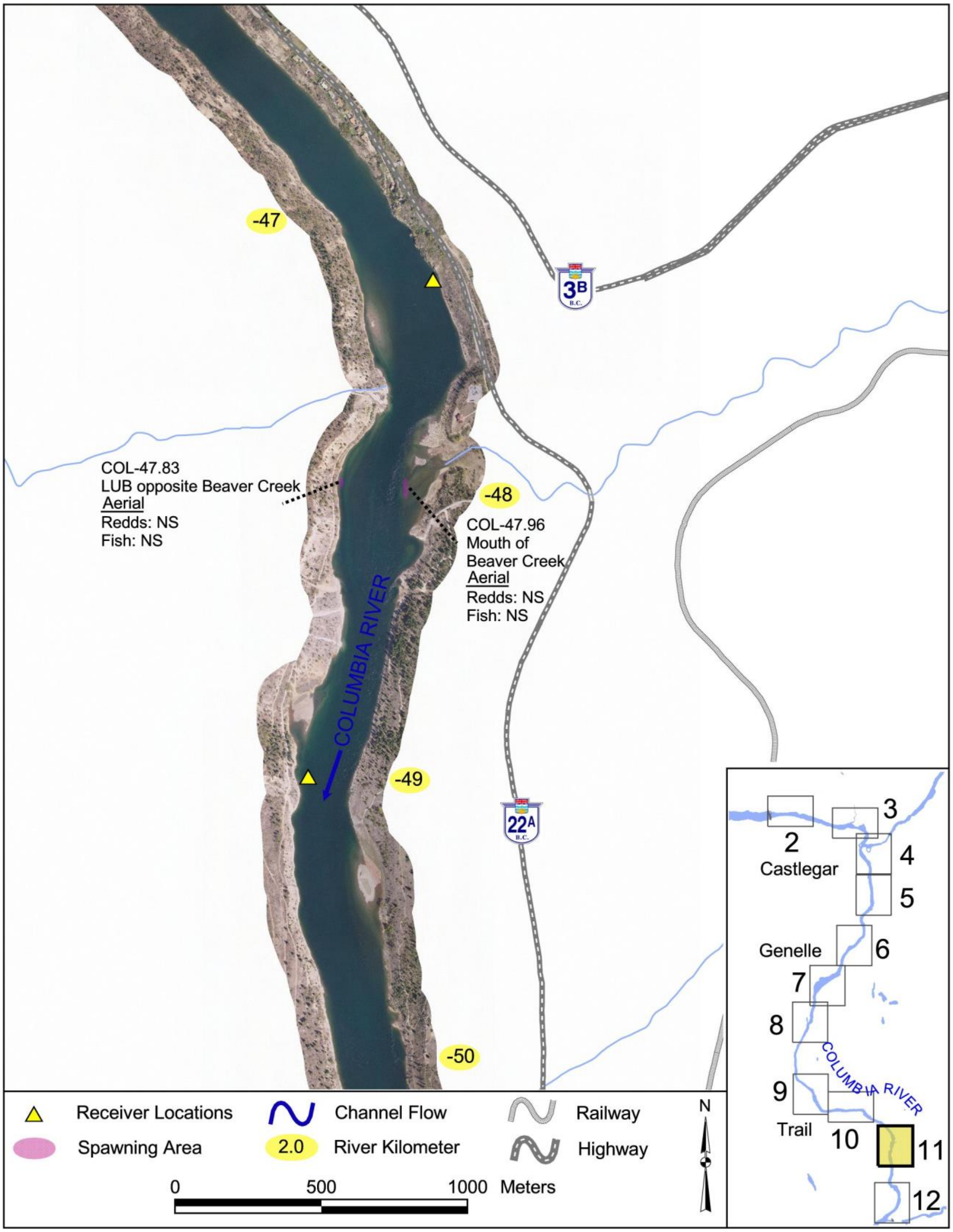

Figure A10. Spawner and redd counts by location in the Beaver Creek area in 2014 (NS=Not Surveyed).

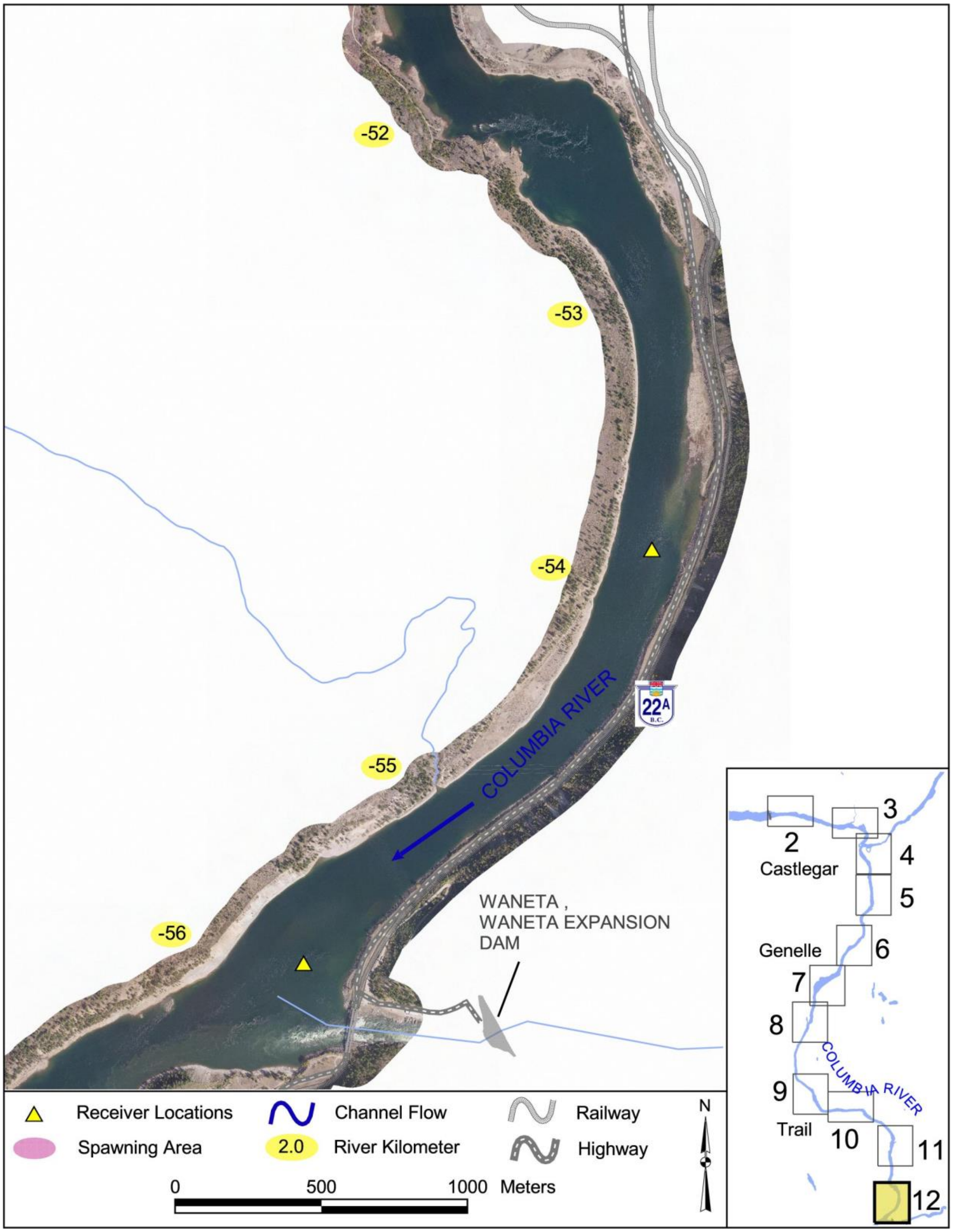

Figure A11. **Spawner and redd counts by location in the Waneta Dam area in 2014.**

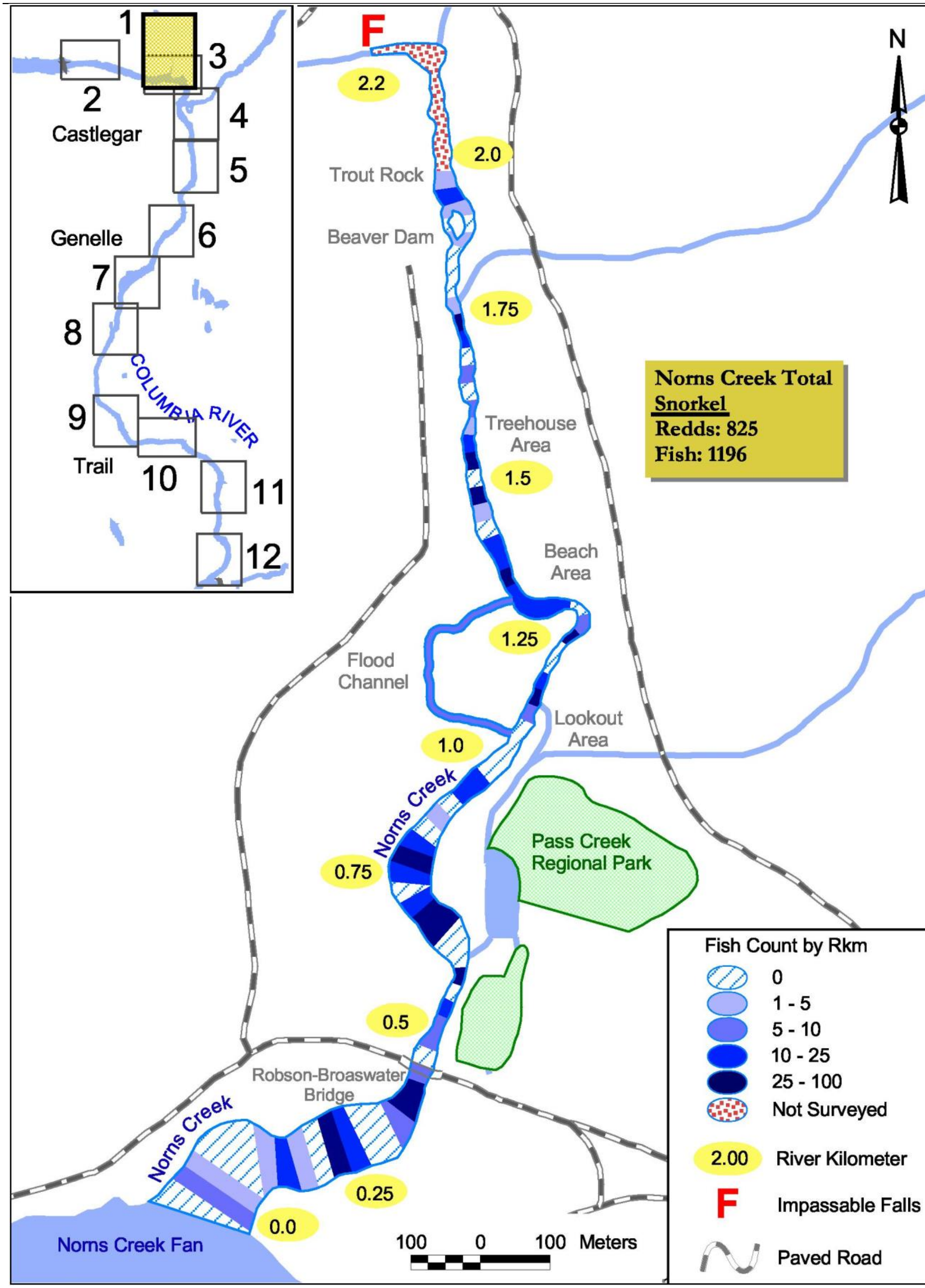

Figure A12. **Snorkel survey spawner and redd counts in Norn's Creek on May 7, 2014.**

APPENDIX B

2014 Spawner and Redd Counts with AUC Estimates and Viewing Conditions

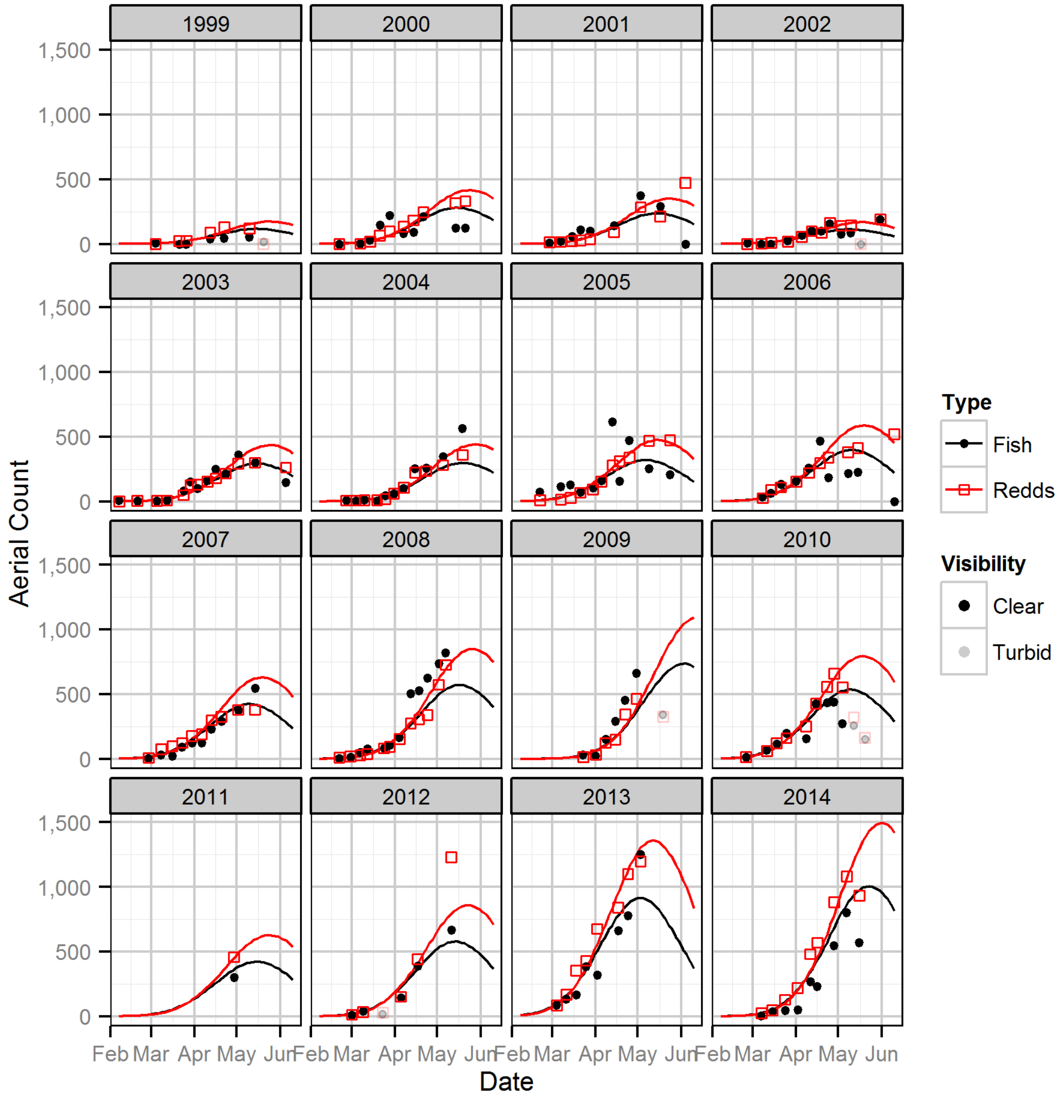

Figure B1. **The spawner and redd counts for the Lower Columbia River above the Kootenay River with the AUC-based estimates of the expected counts 1999-2014.**

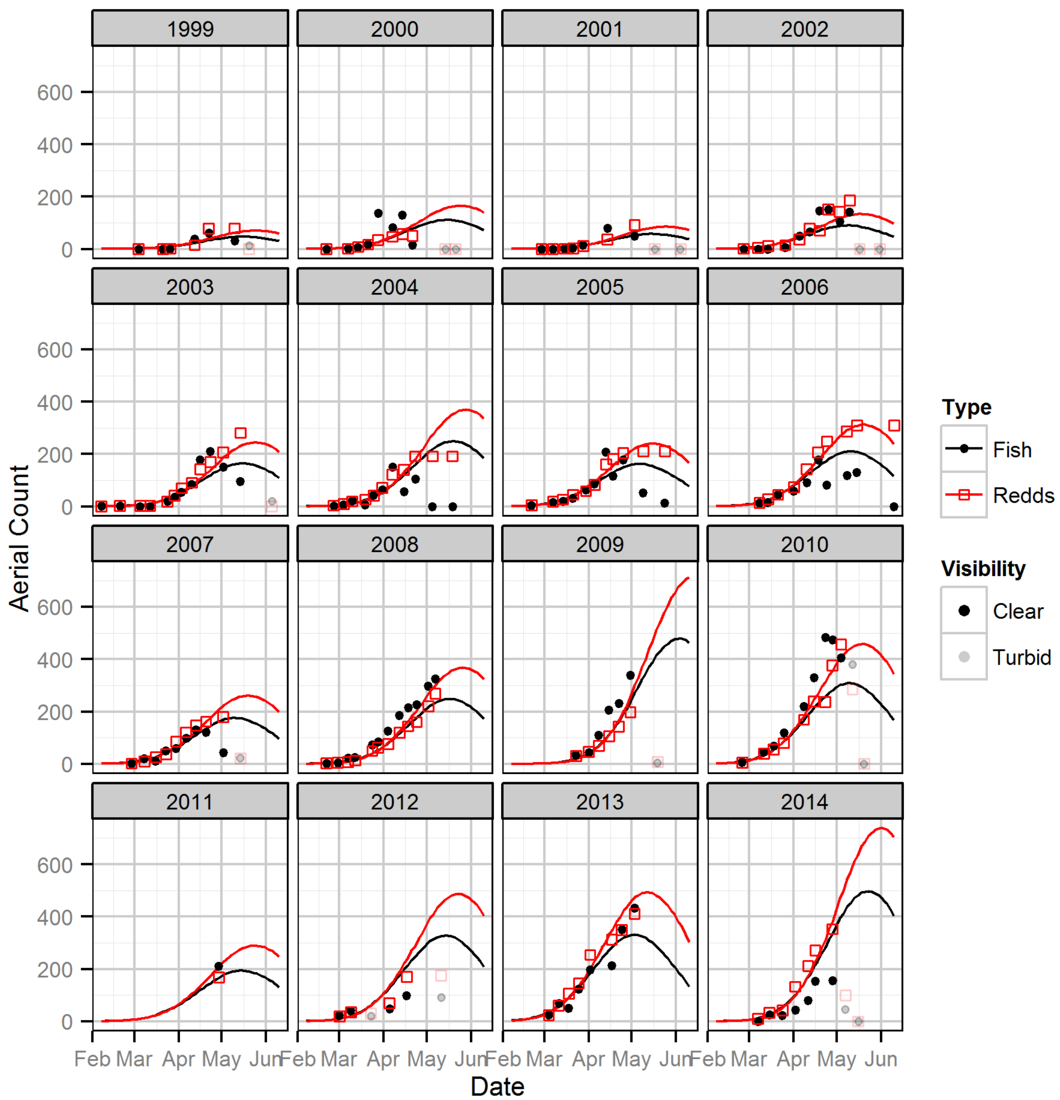

Figure B2. **The spawner and redd counts for the Kootenay River below Brilliant Dam with the AUC-based estimates of the expected counts 1999-2014.**

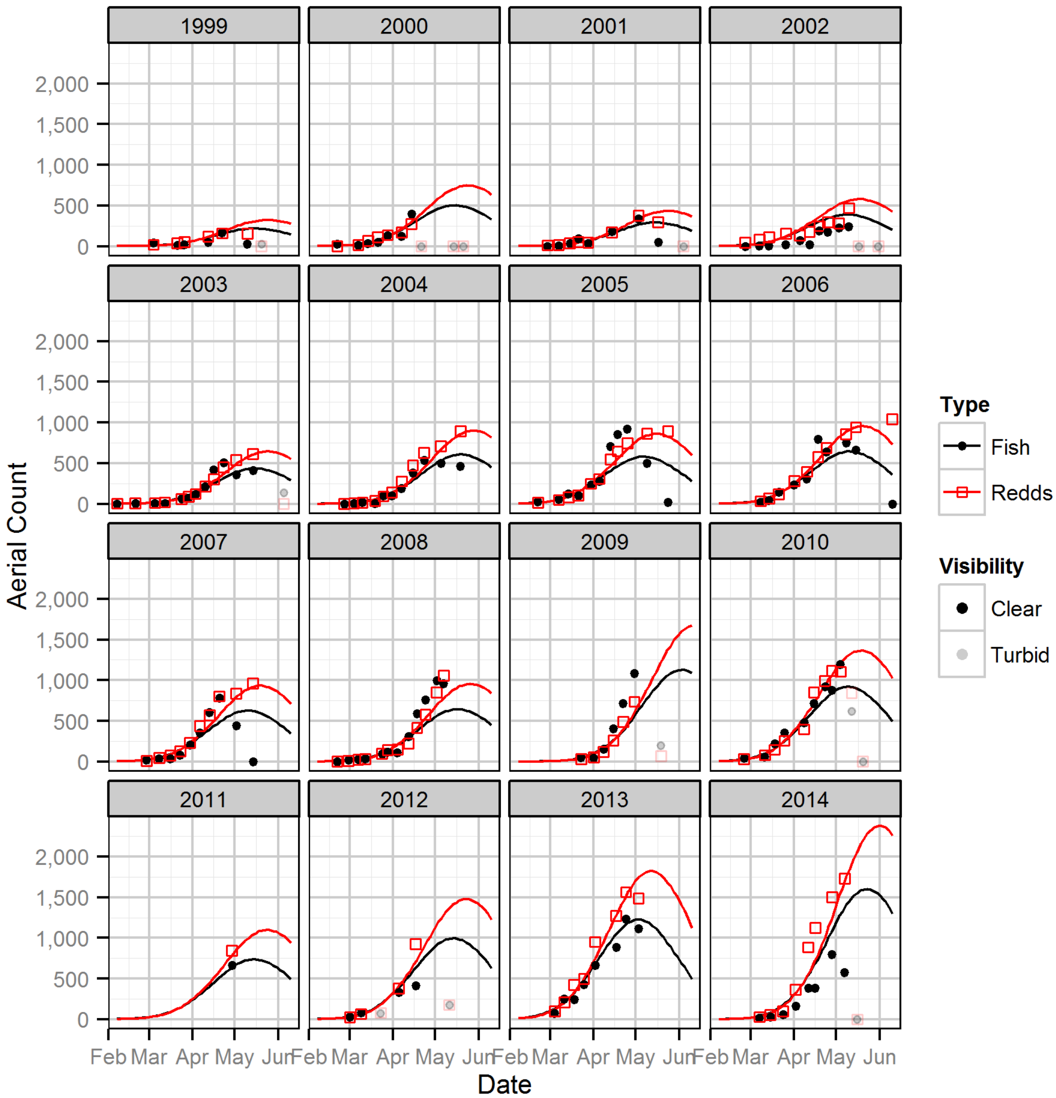

Figure B3. **The spawner and redd counts for the Lower Columbia River below the Kootenay River with the AUC-based estimates of the expected counts 1999-2014.**

APPENDIX C

2014 Model Code and Parameter Estimates

Model Code

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

Variable/Parameter	Description
bPeakSpawnerArrivalTiming	Timing of peak of spawner arrival
bReddObserverEfficiency	Redd observer efficiency
bReddPerSpawner	Number of redds per spawner
bReddResidenceTime	Redd residence time
bSpawnerAbundanceSite[i]	Intercept for spawner abundance at i*th* site
bSpawnerObserverEfficiency	Spawner observer efficiency
bSpawnerResidenceTime	Spawner residence time
Dayte[i]	Day of the year of the i*th* count
Fish[i]	Number of fish observed on i*th* count
Redds[i]	Number of redds observed on i*th* count
sFishDispersion	SD of overdispersion for Fish
Site[i]	Site of the i*th* count
sPeakSpawnerArrivalTimingYear	SD of effect of Year on bPeakSpawnerArrivalTiming
sReddsDispersion	SD of overdispersion for Redds
sSpawnDuration	SD of the duration of spawning
sSpawnerAbundanceSiteYear	SD of effect of Site within Year on bSpawnerAbundanceSite
sSpawnerAbundanceYear	SD of effect of Year on bSpawnerAbundanceSite
Year[i]	Year of the i*th* count

Area-Under-The-Curve - Model1

```
model {

 sSpawnDuration ~ dunif(14, 42)

 bPeakSpawnerArrivalTiming ~ dnorm(130, 14^-2)

 bSpawnerResidenceTime ~ dunif(14, 21)
 bSpawnerObserverEfficiency ~ dunif(0.9, 1.1)

 bReddObserverEfficiency ~ dunif(0.9, 1.1)
 bReddResidenceTime <- 35

 bReddPerSpawner ~ dunif(0, 4)

 sPeakSpawnerArrivalTimingYear ~ dunif(0, 28)
 sSpawnerAbundanceYear ~ dunif(0, 2)
 for (i in 1:nYear) {
  bPeakSpawnerArrivalTimingYear[i] ~ dnorm (0, sPeakSpawnerArrivalTimingYear^-2)
  bSpawnerAbundanceYear[i] ~ dnorm (0, sSpawnerAbundanceYear^-2)
 }
```

```
  sSpawnerAbundanceSiteYear ~ dunif (0, 2)
  for (i in 1:nSite) {
    bSpawnerAbundanceSite[i] ~ dnorm (5, 5^-2)
    for (j in 1:nYear) {
      bSpawnerAbundanceSiteYear[i, j] ~ dnorm (0, sSpawnerAbundanceSiteYear^-2)
    }
  }

  sFishDispersion ~ dunif(0, 2)
  sReddDispersion ~ dunif(0, 2)
  for (i in 1:length(Fish)) {
    ePeakSpawnerArrivalTiming[i] <- bPeakSpawnerArrivalTiming +
bPeakSpawnerArrivalTimingYear[Year[i]]

    log(eSpawnerAbundance[i]) <- bSpawnerAbundanceSite[Site[i]] + bSpawnerAbundanceYear[Year[i]] +
bSpawnerAbundanceSiteYear[Site[i], Year[i]]

    eFish[i] <- (pnorm(Dayte[i], ePeakSpawnerArrivalTiming[i], sSpawnDuration^-2) - pnorm(Dayte[i],
ePeakSpawnerArrivalTiming[i] + bSpawnerResidenceTime, sSpawnDuration^-2)) *
eSpawnerAbundance[i] * bSpawnerObserverEfficiency

    eRedds[i] <- (pnorm(Dayte[i], ePeakSpawnerArrivalTiming[i], sSpawnDuration^-2) - pnorm(Dayte[i],
ePeakSpawnerArrivalTiming[i] + bReddResidenceTime, sSpawnDuration^-2)) * eSpawnerAbundance[i] *
bReddPerSpawner * bReddObserverEfficiency

    eFishDispersion[i] ~ dgamma(1 / sFishDispersion^2, 1 / sFishDispersion^2)
    eReddDispersion[i] ~ dgamma(1 / sReddDispersion^2, 1 / sReddDispersion^2)

    Fish[i] ~ dpois(eFish[i] *  eFishDispersion[i])
    Redds[i] ~ dpois(eRedds[i] *  eReddDispersion[i])
  }
}
```

Stock-Recruitment

Variable/Parameter	Description
eRecruits	Expected number of Recruits
k	Maximum Recruits
R0	Maximum Recruits per Stock
Recruits	Number of age-1 individuals the following year
sRecruits	SD of log-normally distributed residual variation in Recruits
Stock	Number of spawners

Stock-Recruitment - Model1

```
model {

  R0 ~ dnorm(2900 * 0.5^5, 50^-2) T(0, )

  k ~ dlnorm(10, 5^-2)

  sRecruits ~ dunif(0, 5)
  for (i in 1:length(Stock)) {
    eRecruits[i] <- R0 * Stock[i] / (1 + Stock[i] * (R0 - 1) / k)
    Recruits[i] ~ dlnorm(log(eRecruits[i]), sRecruits^-2)
  }
}
```

Model Parameters

The posterior distributions for the *fixed* (Kery and Schaub 2011 p. 75) parameters in each model are summarised below.

Area-Under-The-Curve

Parameter	Estimate	Lower	Upper	SD	Error	Significance
bPeakSpawnerArrivalTiming	126.1914	120.9502	131.8695	2.7488	4	0
bReddObserverEfficiency	0.9955	0.9046	1.0934	0.0561	9	0
bReddPerSpawner	0.7661	0.6157	0.9294	0.0851	20	0
bReddResidenceTime	35.0000	35.0000	35.0000	0.0000	0	0
bSpawnerAbundanceSite[1]	7.3473	6.9451	7.7525	0.2086	5	0
bSpawnerAbundanceSite[2]	6.6450	6.2269	7.0652	0.2122	6	0
bSpawnerAbundanceSite[3]	7.8584	7.4406	8.2831	0.2117	5	0
bSpawnerObserverEfficiency	1.0061	0.9060	1.0948	0.0564	9	0
bSpawnerResidenceTime	17.0225	14.1652	20.5962	1.8557	19	0
sFishDispersion	0.7832	0.7241	0.8411	0.0303	7	0
sPeakSpawnerArrivalTimingYear	8.2512	5.3229	13.1978	2.0025	48	0

sReddDispersion	0.2851	0.2589	0.3135	0.0144	10	0
sSpawnDuration	27.8910	26.6355	29.2164	0.6708	5	0
sSpawnerAbundanceSiteYear	0.2206	0.1575	0.3013	0.0373	33	0
sSpawnerAbundanceYear	0.6642	0.4296	1.0110	0.1593	44	0

Rhat	Iterations
1.02	8e+05

Stock-Recruitment

Parameter	Estimate	Lower	Upper	SD	Error	Significance
k	2.350e+04	1.971e+04	2.750e+04	2009.0000	17	0
R0	1.084e+02	3.689e+01	2.012e+02	43.1080	76	0
sRecruits	3.208e-01	2.157e-01	4.815e-01	0.0706	41	0

Rhat	Iterations
1.09	10000