Critical Spawning Habitats and Abundance of Bull Trout in the Williston Reservoir Watershed, 2019

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EXECUTIVE SUMMARY

Until 2012, the Fish and Wildlife Compensation Program (FWCP) monitored Bull Trout in the Williston Reservoir watershed primarily using foot surveys to count spawning sites or "redds" in index sections of four known spawning tributaries, to assess population growth rate or trend. The redd count program was initiated in the Davis River in 2001, followed by Misinchinka River and Point Creek in 2006. The addition of Scott Creek in 2009 completed the present-day system of annual index streams. This remains a core component of annual Bull Trout monitoring activities in the watershed. Beginning in 2012, two new components were added to the study to enable conservation status assessments at broader spatial scales and to identify critical natal habitats throughout the Williston Reservoir watershed. These were: 1) development of a helicopter-based, calibrated aerial redd count methodology for application at large spatial scales (i.e. major tributary systems) to delineate critical habitats, approximate spawner abundance, and identify new potential index sites; and 2) increasing the spatial coverage of abundance trend monitoring by adding new foot survey index sections delineated on the basis of the aerial redd count data. In providing these data, the study addresses Objective *1c-3* of FWCP's *Streams Action Plan*: "Undertake Bull Trout monitoring as per recommendations of the monitoring program and develop specific, prioritized recommendations for habitat-based actions which correspond to the monitoring results."

The completion of surveys in 2019 extends the time series of redd count data to 16 years (over a 19-year period) for the Davis River, 10 years (over a 13-year period) for the Misinchinka River, 11 years (over a 14-year period) for Point Creek, and 9 years (over an 11-year period) for Scott Creek. Meaningful trends in Bull Trout spawner abundance are not apparent in the time series of redd count data for Davis River, Misinchinka River, and Point Creek due to substantial inter-annual variability among redd counts in combination with the relatively short duration of each data set. September 2018 redd counts in Point Creek were above the long-term average, while the counts in the Davis and Misinchinka rivers were well below average. A significant, negative trend is evident for the Scott Creek population, however, which has exhibited a concerning, steep decline in abundance over a relatively short period of time.

In 2019, the calibrated, aerial redd count methodology was applied to accessible reaches (totaling roughly 270 km) of tributaries to the eastern shore of Parsnip Reach, to the lower and middle Ospika River watershed, and to the Chowika Creek watershed, all of which drain the western slope of the Rocky Mountains. The survey of the eastern shore of Parsnip Reach confirmed the presence of populations of large-bodied, migratory Bull Trout in Scott Creek and Weston Creek. Minor populations were identified in Patsuk Creek and Cut Thumb Creek, which have short accessible lengths, and no redds were observed in tributaries south of Cut Thumb Creek including Tony Creek, Tutu Creek, Mugaha Creek, Chichouyenily Creek, and Mischinsinlika Creek. Expansion of all aerial counts in tributaries to the east shore of Parsnip Reach, accounting for redd detection probability <1 and assuming 2 spawners per redd, results in a minimum population estimate of approximately 130 spawners.

In contrast to the limited distribution and abundance of adfluvial Bull Trout in Parsnip Reach tributaries, extensive critical habitats and large populations were discovered in the Ospika River and Chowika Creek watersheds, with minimum population estimates being roughly 520 and 220 spawners, respectively. These data, when combined with data acquired in 2015 for the Davis River and 2016 for the Ingenika River, suggest a major population of large-bodied, migratory Bull Trout utilizing tributaries on both shores of Finlay Reach.

Aerial redd count data were combined with juvenile Bull Trout sampling records to delineate 16 new critical habitat segments for large-bodied, migratory Bull Trout in the Williston Reservoir watershed. Additionally, the boundaries of 4 previously-assessed critical habitat segments were refined.

Two new ground survey index sections were also surveyed in 2019: Gauvreau Creek (lower Ospika River watershed: 62 redds) and Chowika Creek (60 redds). A total of 18 index sections are now available for monitoring spawner abundance in the Williston Reservoir watershed representing 12 populations that are likely to be at least partially independent.

Calibration data have accumulated over the multi-year period of this study, and helicopter-based aerial redd counts can now be compared to subsequent counts from traditional foot surveys in 28 reaches. A quantitative assessment of the calibrated aerial redd count methodology was therefore a priority for this year's report. In our assessment, aerial counts performed moderately well as a predictor of redd abundance on the ground, suggesting that the method is useful in northcentral British Columbia for identifying key spawning streams and indicating the relative importance of each. However, given detection probability <1 and its substantial variability among sites, it is clear that unadjusted aerial redd counts are inappropriate for applications in northcentral British Columbia where accurate, precise knowledge is required of the level of Bull Trout spawning activity. We have also found that application of an aerial redd detection probability model significantly improved the fit of the modeled detection probability estimates to empirical redd count data, which should improve the utility of future aerial redd count data and the reliability of inferences drawn from them. The three variables included in the best model can all be readily estimated visually from the air.

Our main recommendation is for a 5-year program review following the 2020 field season (if funded), which would include: 1) an updated conservation status assessment 2) a recommended strategy for Bull Trout habitat conservation actions, 3) a detailed schedule of foot surveys in index sections covering a minimum of 15 populations, 4) recommendations for an analysis of limiting factors based on Bull Trout distribution and abundance data collected to date, and 5) a recommendation on how to improve this study's ability to monitor the effects of climate change on Bull Trout and identify potential adaptations.

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1.0 INTRODUCTION

The Bull Trout (*Salvelinus confluentus*) is among the most sensitive of British Columbia's wildlife species. The Bull Trout is also one of the most highly-valued fish species in the upper Peace Basin. Migratory Bull Trout, which grow to sizes of 80 cm or more on a piscivorous diet, provide a rare opportunity for big fish in streams of the Williston Reservoir watershed, and are targeted in both subsistence and recreational fisheries. Because of high value and conservation concern for the species, the Bull Trout is a priority species for both the Fish and Wildlife Compensation Program – Peace Basin (FWCP), which was established to conserve and enhance fish and wildlife resources affected by BC Hydro dam construction, and for British Columbia's Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), the lead agency responsible for management of freshwater fisheries in the province. This study, conducted since 2014 by a partnership between FLNRORD, McLeod Lake Indian Band, Tsay Keh Dene Nation-owned consultants Chu Cho Environmental, and scientific advisor John Hagen, monitors the status of Bull Trout populations in the Williston Reservoir watershed and also identifies and prioritizes critical habitats for potential conservation actions.

Bull Trout populations have declined in many areas of their native range, particularly in the United States and in southern parts of their Alberta and British Columbia distributions. Population declines appear to be due to the cumulative effects of habitat degradation, non-native species introductions, overharvest, and fragmentation of watersheds caused by dam construction (Rieman and McIntyre 1993; Rieman et al. 1997; Paul and Post 2001; Post and Johnston 2002; High et al. 2009; Rodtka 2009; Hagen and Decker 2011; Kovach et al. 2016). Loss of the migratory form (adfluvial, fluvial) in particular is evident in many populations, and many remaining populations in the U.S.A. persist only as small-bodied residents isolated in headwater streams (Nelson et al. 2002). Because of these human-caused population declines, along with naturally small population sizes, limited or declining distributions, and elevated threats, the Bull Trout is considered a species of conservation concern throughout its distribution in the contiguous United States, Alberta, and British Columbia (Lohr et al. 2000; Rodtka 2009; Hagen and Decker 2011; COSEWIC 2012; USFWS 2015). Bull Trout populations in the Williston Reservoir Watershed belong to the 'Western Arctic' Designatable Unit (DU)[1] as recognized by the Committee on the Status of Endangered Wildlife in Canada, and have been assigned a ranking of 'Special Concern' by COSEWIC (COSEWIC 2012).

Because of the greater threats faced by populations of large-bodied, migratory Bull Trout and the high value placed on them by humans, since 2001 these populations have been the focus of FWCP Bull Trout monitoring efforts in the Williston Reservoir watershed. Until 2012, the monitoring program's sole methodology consisted of annual counts of spawning sites or "redds"[2]

[1] Infraspecific units that are distinguishable from, and have different extinction probabilities than, the species as a whole (Green 2005 as cited in McPhail 2007).

[2] Redds are excavations in the substrate associated with spawning activity and egg deposition (Leggett 1980; Rieman and Myers 1997; Dunham et al. 2001).

in index sections of four known spawning tributaries, to assess population growth rate or trend. The redd count program was initiated in the Davis River in 2001, followed by Misinchinka River and Point Creek in 2006. The addition of Scott Creek in 2009 completed the present-day system of annual index streams (Andrusak et al. 2012). Since inception, the monitoring program has retained consistent field methods in these index reaches to facilitate assessments of trend.

Although population trend is one of the most important indicators of conservation status (O'Grady et al. 2004), trend data from a relatively small number of index sites is inadequate for assessing conservation status at the scale of the entire Williston Reservoir watershed, or within conservation units making up the watershed ('core areas:' [3] Hagen and Decker 2011). Total adult abundance, distribution, and threats are also key indicators of status for fish populations (McElhany et al. 2000; USFWS 2005). Trend data also do nothing to indicate critical habitat locations in other watersheds, where conservation and enhancement actions are to be located and threats assessed.

Beginning in 2012, new components were added to the study to enable conservation status assessments at broader spatial scales and to identify critical spawning habitats throughout the Williston Reservoir watershed (reviewed in: Hagen and Spendlow 2016). The first of these new components was the development and application of a calibrated, aerial redd count methodology at large spatial scales (i.e. major tributary systems) in order to delineate critical habitats, estimate spawner abundance, and identify new potential index sites. Prior to 2019, this methodology had been applied to the whole accessible portions of the Parsnip (Hagen et al. 2015), Davis (Hagen and Spendlow 2016), Ingenika (Hagen and Spendlow 2017), Mesilinka (Hagen and Spendlow 2018), Osilinka (Hagen and Spendlow 2018) and Omineca (Hagen and Spendlow 2019) watersheds.

The second new component involved increasing the spatial coverage of population trend monitoring by adding new on-the-ground index sections delineated on the basis of the aerial count data. The target frequency for future surveys of these index sections is a minimum of 5 years over a 15-year period (Hagen and Spendlow 2016).

Field activities in 2019 were conducted by personnel of FLNRORD, consultant John Hagen and Associates, and study partners McLeod Lake Indian Band (MLIB) and Chu Cho Environmental (CCE). This report contains the results of four study components:

1. 2019 redd count data from long-term foot survey index sections within the Davis, Point, Scott, and Misinchinka watersheds.
2. Redd count data from foot surveys conducted in additional index sections located in Point Creek and the Davis River, which are relatively new additions to the monitoring program and are not included in the long-term trend analysis.

[3] Groups of populations interconnected or potentially interconnected through gene flow, which are approximately independent from other such groups.

3. Calibrated aerial redd surveys of previously-unsurveyed watersheds on the eastern shores of Williston Reservoir's Parsnip Reach and Finlay Reach.
4. Redd count data from foot surveys conducted in new index sections located in the Ospika and Chowika watersheds on Finlay Reach.

2.0 GOALS AND OBJECTIVES

The FWCP is partnership between BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations and public stakeholders. In the Peace Region, FWCP's aim is to conserve and enhance fish and wildlife impacted by the construction of the W.A.C. Bennett and Peace Canyon dams on the Peace River, and the subsequent creation of the Williston and Dinosaur Reservoirs.

The primary goal of the spawner abundance monitoring study is to ensure Bull Trout persistence in perpetuity in all core areas of the Williston Reservoir watershed. The second goal of the project is to facilitate on-the-ground conservation and enhancement actions within these core areas.

Bull Trout spawner abundance monitoring does not in itself ensure the success of conservation and enhancement measures. Instead, redd counts are indicators of the success of those measures, and also indicators of critical habitats where conservation and enhancement actions should be directed. The redd count program is therefore an important enabler of science-based conservation and enhancement of Williston Reservoir Bull Trout.

In support of these two goals, the project had the following objectives for 2019:

1. To complete Bull Trout redd counts in established index sections of the Williston Reservoir watershed (Davis River, Point Creek, Scott Creek, Misinchinka River), using a foot survey-based methodology consistent with past surveys, and to evaluate trend over time within index sections.[4]

2. To apply the calibrated aerial redd count methodology in previously-unsurveyed watersheds located on the eastern shores of Parsnip Reach and Finlay Reach, in order to identify critical natal habitats, estimate spawner population size, and delineate potential index sections for future ground surveys.

3. To complete foot survey-based, Bull Trout redd counts within new index sections located in tributaries to the eastern shores of Parsnip Reach and Finlay Reach, to provide baseline estimates of spawner abundance for future comparisons.

[4] Note that new index sections added in the Davis River and Point Creek more recently are not included in the long-term trend analysis.

4. To utilize accumulated aerial redd count calibration data in the most comprehensive evaluation of the aerial redd count methodology conducted so far, and to identify potential models to improve estimates of aerial redd detection probability in future.

In fulfilling these objectives, the study addresses Objective *1c-3* of the *Streams Action Plan* (FWCP 2014):

> Undertake Bull Trout monitoring as per recommendations of the monitoring program and develop specific, prioritized recommendations for habitat-based actions which correspond to the monitoring results (FWCP 2014).

3.0 STUDY AREA

Williston Reservoir, which reached full pool in 1972 (Hirst 1991), flooded approximately 350 km of the Peace, Finlay, and Parsnip river valleys resulting in drastic changes to the ecologies of these watersheds and patterns of human settlement and land use. Diverse stream habitats in adult rearing environments for Bull Trout were replaced by a single, monomorphic reservoir, which eventually became populated with a different fish community including new prey and competitor species such as Kokanee (*Oncorhynchus nerka*) and Lake Trout (*Salvelinus namaycush*), respectively. Reservoir creation facilitated widespread forestry in formerly inaccessible watersheds, and the flooding also severely altered traditional patterns of human settlement, resource use, and travel (Herkes and Kurtz 2014).

In British Columbia, the geographic distribution of the Bull Trout is closely associated with the mountains, reflecting the species' requirements for cold water habitats. Bull Trout are widely distributed within the Williston Reservoir watershed, much of which drains mountainous areas (Hagen and Decker 2011). However, life history, abundance, and population structure have been largely unknown outside of index systems. In lieu of genetic population structure data, Hagen and Decker (2011) delineated preliminary conservation units (core areas) for the Williston Reservoir watershed based on the geography of the basin. The system of core areas is meant to be a proxy for the potential metapopulation structure. The distribution of Bull Trout in the Williston Reservoir watershed is comprised of the 'Upper Finlay,' 'Lower Finlay,' 'Finlay Reach,' 'Omineca,' 'Peach Reach,' 'Parsnip Reach,' and 'Upper Parsnip' core areas.

Index sections surveyed annually within the Misinchinka River, Davis River, Point Creek, and Scott Creek are located roughly 50, 180, 70, and 60 km, respectively, by air from Mackenzie (Figure 1). The Misinchinka River (Upper Parsnip core area) is a tributary to the Parsnip River, although it is known to have a primarily adfluvial population of Bull Trout (Langston and Cubberley 2008), while Davis River (Finlay Reach core area), Point Creek (Peace Reach core area), and Scott Creek (Parsnip Reach core area) are direct tributaries of the reservoir (Figure 1). All four index streams originate in the Rocky Mountains.

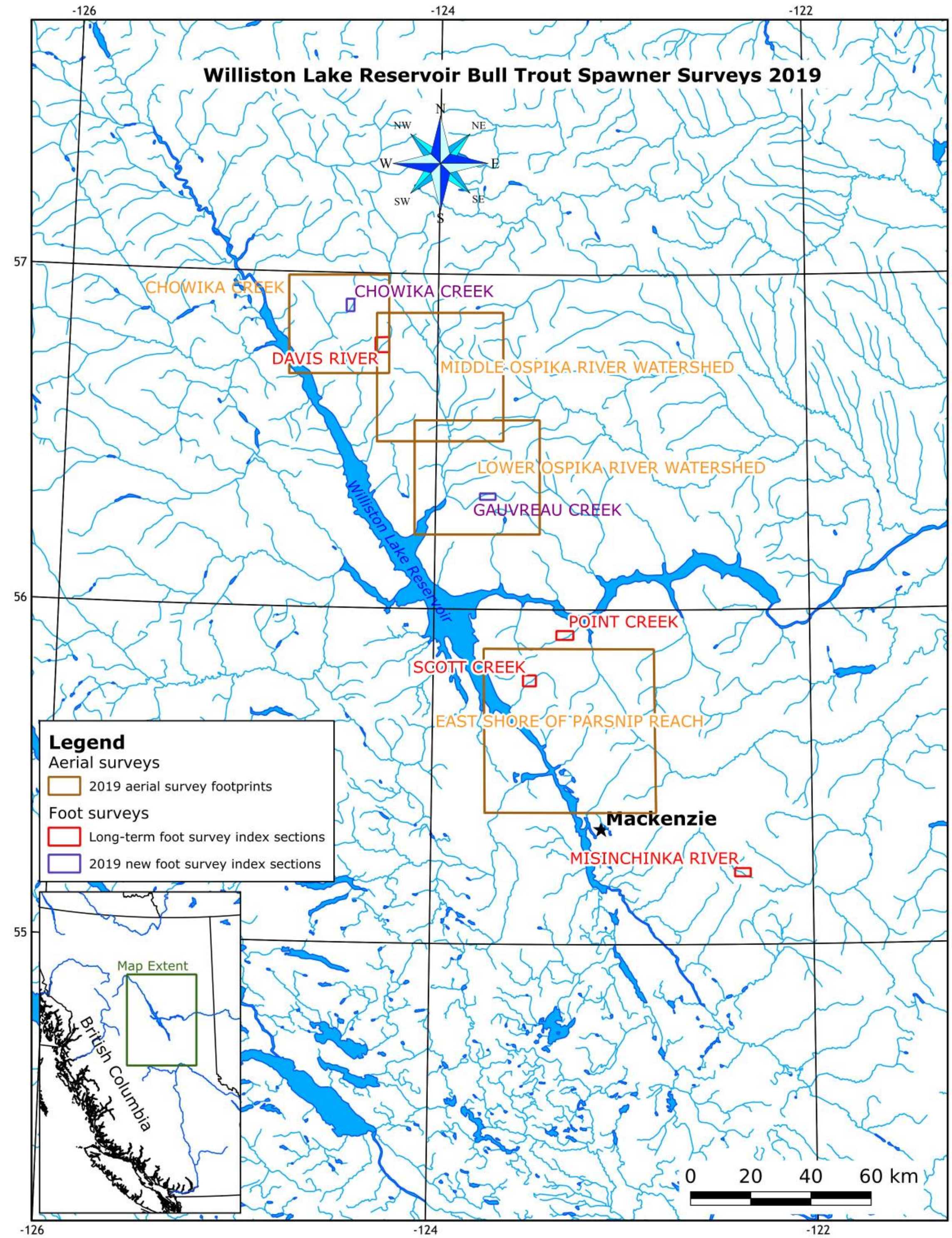

Figure 1. Overview map of the Williston Reservoir basin showing areas monitored for Bull Trout spawning activity using redd counts in 2019. Orange, red, and purple rectangles correspond with areas depicted in maps of aerial surveys, foot surveys in long-term index sections, and foot surveys in new index sections, respectively.

The Misinchinka and Davis rivers have relatively long accessible lengths of approximately 90 and 55 km, respectively (Andrusak et al. 2012), and the distribution of spawning activity is known to extend well beyond the boundaries of the respective index sections (Langston and Cubberley 2008; O'Brien and Zimmerman 2001). In contrast, Point and Scott Creeks have shorter accessible lengths of 8 and 18 km, respectively (Andrusak et al. 2012), and current redd count surveys cover the entire known distribution of spawning (Hagen and Pillipow 2013). All four index systems do not have glacial origins and typically experience low, clear flows during the survey period, which annually occurs in the third week of September following the completion of spawning.

Tributaries to the eastern shores of Parsnip Reach and Finlay Reach also originate in the Rocky Mountains, and many have relatively short accessible lengths (Hagen and Weber 2019). The exception is the relatively large Ospika River watershed (Figure 1), which is likely to have an accessible length of 200 km or more (including tributaries).

4.0 SURVEY METHODS

4.1 Redd identification

A redd is a pit excavated in to the stream bed material by female Bull Trout during spawning. Fertilized eggs are deposited in to this pit, which are then covered by gravel swept in to place by the female (Leggett 1980). Redds have a highly characteristic overall appearance that typically includes the following: 1) a backstop of gravel deposited onto the undisturbed bed material, 2) a deposit made up of gravels continuous with this backstop and continuing upstream into the pit, 3) a broad, horseshoe-shaped pit upstream of and alongside the deposit resulting from the sweeping of gravels from all sides (sometimes just one side) to cover the eggs, and 4) a bright appearance of the redd relative to surrounding undisturbed bed material (caused by disturbance of algae- or sediment-coated rocks). In addition to these cues, redds of large-bodied, migratory Bull Trout in the Williston Lake watershed are large ($2.5\ m^2 \pm 0.52\ m^2$), which facilitated their identification during this study.

During our study, a further determination was whether fish had actually spawned at a location where an excavation had been started. We use the term 'test pits' to describe excavations that are often small and relatively narrow and contain little or no gravel in the pit ahead of the backstop, which would denote at least one egg deposition event (Leggett 1980). During this study, test pits were not included in the redd count or recorded. Test pits of this description have previously been excavated and few have been found to contain eggs (personal observation of author Hagen).

Superimposition of redds upon one another is common, especially in areas of limited gravel, high redd abundance, or where spawning is highly concentrated. Block (1955) for example observed one male Bull Trout spawn with three females in succession at a single redd location, which expanded with each spawning event. When superimposed redds were encountered during this study, counts were based on a subjective evaluation, with the most recent complete redd(s) counted and the disturbed remains of prior redds estimated in relation to it.

4.2 Foot surveys

Foot surveys in index sections (Figure 1) were conducted between September 16 and September 21, 2019, by two-person crews. Observers wore waders suitable for travel along slippery stream channels, and polarized sunglasses to cut glare on the water surface. Observers walked downstream and positioned themselves to gain the best view of potential spawning locations, and recorded the number of redds and fish (if any were still present) in waterproof notebooks. All redd locations and important habitat features were recorded using hand-held GPS units.

Observer experience and training are important factors improving the reliability of redd counts (Muhlfeld et al. 2006; Howell and Sankovich 2012). Redd identification criteria (Section *4.1*) were therefore discussed and standardized between the two field crews at the beginning of the redd count study. Training of less experienced personnel of Tsay Keh Dene-owned Chu Cho Environmental and McLeod Lake Indian Band continued throughout the survey period, and they were always paired with experienced observers (minimum >3 years).

Figure 2. Bull Trout redds in a spawning tributary of the Williston Reservoir watershed.

In 2019, foot survey-based redd count surveys were conducted in long-term index sections in the Davis River, Point Creek, Scott Creek, and the Misinchinka River. Two recently-added index sections in the Davis River and one in Point Creek were also surveyed for the fourth and fifth consecutive seasons, respectively. Two new ground survey index sections were delineated and surveyed for the first time in 2019: Gauvreau Creek (lower Ospika River watershed) and Chowika Creek (tributary to Finlay Reach).

4.3 Aerial redd surveys

Helicopter-based, aerial redd surveys in tributaries to the eastern shores of Parsnip Reach and Finlay Reach (Figure 1) were conducted on September 18, 19, and 20, 2019 by three-person crews (including the pilot). The aerial survey consisted of redd observations (Figure 3) made during low-level helicopter flights along the accessible lengths of each selected system (including suitable tributaries).

During aerial surveys two observers wearing polarized sunglasses scanned the stream from the same side of the helicopter. The dedicated observer, who sat in the front seat of the helicopter with the door removed,[5] generally kept his or her attention focused on the stream bed. The assisting observer also made redd observations, but had the additional duties of recording waypoints on a portable GPS unit, and writing down associated field notes (redd counts, habitat observations). Test pits were not discriminated from the air unless they were exceptionally small, but superimposed redds were identified where possible. The target height for surveys was roughly 50 m above the stream, which enabled a relatively good view of redds below the helicopter and also of upcoming areas, but higher elevations were often dictated by the height of stream banks and riparian forest. The ideal orientation of the observers was with the sun at their backs, but this was not always possible as wind direction and intensity frequently dictated the direction of safe travel. Aerial surveys were conducted prior to any ground-truthing within the same sections, to avoid bias related to advance knowledge. Aerial redd surveys are challenging and during this study have only been conducted by the most experienced crew available (average >10 years in all cases).

Ground truthing of aerial redd surveys was conducted on foot in reaches that had also received an aerial survey. Ground surveys were not conducted in reaches where no redds were counted from the air, precluding insights into the risk of not detecting small populations. The reason for this was that spawning zones comprised a small proportion of the total amount of stream habitat available to migratory Bull Trout, and we felt that randomly-selected stream reaches with zero counts would be unlikely to contain redds unless a large number of reaches were surveyed. Such an approach was precluded by the study budget.

[5] A large, sliding window on the door has also been utilized without removing the door, with improved survey efficiency and comfort.

Figure 3. Bull Trout redds observed from the air in a spawning tributary of the Ospika River watershed.

Beginning in 2012, we developed a number of hypotheses a priori about which habitat factors would most limit the efficacy of aerial redd surveys, particularly habitat attributes that could be estimated subjectively from the air. Visual estimates of these attributes, based on observations made at a location(s) deemed to be representative of the reach as a whole, were made during ground surveys in 2019 and included the following 11 substrate and cover variables: proportion fine substrates <2 mm, proportion gravel 2 mm-6 cm, proportion cobble 6 cm to 25 cm, proportion boulder > 25 cm, D90[6], bed material contrast (brightness of redd relative to undisturbed material), proportion large wood debris cover, proportion turbulence cover, proportion overhead cover (including crown closure), wetted width of stream, stream channel width, and riparian forest height.

4.4 Analyses

4.4.1 Population trend.

Analysis of trend in four long-term index sections located within the Davis, Point, Scott, and Misinchinka watersheds was conducted using simple linear regression on square root-

[6] bed material particle size for which 10% of the stream bed is comprised of larger particles.

transformed count data. While this approach does not account for process or observation error in the time series of count data, it considered less conservative relative to modern alternatives, which is potentially advantageous in a situation of declining trend where early detection is desirable (reviewed in Kovach et al. 2016).

4.4.2 Calibration of 2019 aerial redd counts.

In the application of the aerial survey methodology since 2014, when it was first applied to previously-unsurveyed watersheds, the number of redds present on the ground has been estimated by adjusting the aerial count by the aerial redd detection probability for each surveyed stream reach, which in turn is estimated by comparing aerial versus ground counts in the reach's calibration site (i.e. a two-stage sampling design; Hankin and Reeves 1988). This method for adjusting the aerial redd survey results was also utilized in 2019.

For stream reaches that did not received a ground survey to calibrate the aerial counts, an estimate of overall detection probability was utilized. Estimates of aerial redd detection probability are proportions, and therefore assumed to be binomially-distributed. Overall detection probability was estimated as the value that maximized the binomial probability (sum of the binomial log-likelihoods; Haddon 2001) of the observed aerial counts across all calibration sites surveyed since 2012, given the observed ground counts in the same respective sections.

In utilizing the estimated number of redds to make inferences about adult population size, we have utilized an assumption of 2 spawners per redd (e.g. Hagen and Decker 2011). Independent population estimates necessary for evaluating this assumption are unavailable for the Williston Reservoir watershed.

4.4.3 Delineation of critical habitats.

Although the delineation of critical habitats was based primarily on the aerial redd count data, we also reviewed information contained in a variety of provincial and regional databases (FLNRORD data on file) to refine estimates of critical juvenile Bull Trout habitats where possible. To assess critical juvenile habitats using GIS software, we queried (where possible) body length, weight, life history stage, comments, and total count of individuals captured for fish layers. For a summary of layers valuable for critical habitat analysis, and their availability, please refer to Table 4.1 of the FWCP Bull Trout information synthesis document (Hagen and Weber 2019). Critical juvenile rearing habitats always included critical spawning habitats, because these areas are also utilized for egg incubation, and are typically also the most important areas for rearing of young-of-year and older juveniles. Critical juvenile rearing may also occur downstream of spawning areas if physical and ecological conditions are suitable, and such areas were included in the critical juvenile rearing segments when 1) fry (<55 mm) and/or juvenile (<170 mm) Bull Trout were present as indicated by fish length data; 2) the frequency of occurrence was relatively high (i.e. more than a single individual); and 3) Bull Trout were numerically dominant over Rainbow Trout at the site.[7]

4.4.4 Evaluation of the aerial redd count methodology 2012-2019.

The performance of the aerial redd count method was evaluated using the ground survey counts from the same sections as the baseline. Redd counts made during ground surveys themselves may be relatively inaccurate and imprecise indicators of adult Bull Trout abundance (Dunham et al. 2001; Al-Chokhachy et al. 2005), but numerous attributes of the method have made it the standard index of adult Bull Trout abundance across the species' range (Maxell 1999; Dunham et al. 2001; Kovach et al. 2018).

We evaluated the ability of aerial redd counts to predict corresponding ground survey counts over the 2012-2019 period using simple linear regression, following square root-transformation of the count data to better meet assumptions of normality and homoscedasticity. As described above, the accuracy of the aerial survey, or detection probability, was estimated for each calibration reach as the aerial count divided by the ground survey count and expressed as a proportion. Proportions from 0 to 1 are binomially, as opposed to normally, distributed. Therefore, we described the precision (variability) of the detection probability parameter among sites following arcsine-square root transformation of the site-level detection probability estimates to better conform to the normality assumption (Zar 1996).

A question of key interest to our team was whether predictions of aerial redd detection probability could be improved through the use of a model incorporating physical habitat variables. We defined a series of candidate models representing different hypotheses about effects of reach-level habitat variables on aerial redd detection probability, and then compared these models using an information-theoretic approach (Burnham and Anderson 2002). From the habitat variables that had been collected during calibration surveys, three uncorrelated, visually-estimated predictor variables were selected that had a logical potential to influence detection probability, and which could be estimated from the air during future surveys. These were: 1) the proportion of the wetted stream bed material comprised of gravel (GRAVEL), 2) the proportion of the wetted stream width obscured by overhead vegetation cover (OH) including crown closure, and 3) the categorical estimate (high, medium, low) of redd contrast (brightness) relative to the surrounding undisturbed bed material (CONTRAST).

We utilized logistic regression to model the relationships between predictor variables and detection probability. Logistic regression does not make assumptions about the distributions of predictor variables (Tabachnick and Fidell 2001), so proportions GRAVEL and OH were not transformed prior to analysis. CONTRAST was included as a predictor variable by constructing contrast-stratified models with the three categories 'high,' 'medium,' and 'low' treated as dummy-coded variables. The set of models included a global model with all predictors and

[7] The numerical dominance of Bull Trout over Rainbow Trout is a key indicator of thermal suitability for Bull Trout (Parkinson and Haas 1996; Parkinson et al. 2012).

potential interactions, a series of simpler models, and a constant-only model. Model parameters were estimated by maximizing the sum of the log likelihoods of the binomial probability of the aerial counts across the three categories of redd contrast.

We used the Akaike information criterion corrected for small sample size (AIC_c) for the comparisons among models, after first testing for overdispersion in our count data by computing the parameter $\hat{c}$, which is the goodness-of-fit chi-square statistic of the global model divided by the degrees of freedom (Burnham and Anderson 2002). The expected value for $\hat{c}$ is 1 when the data conform to the simple variance assumptions based on the binomial distribution. The model with the lowest AIC_c score is considered to be the closest in the set of candidate models to the unknown reality that generated the data. We computed the strength of evidence for each candidate model being the best in the set by computing the likelihood of each model given the data $\mathcal{L}(g_i|x)$, then normalizing these likelihoods as a set of Akaike weights w_i (Burnham and Anderson 2002).

5.0 RESULTS

5.1 Survey conditions

The summer of 2019 was wet, resulting in above-average discharge during a portion or all of the spawning and survey periods, which extend from late August to late September for Williston Reservoir tributaries (Water Survey of Canada stations: Figure 4 – 07EC004 Ospika, Figure 5 – 07EE007 Parsnip). Stream flow conditions during the September 16-21 study period were suitable for safe travel along streams in all locations except Scott Creek, where the survey team was confined to one bank. Because redd detection was likely compromised by the inability to cross Scott Creek, this stream also received a subsequent aerial survey. Redds in most locations appeared to be well-defined and easy to identify, with the exception of a small number of redds in Chowika Creek, which showed evidence of redd flattening and siltation presumably related to the timing of spawning relative to high flows (Figure 4).

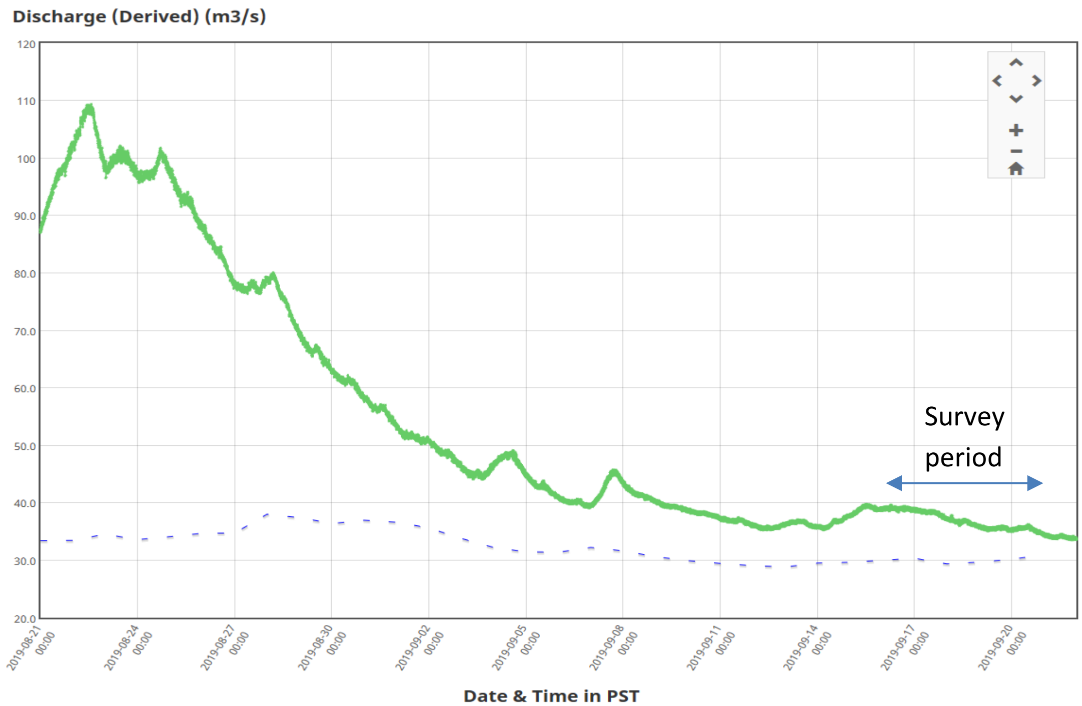

Figure 4. Estimated discharge (solid line) relative to mean discharge (dashed line) August 21-September 21, WSC station 07EB002 Ospika River above Aley Creek.

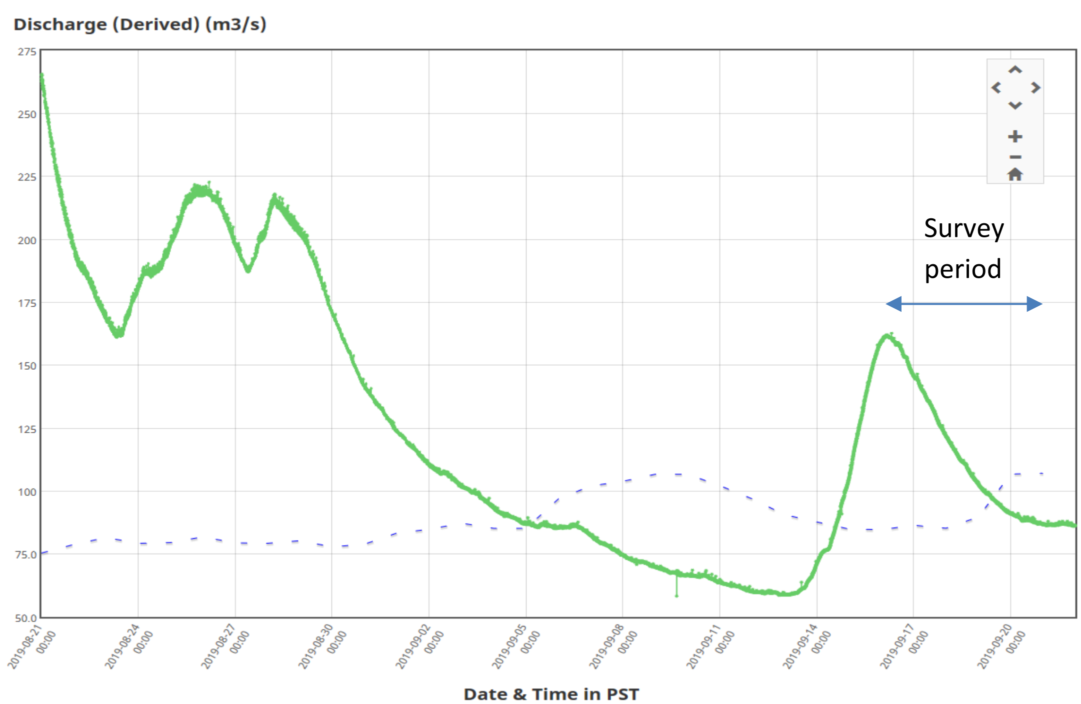

Figure 5. Estimated discharge (solid line) relative to mean discharge (dashed line) August 21-September 21, WSC station 07EE007 Parsnip River above Misinchinka River.

5.2 2019 foot surveys

5.2.1 Trend in long-term index sections

As the first objective of the 2019 field program, foot surveys were completed in the four long-term index sections located in the Davis River (September 19; Figure 6), Point Creek (September 17; Figure 7), Scott Creek (September 17; Figure 8), and Misinchinka River (September 16; Figure 9). The completion of surveys in 2019 extends the time series of redd count data to 16 years (over an 19-year period) for the Davis River (Table 1; Figure 10a), 10 years (over a 13-year period) (Table 1; Figure 10b) for the Misinchinka River, 11 years (over a 14-year period) for Point Creek (Table 1; Figure 10c), and 9 years (over an 11-year period) for Scott Creek (Table 1; Figure 10d). Beaver dam obstructions located downstream of preferred spawning locations in the Misinchinka River remained passable at the time of the 2019 foot survey, in contrast to 2017 and 2018 when these obstructions were barriers to most Bull Trout and a representative count from this section was unavailable (Hagen and Spendlow 2017, 2018).

The 2019 Davis River count of 36 redds is, by a small margin, the lowest on record and well below the long-term average of 60 (Table 1). This is the longest time series and is the only one of the four exhibiting a slight positive trend (Figure 10a). Variability among years is substantial, however, and the trend not significant when analyzed using natural log-transformed count data ($t = 1.05$, $P = 0.31$, $n = 16$).

The Misinchinka time series exhibits a non-significant decline ($t = -1.66$, $P = 0.14$, $n = 10$; Figure 9b), but the influence of beaver dam obstructions on low counts of 22 and 23 redds from 2016 and 2019 may be suspect.[8] Unfortunately, no knowledge of these obstructions is available prior to 2017.

The Point Creek time series is characterized by high variability obscuring any potential trend ($t = 0.0887$, $P = 0.93$, $n = 11$; Figure 9c), with redd counts ranging eight-fold over just 11 years' redd count data. The 2019 count of 30 redds is above the long-term average. When considered along with the count of 29 in 2018, this represent a substantial rebound from the count of 7 redds in 2017, which was the second lowest on record (Table 1).

At this point in time, the Scott Creek time series is the only one exhibiting a significant, negative trend in abundance ($t = -3.01$, $P = 0.020$, $n = 9$; Figure 9d), which is of concern. It is important to note that high water conditions in 2019 (section *5.1*) resulted in a compromised foot survey of Scott Creek index sections in 2019 during which only 25 redds were counted (Figure 8). The estimated redd abundance of 38 was derived from an aerial count made subsequent to the foot survey, to which the 2012 aerial redd detection probability estimate of 60% for Scott Creek was applied (see section *5.2.1*). Irrespective, other recent redd count data from Scott Creek also indicate a declining trend.

[8] These obstructions were considered migration barriers for most Bull Trout spawners in 2017 and 2018.

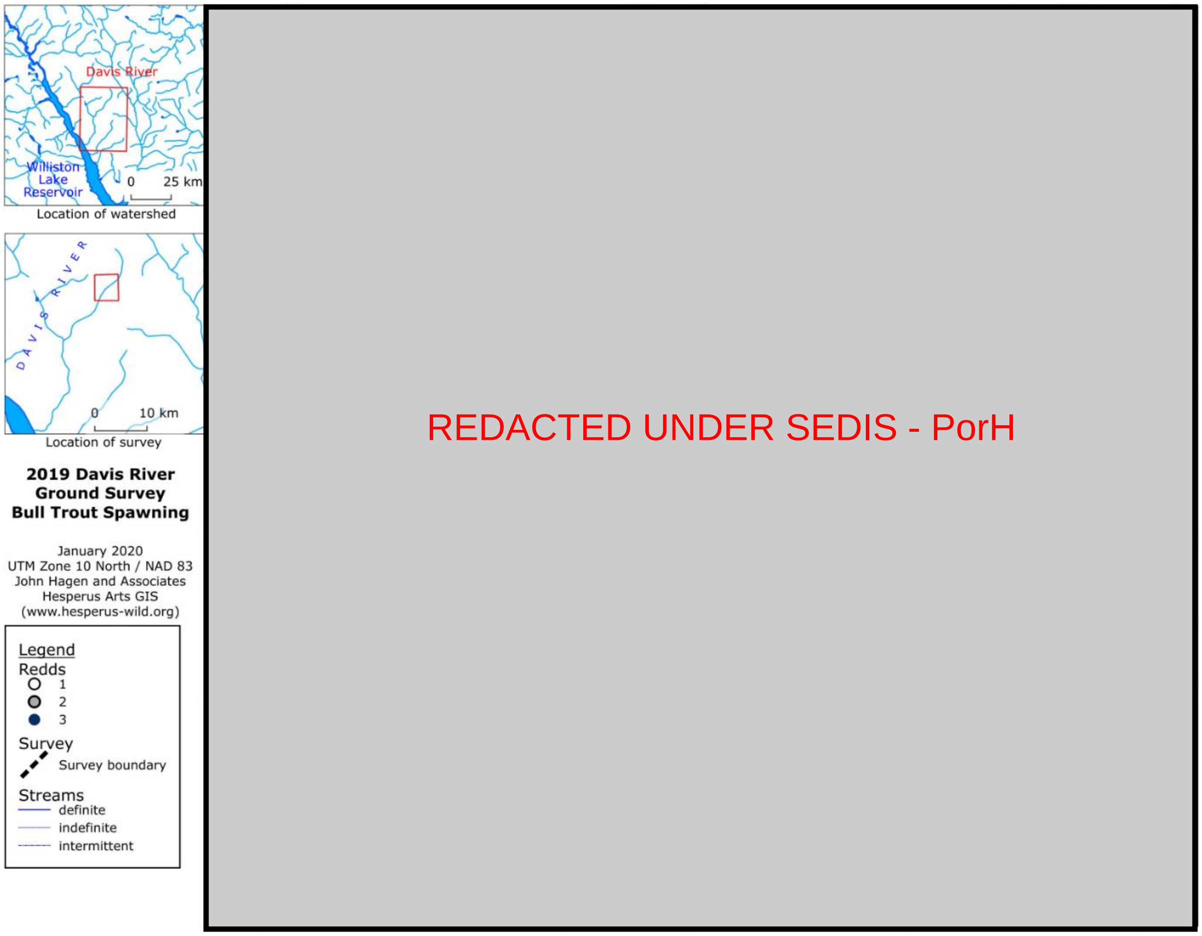

Figure 6. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during 2019 foot surveys of 3 index sections located within the Davis River watershed. The Davis River is a tributary to the Finlay Reach of Williston Reservoir. The 'Trib 2' and 'Trib 3' are new index sections surveyed for the first time in 2015 and 2016, respectively

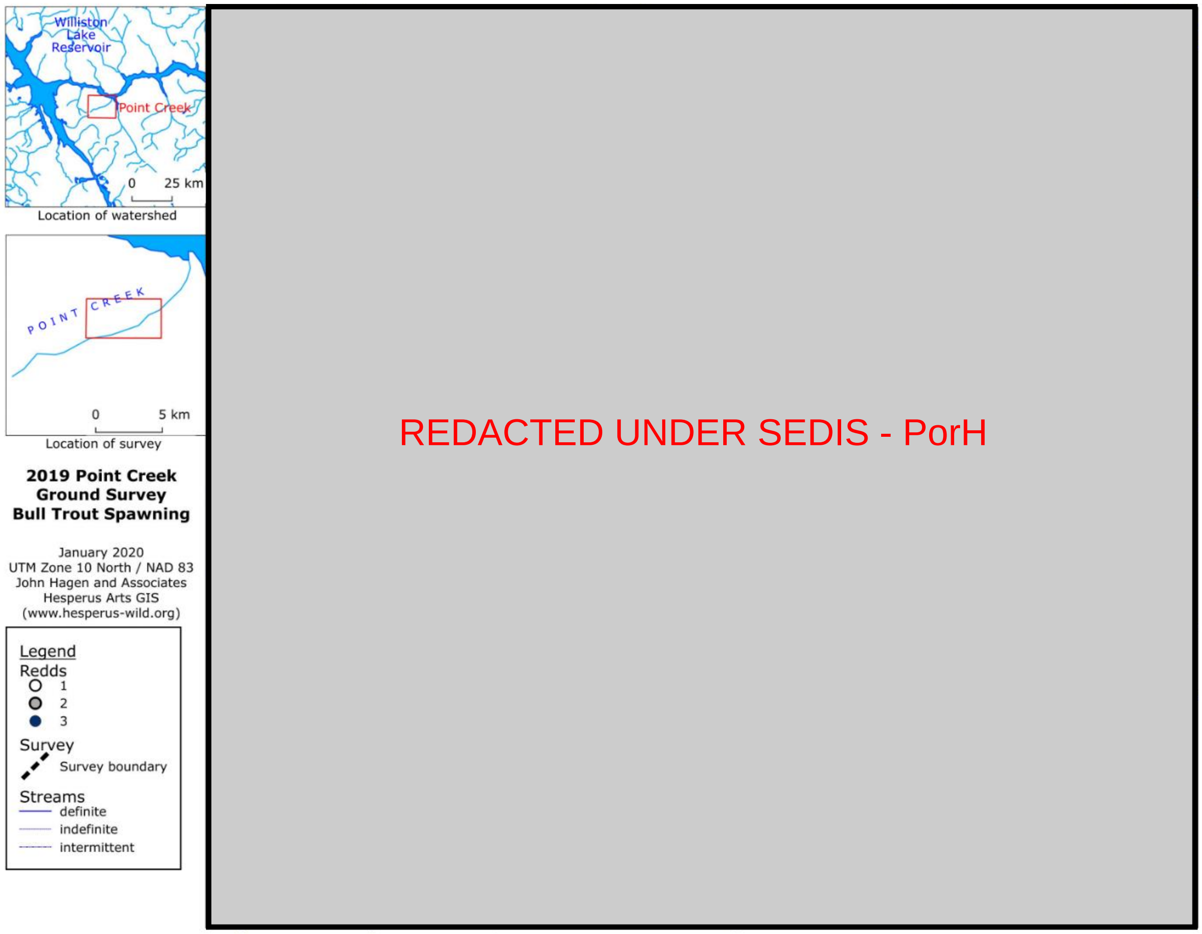

Figure 7. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during 2019 foot surveys in a long-term index section of Point Creek, a tributary to the Peace Reach of Williston Reservoir, and in a new index section ('Upper') surveyed for the first time in 2013.

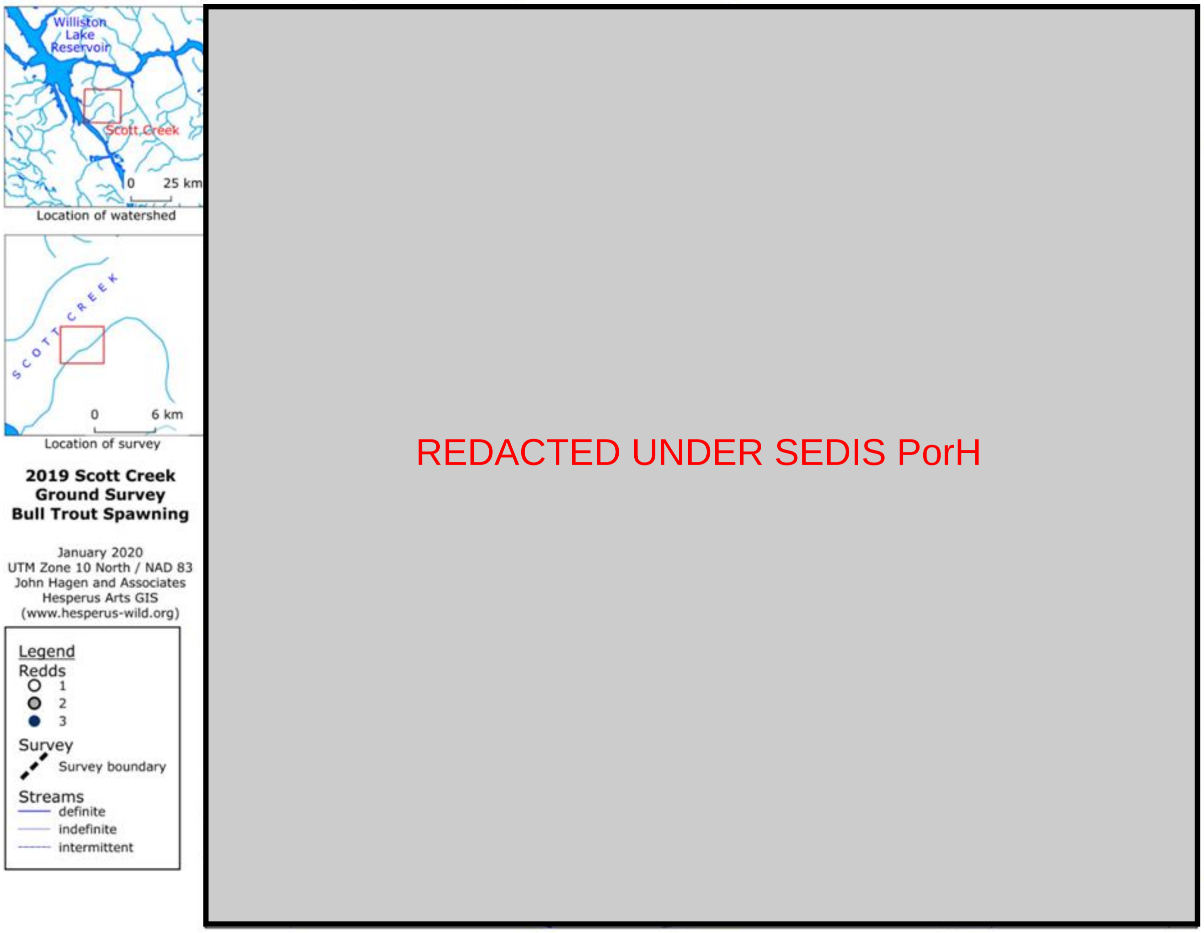

Figure 8. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during 2019 foot surveys of two long-term index sections in Scott Creek, a tributary to the Parsnip Reach of Williston Reservoir. Due to high water conditions at the time of the foot survey, the 2019 entry in the Table 1 time series is based on an aerial survey in 2019 expanded by the detection probability previously estimated for Scott Creek (see Table 5).

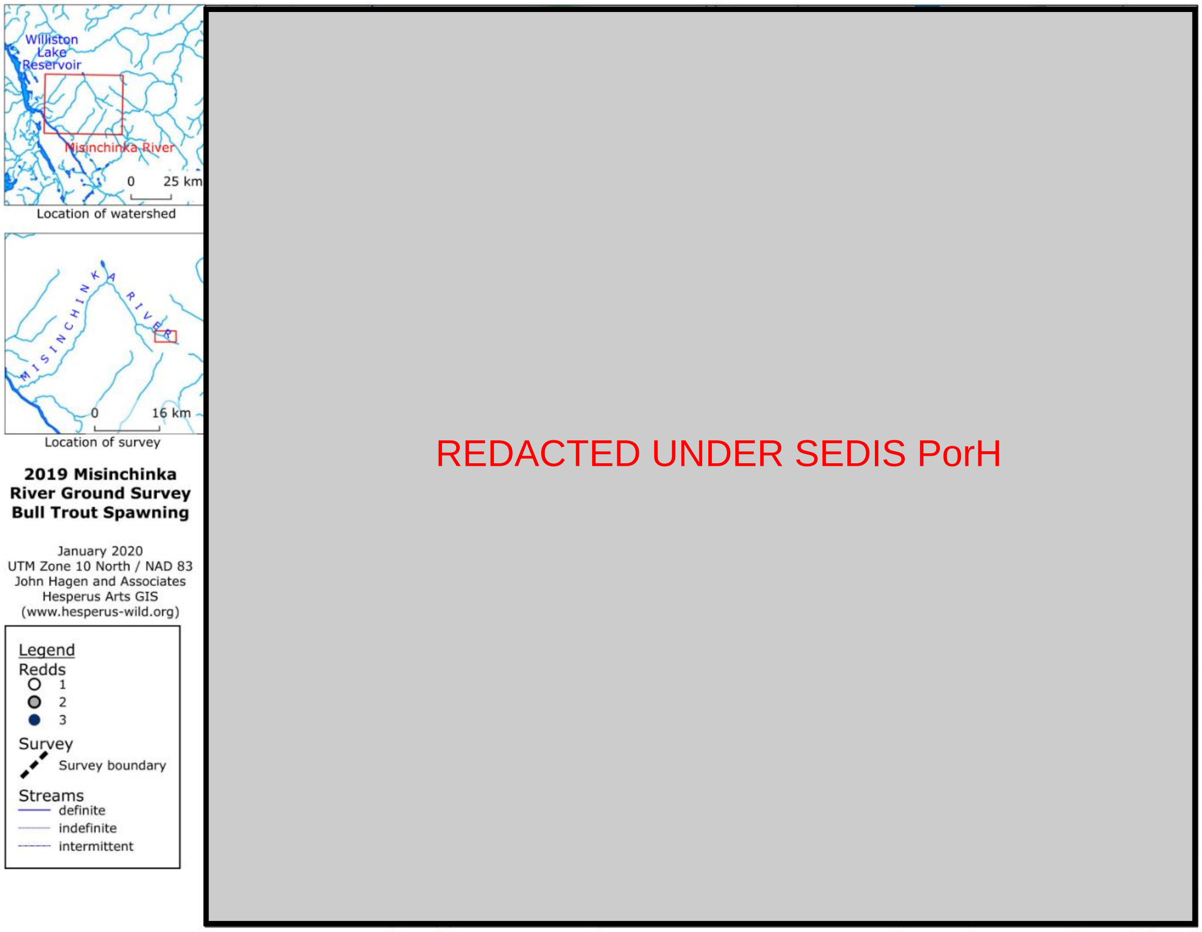

Figure 9. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during 2019 foot surveys of the long-term index section of the Misinchinka River, a tributary to the lower Parsnip River.

Table 1. Counts of Bull Trout redds in long-term foot survey index sections of four Williston Reservoir spawning tributaries, 2001-2019.

Stream	Length surveyed (km)	Redd count 2001	2003	2004	2005	2006	2007	2008	2009	2010	2012	2013	2015	2016	2017	2018	2019	*2001-2018 average*
Davis	3.9	39	42	69	43	67	37	54	65	85	61	62	84	49	61	77	36	*57*
Misinchinka	5.0					58	44	37	35	50	67	50	55	22	na	na	23	*23*
Point	4.2					39	21	18	5	24	40	23	na	26	7	29	30	*30*
Scott	4.4								58	106	72	84	60	59	41	51	38*	*51*

*23 aerial redds X 60% efficiency = 38 redds

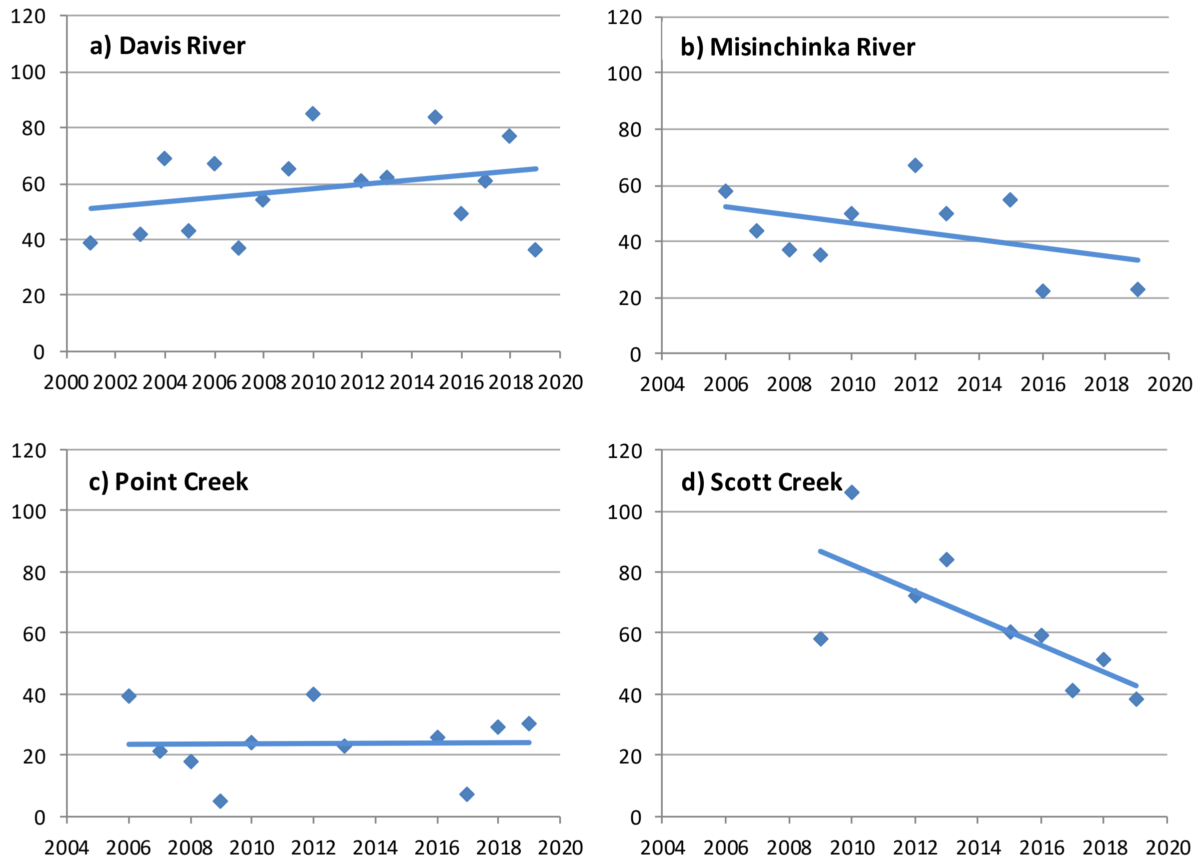

Figure 10. Counts of Bull Trout redds within long-term foot survey index sections of a) Davis River, b) Misinchinka River, c) Point Creek, and d) Scott Creek, 2001-2019.

5.2.2 Redd counts in new index sections of the Williston Reservoir watershed

In addition to the four long-term index sections in the Davis River, Misinchinka River, Point Creek, and Scott Creek, new index sections have been added to the Bull Trout abundance monitoring program since 2013 (Table 2; Figure 11). These additions have been made for two purposes: 1) to account for a greater proportion of the total spawning distribution in the streams with the four long-term index sections, and 2) to expand the network of index sections to include streams from all core areas and across a greater diversity of spawner abundance, levels of land use, and ecological conditions (Hagen and Spendlow 2016).

To account for a greater proportion of the total spawning distribution in the Point, Davis , and Misinchinka watersheds, four new index sections were added to ground surveys in these streams beginning in 2013 (Point Creek; Figure 7), 2016 (Davis River; Figure 6), and 2018 (Misinchinka River; Hagen and Spendlow 2019), respectively. The new index section added in 2013 increased the sampling fraction from 69% to 100% of the total estimated redd abundance in Point Creek (Figure 6: ‘Section 1’), based on 2012 aerial survey data (Hagen and Pillipow 2013). The two new index sections added to the Davis River ground survey, in two tributary reaches adjacent to the existing long-term index section (Figure 6: 'Trib 2' and 'Trib 3'), increased the sampling fraction from 17% to 54% of the total estimated redd abundance (based on aerial survey data collected in 2015; Hagen and Spendlow 2016). The addition of the new section in unnamed tributary 236-073000-78200 of the Misinchinka River watershed was made to address the presence of beaver dam obstructions limiting access to preferred spawning habitat in the regular long-term index section in the mainstem (Hagen and Spendlow 2018).

Since 2013 spawner numbers in these new index sections (excepting Davis Trib #2) have been highly variable among years (Table 2). In the new index section of Point Creek, upstream of the long-term section, redd counts have varied substantially from 22 in 2013 to 0 in 2019 over the five years' monitoring data (Table 2). In the new Davis River index sections, the relatively stable redd count in Davis Trib #2 is contrasted by the Trib #3 count, which dropped dramatically from 72 redds in 2016 to 0 redds in 2019, following construction of a series of impassable beaver dams beginning in 2017 (Figure 11). In 2019, the new index section in unnamed Misinchinka River tributary 236-073000-78200 was not surveyed because beaver dam obstructions in the mainstem appeared to be passable when viewed from the air.

Figure 11. One of a series of beaver dams restricting access since 2017 to preferred spawning habitat in 'Davis Trib #3' index section, upper Davis River watershed.

Since 2013, 10 new index sections have also been added in watersheds outside of those with the 4 long-term index sections (Table 2). In 2019, foot surveys were successfully completed in new index sections identified in Gauvreau Creek and Chowika Creek during the aerial surveys of tributaries of the eastern shore of Finlay Reach (section *5.2*). Substantial concentrations of spawning activity were discovered in both watersheds. A total of 62 redds were enumerated in the new, 4.9-km index section located in upper Gauvreau Creek (lower Ospika River watershed) (September 20; Figure 12), while 60 redds were counted in the new, 4.4-km index section located in the upper Chowika Creek watershed (Finlay Reach) (September 21; Figure 13).

Survey results are meant to provide at a minimum a baseline for future comparison. Ideally, however, surveys of these new index sections will be conducted in future on a periodic basis (e.g. 5 out of every 15 years), to evaluate trend, as discussed in section *6.1*. A total of 18 long-term and new index sections are now available for monitoring spawner abundance in the Williston Reservoir watershed representing 12 populations that are likely to be at least partially independent (i.e. not part of the same watershed or not in close proximity) (Table 1, Table 2). This total is expected to grow to at least 15 independent populations following the 2020 field season (if funded) (see section *6.1*).

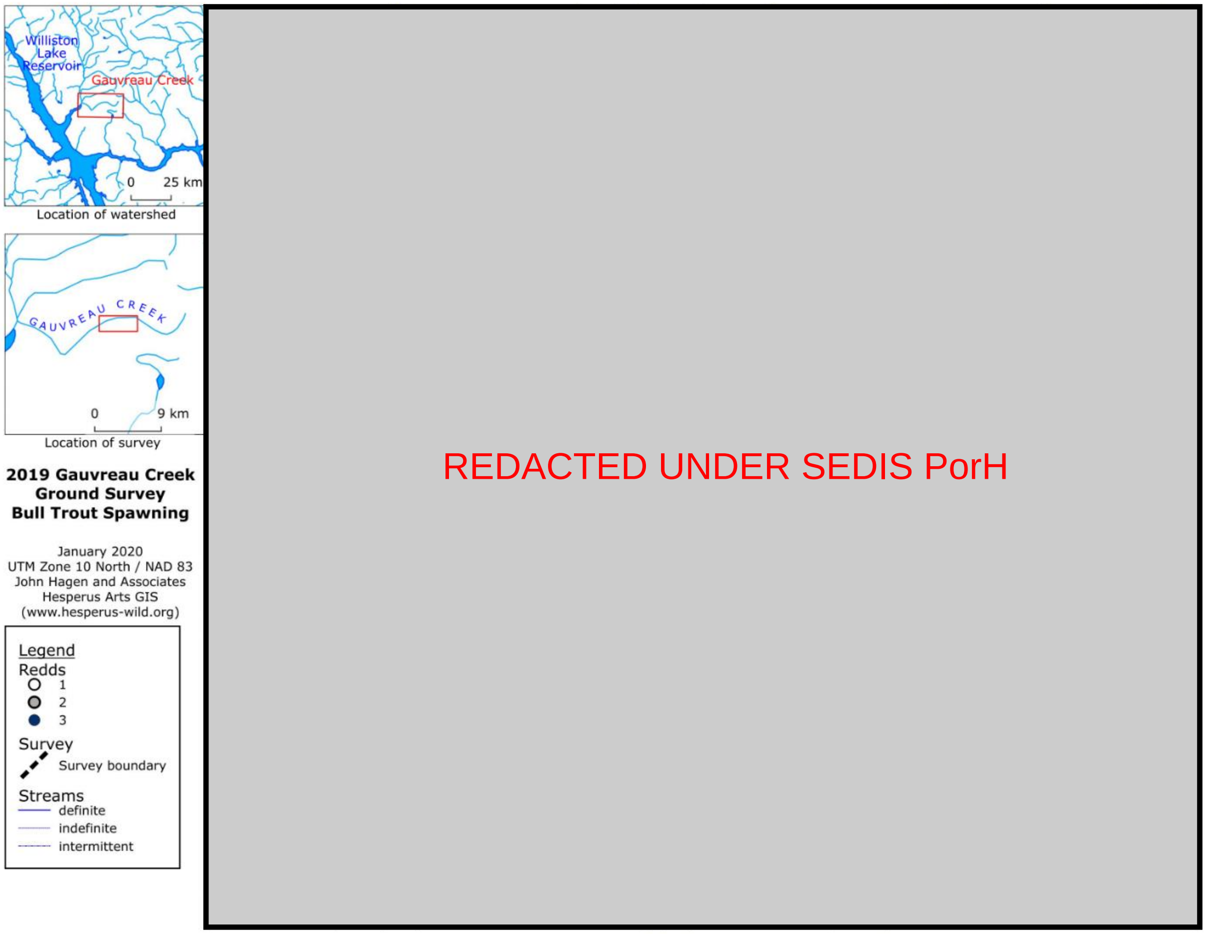

Figure 12. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during a foot survey of a new index section located in Gauvreau Creek in the lower Ospika River watershed, September 2019.

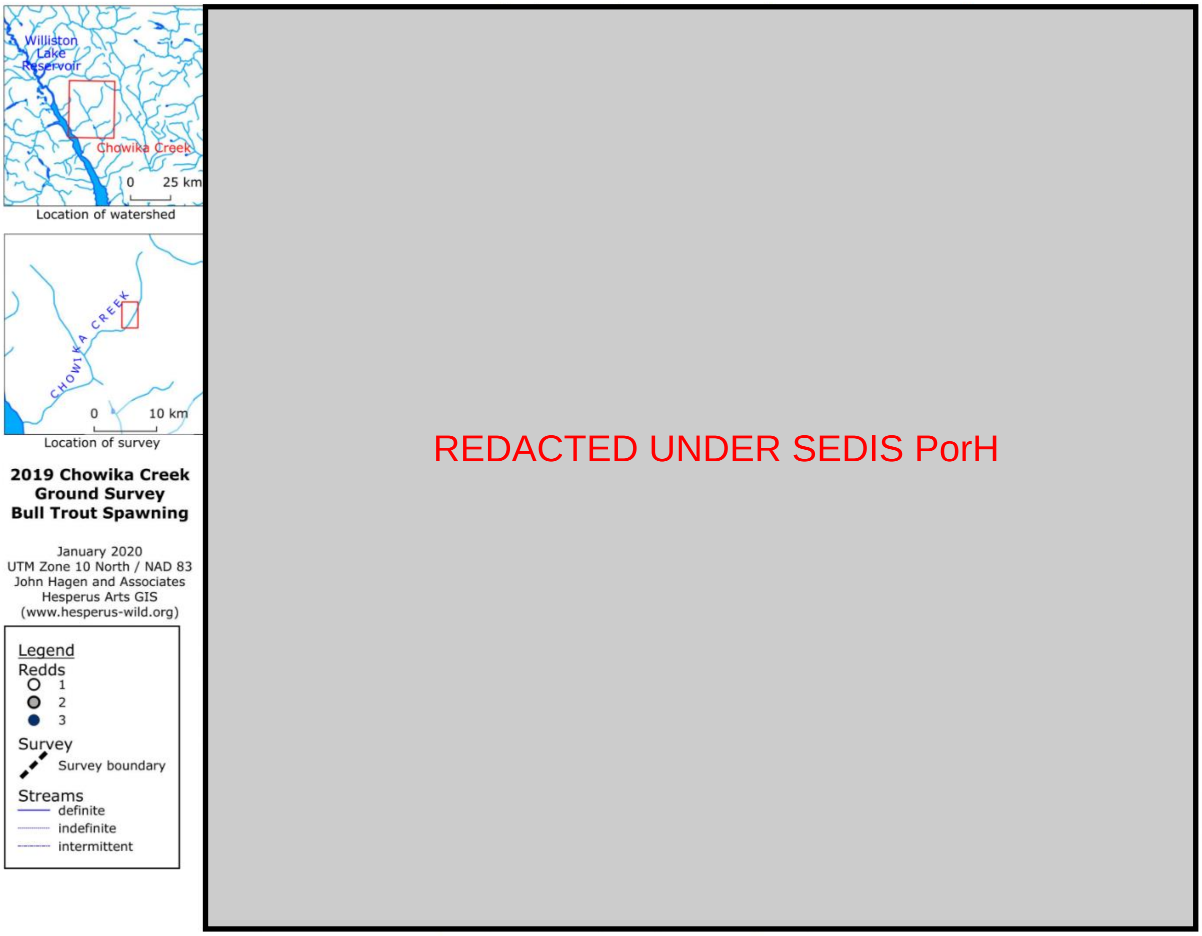

Figure 13. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) counted during a foot survey of a new index section located in Chowika Creek, September 2019.

Table 2. Bull Trout redd counts in new index sections of the Williston Reservoir watershed established since 2013, in a) sections adjacent to existing index sections to increase sampling fraction, and b) new watersheds.

Population	Stream Section	Section Length (km)	UTM bottom; UTM top	Redds in New Section						
				2013	2014	2015	2016	2017	2018	2019
a) Adjacent to long-term index sections (to increase sampling fraction)										
Point Creek	Upper mainstem (Section 1)	1.6		22	-	-	4	4	11	0
Davis River	Trib #2 (Unnamed 230-966200-75300)	1.2	REDACTED UNDER SEDIS PorH			35	35	30	50	42
Davis River	Trib #3 (Unnamed 230-966200-75600)	2.6				na	72	20	21	0
b) New watersheds										
Misinchinka River	Unnamed 236-073000-78200	1.2							16	-
Anzac River	Unnamed 236-313100-60100	1.8			26	21	26	-	-	-
Anzac River	Upper mainstem	1.4					8	-	-	-
Pelly River	Upper mainstem	5.5						61	-	-
Upper Mesilinka	Lay	3.6						25	32	-
Upper Osilinka	Upper mainstem	4.2						25	22	-
Upper Osilinka	Unnamed 238-024000-74400	3.8						22	18	-
Lower Omineca	Big Creek	2.7							26	-
Upper Omineca	Carruthers Creek	4.6							38	-
Lower Ospika	Gauvreau Creek	4.9								62
Chowika Creek	Upper mainstem	4.4								60

5.2 2019 aerial surveys

5.3.1 Redd distribution in tributaries to Parsnip Reach, Finlay Reach

Over the September 18-20 period in 2019, the calibrated aerial redd count methodology was applied to potentially suitable reaches[9] in tributaries on the eastern shore of Parsnip Reach (Figure 14), in the lower and middle Ospika River watershed (Figure 15, Figure 16, respectively), and in the Chowika Creek watershed (Figure 17). Aerial surveys were generally conducted from the stream mouth to the migration barrier, or to the upstream extent of estimated habitat suitability if no migration barrier was present. A total of roughly 270 km of accessible stream habitat was surveyed. In the course of the surveys, migration barriers were observed that in many cases had not previously been identified within the Fish Obstacles layer of the BC Geographic Warehouse – these are recorded in Table 3.

Tributaries to the eastern shore of Parsnip Reach do not appear to be utilized by significant populations of large-bodied, migratory Bull Trout (Table 4), with the exception of the long-term index section in Scott Creek (23 aerial redds; Figure 14) and Weston Creek (11 redds; Figure 14). A strong pattern of increasing distribution and abundance with increasing distance from Mackenzie was evident in the northern direction, and no redds were observed in tributaries south of Cut Thumb Creek including Tony Creek, Tutu Creek, Mugaha Creek, Chichouyenily Creek, and Mischinsinlika Creek (not mapped). Very small populations were indicated in Patsuk Creek (2 redds) and in Cut Thumb Creek (2 redds), which had relatively short accessible lengths (Figure 14). Expansion of all aerial counts in tributaries to the east shore of Parsnip Reach, accounting for redd detection probability <1 and assuming 2 spawners per redd, results in a minimum population estimate of approximately 130 spawners (Table 4).

In 2019, surveys of tributary watersheds on the eastern shore of Finlay Reach were limited to the lower (downstream of an entrenched canyon) and middle (up to and including the McCusker Creek watershed) portions of the Ospika River watershed (Figure 15, Figure 16, respectively) and to the Chowika Creek watershed (Figure 17). In contrast to tributaries to Parsnip Reach, substantial populations of Bull Trout were identified in both the lower Ospika and Chowika watersheds (Table 4). In the lower Ospika River watershed, key spawning zones were located in three unroaded watersheds on the eastern bank of the Ospika with substantial accessible lengths: Gauvreau Creek (72 aerial redds; Figure 15), Stevenson Creek (31 redds), and Aley Creek (22 redds). Smaller populations were detected in Steve Creek (2 redds; Figure 2), where a population of large-bodied spawners is known from previous work (reviewed in Hagen and Weber 2019), and unnamed tributary 230-935100-11500 (4 redds).

[9] Generally: 3rd order and larger tributaries of 10 km length or more draining higher elevations.

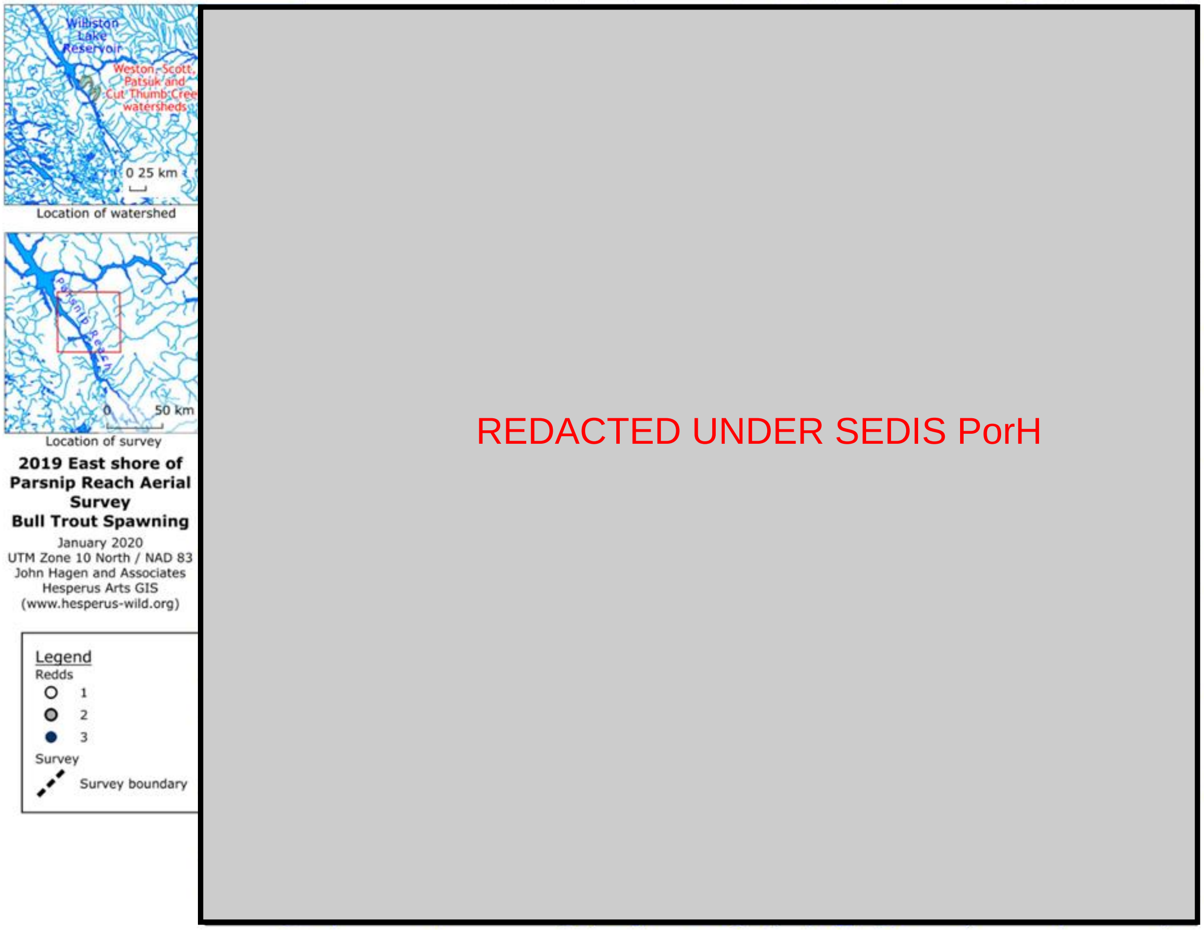

Figure 14. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) observed during aerial surveys of tributaries on the eastern shore of Parsnip Reach, Williston Reservoir, September 2019.

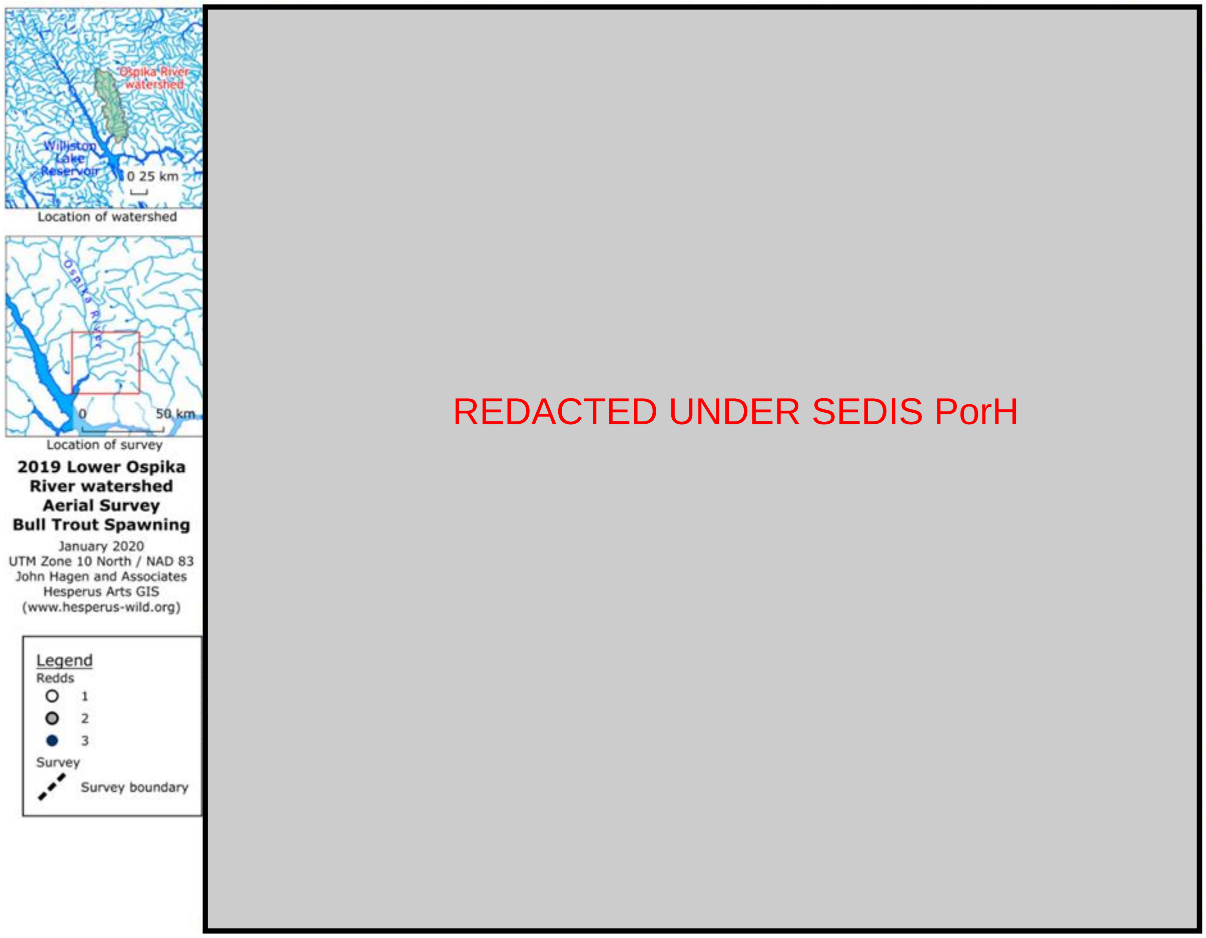

Figure 15. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) observed during aerial surveys of tributaries to the lower Ospika River, Williston Reservoir watershed, September 2019.

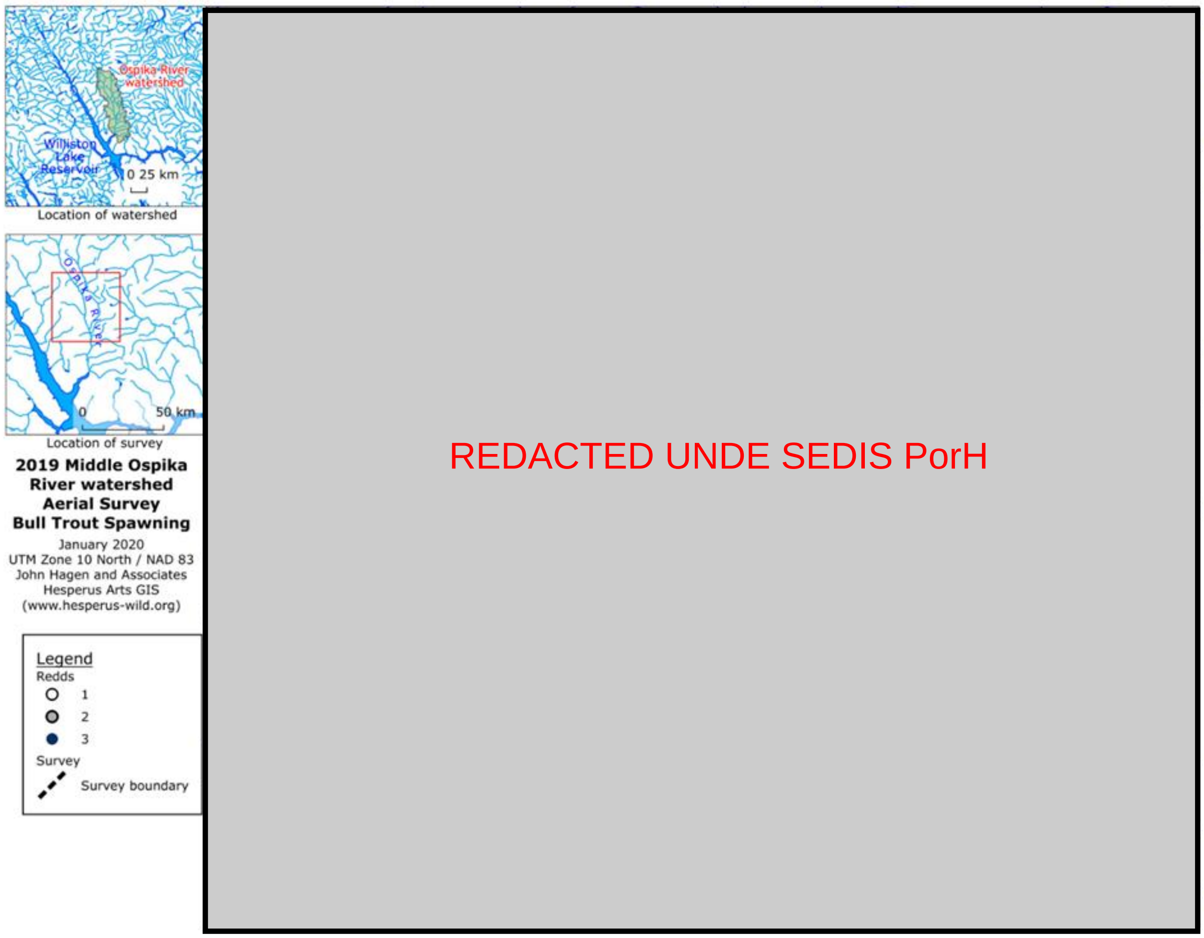

Figure 16. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) observed during aerial surveys of tributaries to the middle Ospika River, Williston Reservoir watershed, September 2019.

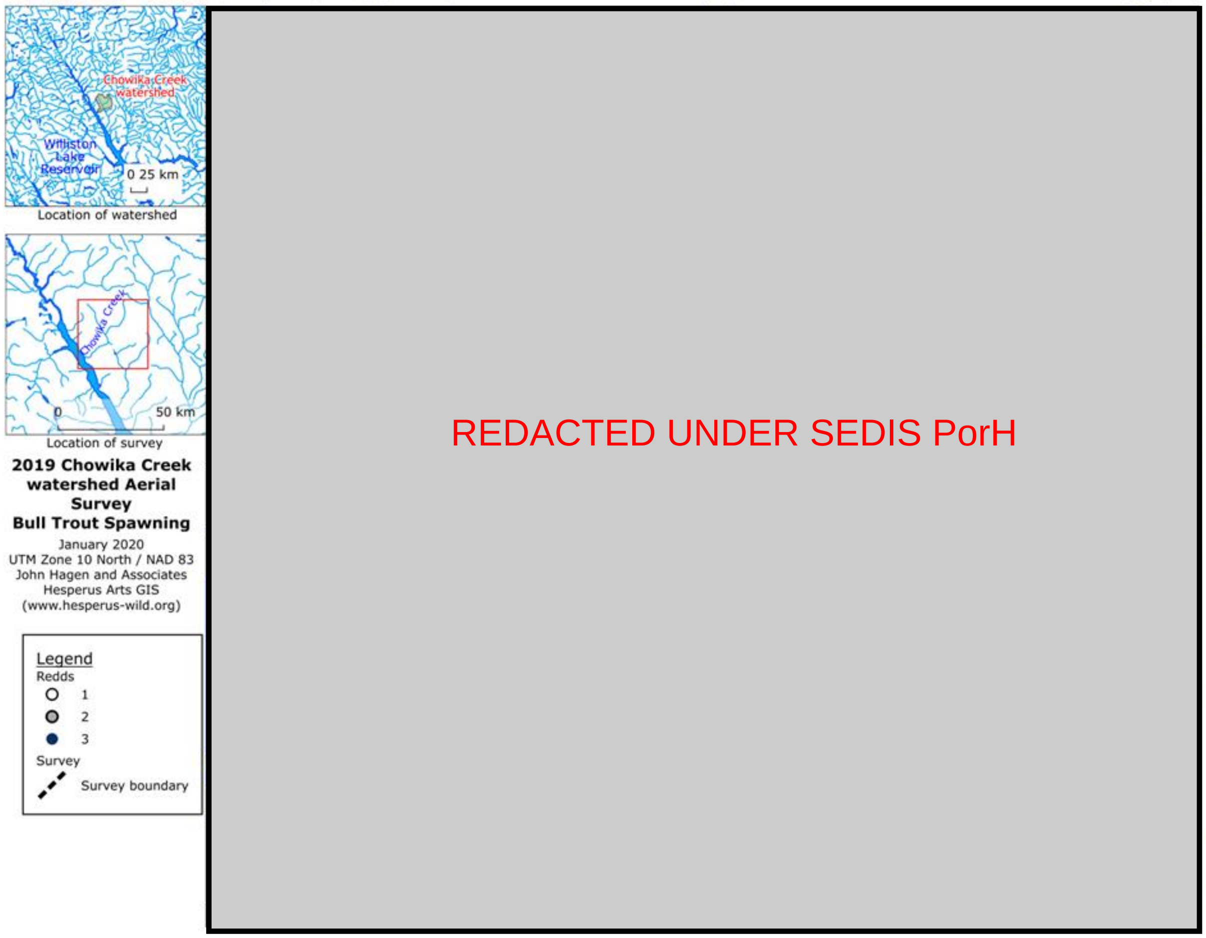

Figure 17. Locations of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) observed during aerial surveys of Chowika Creek, Williston Reservoir watershed, September 2019.

Table 3. Bull Trout migration obstructions identified during aerial surveys of tributary reaches on the eastern shores of Parsnip Reach and Finlay Reach, September 2019. Heights are in meters.

Stream	Section	Obstruction type	Height	Assessment	UTM
Weston	Mainstem	Chute obstruction	2.0	Potential barrier	10 U 466401 6189401
Weston	Mainstem	Waterfall impassable	4.5	Impassable	10 U 466696 6189678
Six Mile	Mainstem	Beaver dam impassable	1.0	Impassable	10 U 473988 6165744
Six Mile	Patsuk	Waterfall impassable	3.0	Impassable	10 U 477838 6167820
Cut Thumb	Mainstem	Waterfall impassable	5.0	Impassable	10 U 481654 6156556
Tony	Mainstem	Beaver dam impassable	1.0	Impassable	10 U 485801 6150012
Tutu	Mainstem	Beaver dam impassable	1.0	Impassable	10 U 486470 6144628
Mugaha	Mainstem	Waterfall impassable	5.0	Impassable	10 U 493622 6146021
Chichouyenily	Mainstem	Waterfall obstruction	2.5	Potential barrier	10 U 500772 6134467
Mischinsinlika	Mainstem	Cascade obstruction	2.0	Potential barrier	10 U 506906 6125603
Mischinsinlika	Mainstem	Waterfall impassable	3.0	Impassable	10 U 512514 6133354
Gauvreau	Mainstem	Chute impassable	3.0	Impassable	10 V 458953 6243669
Stevenson	Mainstem	Waterfall impassable	4.0	Impassable	10 V 458339 6251618
Ospika	230-935100-09300	Waterfall impassable	8.0	Impassable	10 V 439359 6253545
Aley	Mainstem	Waterfall impassable	6.0	Impassable	10 V 462376 6258530
Aley	Mainstem	Waterfall impassable	10.0	Impassable	10 V 462517 6258365
Ospika	Mainstem	Chute obstruction	2.5	Passable	10 V 441992 6266230
Ospika	230-935100-30200	Waterfall impassable	10.0	Impassable	10 V 432041 6275106
Ospika	230-935100-34100	Waterfall impassable	6.0	Impassable	10 V 437590 6278845
Ospika	McCusker	Chute obstruction	2.0	Passable	10 V 437056 6292616
Chowika	Mainstem	Chute obstruction	2.0	Passable	10 V 397263 6293250
Chowika	230-986000-30600	Waterfall impassable	3.0	Impassable	10 V 410231 6299585
Chowika	230-986000-67900	Chute obstruction	2.0	Passable	10 V 411511 6303831
Chowika	230-986000-67900	Beaver dam impassable	1.0	Impassable	10 V 413814 6304225
Chowika	230-986000-42100	Beaver dam obstruction	0.5	Potential barrier	10 V 401818 6300616
Chowika	230-986000-42100-50900	Cascade obstruction	2.0	Potential barrier	10 V 398183 6310224
Chowika	230-986000-42100-50900	Waterfall obstruction	3.0	Potential barrier	10 V 398252 6310314

Table 4. Helicopter-based, aerial counts of Bull Trout redds in tributaries on the eastern shores of Parsnip Reach and Finlay Reach, September 2019.

Reach	Aerial redd count	Estimated redd detection probability[1]	Estimated redd abundance	Minimum estimated spawner abundance
Scott Creek	23	60%	38	77
Weston Creek	11	53%	21	42
Patsuk Creek	2	53%	4	8
Cut Thumb Creek	2	53%	4	8
Gauvreau Creek	72	58%	124	248
Stevenson Creek	31	53%	58	117
Steve Creek	2	53%	4	8
230-935100-11500	4	53%	8	15
Aley Creek	22	53%	42	83
230-935100-34100	8	53%	15	30
230-935100-45600-8300	6	53%	11	23
Chowika Creek	34	42%	81	162
230-986000-30600	9	53%	17	34
230-986000-42100	1	53%	2	4
230-986000-67900	6	53%	11	23
Estimated total abundance			*440*	*880*

[1]See section *4.4.2*

In the middle Ospika River watershed, successful passage of Bull Trout through the canyon was indicated by populations detected in unnamed tributary 230-935100-34100 (8 redds; Figure 16), and an unnamed tributary to McCusker Creek 230-935100-45600-08300 (6 redds). After expansion of the aerial counts to account for redd detection probability <1, the minimum adult population size associated with these aerial redd counts is approximately 520 Bull Trout spawners for the Ospika River watershed (Table 4). A substantial increase in this number may occur following the completion of aerial surveys in the upper Ospika River watershed in 2020 (if funded).

The total aerial redd count for the Chowika Creek watershed equates to a minimum population size of roughly 220 spawners in 2019 (Table 4). Spawning was distributed in the upper mainstem of Chowika Creek (34 aerial redds; Figure 17), unnamed tributary 230-986000-30600 (9 redds), and unnamed tributary 230-986000-67900 (6 redds). Notably, only a single redd was observed in unnamed Chowika Creek tributary 230-986000-42100 above a beaver dam obstruction at its mouth.

5.3.2 Critical habitat segments

Aerial redd count data were combined with juvenile Bull Trout sampling records to delineate 16 new critical habitat segments (Table 5). Additionally, the boundaries of 4 previously-assessed critical habitats in Steve Creek and the Chowika Creek mainstem were refined. When added to segments compiled in the 2019 FWCP information synthesis document (Hagen and Weber 2019), this increases the total number of critical habitat segments for the Williston Reservoir watershed to 109. GIS position data for these critical habitat segments are considered to be sensitive data by the BC Government at this point in time, but can be requested for habitat conservation and monitoring purposes as necessary.

Table 5. New critical habitats delineated for Bull Trout populations inhabiting watersheds on the eastern shores of Parsnip Reach and Finlay Reach, 2019. Sampling methods EF and VO refer to electrofishing and visual observation, respectively. Sensitive position data may be requested from author I. Spendlow, FLNRORD Fisheries Section, ian.spendlow@gov.bc.ca

ID	Watershed	Section	Critical habitat	Sampling methods	Information adequacy	UTM bottom; UTM top	Key reference(s)
66	Ospika	Steve (230-935100-05700)	Spawning	VO	Moderate	Redacted	Aecom 2011; this study
	Comments: Large-bodied BT to 67 cm also observed spawning in Steve Creek sites 6, 7 (Aecom 2011)						
67	Ospika	Steve (230-935100-05700)	Juveniles	VO, EF	Low-moderate	Redacted	Aecom 2011; BC Geographic Warehouse 2019
	Comments: limited sampling in lower end, but BT rearing likely extend sto mouth						
78	Chowika	Mainstem	Spawning	VO	Moderate	Redacted	MWLAP 2002 unpublished; this study
	Comments: Redd counts from 1998-2002 period also available in FLNRORD Region 7 Fisheries database.						
79	Chowika	Mainstem	Juveniles	VO, EF	Low-moderate	Redacted	MWLAP 2002 unpublished; Langston and Blackman 1993
	Comments: Fry rearing right to mouth but limited sampling data; obstructions 4-5 km from mouth do not restrict access for spawners						
92	Weston	Mainstem	Spawning	VO	Moderate	Redacted	Slaney 1992; this study
	Comments: Second most important spawning stream in Parsnip Reach after Scott Creek; also identified during fish fence operation in early 1990s						
93	Weston	Mainstem	Juveniles	VO, EF	Low-moderate	Redacted	BC Geographic Warehouse 2020; this study

	Comment: Juvenile rearing down to at least the road crossing						
94	Gauvreau	Mainstem	Spawning	VO	Moderate	Redacted	This study
	Comments: Major tributary to lower Ospika River; ground survey of 62 redds in new index section also						
95	Gauvreau	Mainstem	Juveniles	VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						
96	Gauvreau	230-935100-00800-31000	Spawning, Juveniles	VO	Moderate	Redacted	This study
	Comments: Tributary to Gauvreau C, lower Ospika watershed; high redd density confirmed during calibration survey						
97	Stevenson	Mainstem	Spawing	VO	Low-moderate	Redacted	This study
	Comments: Major tributary to lower Ospika River; upper watershed completely burnt during recent forest fire						
98	Stevenson	Mainstem	Juveniles	EF, VO	Low-moderate	Redacted	BC Geographic Warehouse 2020; this study
	Comments: limited records from lower end but juvenile BT present						
99	Ospika	230-935100-11500	Spawning, Juveniles	EF, VO	Low-moderate	Redacted	BC Geographic Warehouse 2020; this study
	Comments: Unnamed Ospika tributary, poorly suited to aerial survey method; limited EF records from lower end						
100	Aley	Mainstem	Spawning	VO	Low-moderate	Redacted	This study
	Comments: Major tributary to lower Ospika River; pristine habitat condition						
101	Aley	Mainstem	Juveniles	EF, VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						
102	Ospika	230-935100-34100	Spawning	VO	Low-moderate	Redacted	This study
	Comments: Unnamed tributary to Ospika above canyon; juveniles assumed to the mouth						
103	Ospika	230-935100-34100	Juveniles	VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						
104	Ospika	230-935100-45600-08300	Spawning	VO	Low-moderate	Redacted	This study
	Comments: Unnamed tributary to McCusker Creek above its lower canyon						
105	Ospika	230-935100-45600-08300	Juveniles	VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						
106	Chowika	230-986000-30600	Spawning	VO	Low-moderate	Redacted	This study
	Comments: Unnamed South fork of upper Chowika Creek						
107	Chowika	230-986000-30600	Juveniles	VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						
108	Chowika	230-986000-67900	Spawning	VO	Low-moderate	Redacted	This study
	Comments: Unnamed tributary to upper Chowika Creek mainstem						
109	Chowika	230-986000-67900	Juveniles	VO	Low	Redacted	This study
	Comments: Redd data only, juvenile distribution assumed to extend to mouth						

5.3.3 Performance of the calibrated aerial redd count methodology

Three new calibration reaches were surveyed in September 2019 to estimate the accuracy of aerial redd counts, bringing the total number of calibration sites surveyed since 2012 to 28 (Table 6; Figure 18). In our analysis of the accuracy and precision of the methodology to date, aerial redd counts performed moderately well as a predictor of counts made on the ground in simple linear regression (R^2 = 0.84; Figure 19). However, aerial redd counts underestimated the number of redds counted during subsequent foot surveys at all 28 calibration locations, and negative bias was usually substantial (Table 6). Mean detection probability among calibration sites, computed based on arcsine square root-transformed site estimates, was 0.52 ± 0.028. More importantly, aerial redd counts were an imprecise indicator of the counts on the ground at all levels of spawning activity (Figure 19), with detection probability estimates exhibited substantial variability among sites ranging from 0.23 to 0.85 (Stdev = 0.15) (Table 6). Some populations with very low levels of spawning activity, therefore, may not have been detected at all using the aerial method.

A question of key interest to our team was whether predictions of aerial redd detection probability in future could be improved through the use of a model incorporating physical habitat variables. Improved prediction of ground survey counts from aerial redd count data in calibration reaches was indeed possible through the use of aerial redd detection probability models. In our logistic regression analyses the global model containing predictors CONTRAST, GRAVEL, OH, and interactions CONTRAST*GRAVEL, CONTRAST*OH, and GRAVEL*OH resulted in a significant increase in the likelihood of the predictions relative to the constant-only model (χ^2 = 59.1, P <0.001).

In addition to the global model, we evaluated a candidate set of 11 simpler models using AIC_c (Table 7). The best was a model containing all three predictors CONTRAST, GRAVEL, and OH from the global model, but none of the interaction terms. The level of empirical support for all other models was considerably less (Δ_i >2), and simple models containing only CONTRAST or GRAVEL had essentially no support (Δ_i >10; Table 2). The likelihood of this model being the best, as indicated by the ratios of it's Akaike weight w_i to those of other candidate models, was at least three-fold higher than its closest rivals (Table 7).

With respect to the effects of the predictor variables on aerial redd detection probability, increasing CONTRAST and GRAVEL had a positive effect on detection probability, and increasing OH had a negative effect, all as expected. Mean levels of aerial redd detection probability associated with the 'low,' 'moderate,' and 'high' levels of CONTRAST were 0.41, 0.53, and 0.66, respectively. As an indication of the magnitudes of the effects of the latter two predictors on aerial redd detection probability, in the top-ranked model a 4-fold increase in GRAVEL in the bed material from 15% to 60% would correspond to a predicted increase in detection probability of approximately 0.14, while a 13-fold increase in OH cover from 2% to 26% of the wetted stream width would correspond to a decrease of approximately 0.22. These are the ranges observed for these physical habitat variables in calibration reaches.

Table 6. Calibration of aerial redd counts from northcentral B.C. watersheds, 2012-2019. ID numbers identify calibration reaches in Figure 18.

ID	Stream	Date	Observer team	Length surveyed (km)	Aerial redds	Foot survey redds	Detection probability	CONTRAST	GRAVEL	OH	Global Model Predicted *P*
1	Unnamed 236-614900-52600	18-Sep-14	JH, BK	1.3	2	5	0.40	low	0.15	0.25	0.27
2	Hominka River	Sep-2013	JH, BK	5.0	8	15	0.53	low	0.20	0.08	0.43
3	Table River	19-Sep-14	JH, IS	2.2	10	23	0.43	moderate	0.25	0.10	0.58
4	North Anzac River	20-Sep-14	JH, IS	1.1	2	5	0.40	low	0.15	0.05	0.40
5	Unnamed 236-313100-60100	20-Sep-14	JH, IS	1.6	15	26	0.58	high	0.15	0.02	0.66
6	Reynolds Creek	21-Sep-14	JH, BK	1.0	7	11	0.64	moderate	0.50	0.05	0.74
7	Misinchinka River	Sep-2012	RP, JH	5.2	32	67	0.48	moderate	0.20	0.20	0.47
8	Unnamed 236-073000-78200	21-Sep-18	JH, ZS	1.2	5	16	0.31	low	0.20	0.26	0.29
9	Scott Creek	Sep-2012	RP, JH	4.2	43	72	0.60	high	0.22	0.10	0.61
10	Point Creek	Sep-2012	RP, JH	4.1	22	40	0.55	high	0.30	0.10	0.62
11	Davis River	Sep-2013	JH, BK	3.9	29	62	0.47	low	0.20	0.03	0.47
12	Unnamed 230-966200-75300	16-Sep-15	JH, IS	1.1	8	35	0.23	low	0.15	0.20	0.30
13	Unnamed 230-966200-75600	18-Sep-16	JH, SF	2.6	44	72	0.61	moderate	0.60	0.15	0.61
14	Wrede Creek	21-Sep-16	JH, IS	2.1	15	23	0.65	high	0.20	0.15	0.56
15	Frederikson Creek	21-Sep-16	JH, MT	1.4	46	63	0.73	high	0.28	0.05	0.67
16	Attichika Creek	13-Sep-14	JH, DB	5.7	42	60	0.70	high	0.45	0.03	0.74
17	Pelly River	19-Sep-17	JH, IS	5.5	32	61	0.52	low	0.30	0.08	0.54
18	Lay Creek	21-Sep-17	JH, IS	3.6	17	20	0.85	moderate	0.35	0.15	0.55
19	Osilinka River	20-Sep-17	JH, IS	3.4	9	25	0.36	low	0.30	0.20	0.40
20	Carruthers Creek	19-Sep-18	JH, IS	4.6	29	38	0.76	high	0.40	0.07	0.68
21	Big Creek	17-Sep-18	JH, IS	2.7	9	26	0.35	moderate	0.30	0.25	0.42
22	Unnamed 230-935100-00800-31000	20-Sep-19	JH, EB	2.1	14	26	0.54	moderate	0.19	0.10	0.56
23	Gauvreau Creek	20-Sep-19	JH, EB	5.4	36	62	0.58	moderate	0.15	0.10	0.55
24	Chowika Creek	21-Sep-19	JH, EB	4.3	25	60	0.42	moderate	0.25	0.20	0.48
25	Goat River	24-Sep-14	JH, TF	3.7	19	43	0.44	low	0.20	0.15	0.37
26	McLeod Creek	26-Sep-14	JH, TF	5.6	18	32	0.56	moderate	0.18	0.15	0.51
27	Chalco Creek	26-Sep-12	RP, JH	6.6	20	42	0.48	low	0.20	0.12	0.40
28	Walker Creek	28-Sep-12	RP, JH	5.3	17	56	0.30	low	0.17	0.10	0.38

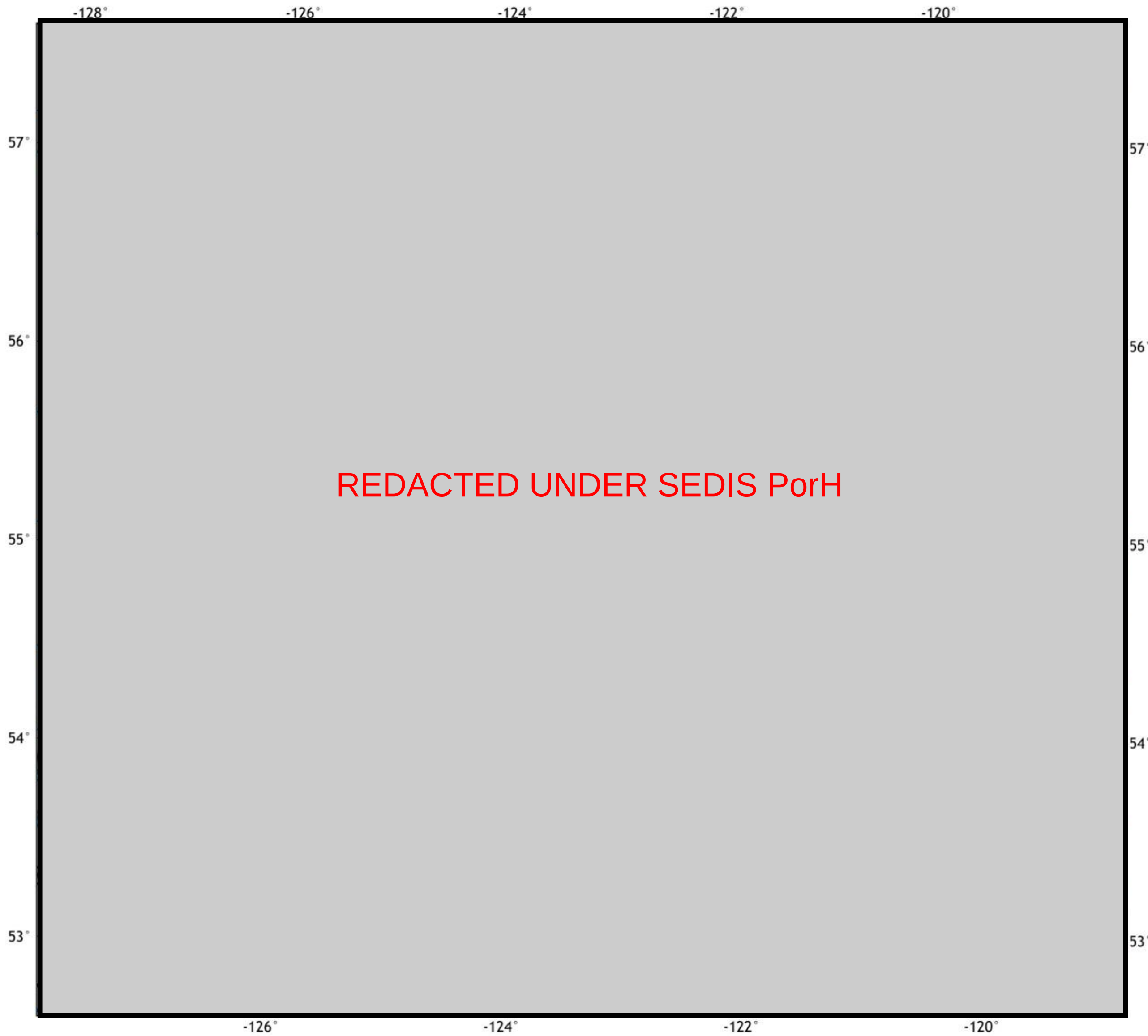

Figure 18. Locations of calibration sites in northcentral British Columbia where aerial redd counts were compared to those made during subsequent foot surveys. Numbers correspond to calibration site ID numbers in Table 6.

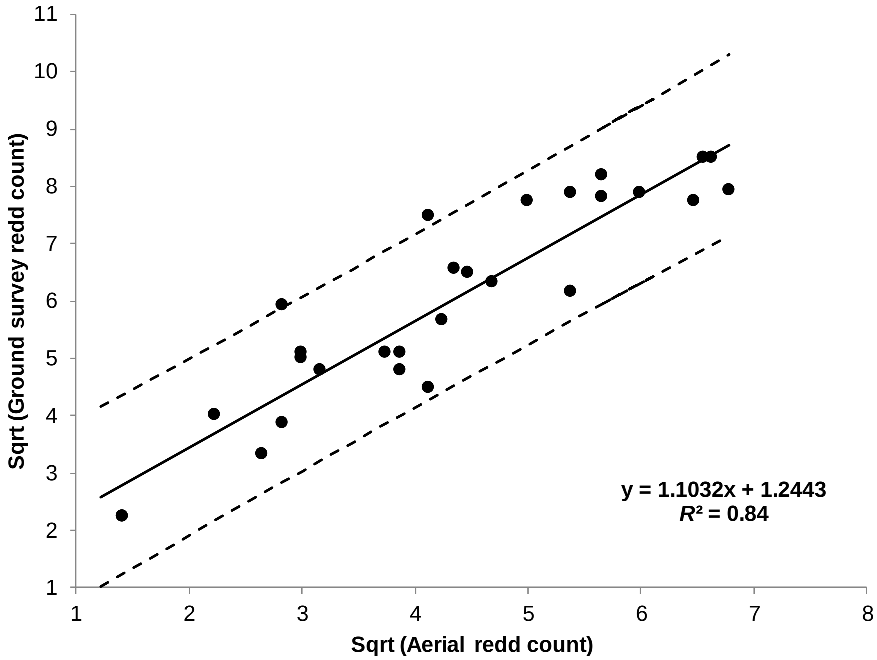

Figure 19. Prediction of ground survey-based redd counts in calibration sites from aerial counts made from a helicopter. Count data are square root-transformed to improve model fit and normalize data, and dashed lines represent 95% prediction intervals.

Table 7. Summary of comparison among candidate models of aerial redd detection probability estimated in 28 calibration reaches of the Williston Lake watershed and adjacent upper Fraser River watershed, British Columbia. Symbols K, Log (L), $\mathrm{AIC_c}$, Δ_i, L ($g_i|x$), w_i, denote 1) the number of estimable parameters, 2) model log-likelihoods, 3) the Akaike information criterion values adjusted for small sample size, 4) the difference in AIC_c values between each model and the model with the lowest AIC_c score, 5) the likelihood that the candidate model is the best among the set, and 6) Akaike weights, respectively (see text for descriptions). Models are listed in order of their AIC_c values.

Model	K	σ Log($\mathcal{L}$)	$\mathrm{AIC_c}$	Δ_i	$\mathcal{L}(g_i \mid x)$	w_i	Evidence ratio
CONTRAST+GRAVEL+OH	6	-66.5	149	0	1	0.479	1
CONTRAST+OH	5	-69.3	151	2.30	0.317	0.152	3.15
CONTRAST+GRAVEL+OH+ CONTRAST*GRAVEL	7	-65.9	151	2.54	0.281	0.134	3.56
CONTRAST+GRAVEL+OH+GRAVEL*OH	7	-66.4	152	3.41	0.181	0.0868	5.51
CONTRAST+GRAVEL+OH+CONTRAST*OH	7	-66.5	153	3.60	0.166	0.0793	6.04
CONTRAST+OH+CONTRAST*OH	6	-69.2	154	5.49	0.0644	0.0308	15.5
OH	2	-75.6	156	6.69	0.0353	0.0169	28.3
CONTRAST+GRAVEL	5	-71.7	156	7.09	0.0289	0.0138	34.6
CONTRAST+GRAVEL+OH+CONTRAST*GRAVEL+ CONTRAST*OH+GRAVEL*OH (Global)	9	-65.5	159	10.1	0.00644	0.00308	155
CONTRAST+GRAVEL+CONTRAST*GRAVEL	6	-71.7	159	10.3	0.00566	0.00271	177
CONTRAST	4	-75.2	160	11.2	0.00361	0.00173	277
GRAVEL	2	-86.5	178	28.6	6.29E-07	3.01E-07	1.59E+06
Constant-only	1	-96.0	194	45.3	1.49E-10	7.11E-11	6.73E+09

6.0 DISCUSSION

6.1 Population trend and limiting factors

Population growth rate, or trend, is one of the most important indicators of conservation status and risk for vertebrate populations (Caughley 1994; McElhany et al 2000; O'Grady et al. 2004; U.S. Fish and Wildlife Service 2005, 2015), and several studies have now assessed the validity of redd counts for assessing Bull Trout trends. When assessed at the scale of individual populations, evidence of substantial fluctuations in population abundance and high observation error (Rieman and Myers 1997; Maxell 1999; Dunham et al. 2001; Al-Chokhachy et al. 2005) have suggested that redd counts are insufficiently precise for rapid, sensitive detection of population changes, although the reliability of the counts can be improved through the use of experienced personnel (Muhlfeld et al. 2006; Howell and Sankovich 2012).

Although we have yet to study the effects of observation error on estimates of population trend anywhere in the Williston Reservoir watershed, it appears true in three of four long-term index reaches (Davis, Point, Misinchinka) that substantial fluctuations in abundance are occurring and likely limiting our ability to detect population changes. The exception at this point may be Scott Creek, the only population to exhibit a significant negative trend over its time series (Figure 10). Results of our aerial survey have additionally suggested that populations of Bull Trout along the eastern shore of Parsnip Reach are small and have a limited distribution (see section *6.2*). A small and declining population of Bull Trout in Parsnip Reach would be of conservation concern. However, Scott Creek also has the most limited time series, and it is premature to emphasize this evidence of declining trend until more data have accumulated. Monitoring goals for evaluating trend are two and three generations for the U.S. Fish and Wildlife Service (USFWS 2005) and Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010), respectively, which would correspond approximately 14 and 21 years, respectively, for typical British Columbia Bull Trout (Hagen and Decker 2011). Given evidence of high inter-annual variability in redd counts in long-term index sections of the Williston Reservoir watershed (Figure 10), these criteria appear appropriate for FWCP – Peace Region also.

Conversely, redd counts are cost-effective and non-invasive, factors which have enabled broad application of this monitoring method across the species' range. This high level of replication (e.g. up to 92 time series >10 years; Kovach et al. 2016) has enabled assessments of Bull Trout population growth rate at much larger spatial scales resulting in important insights in to limiting factors and conservation status, despite the imprecision of individual trend estimates (Baxter et al. 1999; Kovach et al. 2016; Kovach et al. 2018). In the long-term vision of this study (Hagen and Spendlow 2016), we aim to compensate for the lack of precision within individual time series by increasing replication among them. With the establishment of new index sections in the Chowika Creek and lower Ospika River watersheds in 2019, the system of index sections now covers 12 populations that are likely to be at least partially independent (Table 1, Table 2). We recommend a target of 15-20 populations for long-term monitoring, representing all core areas and a range of geographic locations, physical habitat attributes, and levels of land use and angler access.

Following the 2020-2021 season (if funded), we intend to complete the second five-year program review for this study. At that time, a focus will be detailed recommendations about index section selections and monitoring frequency (see section *7.0*). A component of the review will be to assess whether new index sections added adjacent to long-term index sections in the Davis River and Point Creek watersheds are of value. They were added to increase the sampling fraction for these two populations, but pose logistical challenges (i.e. longer days, riskier helicopter landing sites). This will be determined by 1) estimating the effect of combining new and long-term index sections on time series precision, 2) considering whether is it is defensible to adjust older counts to be compatible with the combined index section in future time series analysis, and 3) evaluating the long-term logistical feasibility of retaining the new index sections.

With respect to new index sections added to watersheds that are independent from the long-term index sections, annual monitoring in all new sections is not likely to be possible without prohibitive increases in program costs. A previously-recommended minimum level of effort for index sections used for evaluating limiting factors has been 5 years' monitoring data over a minimum 10-year period (Humbert et al. 2009; Kovach et al. 2016). Even if this objective is achieved, trend data alone may be insufficient given observed levels of interannual variability. A potential complementary approach to assessing limiting factors would be a correlation of existing levels of land use with patterns of Bull Trout distribution and abundance on the landscape, which could utilize data generated from the aerial redd methodology. These two approaches to assessing limiting factors will also be discussed in the upcoming five-year program review.

6.2 Critical natal habitats in watersheds on the eastern shores of Williston Reservoir

The monitoring of population trend in the four index streams Davis River, Misinchinka River, Point Creek, and Scott Creek is an important component of conservation status assessment for Williston Reservoir Bull Trout. However, population data in the forms of distribution, total spawner abundance, and locations of critical habitats may be of even greater importance in achieving the overarching FWCP strategic objectives for conservation, enhancement, and sustainable use of Bull Trout (FWCP 2014).

As mentioned previously, populations of large-bodied, migratory Bull Trout along the eastern shore of Parsnip Reach appear to be relatively small and have a limited distribution centered around Scott Creek and neighbouring Weston Creek (Figure 14). Scott and Weston creeks have been known since the early 1990s to be utilized by large-bodied, migratory Bull Trout (Slaney 1992), but until now the relative importance of Weston Creek to the Parsnip Reach Bull Trout population has been unknown. After expansion of the aerial redd counts for redd detection probability <1 and a simplistic assumption of 2 spawners per redd (section *4.4.2*), the 11 redds observed from the air in Weston Creek (Figure 14) equate to a minimum estimate of approximately 42 spawners in 2019, roughly half that for Scott Creek (Table 4).

For other tributaries on the east shore of Parsnip Reach, prior to this study we had a poor understanding of critical spawning and juvenile rearing habitats for large-bodied, adfluvial spawners from Williston Reservoir (Hagen and Weber 2019). In this study, no Bull Trout redds were observed in small tributaries south of Cut Thumb Creek including Tony Creek, Tutu Creek, Mugaha Creek, Chichouyenily Creek, and Mischinsinlika Creek. Juvenile Bull Trout sampling records exist for many of these systems (Hagen and Weber 2019). Three potential explanations exist for the lack of redds observed in these streams during this study. First, these streams were very small and may have been marginally suitable for the aerial redd count methodology, as discussed in the following section, and very small populations of large-bodied Bull Trout may not have been detected at all. Second, the productivities of these streams may be too low for the adfluvial Bull Trout life history, for example due to the low elevations of accessible habitat and potential competition from Rainbow Trout, and Bull Trout present in these systems may have a stream resident life history and restricted distribution. Third, the distribution and abundance of adfluvial Bull Trout in tributaries to Parsnip Reach may have declined in recent years. Habitat suitability in tributary streams may be relatively low compared to other core areas in the

Williston Reservoir watershed. Aerial survey notes identify multiple areas of channel instability in Weston Creek, evidence of forestry-related habitat degradation including widespread riparian logging in Mischinsinlika Creek, and beaver dams limiting access in the smallest of these streams (Figure 14). With regards to Mischinsinlika Creek, especially, the complete lack of redds was a surprise given the accessible length of this system. A more quantitative assessment of limiting factors (e.g. land use) is a recommendation for future analysis (section *7.0*).

Given small and potentially declining populations of large-bodied, migratory Bull Trout on the eastern shore of Parsnip Reach, and warmer water temperatures and relatively high levels of land in the Nation River and Manson River watersheds,[10] the risk to Bull Trout of the Parsnip Reach core area may be relatively high. Any attempt to use this information to assess conservation status for the core area as a whole, however, is confounded at this point in time by the lack of population structure data validating core area boundaries. This a key information gap for the species across all core areas of the Williston Reservoir watershed (Hagen and Weber 2019).

In 2019, we discovered two strong hubs of Bull Trout abundance in the Finlay Reach core area, in the Ospika River and Chowika Creek watersheds. Tributaries of the lower Ospika River, in particular, provide extensive critical habitats for large-bodied, adfluvial Bull Trout (Table 4, Table 5: Gauvreau, Stevenson, Aley watersheds) and have substantial local populations. While the two populations discovered upstream of the Ospika River canyon appear to be small (Table 4: unnamed tributaries 230-935100-34100, 230-935100-45600-8300), it is important to note that much of the upper Ospika River watershed remains unsurveyed. The upper Ospika River system is in close proximity to the lower Finlay River watershed, and will be surveyed during the 2020 field season (if funded). The upper mainstem of Chowika Creek also provides important critical habitat for a substantial population (Table 4, Table 5), with more restricted spawning zones in unnamed tributaries 230-986000-30600, 230-986000-42100, and 230-986000-67900.

In contrast to the Parsnip Reach core area, productive critical habitats for large-bodied, migratory Bull Trout are distributed widely in the Finlay Reach core area. In addition to large populations in the Ospika River and Chowika Creek watersheds, major populations approaching 1,000 spawners each have also been described in the Davis River and Ingenika River watersheds (Hagen and Spendlow 2016; Hagen and Spendlow 2017). Conservation status for Bull Trout appears to much more secure in the northern arm of the reservoir. In addition to a large and potentially stable (Figure 10a) population of adfluvial fish, known critical habitats are in relatively pristine condition located beyond the end of the road network (Hagen and Weber 2019). This is potentially an early indication of the effects of limiting factors affecting habitat productivity, e.g. land use and the distance from human population centers, but as indicated above a quantitative assessment of limiting factors is a recommendation for future analysis.

[10] Critical natal habitats for large-bodied, migratory populations of Bull Trout have not been discovered in these two watersheds. It is conceivable that observed concentrations of large-bodied Bull Trout may have been presence on foraging migrations, rather than spawning migrations (Hagen and Weber 2019).

6.3 Performance and utility of the calibrated aerial redd count methodology

Given that sufficient calibration data have accumulated over the multi-year period of this study, a quantitative assessment of the calibrated aerial redd count methodology was a priority for this year's report. In our assessment, aerial counts performed moderately well as a predictor of redd abundance on the ground (Figure 19). This suggests that the method is useful in northcentral British Columbia for identifying key spawning streams and indicating the relative importance of each. Given detection probability <1 and its substantial variability among sites (Figure 19, Table 6), however, it is clear that unadjusted aerial redd counts are inappropriate for applications in northcentral British Columbia where accurate, precise knowledge is required of the level of Bull Trout spawning activity. Important examples of such applications include effectiveness monitoring for habitat enhancement experiments (e.g. stream fertilization), studies of limiting factors (e.g. water temperature), and long-term monitoring of population growth rate in index sites (e.g. Saffel and Scarnecchia 1995; Rieman and Myers 1997; Baxter et al. 1999; Dunham et al. 2001; Kovach et al. 2016, 2018; Hagen and Weber 2019).

However, research by Hankin (1984) has identified that uncertainty in the estimate of abundance of a fish population occupying a large area like a stream or river basin is likely to be more strongly affected by high spatial variability in fish abundance among sample sites than by uncertainty in estimates of abundance within sites. Uncertainty in estimates of population size and distribution for larger areas can be reduced by increasing the number of sample sites through the use of rapid assessment methods, of which the calibrated aerial redd methodology is an example. These rapid methods sacrifice accuracy at individual sites to allow a larger number of sites to be sampled for a given amount of sampling effort. The validity of the rapid method is assessed by comparing results to those obtained from more intensive methods with greater precision and accuracy (Hankin 1984; Hankin and Reeves 1988). To properly assess the utility of the calibrated aerial redd count methodology within the Williston Reservoir watershed, therefore, its performance as described above must be weighed against to the efficiency of the method, the potential applications of the aerial redd count data, and the urgency for the information.

In our experience, helicopter-based aerial redd counts have been rapid and efficient. The majority of Williston Lake's tributary streams drain higher elevation areas and mountainous terrain, and were expected a priori to have habitat suitable for the cold water-adapted Bull Trout (Hagen and Decker 2011). The prospect of empirical studies of Bull Trout habitat use using traditional foot surveys, within potentially thousands of kilometers of accessible stream habitat, was daunting to say the least and only expected to be feasible at the temporal scale of decades, not years. In the five years 2014-2019 that the aerial count methodology has been applied to previously-unsurveyed streams in the Williston Reservoir watershed, a total of approximately 1,750 km of accessible stream habitat has been surveyed in 19 days' accumulated effort using roughly 5.5-6 hours per day of helicopter time. This equates to an estimate of approximately 90 km of stream habitat per day, 18-fold higher than our 5 km-per-day normal rate of travel during traditional foot surveys. We now anticipate that two to three more years' effort are required to complete surveys in suitable watersheds around the entire circumference of the reservoir.

During this same time, the number of identified, critical spawning zones has been increased from 4 to 56 totaling 380 km of stream habitat (derived from Hagen and Weber 2019 plus 2019 results from this study). The utility of this information has already been high, in several important respects. First, knowledge of critical spawning zones has allowed us to identify new index reaches for long-term monitoring of population growth rate using traditional ground surveys. As described in section *6.1*, these new index reaches represent a range of geographic locations, physical habitat characteristics, and levels of land use, and should enable improved assessments of limiting factors. Second, estimates of critical habitat locations and abundance at the spatial scale of whole conservation units (core areas: Hagen and Weber 2019) have enabled improved assessments of conservation status and risk.[11] Most importantly, critical habitat locations first identified by the aerial redd count methodology are now candidates for potential habitat conservation actions provided for in British Columbia's *Government Actions Regulation*, following corroboration with on-the-ground redd surveys in at least one additional year. Currently, the majority of critical spawning habitats for Bull Trout of the Williston Reservoir watershed are in productive condition beyond the end of the road network (Hagen and Weber 2019). The urgency for habitat conservation actions is high, given the expected, imminent expansion of the road network in to many of these sub-basins, ongoing colonization of Williston Reservoir by Lake Trout *Salvelinus namaycush*, and expectations for increased water temperature related to land use and climate change (Kovach et al. 2016).

In our application of the aerial redd count method in the Williston Reservoir watershed, a key limitation was the unsuitability of the method for the smallest of tributary streams, which were not surveyed due to high levels of crown closure and overhead vegetation cover necessitating an extremely slow rate of travel. This limitation, in combination with the potential for not detecting very small populations due to variable detection probability, indicates that underestimation bias is likely in our estimates of critical spawning habitats in the Williston Reservoir watershed. This underestimation bias was not evaluated quantitatively during this study but may be important depending on the future use of the monitoring data. In the experience of the authors, redds of large-bodied, migratory Bull Trout have been found in stream sections as small as 2 m wetted width. It is also true in our experience, however, that redds in such streams have made up a small proportion of the total for the population (e.g. Thutade Lake watershed, Hagen 2000), suggesting that aerial redd counts are still likely to be valid for indicating the most important critical habitats affecting the productivity of the population, and for assessing relative abundance among watersheds (a potentially important factor in prioritizing habitat conservation actions). For

[11] The USFWS (2005) *Core Area Conservation Status and Risk Assessment* methodology has been applied outside of the contiguous United States in both British Columbia (Hagen and Decker 2011) and Alberta (Rodtka 2009).

purposes requiring greater precision and accuracy in the redd count data, validation of estimates of critical habitats and abundance using ground surveys will be necessary.

Given that Bull Trout redds are more difficult to identify from the air, and the time available for redd identification limited to seconds rather than minutes, our expectation a priori was that observer experience would be a critical factor affecting aerial redd counts. Because of budget limitations, we conducted aerial surveys only once per stream reach and only with the most experienced crew available. A second key limitation of our study, therefore, is the lack of replication enabling an assessment of the importance of observer experience, and of the repeatability of the aerial counts. Other investigators interested in the method will need to conduct their own evaluation of its validity, therefore, given available personnel and local stream habitat characteristics.

7.0 RECOMMENDATIONS

After the 2015 field season, three over-arching recommendations for the 2016-2020 period were made in a 5-year review of this Bull Trout monitoring program (Hagen and Spendlow 2016):

1. Continue annual monitoring in long-term index sections in the Davis, Point, Scott, and Misinchinka systems until time series for evaluating trend have reached the recommended minimum 2-3 generations.

2. Continue to apply the calibrated aerial redd count methodology at large spatial scales (i.e. major tributary systems) in order to delineate critical habitats, estimate spawner abundance, and identify new potential index sites.

3. Increase the spatial coverage of abundance monitoring by adding new on-the-ground index sections delineated on the basis of the aerial count data.

The 2019 field study described in this report was designed upon the recommendations listed above. The second year of this two-year FWCP funding proposal for the 2019 and 2020 field seasons, which if successful will focus on the lower Finlay River watershed in 2020, will complete the 5-year vision for a 'first draft' estimate of critical natal habitats for large-bodied, migratory Bull Trout around the entire Williston Reservoir watershed.

We have found that application of an aerial redd detection probability model significantly improved the fit of the modeled detection probability estimates to empirical redd count data. The three variables included in the best model, CONTRAST, GRAVEL, and OH, all can be readily estimated visually from the air. To date, these variables have not been visually estimated for reaches that did not also receive a calibration foot survey, and the model cannot be retroactively applied to these reaches. To facilitate application of the model to data generated during future aerial redd surveys in the lower Finlay River watershed (2020-2021 proposal) and elsewhere in the Williston Reservoir watershed, our first recommendation is that the aerial survey methodology be modified to include regular visual estimates of these three model variables.

Surveys of areas that do not receive calibration surveys on the ground will benefit from improved predictions of detection probability, thereby improving the utility of the aerial redd count data and the reliability of inferences drawn from them.

Our second and most important recommendation for next year (if funded) is for a 5-year program review to be included in the final report. This is because specific recommendations for future monitoring priorities for this study were not possible without redd distribution information from tributaries on the eastern shores of Williston Reservoir (this year's study) and from the lower Finlay River watershed (proposed 2020 study), and were not included in 2019's FWCP Bull Trout information synthesis and monitoring framework report (Hagen and Weber 2019). The priorities for the 5-year program review in 2020 would be: 1) an updated conservation status assessment for core areas of the Williston Reservoir watershed, 2) a recommended strategy for Bull Trout habitat conservation actions based on a more complete picture of critical habitats throughout the watershed, 3) a detailed schedule of foot surveys in new and long-term index sections covering a minimum of 15 populations that are expected to be at least partially independent from one another, 4) recommendations for an analysis of limiting factors based on Bull Trout distribution and abundance data collected to date, and 5) a recommendation on how to improve this study's ability to monitor the effects of climate change on Bull Trout and identify potential adaptations.

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