Columbia River Water Use Plan

WLR Monitoring Study No. CLBMON-46 (Year 5)
Lower Columbia River Rainbow Trout Spawning Assessment
Study Period: January to July 2012

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Prepared for:
BC Hydro
Castlegar, BC

January 17, 2013 – Final Report

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WLR Monitoring Study

LOWER COLUMBIA RIVER RAINBOW TROUT SPAWNING ASSESSMENT 2012

CLBMON-46 (Year 5)

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Cover Photo: Aerial view of Norn's Creek Fan during Rainbow Trout spawning enumerations on May 11, 2012.

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EXECUTIVE SUMMARY

Each spring, thousands of Rainbow Trout spawn in the Lower Columbia River (LCR) below Hugh L. Keenleyside Dam (HLK) as well as in the Lower Kootenay River (LKR) below Brilliant Dam. The regulated spring hydrograph prior to 1992 had discharge from HLK Dam decreasing during the March to May period. This resulted in substantial numbers of Rainbow Trout redds being dewatered and possible population level effects. Starting in 1992, BC Hydro began stabilizing the spring discharge releases from HLK to reduce the number of Rainbow Trout redds dewatered. This spring operational regime of stable or increasing flows from April 1- June 30 is referred to as Rainbow Trout Spawning Protection Flows (RTSPF). 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.

The current state of knowledge on Rainbow Trout spawner abundance in the LCR and the LKR with respect to BC Hydro's management questions for CLBMON-46 is provided in the following table.

Management Question	Status
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 dam?	The number of Rainbow Trout spawners and redds has increased since 1999. RTSPF may be responsible for the increase. Proposed experimental flow manipulations may clarify the role of the hydrograph in influencing the Rainbow Trout abundance.
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 dam?	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).
Does the implementation of RTSPFs 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 dam?	Yes. Over all years of analysed data since 1999, the mean stranding rate of redds has been 0.75%. Previous to RTSPF implementation, approximately 50% of the estimated 30 redds on 21 April, 1990 were dewatered and in the 1991 spawning season, 75% of the redds were estimated to be exposed by decreasing flows in June.

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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) is of substantial ecological and recreational importance. Each spring, thousands of fish spawn in the mainstem of the two rivers as well as in the major tributaries of the Columbia (Hildebrand and McKenzie 1995, Heaton and Hildebrand 1997a, 1997b, Hildebrand et al. 2004, Ford and Hildebrand 2007, Baxter 2011, Thorley and Baxter 2011, Arndt 2000, Arndt and Klassen 2004). The Rainbow Trout spawning in these various areas constitute a single genetic population (Taylor 2002) and are managed accordingly.

This population of Rainbow Trout (RB) has been studied since 1999 with various forms of the current spawner assessment program to annually monitor 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. Since 1992 BC Hydro has also monitored RB redds in shallow water areas to identify those at risk of dewatering. If a flow reduction results in dewatering, the redds are excavated and the salvaged eggs are transferred to more suitable gravels (Baxter 2010a, 2010b, 2011, 2012a). The LCR RB have also been studied since 2001 with the Large River Indexing program (e.g., Ford et al. 2012). The main goal of the study programs has been to understand the biology, life history and population trends of the LCR's Rainbow Trout and to assess the effects of operational regimes on these fish.

Prior to 1992, the discharge from HLK typically decreased during the March to May period (Figure 1). This hydrograph resulted in substantial numbers of Rainbow Trout redds being dewatered with potential effects on the abundance of the adult population (Hildebrand and McKenzie 1995). BC Hydro therefore altered the spring operational regime to keep river levels stable or increasing from April 1 – June 30 and agreed to consult with the government agencies regarding the timing and rampdown method from mountain whitefish protection flows in March to Rainbow Trout protection flows in April (Hildebrand and McKenzie 1995, BC Hydro 2005). This operational regime is known as the Rainbow Trout Spawning Protection Flows (RTSPF) and has been implemented every year since 1992 (BC Hydro 2007).

The constant or increasing river levels from April-June for the RTSPF require approximately 1 million acre feet (MAF) 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).

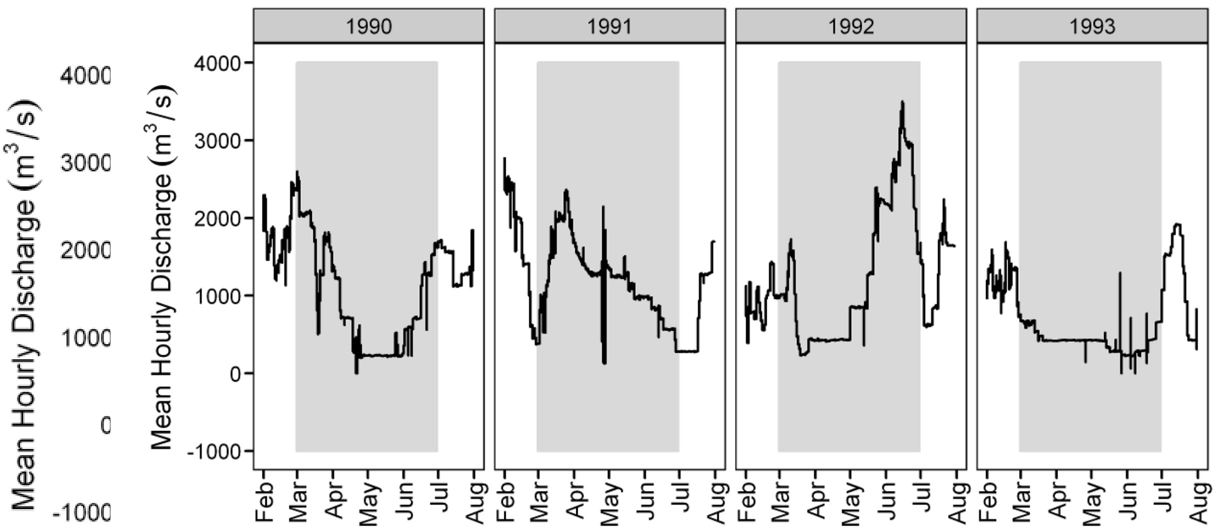

Figure 1. Mean hourly discharge at HLK, February to June, 1990 to 1993. The shaded areas indicate the main window of Rainbow Trout spawning, although spawning can commence as early as January and persist into July.

The following key 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 Terms of Reference 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. Discussions are ongoing (Baxter 2012b) to implement an alternate spring flow regime for assessing its impact on the Rainbow Trout population. This experimental approach has been successful in other systems such as the Colorado (Korman et al. 2011). Another complementary approach, which may be possible upon completion of the River 2D model for the LCR and LKR as part of CLBMON-47 (BC Hydro 2007b), is to combine Habitat Suitability Curves (Rosenfeld 2003) with a substrate map, the 2D model output (Hatten et al. 2009) and a stock-recruitment curve (Rose *et al.* 2001). The combination of these three data streams could produce a Habitat Suitability Stock-Recruitment (HSSR) model.

2.0 METHODS

2.1 Mainstem Spawner and Redd Surveys

The entire mainstem of the Canadian portion of the LCR below HLK and the LKR below BRD (Figure 2) 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. 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. 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 to delineate redds that may require redd salvaging, and to confirm possible new spawning areas seen from the air (Baxter 2011).

In 2011, due to the economic and logistical issues associated with BC Hydro's new helicopter safety regulations, only a single aerial survey was completed and at the request of BC hydro the majority of the monitoring program was changed to focus on spawners and redds in Norn's Creek (Thorley and Baxter 2012). In 2012, the usual survey methods were resumed with six helicopter surveys and weekly boat surveys conducted (Table 1). The number of days between helicopter surveys during the 2012 field season ranged from 8 to 25; the larger time gaps between surveys were due to managing the dynamic nature of helicopter safety regulations. The survey completed on March 23, 2012 was the only survey in the 2012 field season to use a twin engine helicopter and although this allowed a lower altitude survey to occur, the opposite direction rotation of the twin engine rotors disallowed the usual side slipping manoeuvre that enables the observers to obtain a clear view of the redds and spawners. The twin-engine helicopter also had poor window clarity and substantial vibrations from the engine, which negatively affected the ability to observe.

Table 1. Helicopter and boat based redd survey schedule for 2012.

Date	Survey Type(s)
February 11	Boat survey
March 1	Single engine helicopter, Boat survey
March 9	Single engine helicopter, Boat survey
March 23	Twin engine helicopter, Boat survey
March 29	Boat survey
April 5	Single engine helicopter, Boat survey
April 13	Boat survey
April 17	Single engine helicopter, Boat survey
April 27	Boat survey
May 4	Boat survey
May 11	Single engine helicopter, Boat survey

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. Previous years' surveys were conducted between 30 and 50m above ground level. The 2012 surveys were completed at 150m above ground level as per new safety regulations. The exception to this was the twin-engine survey on March 23, 2012, which was completed at the previously used levels of 30 to 50m above ground level.

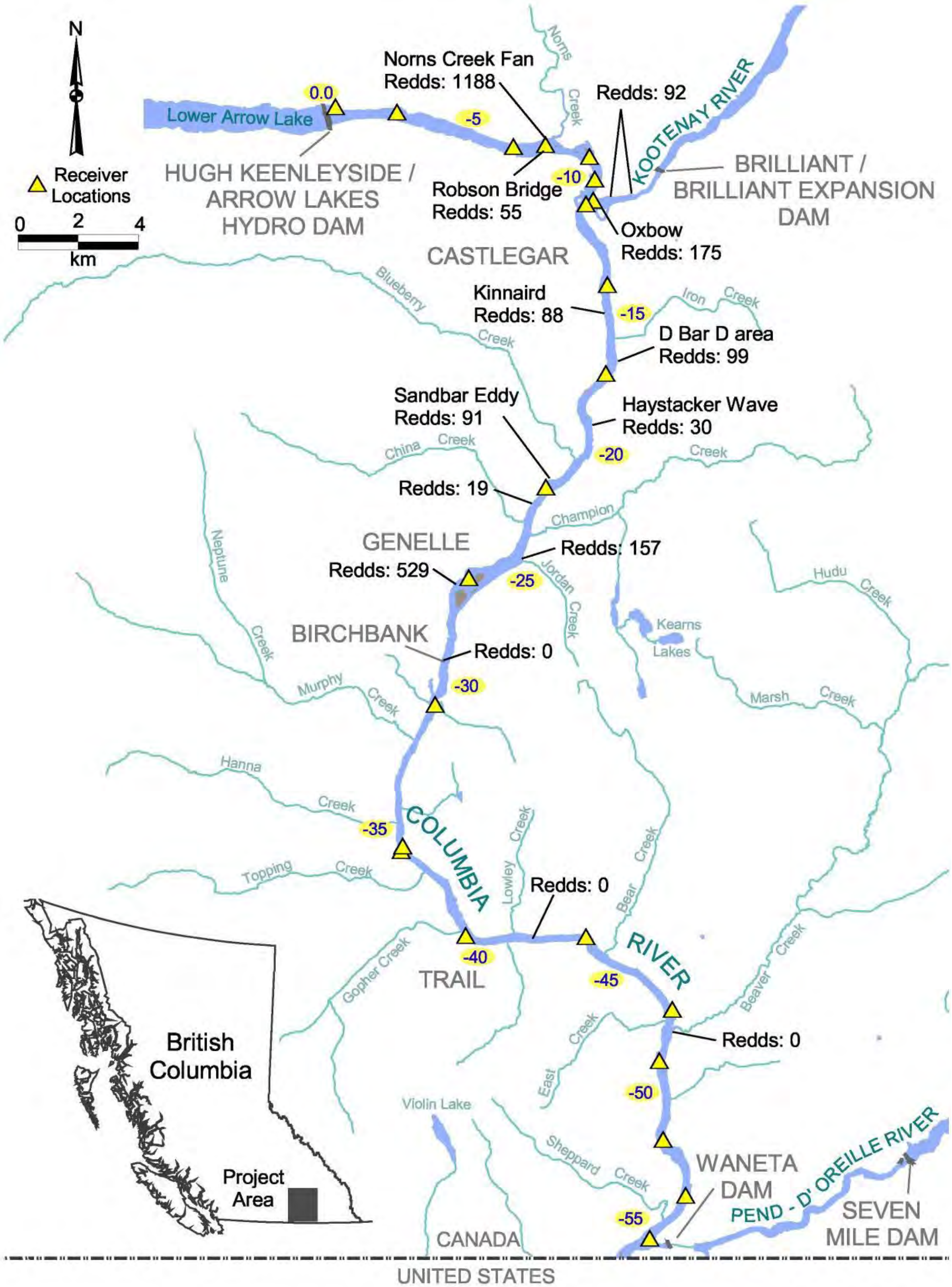

Figure 2. Study area for the Rainbow Trout spawning assessment program within the Lower Columbia and Lower Kootenay Rivers. The yellow circled numbers indicate the river kilometre downstream of HLK dam, and the yellow triangles indicate acoustic receiver locations.

2.2 Spawner and Redd Abundance and Spawn Timing

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 each type of data. The study area was divided into three sections and the abundance estimated for each section. The sections were: the Lower Columbia River above the confluence with the Lower Kootenay River, the Lower Kootenay River below Brilliant dam and the LCR below the confluence with the LKR. The models' variables, parameters, distributions and assumptions are fully described in Appendix B.

Key assumptions of the model include:

- Spawner (or redd) arrival and departure are normally distributed.
- The duration of spawning is constant across years.
- The timing of spawning is affected by the standardized day of the year when the mean weekly water temperature at Norn's Creek Fan first reaches or exceeds 5°C. The day of the year is standardized by subtracting the mean of the days of the year (when the temperature reached or exceed 5°C) and dividing by the standard deviation.
- The redd model does not distinguish between test redds and egg-bearing redds.
- The total number of spawners (or redds) varies by section as a fixed effect and year and section within year as random effects.
- The residence time is between 7 and 14 days for spawners and 15 and 28 days for redds. The spawner residence time was based on previous fish fence data for Norn's creek which had a range of 2-17 days residence for spawners (Hildebrand and Mckenzie 1995) and the redd residence time was based on previous years' field observations on the LCR
- The observer efficiency was assumed to vary between 0.9 and 1.1 for spawners and 1.0 for redds. Values greater than 1.0 correspond to overcounting.
- Simultaneous declines in both spawners and redds are thought to be caused by poor viewing conditions (turbidity) and the affected spawner (or redd) counts are excluded from the analyses.
- The residual variation in the spawner (or redd) counts is described by an overdispersed Poisson distribution (Poisson-gamma distribution).

2.3 Acoustic Telemetry

To collect information on Rainbow Trout spawn timing and residence time, 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 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 to reduce capture stress and were tagged by a Mountain Water Research/Poisson Consulting Ltd. field crew. The same tag type and frequency of tag was utilized to continue to make use of the existing array of 25 acoustic receivers maintained by BC Hydro in the mainstem of the LCR to detect acoustically tagged white sturgeon (*Acipenser transmontanus*). The locations of the 28 acoustic receivers are mapped in Figure 2.

The biometric and capture data for the fish tagged in 2012 are shown in Table ; 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 Rainbow Trout tags drop to an extremely low pulse rate after May 31st of each year and then turn back on to a regular pulse rate at the end of September. The battery of each tag is estimated to last 1701 days (4.6 years).

In order to detect the fish in the Norn's Creek Fan area during the 2012 spawning season one Vemco VR2W receiver was deployed on February 9, 2012 and retrieved on June 2, 2012. Only the fish tagged in 2010 would have been detectable during this time.

Table 2. Acoustic tag identification, date, location of capture, length, weight and visually estimated sex of twenty acoustically tagged Rainbow Trout by river km in the Lower Columbia River

Acoustic Tag	Date Tagged	River	River Location	Fork Length (mm)	Weight (g)	Sex
1143859	July 20, 2012	Lower Columbia	Waldie Island	467	1200	_
1143860	July 20, 2012	Lower Columbia	Waldie Island	411	900	_
1143862	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	546	2000	_
1143863	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	450	1100	M
1143878	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	472	1100	F
1143861	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	440	1100	_
1143877	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	490	1300	_
1143876	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	460	1100	F
1143875	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	404	800	_
1143874	Nov 13, 2012	Lower Columbia	Norn's Creek Fan	430	1000	F
1143873	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow - Left	505	1300	F
1143872	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow - Left	410	800	F
1143871	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	480	1200	M
1143870	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	460	1200	F
1143868	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	480	1300	M
1143867	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	495	1300	F
1143866	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	455	1000	M
1143865	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow - Left	450	1100	F
1143864	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow – Left	430	900	F
1143869	Nov 14, 2012	Lower Kootenay	Kootenay Oxbow - Left	460	1100	F

2.4 Vemco Receiver Range Testing

In order to facilitate interpretation of the Norn's Creek Fan detection data, range testing was conducted on March 10 and May 25, 2012. Two acoustic V16-6x tags with non-random pulse intervals of 60 seconds (s) were used for the range testing. The test tags were attached to a portable mooring system 50 cm above the substrate and placed at 100 m intervals (test zones) from the receiver in all directions. A total of 57 test zones were checked and located by a preloaded digital map on a 16-channel GPS chartplotter. At each test zone, the tags were submerged for a minimum 360 s. During each test interval, the research vessel was moved out of the area and the engine stopped to prevent interference with the acoustic signal. Once all of the test zones were complete the Vemco VR2W was downloaded to obtain the range testing data. The data were then analysed to determine the range detection results.

2.5 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 (K. Scheer and O. Schoenberger, Freshwater Fisheries Society of BC, pers. comm., 2010; Thorley et al. 2012). 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 suggests that surface water temperatures approximate the ATUs experienced by the developing embryos.

2.6 Stock-Recruitment Relationship

There are three sources of data for Rainbow Trout stock recruitment in the LCR: the spawner counts, the redd counts (e.g., Thorley and Baxter 2011) and the boat electrofishing captures (Ford et al. 2012). All three data types are 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 against the previous year's AUC-based redd abundance estimates and the patterns were assessed.

3.0 RESULTS

3.1 Spawner and Redd Abundance and Spawn Timing

The spawner and redd counts from the six aerial surveys conducted in 2012 were each modeled to produce abundance estimates by year (Figure 3 and 5) and annual spawn timing estimates (Figure 4 and 6). The abundance of Rainbow Trout as predicted by spawner surveys for 2012 was 8,503 fish

(95% CI 4,265 -18,006). This is a decrease of approximately 500 fish from the previous year's estimate and 4.7 times higher than the low abundance estimate from 1999 of 1,794 fish (Figure 3). The modeled abundance of Rainbow Trout based on the redd surveys for 2012 was 8,701 fish (95%CI 5,920-13,715). This number of redds was up ~2,500 from the 2011 estimate and 4.3 times higher than the low value from 1999 (Figure 5).

The peak spawn timing as predicted from spawner surveys for 2012 had an estimated mean date of April 28 (95% CI March 8 – June 18) (Figure 4). The peak spawn timing as predicted from redd surveys had an estimated date of May 9 (95% CI March 14 – July 5) (Figure 6). The surface water temperature at Norn's Creek Fan was not a significant predictor of the timing of spawning at the 5% level (the p-value was 0.35 for spawners and 0.28 for redds).

The spawner and redd counts throughout the study area for the 2012 surveys are mapped in Appendix A. The spawner and redd counts for each of the three sections of the study area and their AUC estimates and quality of viewing conditions are plotted in Appendix C.

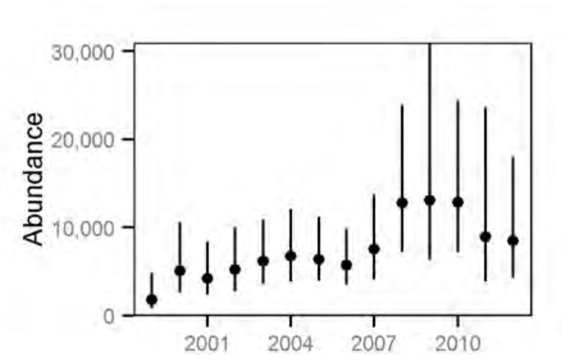

Figure 3. Annual estimates of abundance of Rainbow Trout spawners in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam from 1999-2012 with 95% credibility intervals. The estimates are derived from spawner counts.

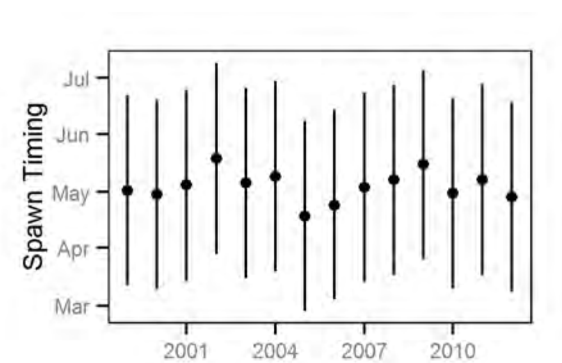

Figure 4. Annual estimates of spawn timing of Rainbow Trout spawners in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam from 1999-2012. The bars indicate the upper and lower bounds for 95% of the spawning. The estimates are derived from spawner counts.

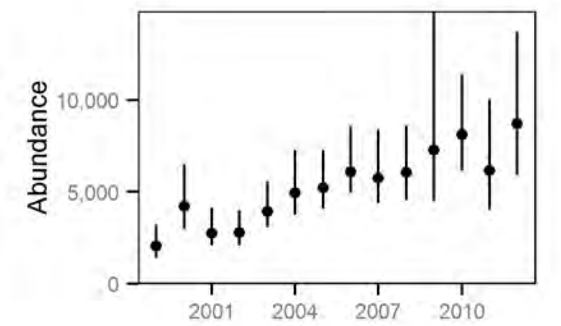

Figure 5. Annual estimates of abundance of Rainbow Trout redds in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam from 1999-2012 with 95% credibility intervals. The estimates are derived from the redd counts.

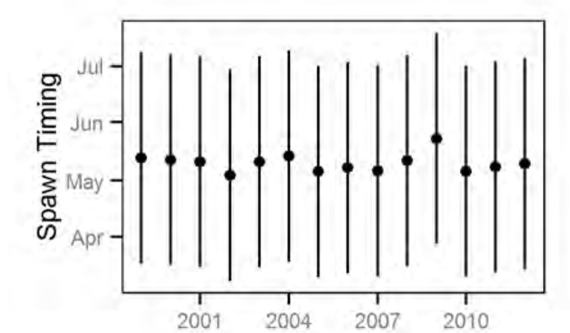

Figure 6. Annual estimates of Rainbow Trout spawn timing in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam from 1999-2012. The bars indicate the upper and lower bounds for 95% of the spawning. The estimates are derived from redd counts.

The slope of the correlation between the annual spawner and redd abundance estimates was 0.67 and the correlation coefficient 0.94 (Figure 7. Redd abundance estimates versus annual spawner abundance for the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012.). A slope of 1 between the two estimates would mean that each female is constructing two redds (assuming a sex ratio of 1:1) so the slope of 0.67 suggests that each female is estimated to be building 1.34 redds, based on the current modeling assumptions. This number of redds per spawner could be skewed by either model or observer error in either the spawner abundance model, the redd abundance model or in both.

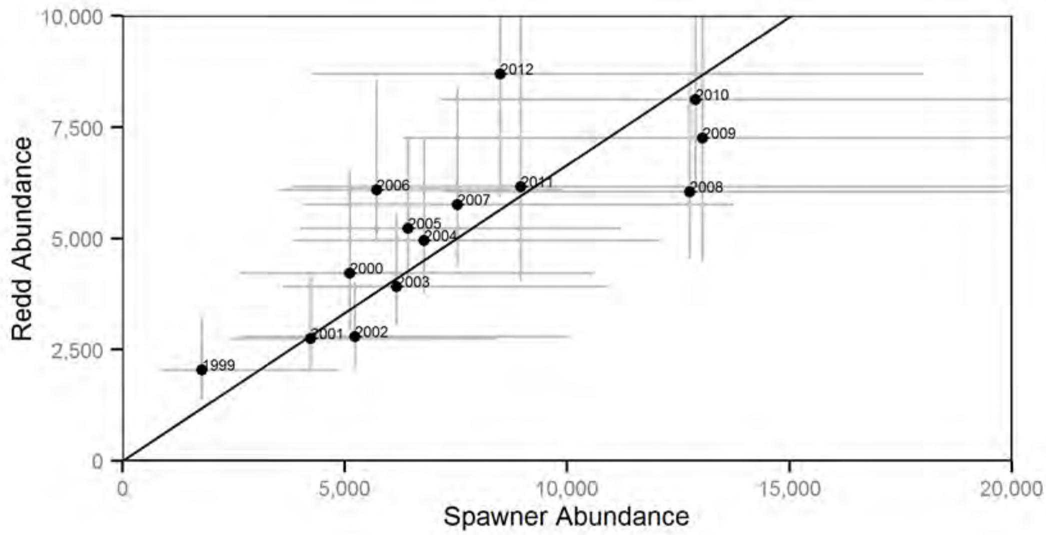

Figure 7. Redd abundance estimates versus annual spawner abundance for the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012. The bars represent 95% credibility intervals.

During the 2012 redd salvaging surveys 25,440 eggs were excavated from thirty-six dewatered redds, twenty-four of which contained eggs. All dewatered redds in the 2012 redd salvaging surveys were located within the Norn's Creek Fan area (Baxter 2012a). When the total number of redds constructed in the whole study area was considered in relation to the number of dewatered redds for each survey year, the mean percentage of redds that dewatered was 0.75% and ranged from near zero to 2% (Figure 8).

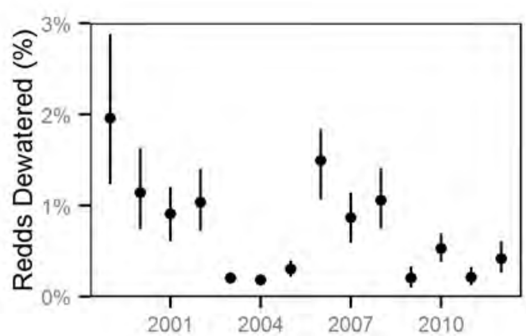

Figure 8. Percentage of redds dewatered in the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam by year from 1999 to 2012. The bars represent 95% credibility intervals.

3.2 Acoustic Telemetry

Of the 16 Rainbow Trout acoustically tagged in 2010, six were detected by the receivers on Norn's Creek Fan in 2011 and three in 2012 (Figure 9). 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 average residence time was 15.9 days when a fish was considered to be resident for one day if it was detected at least once in a 24 period and 13.7 days when the fish was considered to be resident for one day if it was detected at least once during daylight hours in each 24 period. The calculated residence times did not require the fish to be detected in consecutive days but instead represent the total of number of days fish were detected during the spawning period. The 2011 detections differ slightly from those in last year's report (Thorley and Baxter 2012) as the detections in the current report are based on those at a single receiver (in last year's report the detections were from three receivers combined).

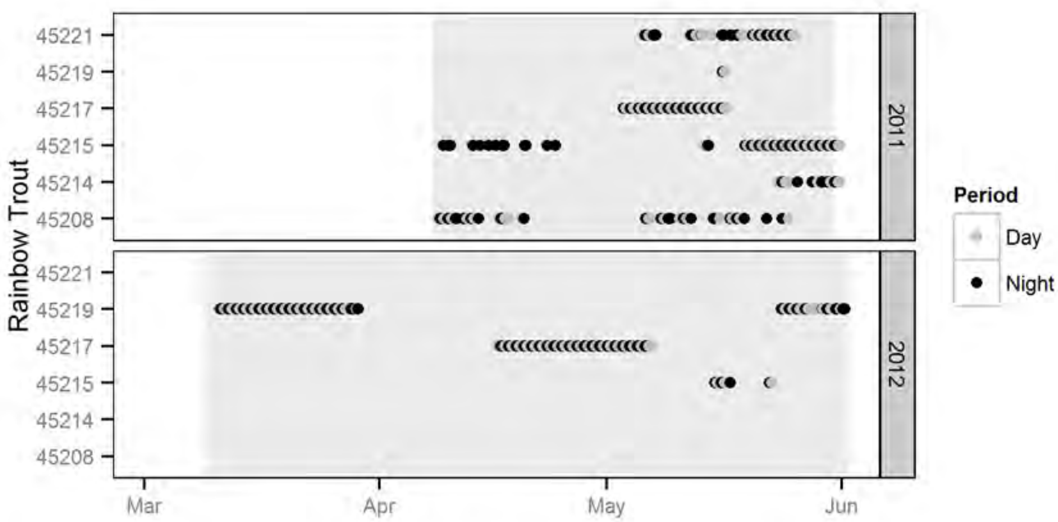

Figure 9. Norn's Creek Fan Rainbow Trout acoustic tag detections. The period of receiver deployment is indicated by the grey area. The Rainbow Trout numbers correspond to acoustic tag codes.

As well as the acoustically tagged Rainbow Trout, the receiver on Norn's Creek Fan also detected 25 white sturgeon. Six of the white sturgeon were present in the area for a substantial span of time during the Rainbow Trout spawning period (Figure 10).

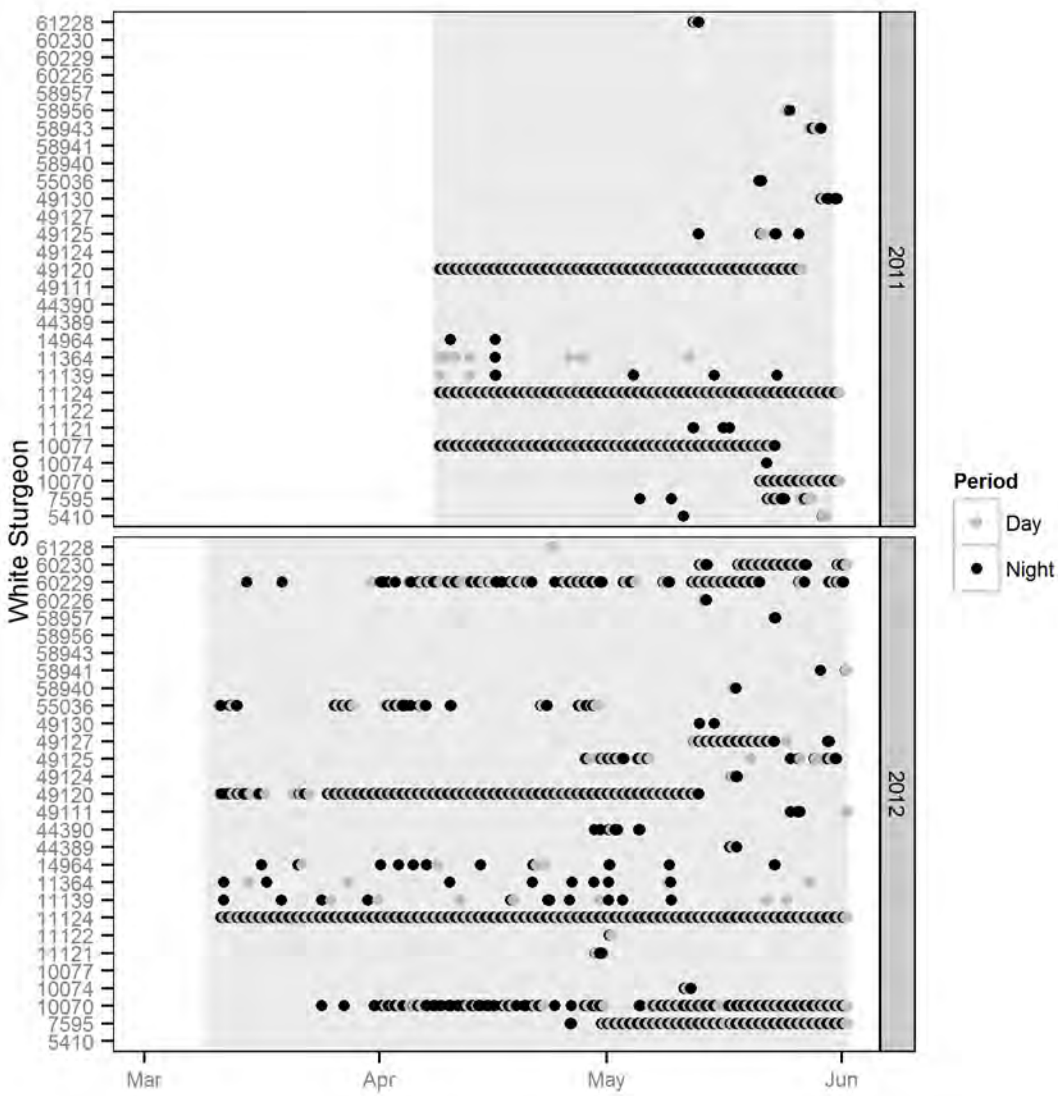

Figure 10. **Norn's Creek Fan white sturgeon trout acoustic tag detections. The period of receiver deployment is indicated by the grey area. The white sturgeon numbers correspond to acoustic tag codes.**

3.3 Vemco Receiver Range Testing

The results of the range-testing, presented graphically in Figure 11, indicate that the location of the receiver covered most of the spawning area at Norns Creek Fan and had a maximum range of 350 m. Of the 57 sites tested only 15 resulted in detections. The receiver detected acoustic tags as far west of the fan as 100 m upstream of the old Robson boat launch and downstream to approximately 50 m up from the Robson highway bridge on the right bank (Figure 11). There were no detections of the test tag on the left bank of the LCR downstream of Norn's Creek, likely due to the interference from the substrate. The range testing detection percentages show approximately a 85% detection success within 100 meters of the receiver (Figure 12), where the majority of spawning occurs. The data collected from the range testing on March 10, 2012 are not reliable due to a faulty tag and receiver issues therefore the range testing conducted on May 25, 2012 was used for this study.

Figure 11. **Norn's Creek Fan acoustic receiver detection range for 2012 deployment period.**

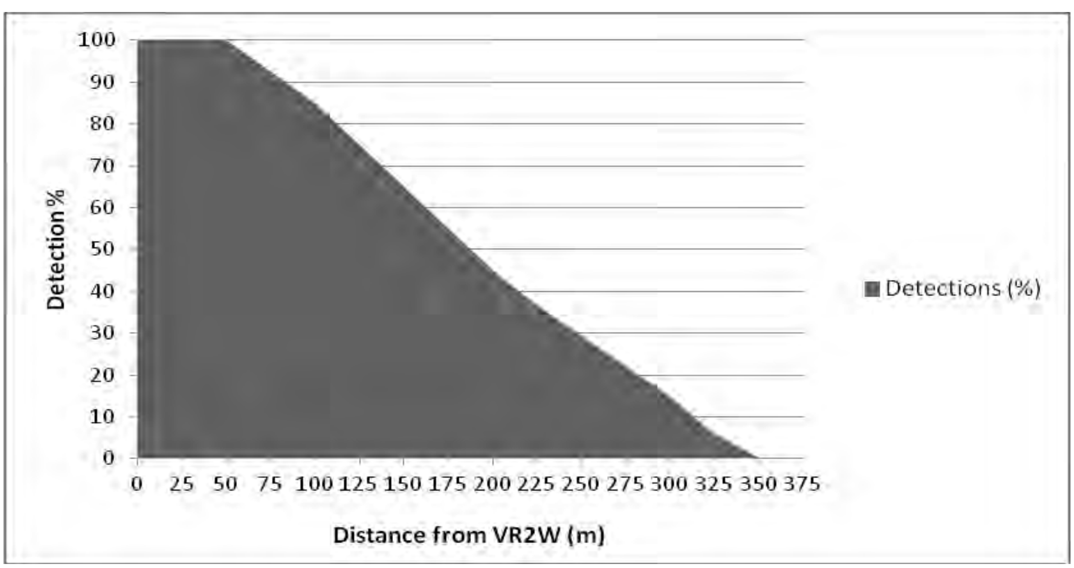

Figure 12. **Norn's Creek Fan Vemco VR2W range testing detection percentages for 2012 deployment period.**

3.4 Fry Emergence Timing

The fry emergence timing estimates incorporate modeled spawn timing and water temperatures for the calculation of the ATUs. The spawn timing results are described above in Section 3.1. The water temperatures used in the fry emergence modelling were recorded at Norn's Creek Fan. This data series is the most extensive for water temperature in the study area, going back to 1999. It was plotted with mean and range of temperatures throughout the spawning and emergence periods to describe trends (Figure 13). 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 (e.g., Thorley et al. 2012) and reaches 17°C in early July, a temperature associated with increased embryonic mortality (Humpesch 1985) (Figure 13).

The water temperatures as recorded at Norn's were then assessed to determine their equivalency to those recorded at Birchbank (LCR River Km ~30). This was done to determine if Norn's temperatures could be used for calculating Rainbow Trout fry emergence timing for the entire study area over the study's duration (Figure 14) as Birchbank did not start recording temperatures until 2005. There is generally strong agreement between the two temperatures with the biggest differences seen in June when Birchbank temperatures tend to be higher on average (Figure 14).

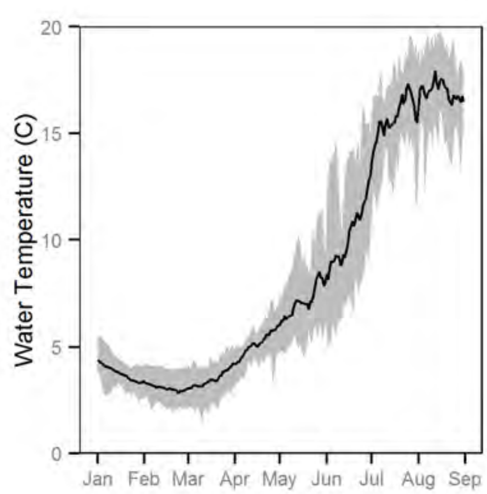

Figure 13. Mean daily surface water temperature at Norn's Creek Fan from January to August for the years 2000 to 2012. The black line indicates the average temperature, while the grey band indicates the range.

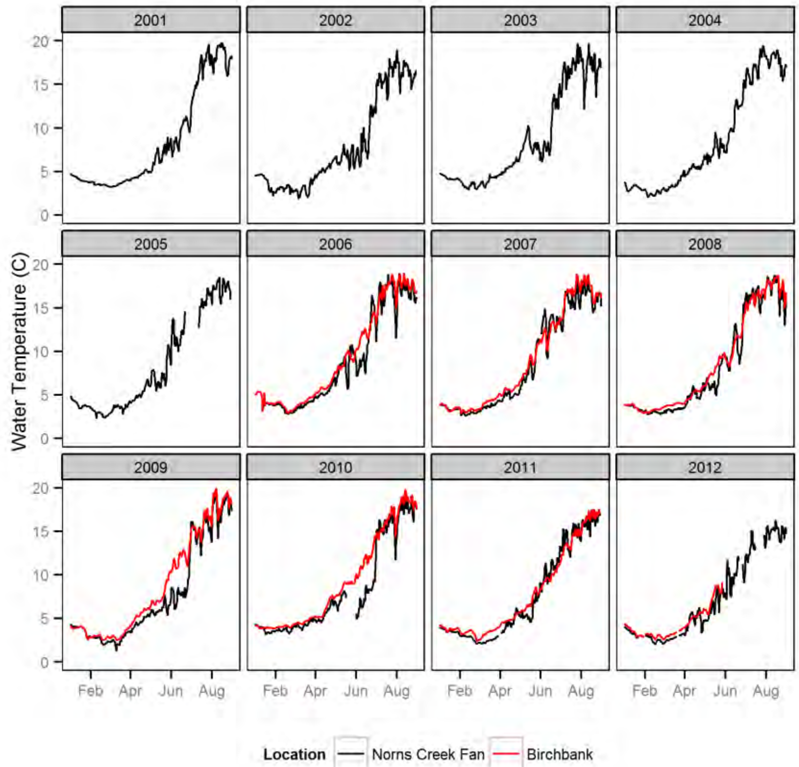

Figure 14. Mean daily surface water temperature at Norn's Creek Fan and Birchbank gauging station from January to August for the years 2001 to 2012.

The peak date of emergence for the 2011 spawn year as predicted from the spawner counts was July 1 (Figure 15). This is approximately two weeks later than the earliest predicted peak emergence date of June 15 from 2005 and seven days earlier than the latest predicted peak emergence date of July 8 from the 2009 and 2002 spawn years. The peak date of emergence for the 2011 spawn year as predicted from the redd counts was also July 1 (Figure 16). The latest predicted spawning date from the redd data was July 11 in the spawn year of 2009 and the earliest date was June 26 from the 2006 spawn year (Figure 16). Missing temperature data in some years did not allow estimates of peak emergence timing and/or bounds for emergence of 95% of the fry (Figure 15, Figure 16).

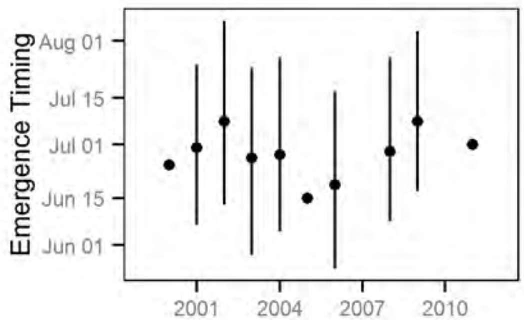

Figure 15. Annual estimates of the timing of emergence of Rainbow Trout fry from 2000 to 2011 in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam from 1999-2012. The bars indicate the upper and lower bounds for emergence of 95% of the fry. The estimates are derived from the spawner counts and surface water temperature at Norn's Creek Fan.

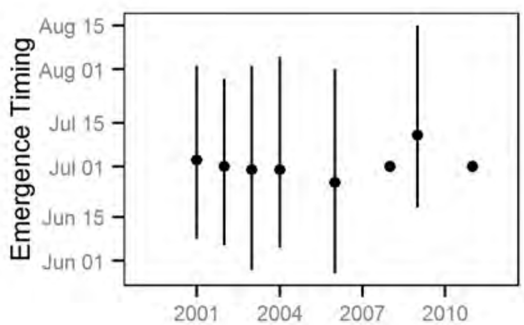

Figure 16. Annual estimates of the timing of emergence of Rainbow Trout fry from 2001 to 2011 in the Lower Columbia River below Hugh L. Keenleyside dam and the Lower Kootenay River below Brilliant Dam. The bars indicate the upper and lower bounds for emergence of 95% of the fry. The estimates are derived from the redd counts and the surface water temperature at Norn's Creek Fan.

3.5 Stock-Recruitment Relationship

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. 2011) has three peak years of age-1 abundance for the 2001, 2006 and 2010 spawn years (Figure 17). The roughly quadrupled number of redds over the 11 years where there are data for all three indices (1999-2010) does not mirror numbers of age-1 recruits (Figure 17). The best recruitment year for age-1 RB to date was in 2001 with the 2000 spawn year, the 2010 spawn year and 2006 spawn year in second, third and fourth places respectively.

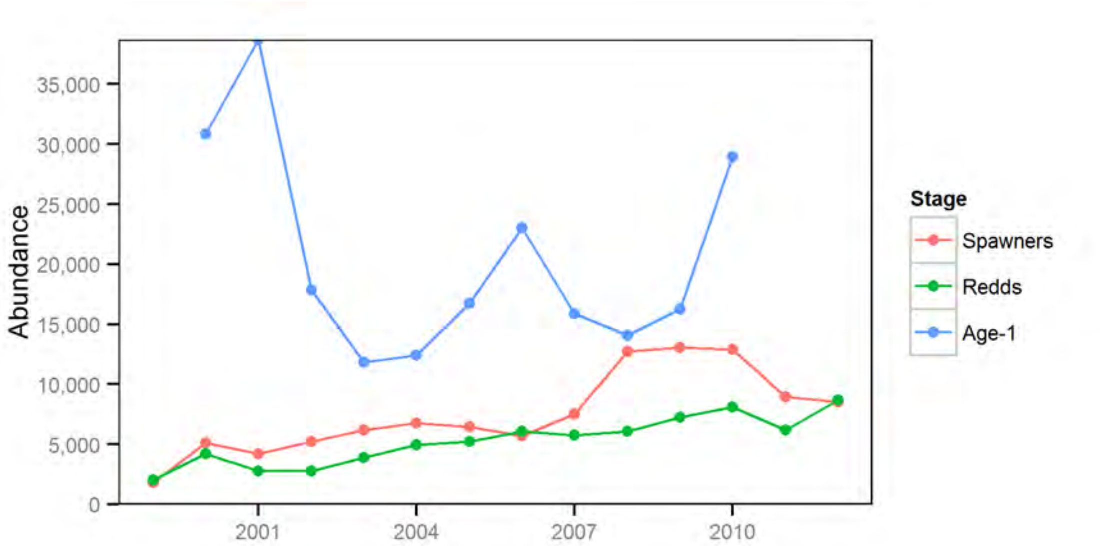

Figure 17. Spawner, redd and subsequent age-1 Rainbow Trout abundance estimates by spawn year for the Lower Columbia River below Hugh L Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012.

The plots of age-1 RB abundance vs. spawner abundance and vs. redd abundance in the study area do not show clear patterns of either completely density independent or completely density dependent stock-recruitment dynamics (Figure 18, Figure 19). Interestingly, the two highest juvenile abundances which resulted from the 2000 and 2001 spawn years (Figure 17) were produced by relatively low spawner abundances (Figure 17). The relationship between age-1 RB and spawners suggests that recruitment of age-1 RB is unaffected as long as a minimum of 5,000 spawners are present in the system (Figure 18).

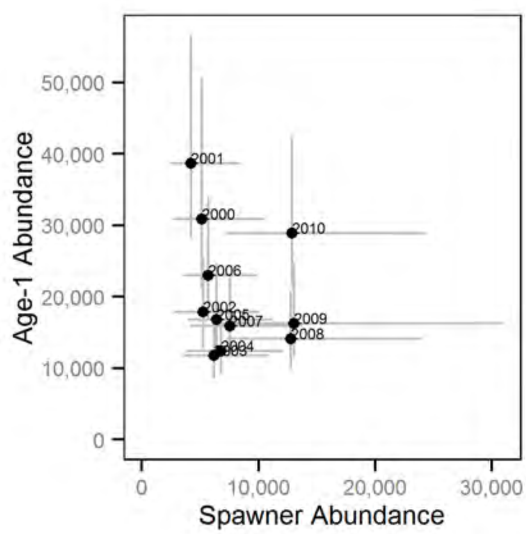

Figure 18. Number of age-1 Rainbow Trout vs. number of spawners the previous year for the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012. The vertical and horizontal bars represent 95% credibility intervals. The years indicate the spawn year.

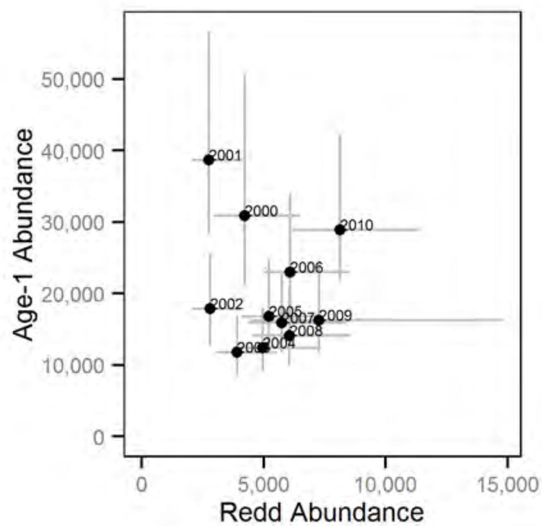

Figure 19. Number of age-1 Rainbow Trout vs. number of redds the previous year for the Lower Columbia River below Hugh L. Keenleyside Dam and the Kootenay River below Brilliant Dam from 1999 to 2012. The vertical and horizontal bars represent 95% credibility intervals.

4.0 DISCUSSION

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 support a quadrupling of RB spawners and redds in the Lower Columbia and Lower Kootenay Rivers since the study program commenced in 1999. However, it is undetermined whether this increase is due to RTSPF, as a number of environmental and biological factors have also changed (e.g., the opening of 26 km of Blueberry Creek for Rainbow Trout spawners (Arndt and Klassen 2004), the fertilization program in Kootenay Lake and Arrow Lakes Reservoir).

The accuracy and magnitude of the redd and spawner 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 7 to 14 days and redd residence time was assumed to be described by a uniform distribution from 15 to 28 days. If this assumed residence time is too high, it will result in an underestimate of the spawner and redd abundance and if it is too low, it will result in an overestimate. It is a similar situation for the assumed observer efficiencies. If they are too high an underestimate will result and the opposite if they are too low. Furthermore, interpretation of the spawner residence time at Norn's Creek Fan is complicated by the fact that fish may spend time at multiple spawning locations throughout the study area which would make the acoustic-tag based residence time estimates too low; furthermore, the detection area may have included deeper holding water in the mainstem LCR which would make the residence time estimates too high. Redds have been observed in depths up to 6m (Hildebrand and McKenzie 1995) and more recently up to 9m (Thorley and Baxter 2011) so the deeper holding areas may or may not contain redds.

It is also important to be aware that the AUC-based estimates exclude fish spawning in tributaries (other than the Lower Kootenay River), at deep-water sites and downstream of the US Border. The current state of knowledge with regard to the numbers of fish spawning at these three different types of habitat 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 twenty acoustically tagged fish from this study year should contribute to our knowledge of adult fish movements.

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, it is proposed that alternative flow scenarios be tested (Baxter 2012b). The proposed study plan which will be discussed at the interim review stage of the WLR programs 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 (Figure 19). It is further proposed that this alternative flow scenario be implemented for three consecutive 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.

An alternate approach to assessing the link between the spring discharge regime and recruitment to the adult population of Rainbow Trout is to combine Habitat Suitability Curves with substrate maps, the output of a two-dimensional hydrodynamic model and a stock recruitment relationship to produce a HSSR model as suggested in Thorley and Baxter (2012). A two-dimensional depth-velocity model is slated for completion on the LCR above the LKR and the LKR and if reliable, it could describe the depths and velocities throughout a section of river which, if combined with a substrate map and HSCs, could be used to predict the amount of habitat and the distribution of spawning (Hatten et al. 2009).

A stock-recruitment curve can be used to model the relationship between the number of eggs surviving to emergence and the number of individuals at a subsequent life-stage (Rose et al. 2001). Due to density-dependent competition such curves typically involve a minimum egg threshold above which there is little to no benefit to the adult population. In order to generate such a curve two time series are required: the number of spawners, which provides a proxy for number of eggs deposited, and the number of individuals at a subsequent life-stage. The current program has been monitoring the number of spawners since 1999 while the indexing program has been monitoring the number of age-1 fish since 2001.

The first analysis of the stock-recruitment relationship between spawners and age-1 fish was conducted by Thorley (2009) and found that the compensatory model was supported more highly than the density independent model. It suggested that the number of eggs being deposited was in excess of the threshold above which a proportion of the eggs might be dewatered with little to no consequences for the abundance adult population. The compensatory model is also suggested by the fact that a reduction in the number of spawners may have little to no effect on recruitment based on the highest recruitment years occurring in the years with the lowest spawner abundance in 2000 and 2001. However, the relationships were not strong and were based on temporally autocorrelated and relatively sparse data. This remains the case in the data with the three additional years. The proposed alternate flow regime that would dewater 25% of the RB redds may generate data that would allow the alternate stock-recruitment hypotheses to be tested more robustly.

4.2 Management Question 2

The second management question concerns the spatial distribution (and associated habitat area) of spawning. As discussed by Thorley & Baxter (2011) the spawner and redd count data indicate that the spatial distribution and habitat area of spawning have increased but only since 2008. As RTSPF have been implemented since 1992 it is unclear why they would be responsible for this increase. A more likely explanation is that as spawner abundance has increased particular areas have become saturated and as a result fish have begun to utilize additional locations.

The date when 5°C is attained in the spring has been predictive of the onset of spawn timing in other systems (Hartman 1969, Thorley et al. 2012) and on average, the water temperatures recorded at Norn's Fan reach 5°C in mid-April (Figure 13). However, the model did not show any significant effect of water temperature on redd or spawn timing.

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. Water temperatures measured on Norn's Creek Fan in 1990-1993 showed rapid decreases of 3-5°C with increases in discharge from HLK dam in the spring-summer period and temperatures exceeding 20°C in the July-August period (Hildebrand and Mckenzie 1995). In more recent years of study, the water temperatures at Norn's Creek Fan show low variability through the early spawning months from January – April and much more variability in May, June and July with potentially lethal temperatures for emerging fry occurring in July and August (Figure 13). By the summer months, water temperatures range between ~17°C and ~19°C. The percentage of rainbow fry that die due to high water temperatures varies with pH, water hardness and the genetic makeup of the population (Kwain 1975, Humpesch 1985, Jobling 1981, Robison et al. 2001). Water temperatures from 15°C to 26.5°C are reported in the literature for mortality of Rainbow Trout with the wide range partly due to reporting of LC_{50} values for some studies and 100% mortality of the test population for other studies, and partly due to the effects of different genetic strains and acclimation regimes (Kwain 1975, Jobling 1981, Humpesch 1985, Robison et al. 2001). Higher water temperatures could exacerbate oxygen limitations by lowering dissolved oxygen levels in the water column while at the same time increasing embryos' oxygen demands through increased metabolic rate. 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 range of emergence timing predicted from the modeling also indicates that some redds with developing eggs may be dewatered at the end of their development window. The discharge from HLK dam increases or stays flat throughout the summer months (Figure 20), but the discharge from BRD decreases over 1000 m^3/s from mid-late June until early August (Figure 21). It is unknown whether all rainbow fry have emerged by that time. 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. Further research specific to this section of the study area including obtaining reliable water temperature data for the LKR during the incubation period and monitoring of egg stages and egg mortality during the summer months would address this data gap.

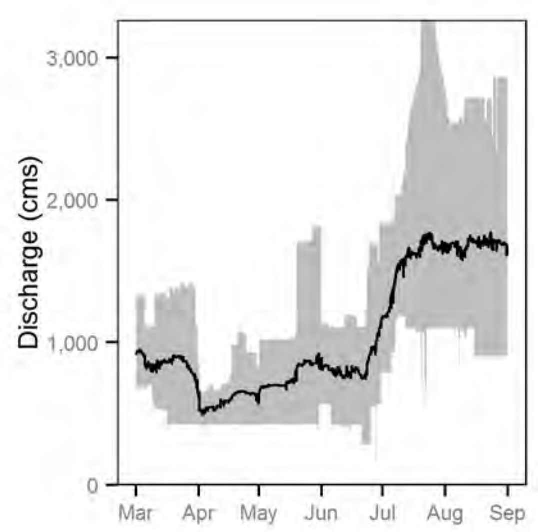

Figure 20. Discharge from HLK dam from 1999-2012. The black line indicates the average discharge, while the grey band indicates the range.

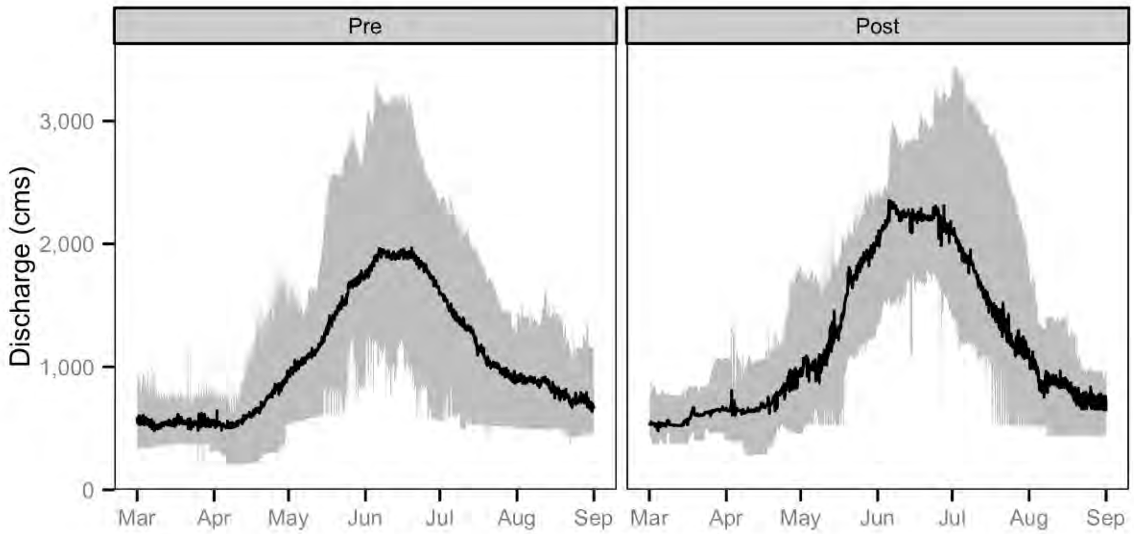

Figure 21. Discharge from Brilliant Dam (BRD) from 1999-2012. The left plot is discharge prior to the time when Brilliant Expansion (BRX) came online in 2007 and the right plot is after BRX entered in operation. The black line indicates the average discharge, while the grey band indicates the range.

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. As a result of the salvage operations commenced in 1999, it is possible to estimate the percent of total egg deposition dewatered on an annual basis and over all years. Using the redd abundance estimates from the hierarchical Bayesian AUC model, the calculations suggest that the mean dewatering rate is 0.75% with the current flow regime. This protects the large majority of the redds from dewatering and is a substantive improvement on the previous dewatering of high numbers of redds in 1990 and 1991 where between 50-75% of the observed redds were exposed by reduced flows (Hildebrand and McKenzie 1995).

5.0 CONCLUSIONS

To date, the program has conclusively answered one of the three management questions (Table). The other two questions have been partially answered by the documenting of the increasing trends in RB abundance and spatial distribution (Table). 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 proposed experimental manipulations in the spring hydrograph are a potentially exciting step towards improving the answers to these management questions (Baxter 2012b) 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 5.

Objectives	Management Questions	Year 5 (2012) 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 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).
	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 1990 and 1991 prior to implementation of RTSPF.

ABBREVIATIONS

Table 4. 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
BRX	Brilliant Expansion Project
BIR	Birchbank Gauging Station
BRD	Brilliant Dam
HLK	Hugh L. Keenleyside Dam
HSSR	Habitat Suitability Stock Recruitment
HSC	Habitat Suitability Curve
KHz	Kilohertz Frequency
LC_{50}	Lethal Concentration that kills 50% of the test animals
LCR	Lower Columbia River
LDR	Lower Duncan River
LKR	Lower Kootenay River
MAF	Million Acre Feet
PIT	Passive Integrated Transponder
s	seconds
SCUBA	Self Contained Underwater Breathing Apparatus
RB	Rainbow Trout
ROV	Remote Operated Vehicle
RTSPF	Rainbow Trout Spawning Protection Flows
TOR	Terms of Reference
WLRTOR	Water Licence Requirements Terms of Reference
WUPWLR	Water Use Plan Water Licence Requirements
WUP	Water Use Plan

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APPENDIX A

2012 Spawner and Redd Count Maps

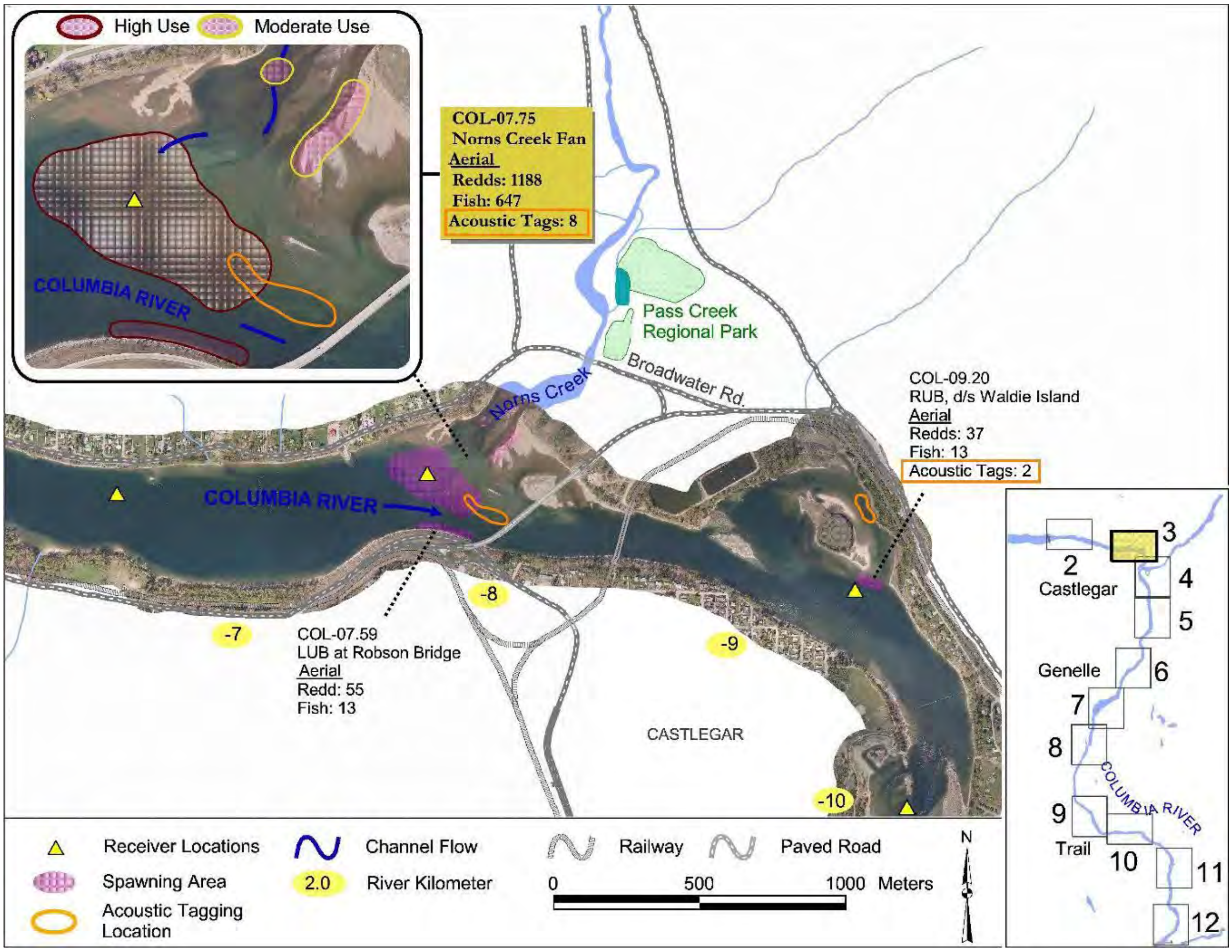

Figure A1. **Spawner and redd counts in Norn's Fan Area in 2012.**

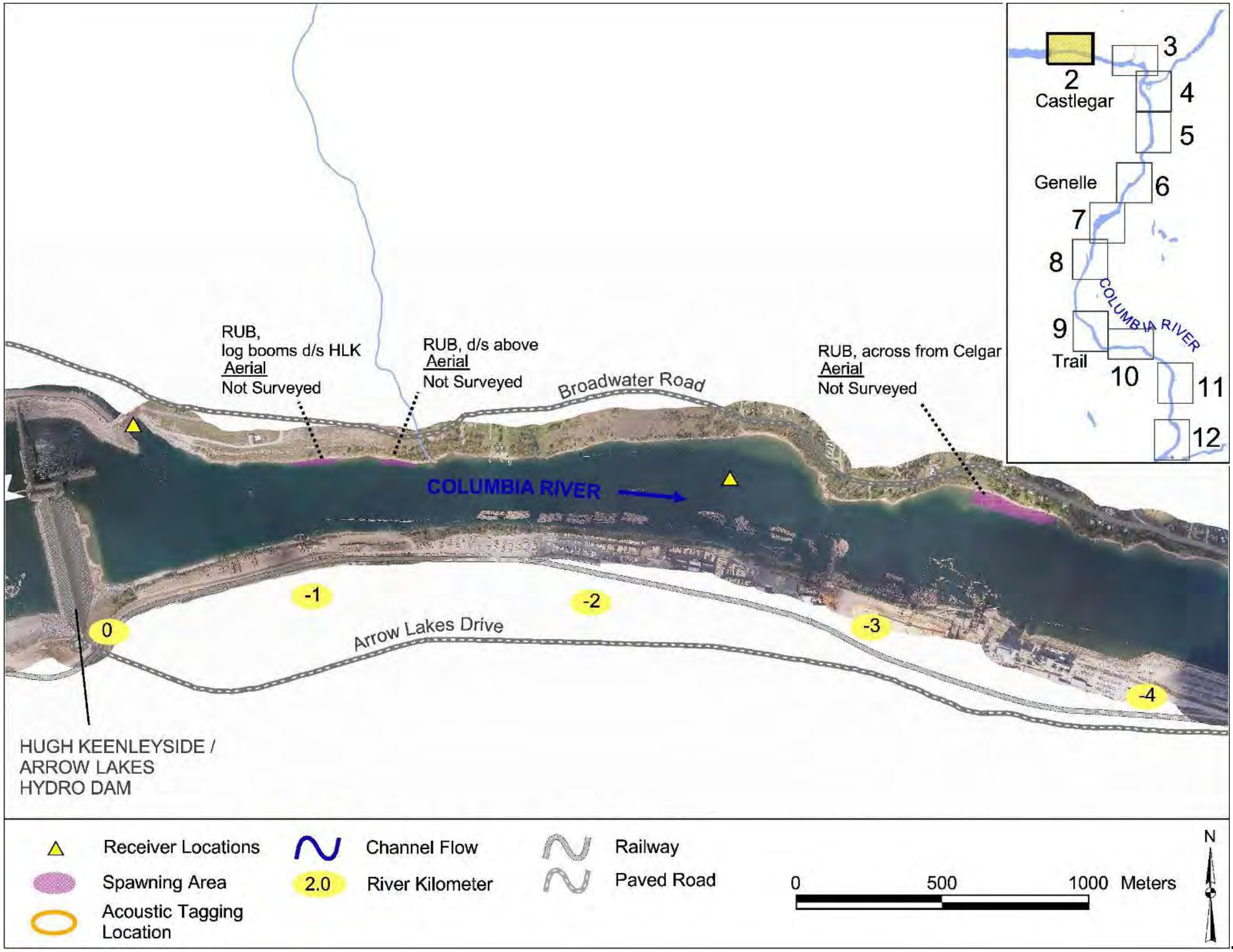

Figure A2. **Spawner and redd counts by location in the HLK Dam area in 2012.**

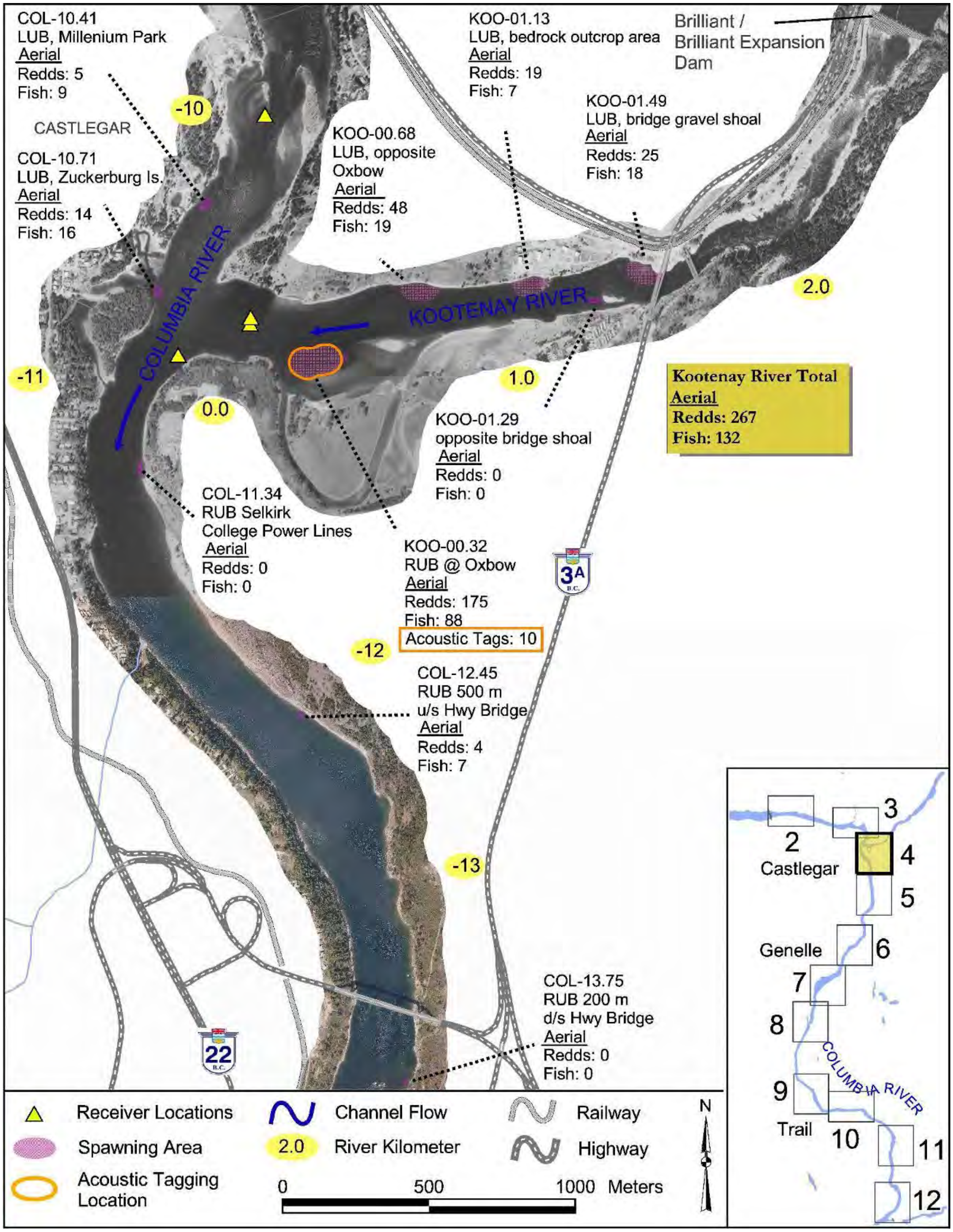

Figure A3. **Spawner and redd counts by location in the Kootenay-Columbia confluence area in 2012.**

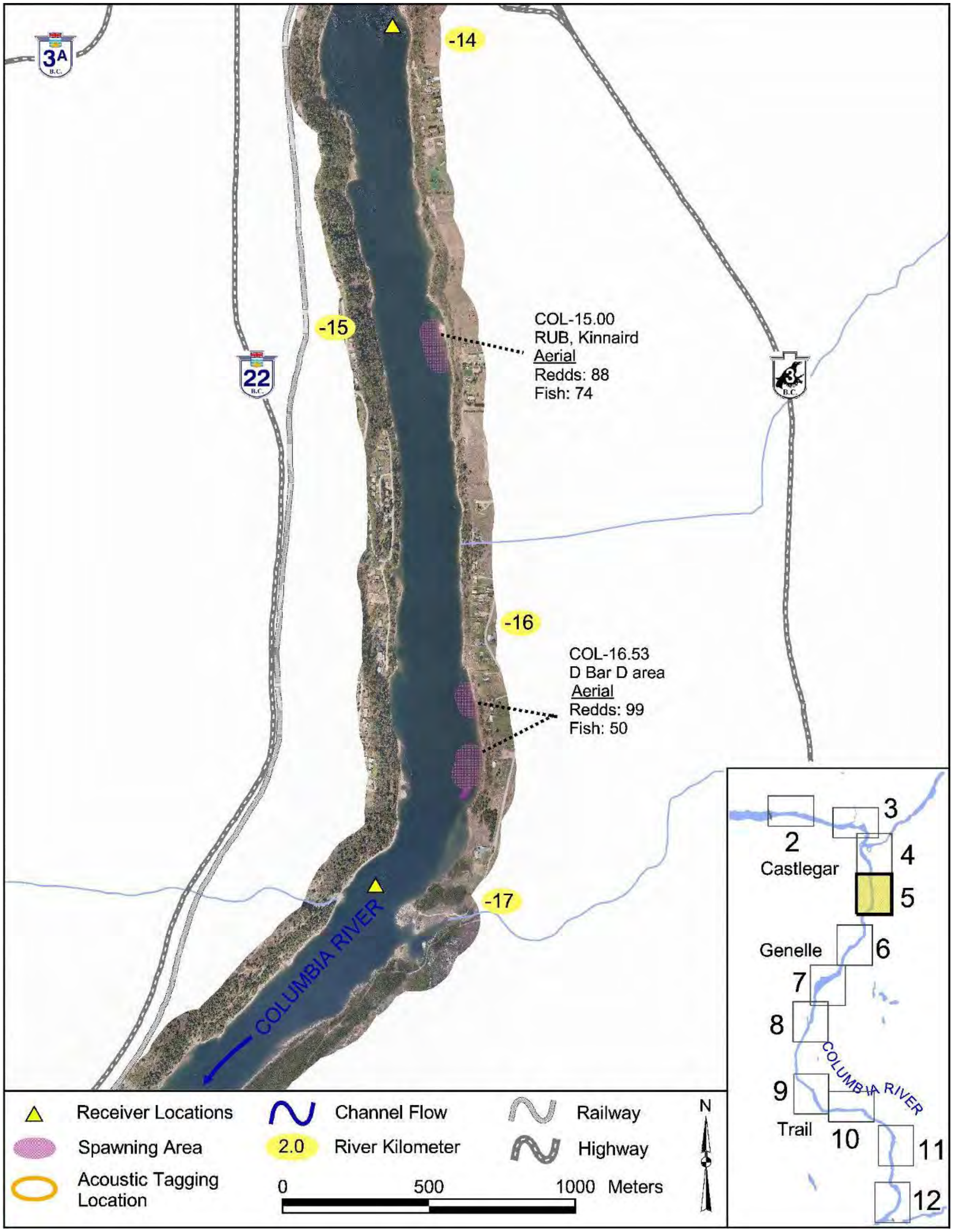

Figure A4. **Spawner and redd counts by location in the D-Bar-D area in 2012.**

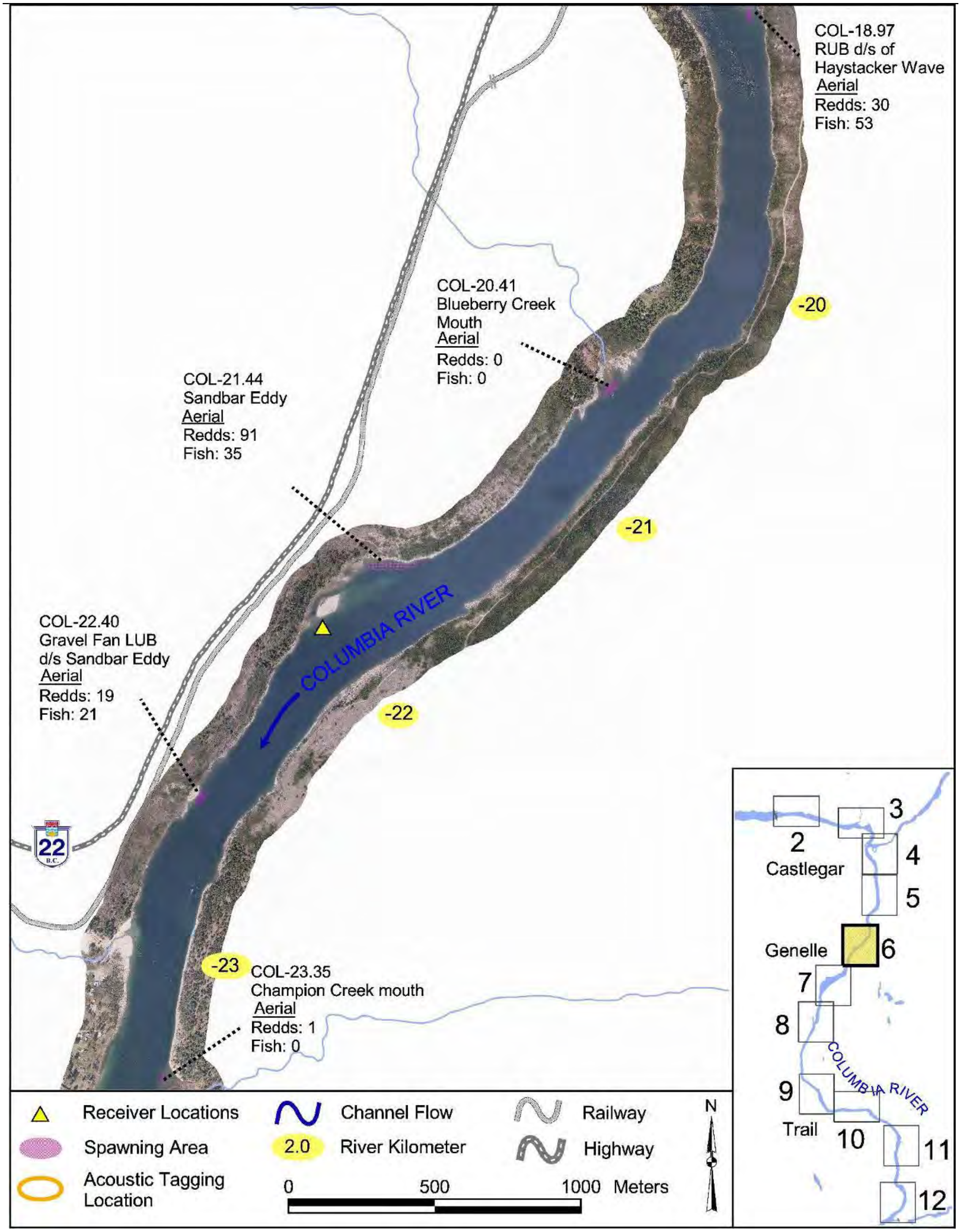

Figure A5. **Spawner and redd counts by location in the Sandbar Eddy area in 2012.**

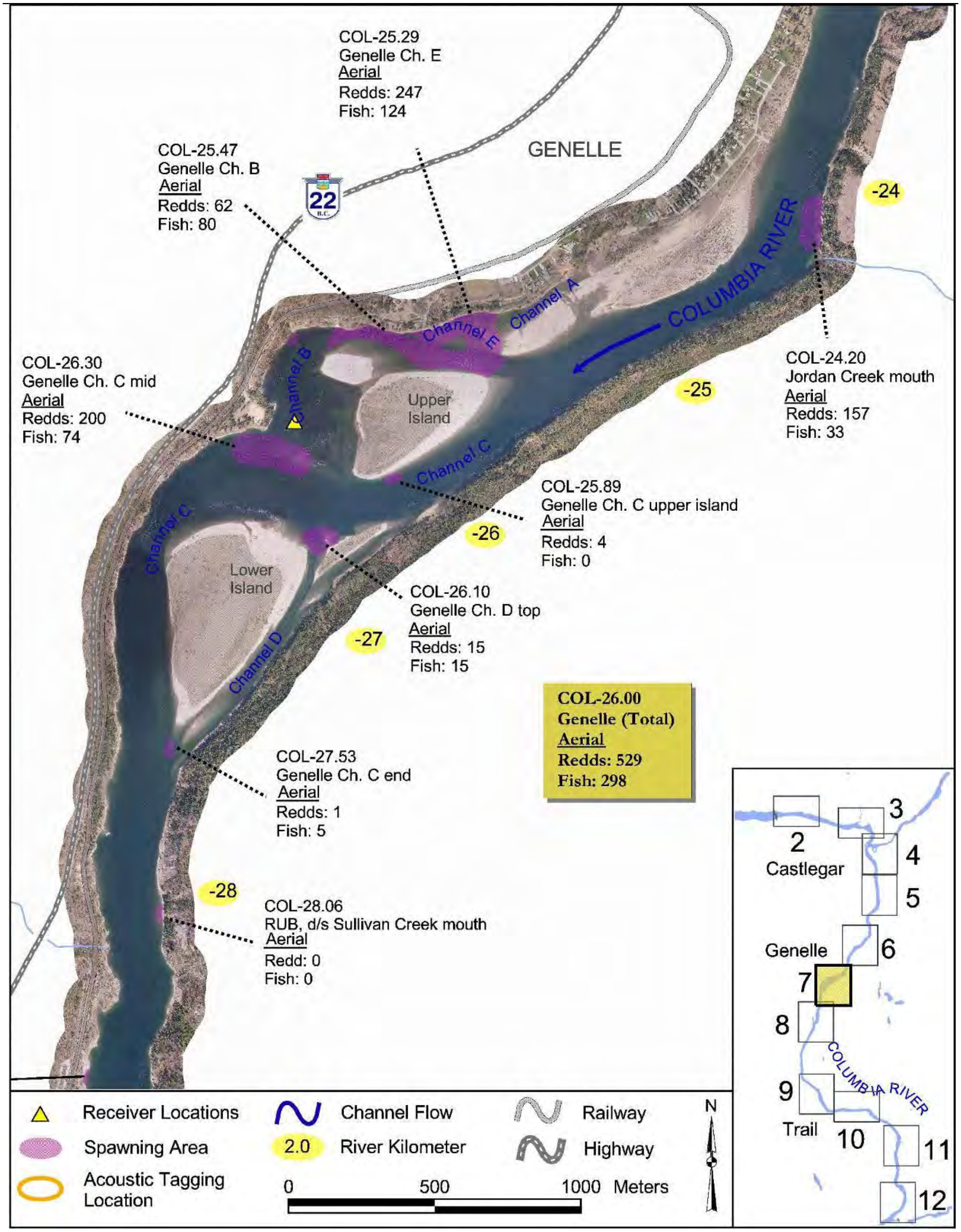

Figure A6. Spawner and redd counts by location in the Genelle area in 2012.

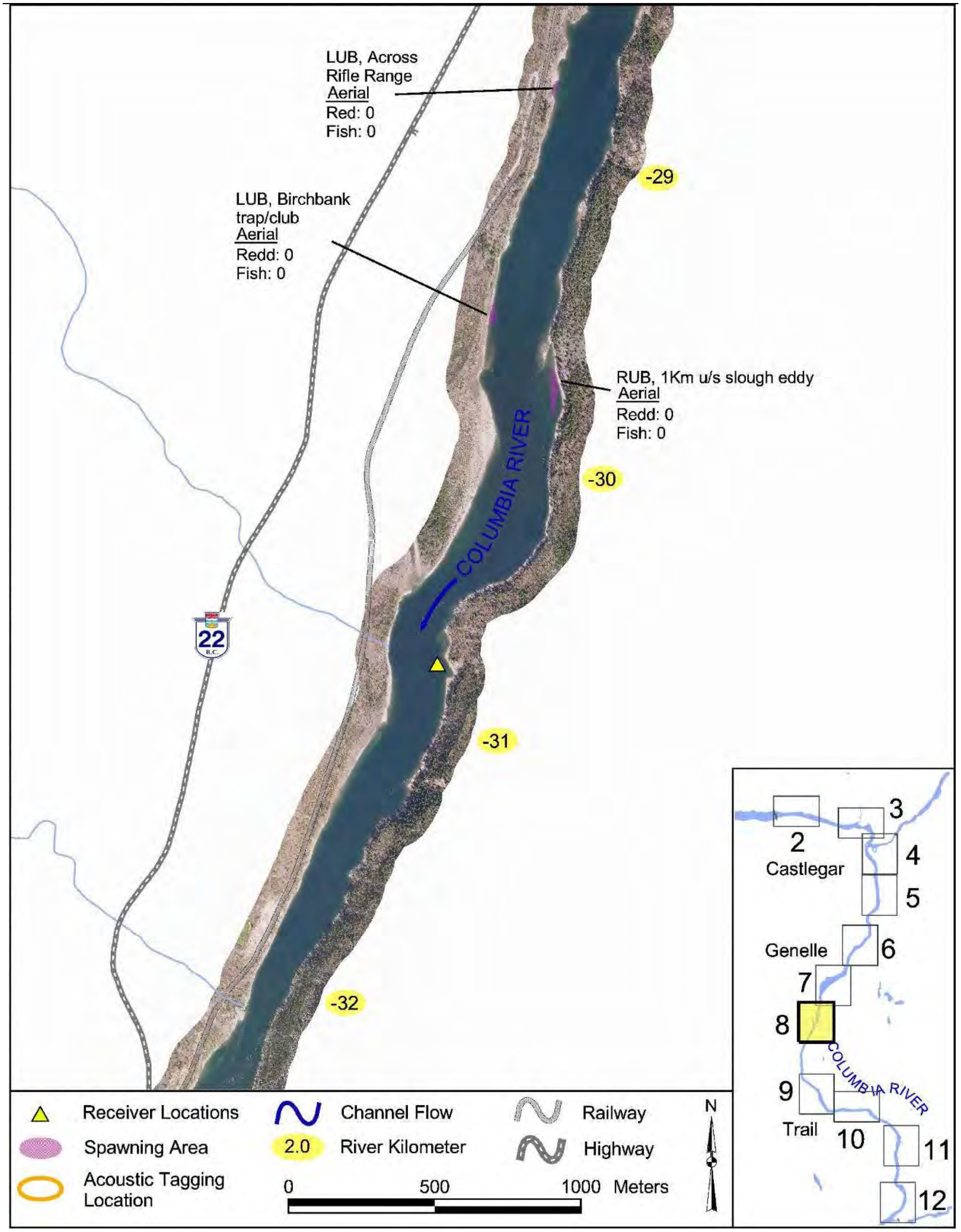

Figure A7. **Spawner and redd counts by location in the Birchbank area in 2012.**

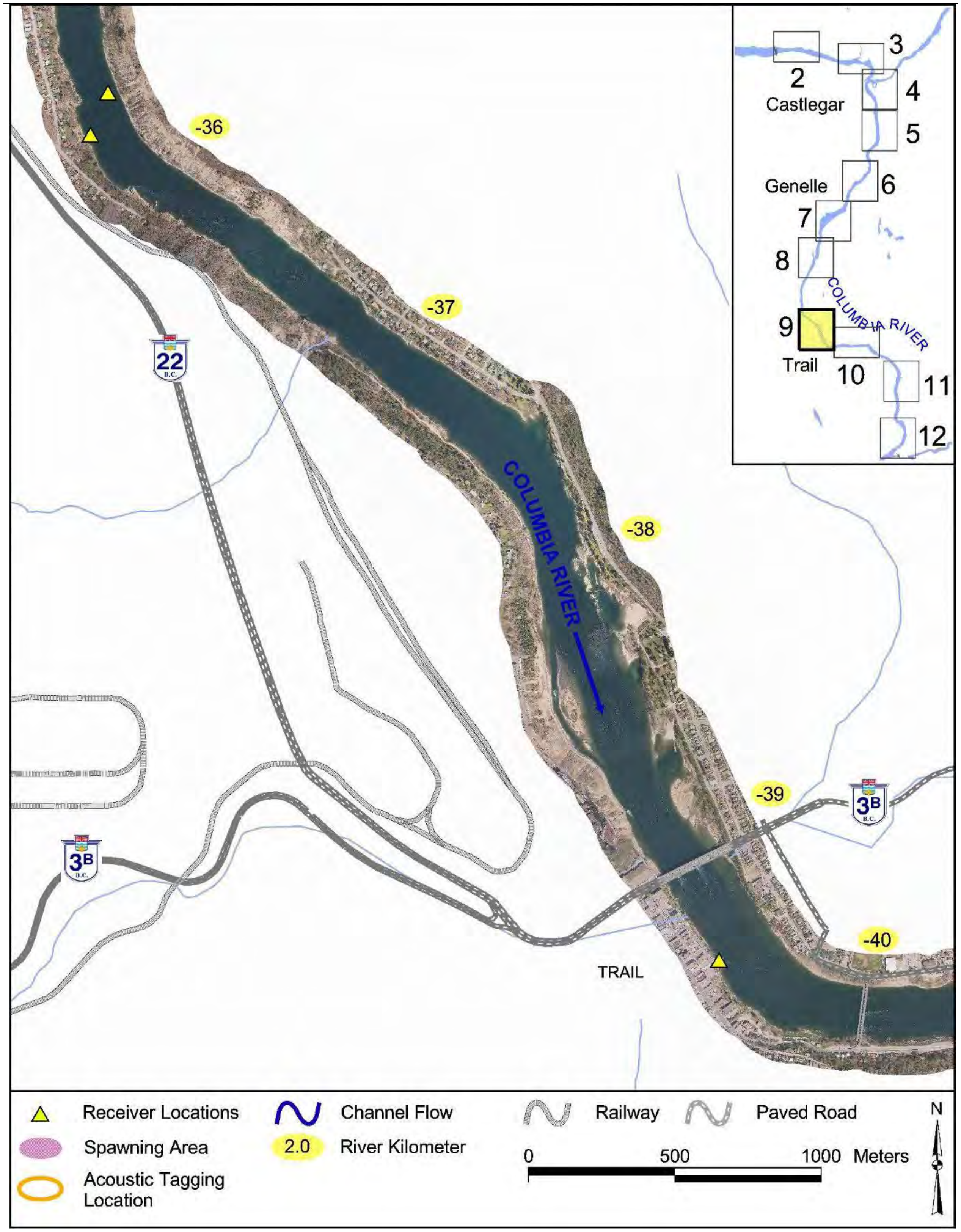

Figure A8. **Spawner and redd counts by location in the Trail area in 2012.**

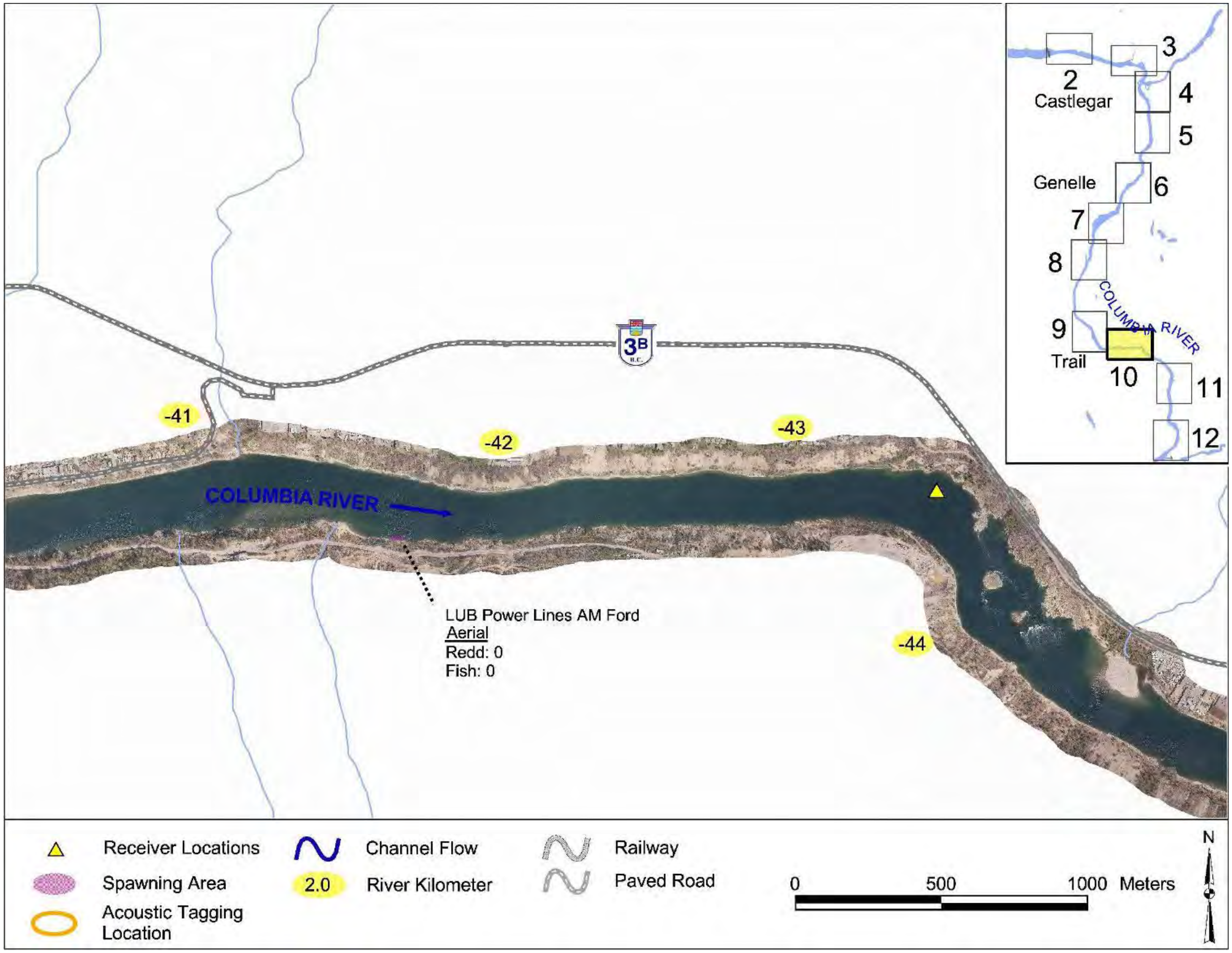

Figure A9. Spawner and redd counts by location in the AM Ford area in 2012.

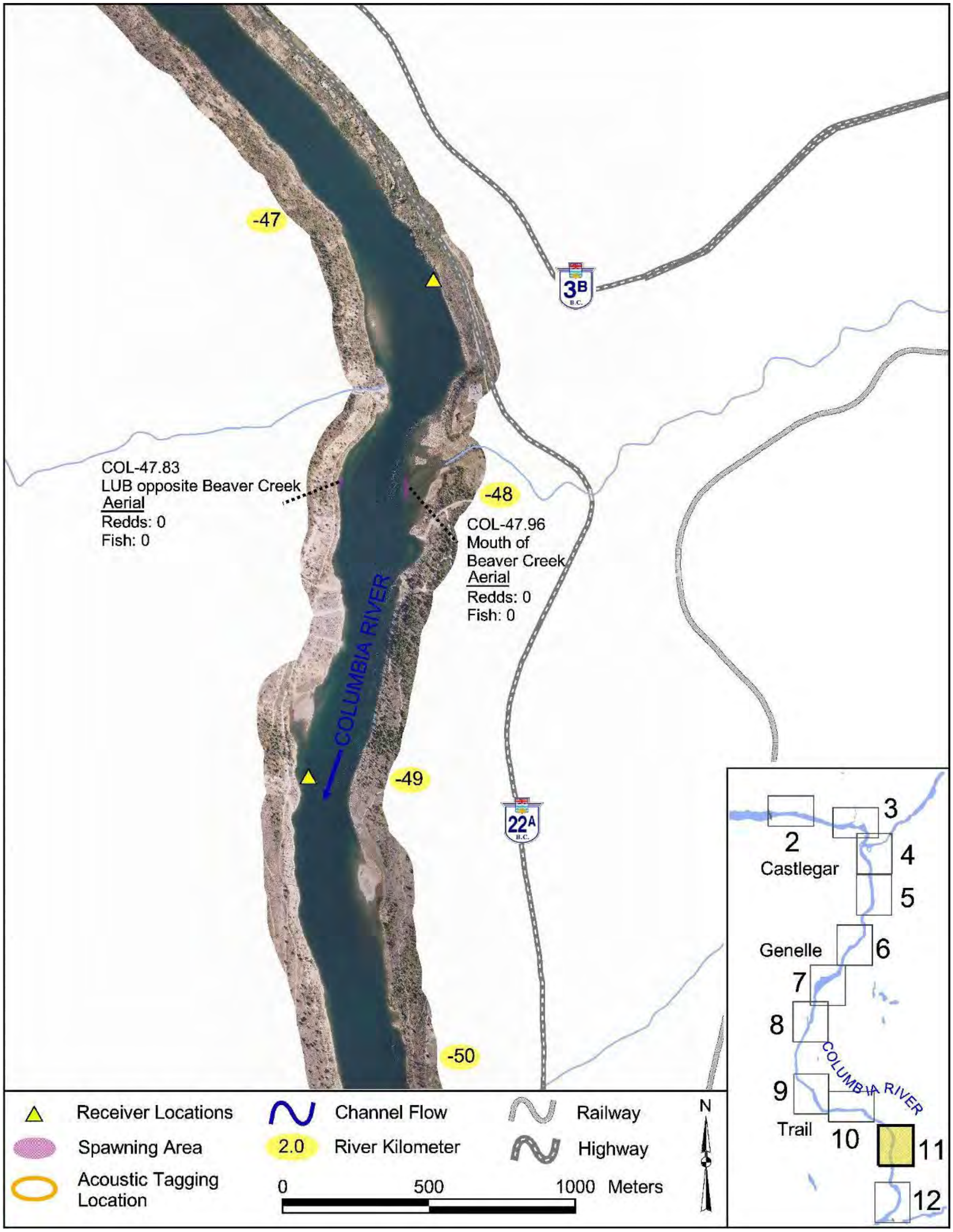

Figure A10. **Spawner and redd counts by location in the Beaver Creek area in 2012.**

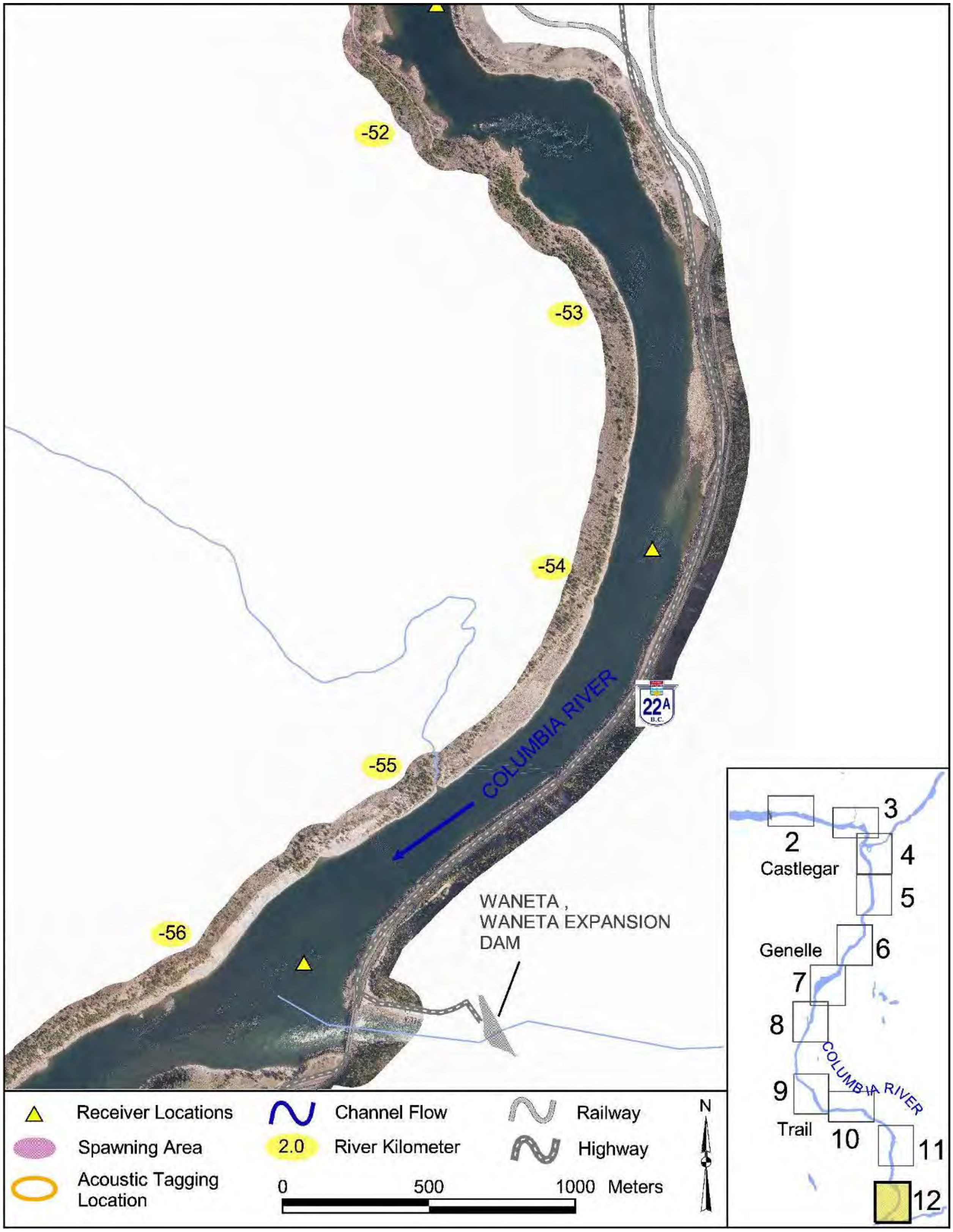

Figure A11. Spawner and redd counts by location in the Waneta Dam area in 2012.

APPENDIX B

2012 Bayesian Analyses Descriptions

Bayesian Analyses

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17 January 2012

1 General Approach

Bayesian models were fitted to the data using the software packages R 2.15.2[9] and JAGS 3.3.0[7] which interfaced with each other via the rjags R package. In general the models 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[3, 5, 4]. Where relevant, the statistical significance of particular parameters was calculated using two-sided Bayesian p-values[1, 6].

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

2 JAGS Distributions, Functions and Operators

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

JAGS Distribution	Description
dbern(p)	Bernoulli distribution
dgamma(a, b)	Gamma 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)	Natural logarithm of x
phi(x)	Standard normal cumulative distribution function
sum(x)	Sum of values in x
x[1:n]	Subset of first n values in x
x^y	Power where x is raised to the power of y

3 JAGS Models

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

3.1 Spawn Count

3.1.1 Variables and Parameters

Variable/Parameter	Description
bAbundance[sc, yr]	Abundance at the scth section in the yrth year
bAbundanceSection[sc]	Intercept for abundance in the scth section
bAbundanceSectionYear[sc, yr]	Effect of the scth section within the yrth year on abundance
bAbundanceYear[yr]	Effect of the yrth year on abundance
bObserverEfficiency	Observer efficiency as a proportion
bPeakTiming	Mean timing of peak spawning
bPeakTimingTemperature	Effect standardised temperature-based predictor on peak timing
bPeakTimingYear[yr]	Effect of the yrth year on peak spawn timing
bResidenceTime	Individual residence time in days
bRho	Overdispersion parameter
bTemperature	Mean of the standardised temperature-based predictor
Count[i]	The ith count
Dayte[i]	Day of the year of the ith count
dError[i]	Expected overdispersion in the ith count
eAbundance[i]	Expected abundance for the ith count
eCount[i]	Expected ith count
ePeakTiming[i]	Expected timing of peak spawning for the ith count
nrow	Number of counts
nSection	Number of sections
nYear	Number of years
sAbundanceSectionYear	SD of the effect of section within year on abundance
sAbundanceYear	SD of the effect of year on abundance
Section[i]	The section of the ith count
sPeakTimingYear	SD of the effect of year on peak spawn timing
sSpawnDuration	SD of the duration of spawning
sTemperature	SD of the standardised temperature-based predictor
Temperature	Standardised temperature-based predictor
Year[i]	The year of the ith count

3.1.2 Model Code

```
model {
  sSpawnDuration ~ dunif(0, 42)

  sPeakTimingYear ~ dunif(0, 42)
  bPeakTiming ~ dnorm(130, 35)

  bResidenceTime ~ dunif(15,28) # redds # ~ dunif(7,14) fish
  bObserverEfficiency <- 1 # redds # ~ dunif(0.9,1.1) fish
  bRho ~ dgamma(0.1, 0.1)

  sAbundanceYear ~ dunif(0, 5)
  sAbundanceSectionYear ~ dunif (0, 5)

  sTemperature ~ dunif(0, 2)
  bTemperature ~ dnorm(0, 1)
```

```
  bPeakTimingTemperature ~ dnorm (0, 35)

  for (yr in 1:nYear) {
    bPeakTimingYear[yr] ~ dnorm (0, sPeakTimingYear^-2)
    bAbundanceYear[yr] ~ dnorm (0, sAbundanceYear^-2)
  }
  for (sc in 1:nSection) {
    bAbundanceSection[sc] ~ dunif(0, 10)
    for (yr in 1:nYear) {
      bAbundanceSectionYear[sc, yr] ~ dnorm (0, sAbundanceSectionYear^-2)
      log(bAbundance[sc, yr]) <- bAbundanceSection[sc] + bAbundanceYear[yr]
        + bAbundanceSectionYear[sc, yr]
    }
  }

  for (i in 1:nrow) {
    Temperature[i] ~ dnorm(bTemperature, sTemperature^-2)
    ePeakTiming[i] <- bPeakTiming + bPeakTimingTemperature * Temperature[i]
      + bPeakTimingYear[Year[i]]
    eAbundance[i] <- (phi((Dayte[i] - ePeakTiming[i])/sSpawnDuration)
      - phi((Dayte[i] - ePeakTiming[i] - bResidenceTime)/sSpawnDuration))
      * bAbundance[Section[i], Year[i]]
    dError[i] ~ dgamma(bRho, bRho)
    eCount[i] <- eAbundance[i] * bObserverEfficiency
    Count[i] ~ dpois (eCount[i] * dError[i])
  }
}
```

References

[1] N. Bochkina and S. Richardson. Tail posterior probabilities for inference in pairwise and multiclass gene expression data. *Biometrics*, 63:1117–1125, 2007.

[2] M. J. Bradford, J. Korman, and P. S. Higgins. Using confidence intervals to estimate the response of salmon populations (oncorhynchus spp.) to experimental habitat alterations. *Canadian Journal of Fisheries and Aquatic Sciences*, 62:2716–2726., 2005.

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

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

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

[6] Y. Lin, S. Lipsitz, D. Sinha, A. A. Gawande, S. E. Regenbogen, and C. C. Greenburg. Using bayesian p-values in a 2 x 2 table of matches pairs with incompletely classified data. *Journal of the Royal Statistical Society Series C*, 58:237–246, 2009.

[7] 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.

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

[9] 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.

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

APPENDIX C

2012 Spawner and Redd Counts with AUC Estimates

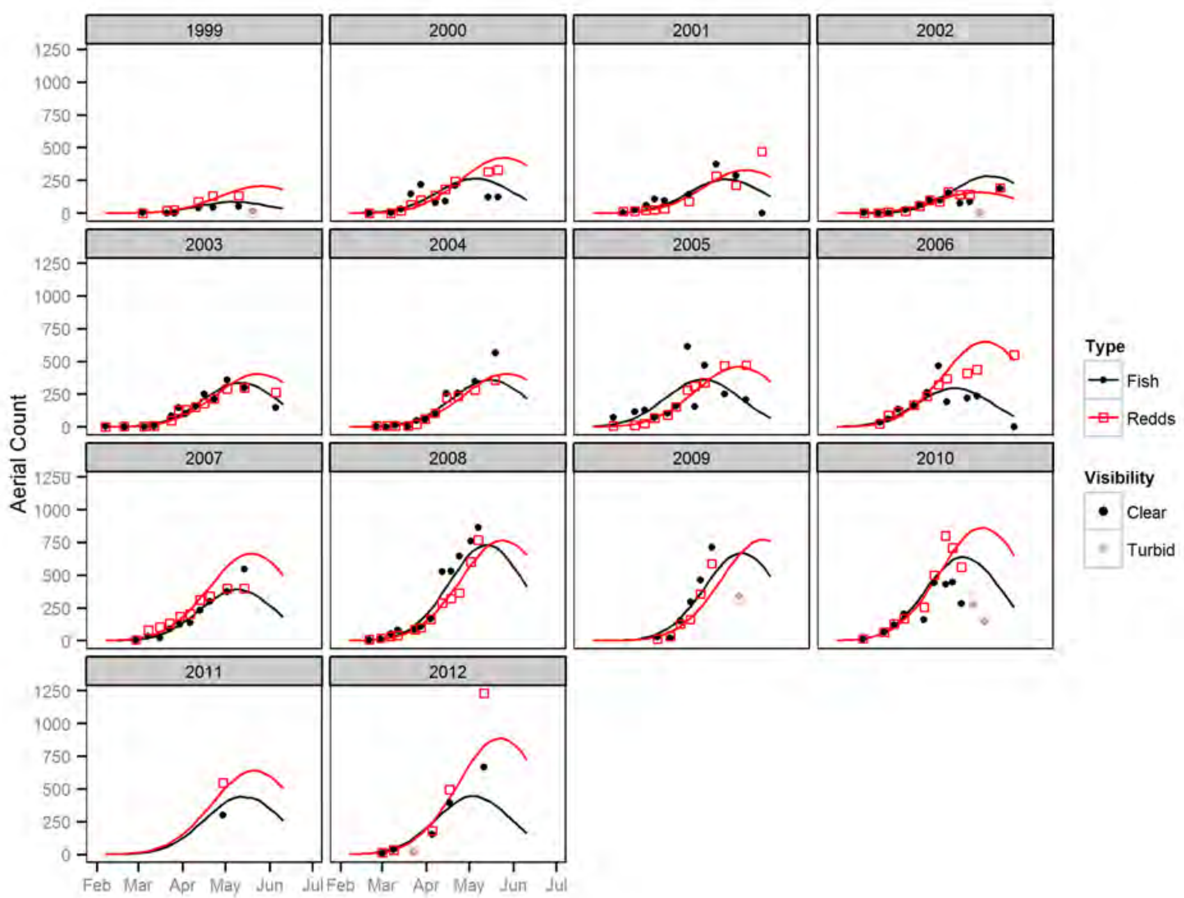

Figure C1. The spawner and redd counts for the Lower Columbia River above the Kootenay River with the AUC-based estimates of the expected counts.

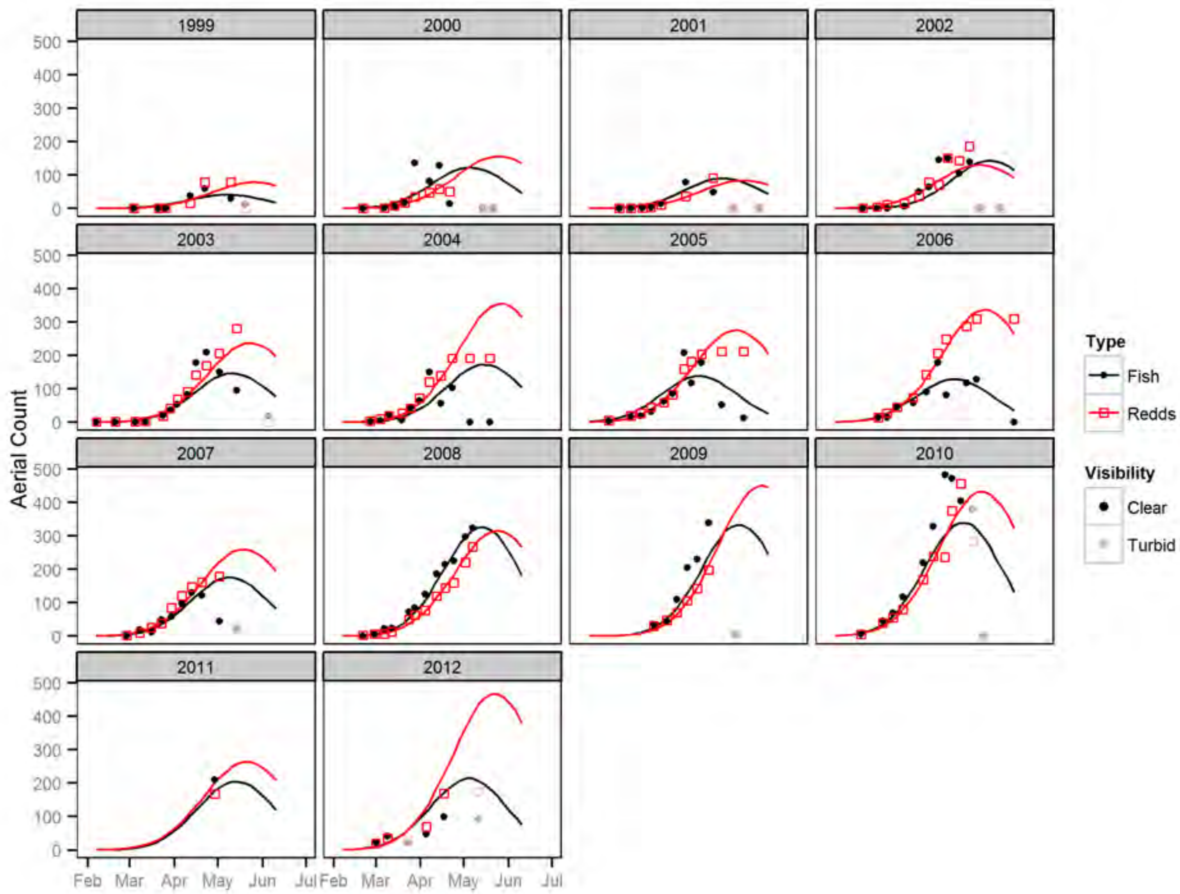

Figure C2. The spawner and redd counts for the Kootenay River below Brilliant Dam with the AUC-based estimates of the expected counts.

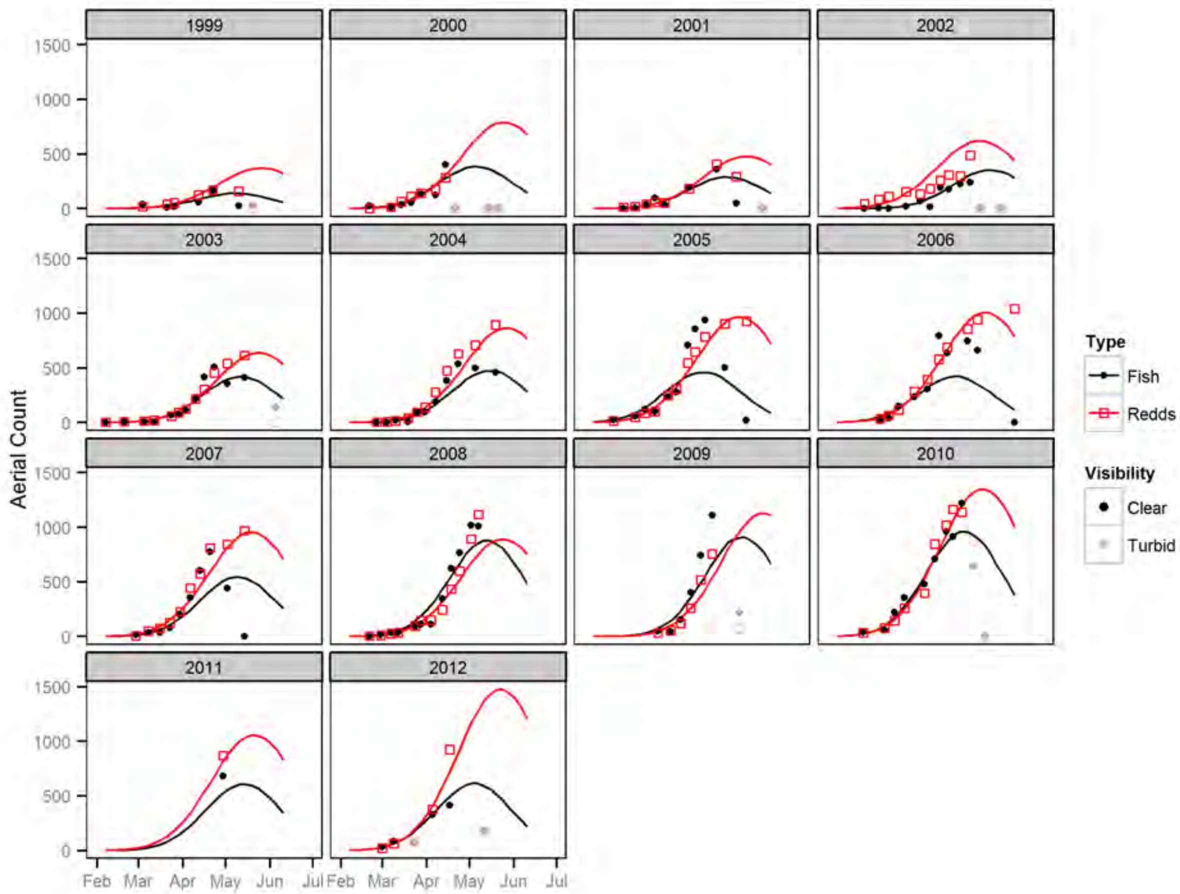

Figure C3. The spawner and redd counts for the Lower Columbia River below the Kootenay River with the AUC-based estimates of the expected counts.