Bull Trout Spawner Abundance and Critical Habitats

Evaluation of Monitoring Requirements and Analysis of Limiting Factors

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Bull Trout Spawner Abundance and Critical Habitats: Evaluation of Monitoring Requirements and Analysis of Limiting Factors

FWCP Project No. PEA-F24-F-3848

Prepared For

Fish and Wildlife Compensation Program – Peace Region
3333 – 22nd Avenue | Prince George, BC | V2N 1B4

Prepared By

Bryce O'Connor, M.Sc.
Chu Cho Environmental
#201-1116 6th Ave | Prince George, BC | V2L 3M6

Mat Ferraro, B.Sc.
Chu Cho Environmental
#201-1116 6th Ave | Prince George, BC | V2L 3M6

John Hagen, M.Sc., R.P.Bio.
John Hagen and Associates
330 Alward St | Prince George, BC | V2M 2E3

Chu Cho Environmental Contact

Bryce O'Connor
250-643-4360
bryce@chuchoenvironmental.com

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Table of Contents

List of Figures

List of Tables

Executive Summary

Since 2001, the Fish and Wildlife Compensation Program – Peace Region (FWCP) has monitored the status of large-bodied, migratory Bull Trout populations in the Williston Reservoir watershed by conducting annual redd counts in index sections of four known spawning tributaries: Davis River (since 2001), Point Creek (since 2006), Misinchinka River (since 2006), and Scott Creek (since 2009). Population trends from the four long-term index streams alone are not representative at the watershed scale. For this reason, we proposed to increase the number of index streams from four to eight with the addition of Lay Creek, Pelly Creek, Pesika Creek, and Reynolds Creek (replaced by Anzac River). The goal of this increased monitoring is to provide a more holistic understanding of Bull Trout population growth rate and limiting factors around the reservoir. This approach will improve confidence in estimating conservation status and provide more certainty for projects investigating factors limiting Bull Trout population viability, which addresses Action #13 PEA.RLR.S04.RI of the Rivers, Lakes, and Reservoirs Action Plan.

Survey conditions were ideal in 2023 with low flows and good visibility in all index sections, so redd detection efficiency was assumed to be high. Population growth rates have varied between the populations in northern (Finlay) and southern (Peace and Parsnip) reaches of the Williston Reservoir. Up to 2023, the Davis River was the only population exhibiting a positive annual growth rate of 2.18%, on average, over the entirety of the survey time series. The number of redds observed in Point Creek in 2023 (28 redds) exceeded the long-term average, and population growth rate improved to 0.03%. Tributaries to Parsnip Reach however have exhibited significant negative population growth over the duration of the redd survey time series. Despite an average count in 2023, significant negative population trend for the Scott Creek population persisted with an estimated -3.77 % decline over the time series. The 2023 count in the Misinchinka River index section is the lowest on record (9 redds) and was greatly affected by limited fish access to the upper river.

The new index streams increase the spatial scope of surveys, which will improve confidence in the assessment of Bull Trout conservation status in the Williston Reservoir watershed. A total of 42 redds were observed in Pelly Creek compared to 48 redds in 2022; a total of 97 redds were observed in Pesika Creek compared to 121 in 2022; a total of 18 redds were observed in Lay creek compared to 32 in 2018; and 34 redds were observed in Anzac River compared to 34 in 2016. Given the increased cost of monitoring on a wider spatial scope, an evaluation of index monitoring requirements was conducted. This evaluation found that time series maintained at 75-100% completion will allow for accurate estimation of population growth rate.

Beginning in 2014 and concluding in 2022, the aerial survey identified critical spawning habitats throughout the Williston Reservoir watershed, a key information gap identified in the 2019 FWCP *Bull Trout Information Synthesis and Monitoring Framework*. The aerial survey data used to create critical habitat spatial layers with collaborator BC Ministry of Water, Land, and Resource Stewardship are now a key outreach product of this study. Those critical habitat layers now provide a means for which cumulative effects assessments can be used to evaluate limiting factors for Bull Trout. A preliminary CEMPRA model run was conducted on the critical habitats layers to test its application as a means of limiting factors analysis. This modeling tool (and other equivalent methodologies not presented here) offer a means of prioritization and ranking of

enhancement and conservation actions that could be undertaken by FWCP. Moving forward we recommend a focused effort on the evaluation of limiting factors for Bull Trout, and subsequent creation of potential on-the-ground enhancement actions targeted to specific critical habitats (i.e., populations). These actions will be prioritized based the results of cumulative effects modeling following the next steps (below), to be completed in winter 2024-2025. These next steps in the evaluation of limiting factors for Bull Trout using the CEMPRA modeling tool (or equivalent methodologies not reviewed here) include:

1. Define high-level objectives of cumulative effects modeling, and modeling framework which can meet those objectives (i.e., Joe Model or Population Model);
2. Define theoretical system capacity for the spatial layer over which the model is applied (adult spawning basins, or juvenile rearing basins);
3. Complete an assessment of habitat suitability curves for Bull Trout in the Williston Reservoir to refine stressor-response relationships in coordination with regional experts;
4. Gather biotic and abiotic data related to the stressor-response relationships which can be used in cumulative effects modeling (guided by the limiting factors presented here in Appendix 1 and those suggested by regional experts):
    a. Distribution data on sympatric species as a proxy for compeition;
    b. Re-run the WHOPR tool on the entire Bull Trout critical habitats geodatabse;
    c. Extract continuous temperature predictions where available and improve estimation of MWMT in critical habitats.

By conducting cumulative effects modeling on all critical habitat polygons with updated data, this project can provide the evaluation of limiting factors and prioritization of on-the-ground enhancement actions within discrete population units.

Acknowledgements

Prepared with financial support of the Fish and Wildlife Compensation Program on behalf of its program partners BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations, and public stakeholders. Additional funding was provided by Tsay Keh Dene Nation's Environmental Stewardship Initiative. Tsay Keh Dene Nation and McLeod Lake Indian Band are gratefully acknowledged for their long-standing support of this study. We also wish to thank Erica Bonderud, Nathan French, Ian Spendow, Luc Turcotte and Chelse Regina for their efforts in the field. Caroline Walters provided GIS support and created the maps used in this report. The authors thank Tom Halbert and Bailey Helicopters Ltd. for providing excellent service and flying expertise. This survey took place on the territories of the McLeod Lake Indian Band, Takla, Nak'azdli Whut'en, Saulteau, West Moberly, Kwadacha and Tsay Keh Dene First Nations.

1 Introduction

The Bull Trout (*Salvelinus confluentus; Chaba*) is among the most sensitive of British Columbia's wildlife species to human activities. Throughout the range of the Bull Trout, including the Williston Reservoir watershed, economic uses of the land have routinely been prioritized over habitat conservation. The consequence of this has been widespread population declines which are most acute in the United States and in southern parts of Alberta and British Columbia (BC) (Rieman and McIntyre 1993; Rieman et al. 1997; Paul and Post 2001; Post and Johnston 2002; High et al. 2008; Rodtka 2009; Hagen and Decker 2011; Kovach et al. 2016). This study is designed to provide information that can be utilized to sustain Bull Trout in the Williston Reservoir watershed for generations to come through investigations of Bull Trout population status, critical habitat locations, natural limiting factors, and anthropogenic threats.

Population declines across the Bull Trout range appear to be due to the cumulative effects of habitat degradation, introductions or range expansions of other species, 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. 2008; Rodtka 2009; Hagen and Decker 2011; Kovach et al. 2016). 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) as recognized by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which has been assigned a ranking of 'Special Concern' (COSEWIC 2012). Western Arctic Bull Trout populations are also on the Government of BC's Blue List of species of Special Concern (formerly Vulnerable) (https://a100.gov.bc.ca/pub/eswp/search.do;jsessionid=5C43A1DC768B5969B667016CAC1B692A).

In the Williston Reservoir watershed, threats to Bull Trout are posed by the introduction and naturalization of Lake Trout in the reservoir, which has typically resulted in competition for prey and the displacement of Bull Trout from lacustrine habitats where it has occurred (Donald and Alger 1993; Langston and Murphy 2008; Kovach et al. 2016), increases in road building and forest harvesting that have been enabled by reservoir inundation (Baxter et al. 1999; Kovach et al. 2016), and by climate change-related stream temperature warming (Isaak et al. 2015, 2016; Kovach et al. 2016). The Bull Trout is extremely sensitive to forestry and other human land uses in natal watersheds and has therefore been recognized by the BC Provincial Government as and 'Identified Wildlife Species at Risk' under the *Identified Wildlife Management Strategy* (BC MWLAP 2004; Hammond 2004; https://www.env.gov.bc.ca/wld/documents/identified/2006Jun_CatSAR.pdf).

The Bull Trout is a highly valued fish species in the upper Peace River Basin. Migratory Bull Trout, which grow to sizes of up to 90 cm on a piscivorous diet, provide a rare opportunity to catch 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 the Fish and

Wildlife Compensation Program – Peace Region (FWCP) and population monitoring has been ongoing since 2001.

Since 2001, the core component of FWCP's abundance monitoring program for large-bodied, migratory populations of Bull Trout has consisted of annual 'redd' counts in index sections of four known spawning tributaries. Redds are gravel nests excavated by the female Bull Trout into which fertilized eggs are deposited (Leggett 1980). Redd counts therefore provide an indication of the spawner population size and can be utilized to assess population growth rate or trend (Rieman and Myers 1997; Maxell 1999; Dunham et al. 2001; Al-Chokhachy et al. 2005; Muhlfeld et al. 2006; Howell and Sankovich 2012). Population 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). The redd count program in the Williston Reservoir watershed was initiated in the Davis River in 2001, followed by Point Creek and the Misinchinka River in 2006, and Scott Creek in 2009 (Andrusak et al. 2012).

In 2015, a five-year review of the program identified other key information needs that were not being addressed (Hagen and Spendlow 2016). First, with only four index sections, replication of redd count data was considered inadequate for reliably assessing population trend at the scale of the entire Williston Reservoir watershed, or within conservation units making up the watershed. Second, while population trend is one of the most important indicators of conservation status (O'Grady et al. 2004), there are other key indicators of status for fish populations including total adult abundance, distribution, and threats (McElhany et al. 2000; USFWS 2005). Values for these indicators can also be estimated using redd counts, but the spatial coverage of the redd count data was inadequate for these purposes. Finally, data indicating the distribution of critical spawning and early rearing habitats, which are limiting in Bull Trout populations (Baxter et al. 1999; Johnston et al. 2007; Kovach et al. 2016) and therefore key targets for conservation and enhancement actions were generally absent outside of the four long-term index sections.[1] It is important to note that in this report, we use the term 'critical habitat' to refer to habitat areas in which limiting factors operate to regulate recruitment of Bull Trout to the next generation (sensu Hagen and Weber 2019), rather than a legal definition linked to the listing of a species as threatened or endangered under the Species at Risk Act.

In 2015, two new components were added to the FWCP redd count program to address these information needs. The first of these new components was the development and application of a rapid, spatially-continuous aerial redd count method to delineate critical spawning habitats and estimate total spawner abundance. Prior to the 2023 field season, this method had been applied to accessible portions of the Parsnip (Hagen et al. 2015), Finlay Reach (Hagen and Spendlow 2016; Hagen et al. 2020, 2021), Ingenika (Hagen and Spendlow 2017), Mesilinka (Hagen and Spendlow 2018), Osilinka (Hagen and Spendlow 2018), Omineca (Hagen and Spendlow 2019), Parsnip Reach (Hagen et al. 2020; Hagen et al. 2023), and Lower Finlay (Hagen et al. 2022) watersheds. A similar study was conducted in tributaries of the Peace Reach in 2016 (Euchner 2017), 2017 (Euchner 2018), and 2021 (Euchner 2022). This effort to map critical habitats

[1] These information needs are now itemized as steps 1 and 2 of the *Recommended sequence of monitoring actions* in FWCP's Bull Trout monitoring framework (Hagen and Weber 2019 [section *6.2.2*]).

for Bull Trout in the Williston Reservoir watershed was completed in 2022. A summary of the program methods, and its outcome is provided in Hagen et al. (2023). The second new component was the establishment of new foot survey index sections to improve spatial replication in the population trend data. In 2023, four new index sections were included in the annual monitoring program (Pelly Creek, Pesika Creek, Lay Creek, and Anzac River).

Prior to 2012, Bull Trout monitoring in the Williston watershed was conducted by FWCP personnel. Over the 2012-2020 period, following the shift to a proponent-driven funding model, this FWCP-funded study was led by the Fisheries Section of BC's Ministry of Water, Land and Resource Stewardship (WLRS; formerly Forests, Lands, Natural Resource Operations and Rural Development [FLNRORD]) in collaboration with consultant John Hagen and Associates (JHA), Tsay Keh Dene Nation (TKDN), and McLeod Lake Indian Band (MLIB). Beginning in 2021, leadership of the study was transferred to TKDN-owned Chu Cho Environmental LLP (CCE) in collaboration with FWCP, WLRS and JHA, with the support of TKDN and MLIB.

The core components of the 2023 spawner abundance monitoring were the continuation of redd count surveys in the four long-term index section, and the inclusion of four new index sections into the annual monitoring program.

In this report we describe the two study components in 2023 and their outcomes. The study was funded by FWCP and supplemental funding was provided by the TKDN/BC Environmental Stewardship Initiative (ESI). An additional focus of this report is the evaluation of index monitoring needs, a preliminary analysis of cumulative effects to assess limiting factors, the results of which will guide enhancement actions among critical habitats for large-bodied, migratory Bull Trout in the Williston Reservoir watershed.

Following the 2022 field season we presented stewardship and monitoring recommendations for Williston Bull Trout, which were informed by collection of data identified in the FWCP Bull Trout information synthesis and monitoring framework document (Hagen and Weber 2019; Hagen et al. 2023). In the Discussion section of this report, we advise where the study results to date put us in FWCP's recommended sequence of monitoring actions. Most importantly, we also make specific recommendations for habitat conservation actions and additional monitoring initiatives based on the accumulated critical habitat assessments and results of population trend analyses. These recommendations, along with a GIS spatial layer delineating critical habitat locations, are key outreach products for FWCP and study collaborators, as well as for First Nations of the Williston Reservoir watershed.

2 Goals and Objectives

The FWCP – Peace Region is a partnership between BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations, and public stakeholders. In the Peace Region, the 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 first goal of the spawner abundance monitoring study in the Williston watershed is to enable conservation actions that maintain or improve the status of Bull Trout populations and the productivity of their critical habitats. The second goal is to directly engage with First Nations of the Williston Reservoir watershed and other study collaborators in Bull Trout stewardship. As such, these goals are aligned with overarching strategic objectives of FWCP's *Rivers, Lakes, and Reservoirs Action Plan* (FWCP 2020).

In support of these goals, the project had the following objectives for 2023:

1. To continue foot surveys of the four long-term index sections in Davis, Point, Scott and Misinchinka watersheds;
2. To improve confidence in assessment of Bull Trout conservation status in the Williston Reservoir watershed by including four additional index sections in Pelly and Pesika Creek, Lay Creek, and Reynolds Creek (replaced by Anzac River), which increased the spatial scope of redd count surveys.

While fulfilling these objectives, the study addresses Action #13 PEA.RLR.S04.RI.13 of the *Rivers, Lakes, and Reservoirs Action Plan* (FWCP 2020):

> "*Conduct monitoring actions that build on the work conducted to date to address data gaps limiting understanding of conservation status, critical habitats, and limiting factors for Bull Trout. Specific studies are defined in the Bull Trout information synthesis and monitoring framework (Hagen and Weber 2019). See Table 6.2a in the monitoring framework for highest priority actions. Work should be used to develop specific conservation or enhancement actions for Bull Trout.*"

3 Study Area

Williston Reservoir, which reached full pool in 1972 (Hirst 1991), flooded approximately 350 km of the Peace River, Finlay River, and Parsnip Rivers 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 reservoir, which eventually became populated by a changed fish community that included new prey and competitor species such as Kokanee (*Oncorhynchus nerka*) and Lake Trout (*Salvelinus namaycush*), respectively. Reservoir creation facilitated widespread forest harvesting activities in formerly inaccessible watersheds, and the flooding also severely altered traditional patterns of human settlement, resource use, and travel (Herkes and Kurtz 2014).

In BC, the geographic distribution of the Bull Trout is closely associated with mountainous environments, reflecting the species' requirements for cold water habitats (Hagen and Decker 2011). Bull Trout are widely distributed within the Williston Reservoir watershed, much of which drains mountainous areas (Hagen and Weber 2019). However, demographic population structure has been unknown due to a lack of genetic data. There is an ongoing investigation of Bull Trout population structure in the Williston Reservoir, but results from that project are not expected until 2025 (FWCP Project No. PEA-F24-F-3847). In lieu of genetic population structure estimates, Hagen and Decker (2011) delineated eight preliminary conservation units, termed 'core areas,'[2] for the Williston Reservoir watershed based on the geography of the basin. These are: Upper Finlay, Lower Finlay, Finlay Reach, Omineca, Peace Reach, Parsnip Reach, and Parsnip core areas. The Thutade core area is isolated above the Cascadero Falls on the upper Finlay River and is considered outside of the reservoir's footprint impact area. Although located downstream of the W.A.C Bennett Dam, the Dinosaur core area, which is comprised of the immediate watershed of Dinosaur Reservoir, also falls within FWCP's mandate.

3.1 Long Term Index Sections

Long term index sections surveyed annually in the Davis River, Point Creek, Scott Creek, and Misinchinka River are located roughly 180, 70, 60, and 50 km, respectively, linear distance from the town of Mackenzie, BC (Figure 3-1). The Misinchinka River (Parsnip core area) is a tributary to the Parsnip River, although it is known to have a primarily adfluvial population of Bull Trout that utilizes the reservoir (Langston and Cubberley 2008; Hagen and Weber 2019), 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 3-1). All four index streams originate on the eastern side of the reservoir high in the Rocky Mountains.

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, and current redd count surveys cover most of the known distribution of spawning (Andrusak et al. 2012; Hagen and Pillipow 2013). All four index systems do not have glacial origins and typically experience low, clear flows during the September survey period, which annually occurs in the third week of September following the completion of spawning.

3.2 New Index Sections

The four long-term index streams (Davis, Point, Scott, and Misinchinka) under-represent the heterogeneity of streams and populations found around the watershed, particularly because three of four streams are located in the southeast portion of the reservoir. The instigation of index monitoring in these streams was based on the best available information at the time, but the aerial redd survey program completed from 2014-2022 greatly expanded known Bull Trout spawning habitats in the Williston Reservoir watershed (Hagen et al. 2023). Using this information, we proposed to increase the number of index streams from four to eight with the addition of Lay Creek, Pelly Creek, Pesika Creek, and Reynolds Creek, which were delineated based on the aerial redd count data (Hagen et al. 2023). During a preliminary aerial survey in 2023, Reynolds Creek was replaced by Anzac River following the discovery of insurmountable fish access

[2] Core areas are defined as groups of populations that are genetically similar and demographically linked (USFWS 2005; Hagen and Decker 2011; Pollard et al. 2015), i.e., are a proxy for the metapopulation structure (Hanski and Gilpin 1991).

issues with the proposed Reynolds Creek index section (see section 5.2.2.4 for details). Collaboration with WLRS staff facilitated the completion of the Anzac River index sections in 2023. New Index sections surveyed in Lay Creek, Pelly Creek, Pesika Creek and Anzac River are located approximately 220, 270, 225, and 85 km, respectively, linear distance from the town of Mackenzie, BC (Figure 3-1).

3.2.1 Rationale for the Selection of New Index Sections

Pelly Creek is a pristine headwater habitat with no existing road access and pre-established index sections identified through the aerial redd survey program (Hagen and Spendlow 2017). This watershed contains a hydrometric station deployed for the Modeling Thermal Regimes project (O'Connor et al. 2024; PEA-F24-F-3845) and had been surveyed twice between 2017 and 2022 prior to 2023. Located in the Finlay Reach core area, this index section is the most northern annually monitored index and contrasts the other long-term indices in the southern portion of the watershed.

Pesika Creek is also a pristine headwater habitat with pre-established index sections identified through the aerial survey program and has several years of redd survey data available from 2020 to 2022. Pesika Creek is located in the Lower Finlay core area; this site will provide comparison to the long-term Davis River index section, while contrasting the other long-term indices in the southern portion of the watershed.

Lay Creek is a moderately disturbed headwater habitat (road and high voltage transmission right-of-way development) with pre-established index sections identified through the aerial redd survey program. Redd surveys completed in 2017 and 2018 provide two years of usable historical data for this index section. This watershed contains a hydrometric station deployed for the Modeling Thermal Regimes project (O'Connor et al. 2024; PEA-F24-F-3845). Lay Creek is located in the Omineca core area and provides contrast to all other indices due to its western location in the watershed and the moderate level of land-use disturbance occurring within it.

The Anzac River is highly disturbed headwater habitat (extensive logging, beetle kill, pipeline development, road networks, and easy recreational access) with pre-established index sections identified during a joint MLIB/FLNRORD study in 2014 to identify critical Bull Trout spawning habitats in the Parsnip River watershed (Hagen et al. 2015). Ground surveys of the Anzac index sections were completed in 2016 with the intent of serving as baseline information for future comparison (Hagen and Spendlow 2017). The combined counts of two index sections Upper Anzac Mainstem and Anzac River Tributary 236-313100-60100 (East Anzac) comprise the index for this stream. The East Anzac index section is in an unnamed tributary of the Anzac River (236-313100-60100) and was surveyed in 2015, 2016, and 2021. In 2021, only the road accessible East Anzac index was surveyed which represents approximately half of the combined index as described here. Caution must be exercised in interpreting the meaning of the count presented for 2021 as redds from the Upper Anzac mainstem are not included in the total. The Upper Anzac Mainstem index was initially surveyed in 2016 (Hagen and Spendlow 2017), and again in 2023. Redd surveys were completed in 2015, 2016, 2021, and 2022 providing four years of previous data for this index section, although 2015 and 2021 surveys were restricted to East Anzac. The Anzac River is located in the Parsnip core area and represents the extreme south reaches of the watershed, demonstrating high contrast to other index sections in terms of its disturbance levels.

[redacted]

Figure 3-1. Overview map of the Williston Reservoir basin showing Bull Trout spawning ground surveys in 2023. Purple bolded lines demarcate long-term index sections and green bolded lines demarcate new index sections. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

4 Methods

4.1 Redd Surveys

Ground surveys of index sections were conducted between September 16 and September 25, 2023, by two-person crews. Observers wore waders suitable for travel along slippery stream channels and polarized sunglasses to cut glare on the water. Observers walked downstream, positioned themselves to gain the best view of potential spawning locations, and recorded the number of redds, habitat notes (e.g., beaver dams, sediment sources) and any fish present. All redd locations and important habitat features were recorded using hand-held GPS units.

Observer experience and training are important factors which improve the reliability of redd counts (Muhlfeld et al. 2006; Howell and Sankovich 2012). Redd identification criteria (Section 4.2) were therefore discussed and standardized between the field crews at the beginning of the redd count study. To support the accuracy and precision of redd counts, the survey crews consisted of experienced observers (minimum > 5 years).

4.2 Redd Identification

A redd is a pit excavated into the stream substrate by female Bull Trout prior to spawning. Fertilized eggs are deposited into this pit and are covered with gravel by the female (Block 1955; Leggett 1980). Redds are visually definitive and typically characterized by the following traits: 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 substrate caused by disturbance of algae or sediment-coated rocks (Figure 4-1). Additionally, redds of large-bodied, migratory Bull Trout in the Williston Reservoir watershed are large (e.g., 2.5 m^2 ± 0.52 m^2), which facilitates their identification during redd count surveys.

Figure 4-1. Survey crew continuing downstream after enumeration of a female Bull Trout (sitting in the middle of the lighter gravel) on her redd. The redd can be identified by the contrasting light-colored substrate and is approximately 2 m long and 1.5 m wide. Point Creek, BC. September 2022.

4.3 Population Growth Rate (Trend) in Long-Term Index Sections

Statistical analysis of population trend in four long-term index sections located within the Davis, Point, Scott, and Misinchinka watersheds was conducted using a linear regression of year on natural log-transformed count data. While this approach does not account for process or observation error in the time series of count data, it is considered less conservative relative to some alternatives, which is potentially advantageous in a situation of declining trend where early detection is desirable (reviewed in Kovach et al. 2016).[3]

Population growth rate is a key indicator of conservation status and risk, and of potential effects of limiting factors (see Section 1). For each of our long-term redd count time series, we computed population growth rate using the formula:

$$Population\ growth\ rate = \frac{N_t - N_0}{N_0 * (t)}$$

Where N_0 is the predicted initial population size and N_t is the predicted population size after time interval t years (i.e., endpoints of the regression line). Log-transformed linear regression predictions were back-transformed using the natural exponent prior to use in the population growth rate calculation.

4.4 Evaluation of Annual Index Monitoring Requirements

Population growth rate is a key indicator of conservation status for vertebrate populations (Caughley 1994; McElhany et al. 2000; O'Grady et al. 2004). To accurately estimate population growth rate, it has been suggested that time series data meet a minimum of 50% completion (e.g., 5 of 10 years retaining the first and last values; Humbert et al. 2009). The review completed by Humbert et al. (2009) assessed sensitivity of population growth rate estimates to missing data points under a model which accounts for process and observation error (i.e., state-space or hierarchical models). The population growth rate estimates presented here do not account for process or observation error in the time series of count data; however, there is an ongoing effort by the Freshwater Fish Ecology Laboratory at UNBC to improve the estimation of population trend (Dr. E. Martins pers. comm.). In the absence of a hierarchical model, we believe it is pertinent to evaluate the impact of missing observations on the current estimation of population trend.

To complete an evaluation of the minimum sampling requirements, the existing long-term index section time series (see Section 3.1) were modified to randomly remove data points. The time series were altered to simulate scenarios where time series completion was 75%, 50% and 25%. The random omission of data points was completed 100 times for each index and for each of these simulations, population growth rate was calculated. Population growth rate was estimated as described in Section 4.3. The mean of all 100 population growth rate estimates and 95% confidence intervals were calculated for each simulated time series.

[3] I.e., Type 1 errors have less serious conservation consequences than Type 2 errors.

The population growth rate estimate from the real time series was viewed as the “true” or known population growth rate estimate in this exercise, and the mean population growth rate estimates and confidence intervals from the simulated time series were plotted and compared against the “true” population growth. We acknowledge the actual “true” population growth rate is an unknown constant which we are estimating under a frequentist statistical framework. By completing this exercise, we look to verify the insights of Humbert et al. (2009) and provide direction to FWCP on minimum sampling requirements given the importance of the time series data, high cost of data collection, and intent to expand work on enhancement actions while continuing to monitor effects of enhancement actions.

5 Results

5.1 Redd Survey Conditions

The Bull Trout spawner abundance monitoring program utilizes visual methods for enumeration of redds and therefore is dependent on clear water and low to average seasonal flows (i.e., good conditions). Weather in the survey region was exceptionally warm and dry in fall 2023. As such, conditions were optimal during the 2023 field program, which was conducted from September 16–25. These conditions were reflected by Water Survey of Canada (WSC) hydrometric stations around the Williston Reservoir watershed (Figure 5-1; Figure 5-2; Figure 5-3).

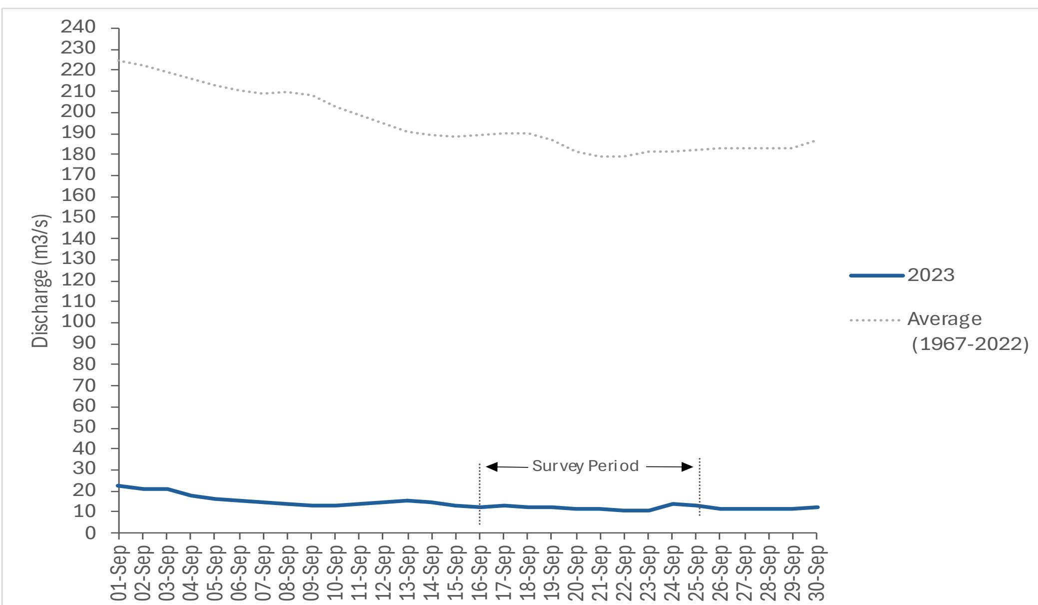

Figure 5-1. Estimated discharge (blue solid line) relative to average discharge (grey dotted line) during the September 16-25 Bull Trout survey period (denoted by vertical black dashed lines) at WSC station 07EA007 (Akie River; a suitable proxy for discharge in the Pesika Creek index section).

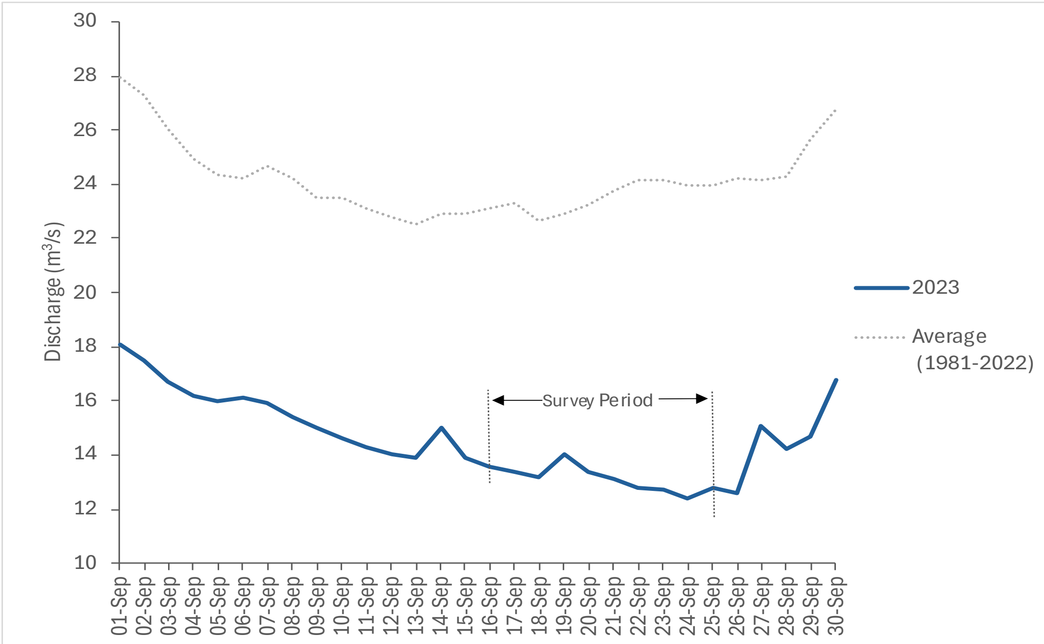

Figure 5-2. Estimated discharge (blue solid line) relative to average discharge (grey dotted line) during the September 16-25 Bull Trout survey period (denoted by vertical black dashed lines) at WSC station 07EB002 (Ospika River above Aley Creek; a suitable proxy for discharge in the Davis River index section).

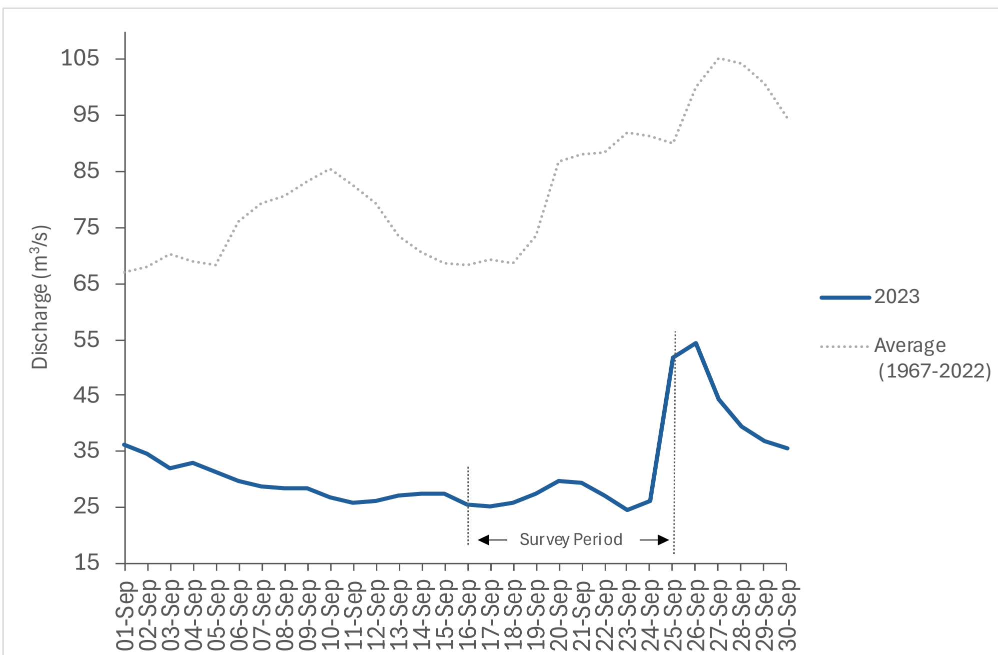

Figure 5-3. Estimated discharge (blue solid line) relative to average discharge (grey dotted line) during the September 16-25 Bull Trout survey period (denoted by vertical black dashed lines) at WSC station 07EE007 (Parsnip River above Misinchinka River; a suitable proxy for discharge in the Anzac and Misinchinka index sections).

5.2 Redd Survey Results

5.2.1 Long-term Index Sections

5.2.1.1 Misinchinka River

The Misinchinka River was surveyed on September 17 and 18, 2023. The unnamed Misinchinka tributary 236-073000-78200 was surveyed on September 17 and the mainstem index section on September 18. Nine redds were enumerated in the mainstem index section, which is 78% below the long-term average of 40 redds for these reaches (Figure 5-4; Figure 5-5). Conditions were excellent during the survey, so redd detection efficiency was assumed to be high.

Unnamed Misinchinka tributary (236-073000-78200) was also surveyed in 2023 to evaluate the effects of beaver dams downstream of the long-term index reach on redd distribution and abundance. A total of 25 redds (Figure 5-5) were observed in the tributary, which was substantially greater than counts in 2018 (16 redds) and 2020 (12 redds), but lower than 2022 (28 redds). These redds were not included in the survey total as they were outside the long-term index section. The results suggest that the upper index section provides preferred spawning habitat; however, variability in spawner distribution, caused by access restrictions, may be a factor that likely affects the Misinchinka River time series. This will be investigated further in 2024 with another survey of the Misinchinka River tributary.

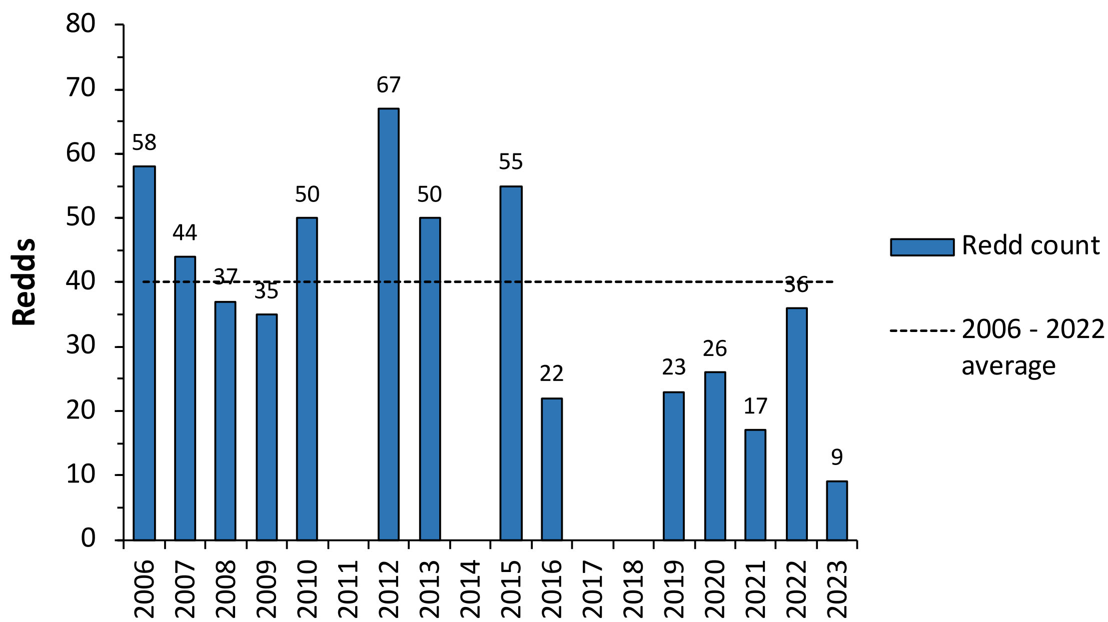

Figure 5-4. Misinchinka River Bull Trout redd counts, 2006 – 2023. The 2023 survey was conducted on September 18. The black dashed line represents the long-term average prior to 2023.

[redacted]

Figure 5-5. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the long-term index section of Misinchinka River, a tributary to the Parsnip Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.1.2 Point Creek

Point Creek was surveyed on September 21, 2023. Despite low water and a complex of 6 beaver dams, 3 of which were new in 2023, a total of 28 redds were observed in the index section. This is 24.7% above the long-term average of 22 redds (Figure 5-6; Figure 5-7), indicating the beaver dams and log jam were not barriers to Bull Trout migration in Point Creek in 2023 but may pose as barriers under different conditions.

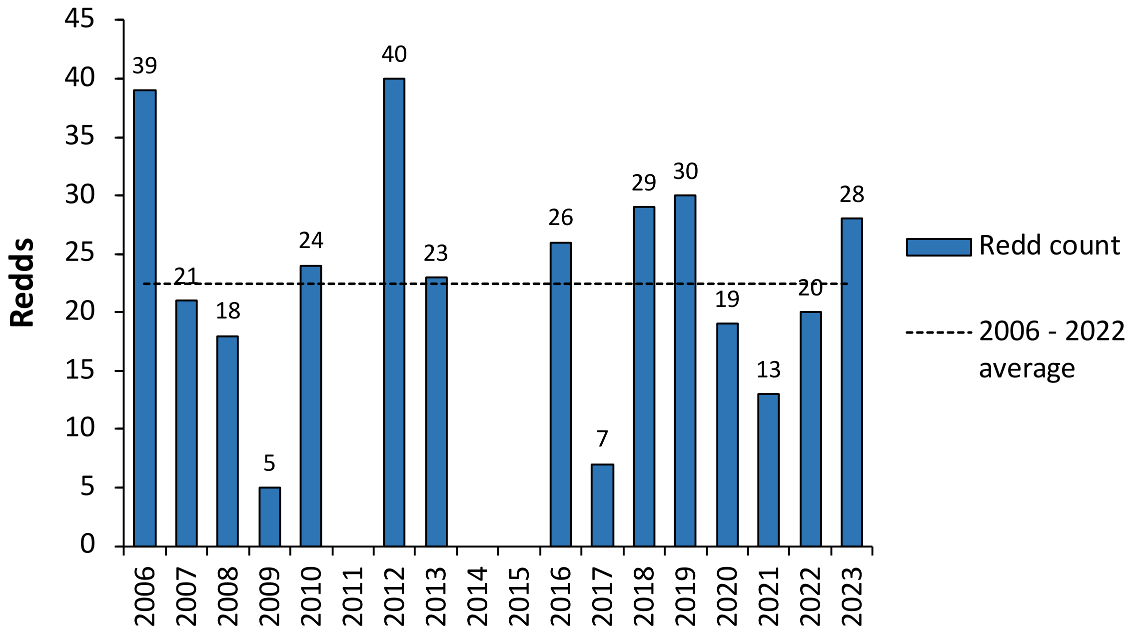

Figure 5-6. Point Creek Bull Trout redd counts, 2006 – 2023. The 2023 survey was conducted on September 21. The black dashed line represents the long-term average prior to 2023.

[redacted]

Figure 5-7. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the long-term index section of Point Creek, a tributary to the Peace Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.1.3 Scott Creek

Scott Creek was surveyed on September 22, 2023. A total of 59 redds were observed in the index sections, which equals the long-term average of 59 redds (Figure 5-8). Forty-eight of these redds were in the upper index section, while 11 redds were in the lower index section (Figure 5-9).

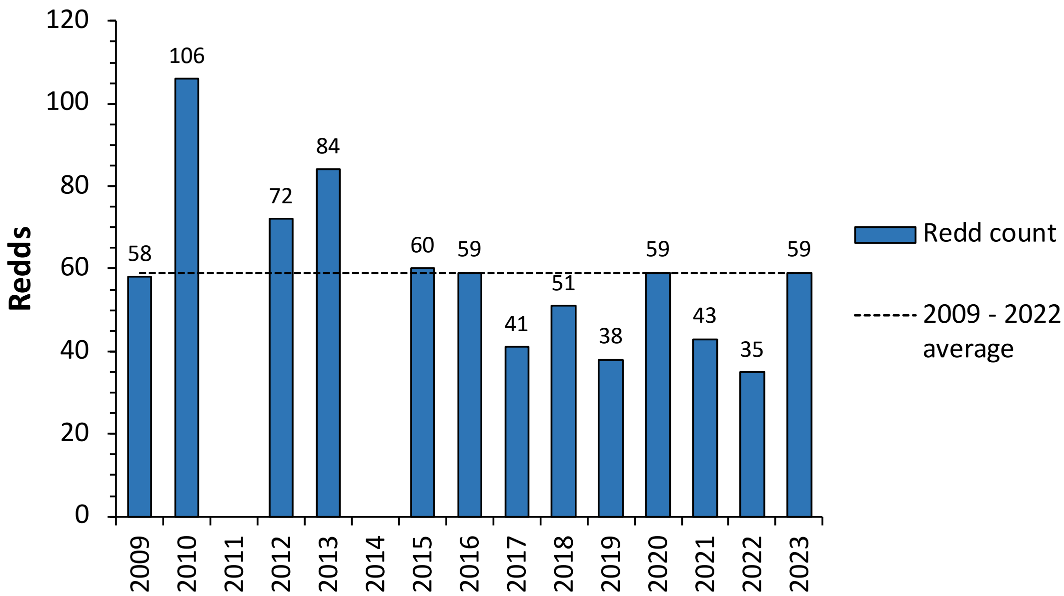

Figure 5-8. Scott Creek Bull Trout redd counts, 2009 – 2023. The 2023 survey was conducted on September 22. The black dashed line represents the long-term average prior to 2023.

[redacted]

Figure 5-9. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the long-term index sections of Scott Creek, a tributary to the Peace Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.1.4 Davis River

The Davis River was surveyed on September 19, 2023. A total of 86 redds were observed in the mainstem index section, which was 45.5% above the long-term average of 59 redds (Figure 5-10; Figure 5-11). Unnamed "Tributary 2" (230-966200-75300) was surveyed prior to the mainstem index section, where 23 redds were enumerated. Furthermore, the lower portion of unnamed "Tributary 3" (230-966200-75600) was surveyed between its confluence with the Davis River and an impassable beaver dam approximately 80 m upstream, where 12 redds were enumerated. The redds from Tributary 2 and 3 were not included in the survey total as they were outside the long-term mainstem index section.

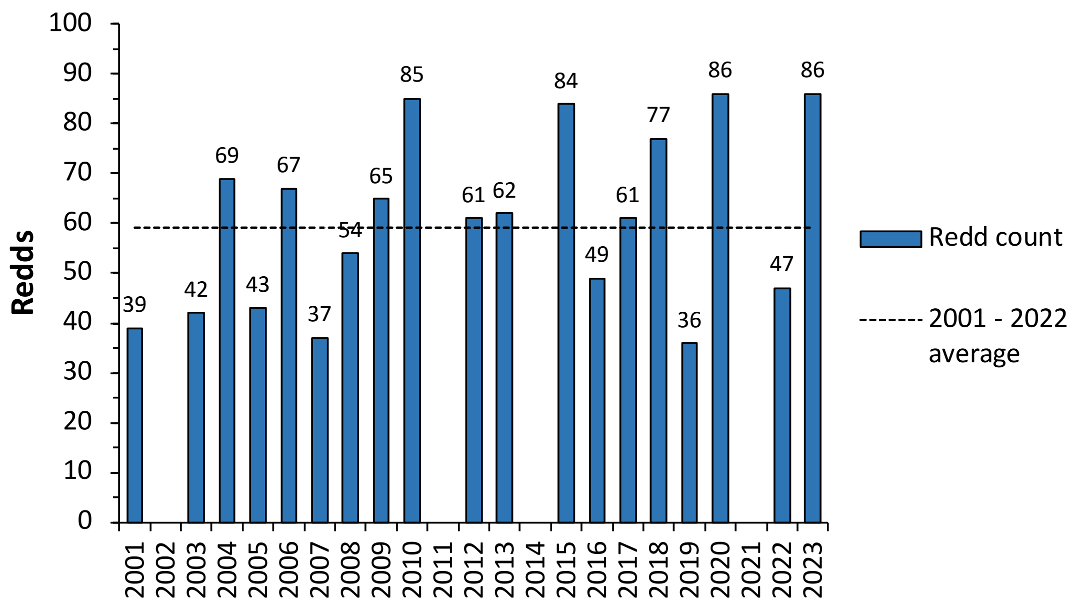

Figure 5-10. Davis River Bull Trout redd counts, 2001 – 2023. The 2023 survey was conducted on September 19. The black dashed line represents the long-term average prior to 2023.

[redacted]

Figure 5-11. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the long-term index section of Davis River, a tributary to the Finlay Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.2 New Index Sections

5.2.2.1 Lay Creek

Lay Creek was surveyed on September 16, 2023. A total of 18 redds were enumerated in the index section (Figure 5-12; Figure 5-13). An additional 8 redds were observed in a subsample in upper Lay Creek canyon, which is above the current index section; therefore, these redds were excluded from the count. The subsample was conducted to assess access to a confined canyon between the upper extent of the index section and the waterfall which contains a small proportion of spawning habitat.

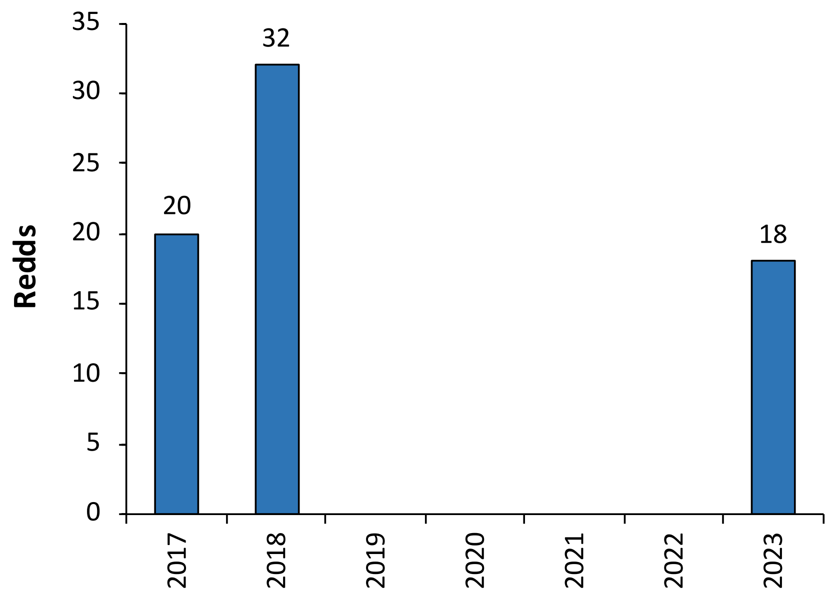

Figure 5-12. Lay Creek Bull Trout redd counts, 2017, 2018 and 2023.

[redacted]

Figure 5-13. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the long-term index section of Lay Creek, a tributary to the Finlay Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.2.2 Pelly Creek

Pelly Creek was surveyed on September 18, 2023. A total of 42 redds were enumerated, of which, 35 were in the upper index section and 7 were in the lower index section (Figure 5-14; Figure 5-15). This was a decrease from 2017 and 2022, when 61 and 48 redds were enumerated, respectively.

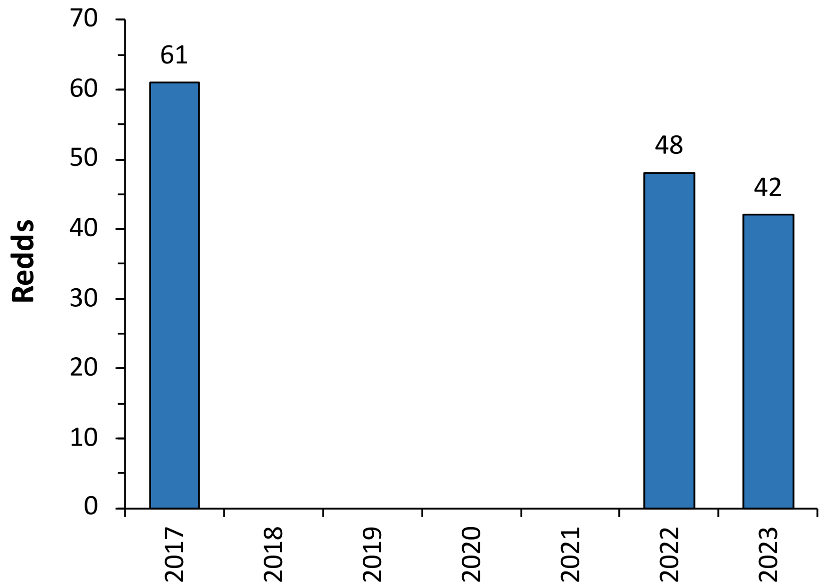

Figure 5-14. Pelly Creek Bull Trout redd counts conducted in 2017, 2022, and 2023.

[redacted]

Figure 5-15. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the new index section of Pelly Creek, a tributary to the Finlay Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.2.3 Pesika Creek

Pesika Creek was surveyed on September 20, 2023. A total of 97 redds were enumerated (Figure 5-16). Thirty-seven redds were counted in the upper index section, while 60 redds were counted in the lower index section (Figure 5-17).

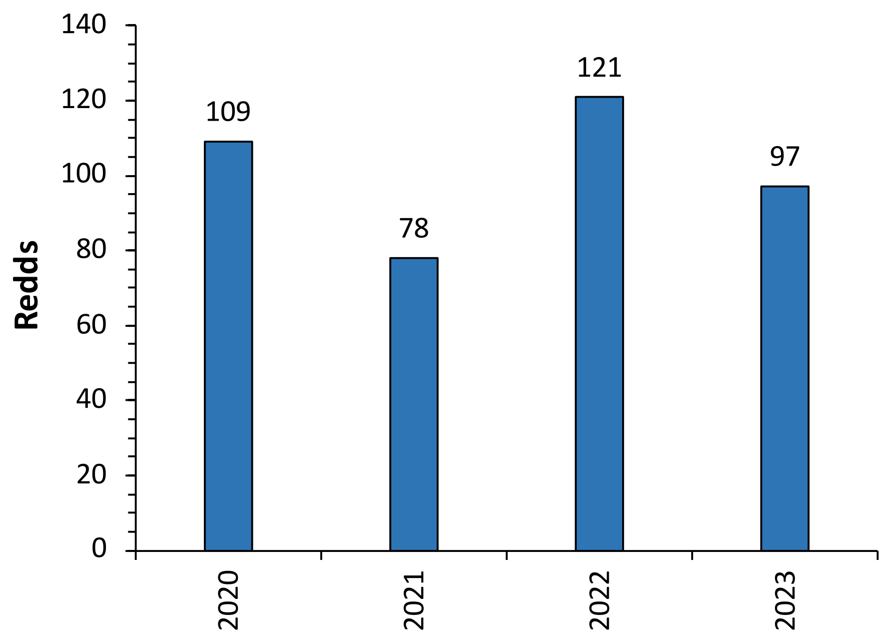

Figure 5-16. Pesika Creek Bull Trout redd counts, 2020 – 2023.

[redacted]

Figure 5-17. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the new index section of Pesika Creek, a tributary to the Finlay Reach of Williston Reservoir, September 2023. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.2.2.4 Reynolds Creek

Reynolds Creek was surveyed from the air on September 17, 2023, to establish a new index section in this stream. The drought conditions of 2023 left Reynolds Creek vulnerable to beaver dam obstruction. During the aerial survey, 2 redds were observed in the proposed index section, which were located below an impassable beaver dam in the bottom portion of the index section. No redds were observed upstream of this beaver dam despite high confidence in aerial observer efficiency as gravel contrast and flying conditions were optimal. The index section was surveyed twice, both up and downstream. One redd was observed directly downstream of the beaver dam obstruction in the index section (in tributary Chuyazega Creek), suggesting an additional ephemerally passable barrier further downstream. The barrier responsible for impeding Bull Trout migration was a potentially impassable beaver dam on the mainstem of lower Reynolds Creek. Eight redds were observed in a highly uncharacteristic reach for Bull Trout spawning direct below this dam. Ground surveys for Reynolds Creek were ruled out due to the variability of aerial redd distribution observed between 2014 and 2023; thus, leading to the exclusion of Reynolds Creek as a viable index section for this study. The Anzac River, which has an existing time series of redd counts, was selected as an alternative index to Reynolds Creek,. See Section 3.2.1 for rationale of this substitution.

5.2.2.5 Anzac River

In 2023, The Upper Anzac Mainstem index was surveyed on September 19 (24 redds) by WLRS staff. Unnamed 'East Anzac' index section (watershed code 236-313100-60100) was surveyed on September 25 (10 redds) by CCE staff, WLRS staff, and FWCP's Peace Region manager, Chelsea Regina. The total number of redds enumerated in the Anzac index sections in 2023 was 34. (Figure 5-18; Figure 5-19; Figure 20).

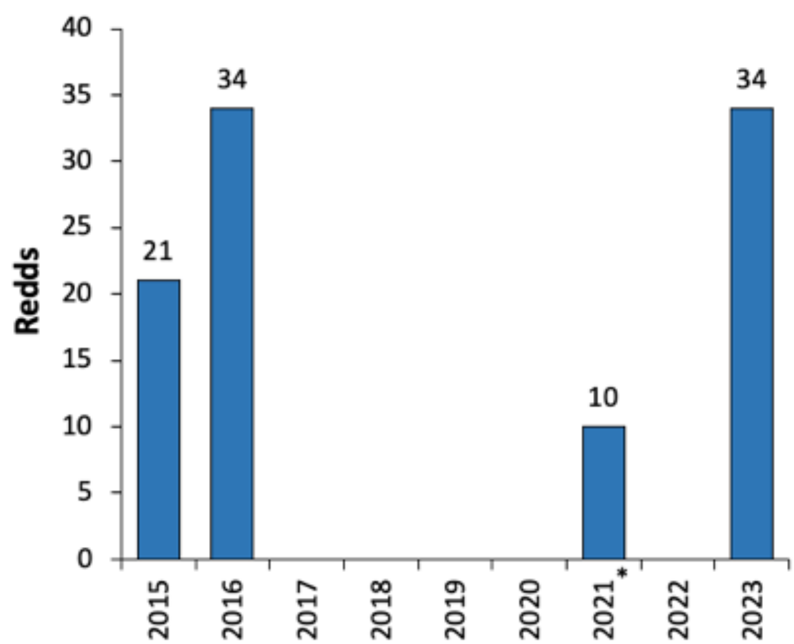

Figure 5-18. Anzac River Bull Trout redd counts, 2015, 2016, 2021, and 2023. The 2023 surveys were conducted on September 19 and 25. In 2021, only road accessible sites were visited, representing approximately fifty percent of the index resulting in an underestimated redd count for the index.

[redacted]

Figure 5-19. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the new index section East Anzac, September 2023. East Anzac and the Upper Anzac Mainstem (see figure 5-20) comprise the Anzac index section. The Anzac River is tributary to the Parsnip River. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

[redacted]

Figure 5-20. Distribution of Bull Trout redds (circles: 1 redd = open circles, 2 redds = grey shading, 3 redds = solid circles) in the new index section in the Upper Anzac Mainstem September, 2023. East Anzac (see figure 5-19) and the upper mainstem comprise the Anzac index. The Anzac River is a tributary to the Parsnip River. Figure redacted due to the presence of data on species sensitive to persecution or harm. For an unredacted report please contact admin@chuchoenvironmental.com.

5.3 Population Growth Rate (Trend) in Long-Term Index Sections

The core component of FWCP's Bull Trout monitoring activities in the Williston Reservoir watershed has been the foot survey-based redd counts in long-term index sites in the Davis, Point, Misinchinka, and Scott watersheds. The purpose of these surveys is to monitor population growth rate of large-bodied, migratory Bull Trout in the reservoir's three main arms.

In 2023, redd counts were at or above average in most long-term index sections, except for Misinchinka River, which was substantially lower than average (Figure 5-21). Weather and river conditions were ideal (i.e., low flow and good visibility) throughout the redd survey season, so redd detection efficiency was assumed to be high in all streams. The completion of foot surveys in the Misinchinka River (September 17,18), Point Creek (September 21), Scott Creek (September 22), and Davis River (September 19) extended the time series of redd count data for these systems to 18 years for Misinchinka (14 surveys) and Point Creek (15 surveys), 15 years for Scott Creek (13 surveys), and 23 years for Davis River (19 surveys) (Table 5-1).

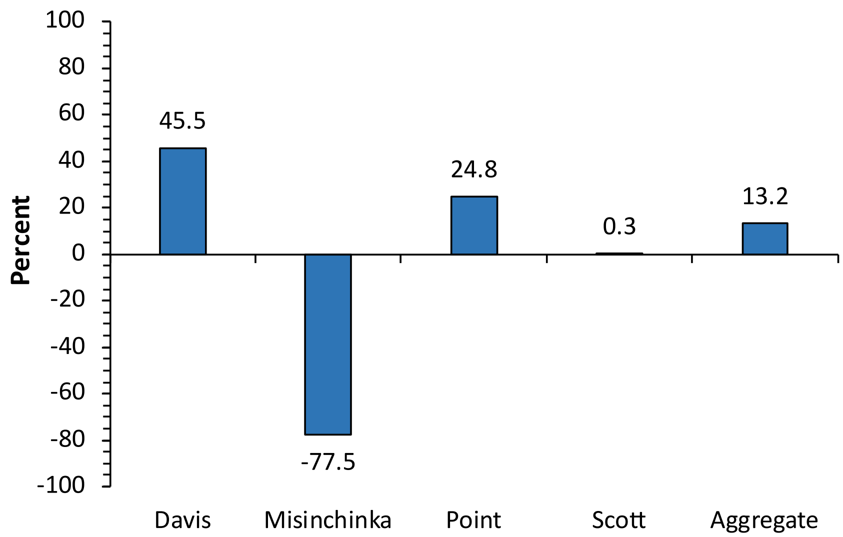

Figure 5-21. Percent deviation of 2023 Bull Trout redd counts from long-term averages in four index streams in the Williston Reservoir watershed.

Table 5-1. Counts of Bull Trout redds in four long-term index streams in the Williston Reservoir watershed. The coefficient of variation describes variation relative to the mean, and time series completion is the number of years surveyed divided by total number of years in the time series.

Year	Davis River	Point Creek	Scott Creek	Misinchinka River
2001	39			
2002	-			
2003	42			
3004	69			
2005	43			
2006	67	39		58
2007	37	21		44
2008	54	18		37
2009	65	5	58	35
2010	85	24	106	50
2011	-	-	-	-
2012	61	40	72	67
2013	62	23	84	50
2014	-	-	-	-
2015	84	-	60	55
2016	49	26	59	22
2017	61	7	41	-
2018	77	29	51	-
2019	36	30	38	23
2020	86	19	59	26
2021	-	13	40	17
2022	47	20	35	36
2023	86	28	59	9
Average (2001 – 2022)	59	22	59	40
Survey Length (km)	3.9	4.8	4.4	5.0
Coefficient of Variation (%)	29.5	44.6	34	42.6
Time Series Completion (%)	83	83	86	77

Population growth rates have varied between the populations in northern (Finlay) and southern (Peace and Parsnip) reaches of the Williston Reservoir (Figure 5-22; Table 5-2). Prior to 2023, the Davis River was the only population exhibiting a positive annual growth rate of 2.18% on average, over the survey time series. Variability among years was substantial, however, and the trend was not significant (i.e., $P < 0.05$) when analyzed using natural log-transformed count data ($t = 1.58$, $P = 0.132$, $n = 19$). The number of redds observed in Point Creek in 2023 (28 redds) exceeded the long-term average, and population growth rate improved to 0.03% ($t = 0.012$, $P = 0.99$, n = 14). This stable trend estimate is encouraging given the variability in the time series for this Peace Reach tributary.

Tributaries to Parsnip Reach have exhibited significant negative population growth over the duration of the redd survey time series. Despite an average count in 2023, significant negative population trend for the Scott Creek population persisted with an estimated -3.77% decline over the time series ($t = -3.90$, $P = 0.01$, n = 13). The 2023 count in the Misinchinka River index section is the lowest on record (9 redds) and was greatly affected by limited fish access to the upper river. A beaver dam complex on the mainstem Misinchinka River appears to have impeded upstream movement for most fish. This was suspected in 2017 and 2018 when low counts were recorded in the index section (Hagen et al. 2020). As discussed in Section 5.2.1.1 it is possible when there is limited access to the upper river, redd counts in the unnamed tributary 236-073000-78200 are higher than previously observed. Given this low count due to poor fish access, 2023 was not included in an updated population growth rate estimate. Population growth rate up to 2022 for the Misinchinka River was -4.14% ($t = -2.73$, $P = 0.01$, n = 13).

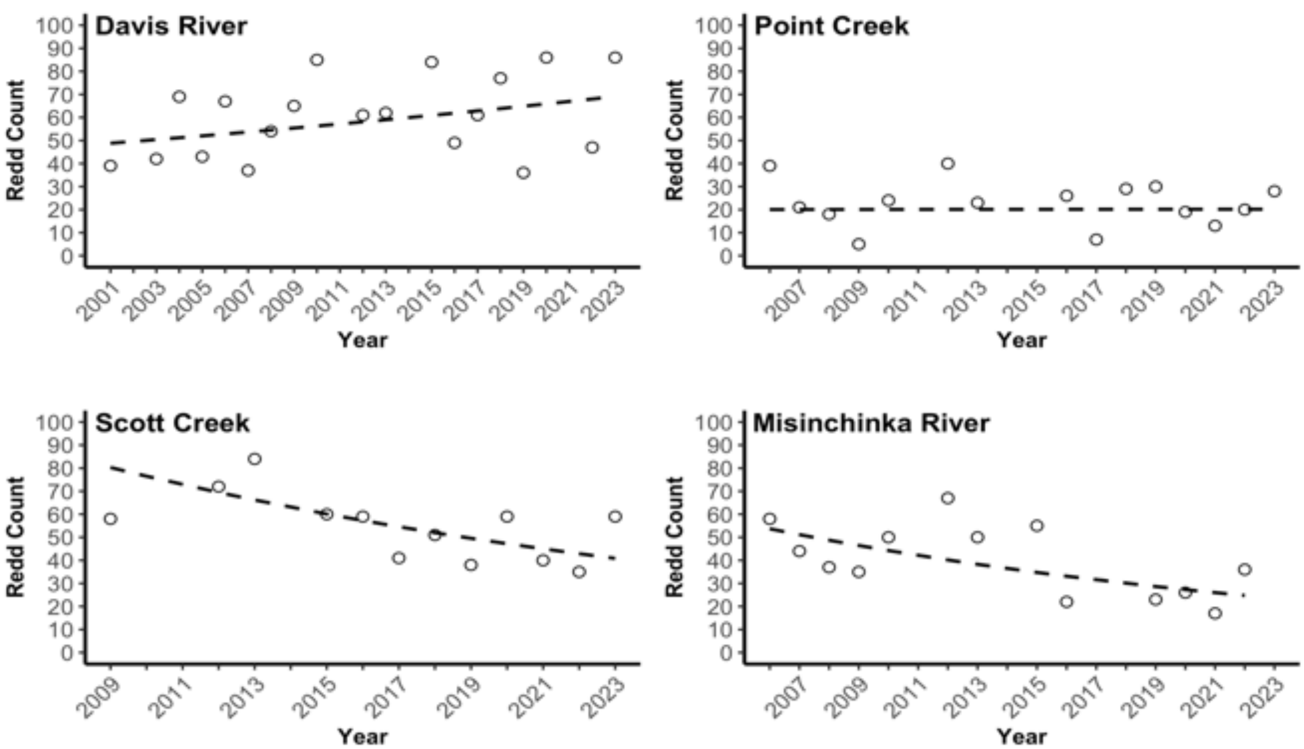

Figure 5-22. Bull Trout counts from the four long-term index sections in the Williston watershed. Points depict individual annual counts and the dashed line depicts the regression trendline of log transformed count on year used to calculate population growth rate.

Table 5-2. Annual population growth rate of Bull Trout populations from four long-term index sections in the Williston Reservoir watershed. Trendline endpoints were used as the values for computing growth rates. Note "t" in "Time Series" column refers to time used in the population growth rate calculation.

Stream	Trendline Equation	Year of First Survey	*Time Series (t)*	*No. of Surveys (n)*	Predicted N_o	Predicted N_t	Annual Growth Rate (%)
Davis River	0.0158x + -27.6921	2001	23	19	48	69	2.18
Point Creek	0.0003x + 2.3328	2006	18	15	20	20	0.03
Scott Creek	-0.0483x + 101.3418	2009	15	13	80	40	-3.77
Misinchinka River	-0.0483x + 100.9705	2006	18	14	54	25	-4.14

5.4 Evaluation of Annual Index Monitoring Requirements

Humbert et al. (2009) found that a time series with 50% completion, retaining the first and last values was suitable for the estimation of population growth rate (5 of 10 years). The simulation of time series completion (i.e., 75%, 50% and 25%) conducted here suggests 50% time series completion is not adequate to estimate population growth rate. A 75% minimum completion should be pursued to ensure an accurate estimate (Figure 5-23).

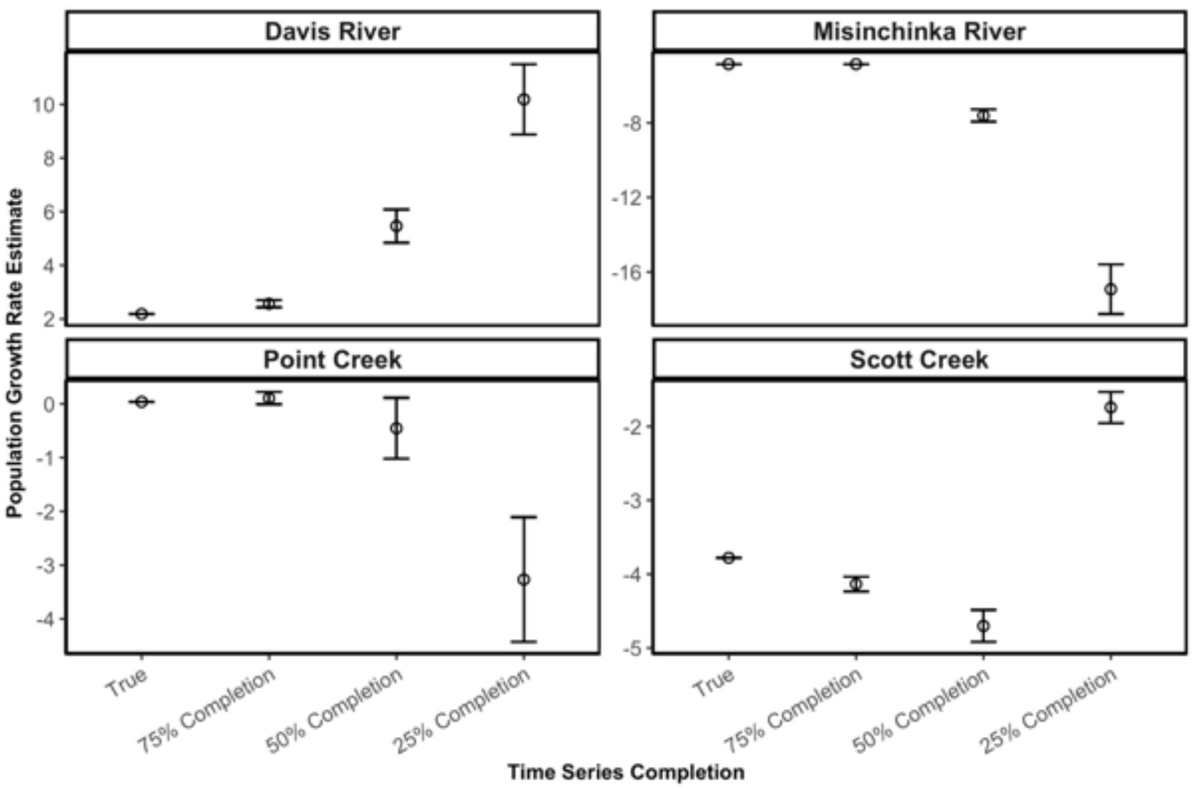

Figure 5-23. Mean population growth rate estimates and 95% confidence intervals for 100 simulations of time series with random value removals. Existing long-term index time series were manipulated to remove 25%, 50% and 75% of the values, retaining the first and last values.

In one simulated time series (Point Creek), the 95% confidence intervals for the 50% complete simulation overlapped the "true" estimate. However, in most other time series only the 75% complete simulations approximated the "true" estimate. One important difference between the simulations presented here, and the suggestions of Humbert et al. (2009) is the regression models used to estimate population growth rate. The inclusion of process and observation error in a hierarchical model could improve the estimation of population growth rate so that 50% completion would be adequate to estimate population trend. However, the risk of committing a type 2 error (failure to reject a null hypothesis; i.e., not seeing a pattern which is present) in a conservation context should be considered before pursuing minimum data requirements. Additionally, the findings were not focused on a particular species (e.g., Bull Trout which mature at 8 years). Considering the life history of the species under study is important in evaluating percent completion of a time series required to attain an accurate estimate.

It's also important to consider that Humbert et al. (2009) suggested data collection at every annual time step may be less important than the quality of estimates and length of time series. Following the evaluation of index monitoring requirements presented here, we recommend that more effort be placed on shorter time series and be spent improving the quality of population growth rate estimates, a key indicator of conservation status. Annual monitoring in index sections does not necessarily need to be pursued if time series are maintained at greater than 75% completion over the generation timing of Bull Trout (i.e., 8 years). This is under the assumption that conservation dollars are being strategically spent on other equally important initiatives (e.g., habitat enhancements or investigation of limiting factors).

6 Discussion

6.1 Conservation Status

Acquiring population data for the purposes of evaluating the status (viability) of priority fish species is the first step in FWCP's recommended sequence of monitoring actions (Hagen and Weber 2019). The conservation status of Bull Trout across their range has been evaluated using the *Core Area Conservation Status and Risk Assessment* method developed by the United States Fish and Wildlife Service (USFWS 2005, 2015; Rodtka 2009; Hagen and Decker 2011). In the method, conservation status and risk rankings are based on categorical estimates for four indicators: 1) *Trend,* 2) *Abundance* (of mature individuals), 3) *Distribution*, and 4) *Threats/Limiting Factors*. The *Core Area Conservation Status and Risk Assessment* method was last applied to population data from the Williston Reservoir watershed in 2019 as part of FWCP's *Bull Trout Information Synthesis and Monitoring Framework* document (Hagen and Weber 2019). The next status assessment was proposed to occur at a 5-year interval (i.e., 2024), but a key factor determining the timing is the improved knowledge of the core area structure based on the Bull Trout genetics study (Hagen et al. 2024; PEA-F24-F-3847).

A desire to improve the knowledge base for these indicators of conservation status in the Williston Reservoir watershed has driven the expansion of FWCP's Bull Trout abundance monitoring program, presented in this report. A framework for habitat conservation was presented by Hagen et al. (2022). The status of abundance and distribution estimates was the focus of Hagen et al. (2023). In the following discussion we present updates on the estimation of population growth rate, a framework for the limiting factors analysis and the ongoing effort to conserve critical habitats in the Williston Reservoir watershed.

6.2 Population Growth Rate (Trend)

Population Growth Rate, or trend, is a key indicator of conservation status for vertebrate populations (Caughley 1994; McElhany et al. 2000; O'Grady et al. 2004), with extirpation a risk in situations of negative population growth, especially as populations decline to critically low levels. Threats are anthropogenic factors which can drive restriction of distributions, small population sizes, and negative trends – unless these can be identified and corrected, the future viability of populations is at risk (Hagen et al. 2021).

In the United States and Canada, the U.S. Fish and Wildlife Service (2005) and COSEWIC (2012), respectively, agree that accurate assessment of population trend requires monitoring to span two to three generations. Minimum age at first spawning for large-bodied Bull Trout in the Williston Reservoir watershed is 8 years on average (Hagen et al. 2019). In 2022, the survey time series for three of the four long-term index streams reached the two-generation threshold for evaluating population trend, with Scott Creek being the exception as monitoring began there in 2009. In 2024 the Davis River index will cross the three-generation threshold. Reaching these milestones in a population monitoring time series is an important achievement because it increases confidence in conservation status assessments of Bull Trout populations in these watersheds. However, the trends being observed are generally concerning. The Davis River Bull Trout population has been the only population amongst these streams that exhibited a positive trend over the duration of the redd survey time series. In 2023, Point Creek was estimated to have a stable trend; however, a high coefficient of variation in the time series, the proximity to the highest abundance of Lake Trout in the Peace Reach, and heightened risk of entrainment through the dam in this reach causes uncertainty for this population. Negative trends were again identified in the Scott Creek and Misinchinka River populations. Furthermore, the survey time series in Scott Creek does not yet span two generations, but steadily decreasing redd counts in this index suggest this population is indeed in decline, despite an average count in 2023.

These declining trends raise questions about the conservation status of Bull Trout in core areas of the Williston Reservoir watershed, particularly because many sub-basins in the watershed, especially in the south and west portions, have experienced substantial disturbance from industrial development. Bull Trout are known to be highly sensitive to such disturbances, with anthropogenic disturbance often attributed to declines in Bull Trout populations (Post and Johnston 2002; Hagen and Decker 2011; Kovach et al. 2016). Habitat condition in the long-term index streams ranges from good to pristine quality and has not been subjected to such industrial impacts. As such, these declining trends are especially concerning and increase the urgency to identify and mitigate limiting factors with on the ground enhancement actions.

The baseline created by redd count surveys in long-term index streams is robust and of great value to the management of Bull Trout in the Williston Reservoir watershed, and in the province of British Columbia (WLRS 2023). The addition of four new index streams in 2023 (Pelly, Pesika, Lay Creeks and Anzac River) will provide the data necessary to evaluate spatial scale of declining population trends and more thoroughly represent the heterogeneity of streams, populations and land use gradients found around the watershed. Population growth rate estimates from these additional indices (within previously unmonitored core areas) will improve the dataset required to properly evaluate Bull Trout conservation status in the Williston Reservoir watershed.

The simulation of time series completion (i.e., 75%, 50% and 25%) conducted here suggests a 75% minimum completion should be pursued to ensure an accurate estimate (Section 5.4). The purpose of the evaluation was to assess whether annual monitoring is required, and if not, how can this monitoring program be more flexible in a future where the funding focus will shift to on the ground conservation and enhancement actions. Monitoring the success of conservation and enhancement actions is important, and finding a balance between the cost of data collection and the quality of inference on population growth rate must be achieved. Annual monitoring in index sections does not necessarily need to be pursued if time series are maintained at greater than 75% completion over sequential generations of Bull Trout (i.e., 8 years). For the remainder of this project (2024-2025) we recommend a high level of effort on new index sections with shorter time series, and effort be expended to improve the calculation of population growth rate by upgrading regression analysis to a hierarchical model.

6.3 Limiting Factors and Cumulative Effects Modeling

As identified above, knowledge of limiting factors and threats is necessary for identifying and designing enhancement and mitigation actions. Acquiring this knowledge is identified as step #3 in FWCP's recommended sequence of monitoring actions for Bull Trout (Hagen and Weber 2019). Substantial investments have been made by FWCP to acquire the necessary population data to evaluate conservation status (step #1) and delineate critical habitats (step #2). This study is now shifting focus to step #3, which corresponds to *Action 13 Conduct monitoring actions that build on the work conducted to date to address data gaps limiting understanding of conservation status, critical habitats, and limiting factors for bull trout* (PEA.RLR.S04. RI.13) in the *Rivers, Lakes, and Reservoirs Action Plan* (FWCP 2020).

Three key potential limiting factors which are data limited have been outlined as critical data inputs for the analysis of limiting factors (Hagen et al. 2023).

1. *Temperature Monitoring in Bull Trout critical habitats*

Water temperature is a key factor affecting the distribution and abundance of Bull Trout. A Maximum Weekly Average Temperature (MWAT) of 11°C has been suggested as the upper limit of thermal suitability for the species (Parkinson et al. 2012), and they are generally not present in streams that exceed 15-16°C for any extended period (Pratt 1992; Swanberg 1997; Westover and Heidt 2004). A partnership of proponents including the University of Northern British Columbia, BC Ministry of Forests (MOF) and Chu Cho Environmental have initiated a broad scale temperature monitoring and modeling project *Investigating Thermal Regimes of the Upper Peace River Basin* (O'Connor et al. 2024; PEA-F-F24-3845). This initiative aims to better understand patterns in thermal habitat availability and how land use and climate change impact thermal regimes and cold-water adapted aquatic ectotherms. This project will provide data for the analysis of temperature as a limiting factor for Bull Trout. Temperature data is collected as time series data at individual points within the watershed, but upon completion of the project model outputs will provide temperature data at the watershed and basin scale. Outputs of the stream temperature models (expected in 2025) can be directly implemented in limiting factors assessments discussed below.

2. *Bull Trout genetic population structure study*

Redd count surveys provide an indication of Bull Trout population trend, but the spatial extent of metapopulations that these counts represent is unknown; therefore, a population structure study had been recommended for the Williston Reservoir watershed. Such a study was initiated in 2023 by Chu Cho Environmental in partnership with BC Ministry of WLRS, UNBC and J.H. and Associates (PEA-F24-F-3847). The results of this study will be used to refine our knowledge of Bull Trout population structure and core area delineation of the Upper Peace Ecological Drainage Unit. Closing this information gap will provide context to Bull Trout redd count data, and provide important metapopulation data to inform where investment in conservation actions or habitat enhancements can be spent most effectively.

3. *Competitive interactions in the Williston Reservoir*

Lake Trout are known to competitively exclude Bull Trout in lacustrine environments where their populations overlap, often resulting in severe Bull Trout population declines (Donald and Alger 1993; Ferguson et al. 2012; Hansen et al. 2016). Lake Trout abundance in Williston Reservoir is anecdotally increasing (O'Connor and Krivenko 2023). As such, development of a Lake Trout stock assessment program was recommended to determine Lake Trout abundance trend in the reservoir and to determine whether actions to manage Lake Trout are required. CCE evaluated potential Lake Trout stock assessment methods in the Williston Reservoir (PEA-F23-F-3644), with the goal of implementing a program in the near future. The findings of that seed project suggest that gathering abundance data for Lake Trout, although important, may not be the most effective way to assess the competitive interactions with Bull Trout. This is due to the potential variability in abundance data, and other insights made into community complexity during the investigation of species interactions in other large reservoirs in British Columbia (Kootenay Lake; Warnock et al. 2021). Equally important for FWCP to consider before investing in abundance monitoring in the Williston Reservoir is the population structure of Lake Trout and their origin, and the specific competitive interface between Bull Trout and Lake Trout. These need to be defined before this biotic limiting factor for Bull Trout can be properly evaluated. CCE proposed an evaluation of index netting methods, which would concurrently gather samples required for evaluation of Lake Trout population structure and the competitive interface between the char species; however, this was not funded for 2024-2025. This speaks to the limited resources available and difficulty in finding coalescence between multiple intensive, logistically challenging monitoring programs. We do recommend that FWCP implement projects which aim to define the competitive interface between char species in the lacustrine environment and evaluate the effectiveness of index netting techniques. It would be pertinent to seek collaboration with the BC Hydro Water Use Plan, and Fisheries Entrainment Strategy so that appropriate resources are available to provide data on this important biotic limiting factor. Without closing the data gap on species interactions in the Williston Reservoir, a limiting factors analysis on Bull Trout will be incomplete. However, we do not recommend withholding investment in conservation and enhancement actions give the incredible depth of data available for the design of such actions in Bull Trout critical habitats.

In pursuit of an initial evaluation of limiting factors, a novel modeling framework was used to conduct an assessment of the data this project and other FWCP funded projects have gathered. The Cumulative Effects Model for Prioritizing Recovery Actions (CEMPRA; MacPherson et al. 2023) was run on select limiting factors for Bull Trout which were outlined at the conclusion of the aerial redd survey program (Hagen et al. 2023). The CEMPRA modeling tool is useful for bridging the gap between listing threats and quantitative population models which define effects, accelerating the threat assessment process, and providing a means to evaluate limiting factors and subsequently re-assess limiting factors after implementation of conservation actions. The modeling tool has had multiple recent applications including assessments of Athabasca Rainbow Trout (Sullivan et al. 2017), Bull trout in Alberta (MacPherson et al. 2023), Chinook Salmon in the Nicola Basin (Pearsall et al. 2022) and the Plains Sucker in Southeastern Alberta (Bayly et al. 2023).

Under the CEMPRA modeling tool, we evaluated a limiting factors analysis using the “Joe Model”, which does not consider population dynamics or density dependence. Although an extension to a more refined population model is possible, we aimed to initially assess the model’s applicability to the data gathered by the aerial redd survey program and subsequent analyses (Hagen et al. 2023). Five limiting factors including maximum weekly maximum temperature (MWMT), hydrological hazard, ECA score, maximum elevation and stream crossings per km^2 which were readily available in the Bull Trout geodatabase, were used to estimate relative system capacity. System capacity (the response) is a user-defined reference condition estimated as the product of the habitat suitability indices for a given species over a defined space (e.g., watershed; MacPherson et al. 2023). It is a proportion (0-1) which describes the condition of habitats relative to a hypothetical reference condition if limiting factors were absent. The model was run on the 8 index monitoring streams and, in addition, all other tributaries in those watersheds which hold Bull Trout spawning habitat (n = 24). The spawning critical habitat basins developed by Hagen et al. (2023) were used as the space over which limiting factors were assessed. Temperature data was available from all 8 monitored index watersheds via the Modeling Thermal Regimes project (O’Connor et al. 2024; PEA-F-F24-3845). The remaining variables were gathered from the Watershed Health Project Omineca Region (WHOPR) tool which was executed for all identified Bull Trout critical spawning habitats mapped by the aerial redd survey program up to February 2023 (Hagen et al. 2023).

A preliminary run of the CEMPRA model provided an important test of the critical habitat data and shows promise as a path forward for limiting factors analysis which can prioritize on the ground enhancement and conservation actions. In this initial run, system capacity estimates produced by the CEMPRA Joe Model were most impacted by MWMT, Hydrological Hazard and Max Elevation in the systems which had available data. The intuitive interpretation of system capacity results and ability to tune differing scenarios of limiting factors (stressor magnitudes) support decision making and provide a means of evaluating the impacts of interventions (MacPherson et al. 2023). It’s widespread uptake and implementation provide merit for its use and flexibility (Bayly et al. 2023 and references therein). The data gathered under the aerial redd survey program is an invaluable resource to support the evaluation of conservation status and limiting factors. A preliminary run through the CEMPRA Joe Model tool has confirmed its usefulness; however, some key considerations should be evaluated before pursuing the CEMPRA tool for application to the whole geodatabase.

Data availability was slightly constraining for this preliminary model run, as some basins surveyed in 2022 have not been assessed using the WHOPR tool. A re-run of the WHOPR tool on the critical habitats geodatabse is needed to extend the CEMPRA model to more watersheds. In addition, temperature data was available only for the 8 watersheds included in the Joe Model at singular points within the watershed. This meant that data from one point in a watershed was used as a stressor magnitude in multiple basins within that watershed (8 watersheds, 24 sub-basin polygons). Stream temperatures have high variability in space, and point samples can underrepresent the heterogeneity of thermal conditions in large watersheds (Steel et al. 2017). Temperature data was available for the 8 watersheds assessed here because they are a focus of the reach scale investigation of thermal habitat patterns in Bull Trout spawning habitats for the Modeling Thermal Regimes project (O’Connor et al. 2024; PEA-F24-F-3845). However, they were deployed in the annually monitored index section so may be misrepresentative of nearby tributaries. Headwater tributaries typically have similar thermal regimes, and spatial autocorrelation is an inherent part of stream networks, increasing confidence in the data's reasonable use in this application (Isaak et al. 2014). For a more nuanced analysis of limiting factors, we plan to utilize the model outputs from the Modeling Thermal Regimes project to more accurately characterize thermal conditions in the assessed watersheds. Basin and watershed scale temperature predictions are in development and should be used in a CEMPRA model following their evaluation.

Further evaluation of limiting factors should be conducted under the CEMPRA tool (or similar methodologies) utilizing data provided by this and other FWCP funded projects (e.g., PEA-F-F24-3845). Temperature predictions from the Investigating Thermal Regimes project can be directly integrated into the CEMPRA model along with the outputs of the WHOPR assessment tool (O'Connor et al. 2024). The ease at which the available abiotic limiting factors data can be run through the CEMPRA model in the interactive Shiny app (see https://github.com/essatech/CEMPRAShiny) is an attractive feature of the tool. However, the time required to extract and organize the data from the Bull Trout critical habitats geodatabase, and clean raw temperature data from the Investigating Thermal Regimes project is nontrivial. In addition a deep level of thought needs to be placed into the rationalization of predictors included in CEMPRA tool and limiting factors analysis. The recommended Joe Model steps consists of:

1. Expert panel to identify key, independent stressors and establish preliminary stressor-response curves
2. Literature review to refine stressor-response curves
3. Estimation of the levels of each stressor within hydrologic units in the Williston Watershed.
4. Computation of cumulative effects by multiplying the independent estimates of stressor effects on system capacity.

The collection of potential limiting factors analysis covariates, their rationalization and assessment of data availability was completed by Hagen et al. (2023; Appendix 1 reprinted here). However, continual evaluation of those limiting factors and how they affect each population is needed. The refinement of stressor response curves (i.e., habitat suitability indices) is an important step, which can have a large influence on the model outputs. We recommend a workshop style assessment of habitat suitability curves for Bull Trout in the reservoir to ensure proper refinement. An additional consideration for future use of the CEMPRA tool is the dearth of available biotic limiting factors data (e.g., Kokanee and Lake Trout abundance; Rainbow Trout distribution) which can describe competitive interactions. Competitive interactions have been shown to compound (interact) with abiotic variables to exacerbate population declines in Bull Trout (Wenger et al. 2011; Kovach et al. 2016). The Joe Model under the CEMPRA tool is limited in its ability to include these interactive effects which are known to exacerbate Bull Trout declines and has an absence of density dependent effects. As reviewed in Hagen et al. (2023) density dependent effects and competition are key limiting factors for Bull Trout in the Williston Reservoir, which are currently data limited.

An extension to a population model is possible, provided the appropriate rates are gathered for the species of interest, but it is important to note that the CEMPRA model will never replace more detailed population modeling; however, this is not its purpose. The great benefit provided by the CEMPRA modeling tool is its ability to rank and prioritize limiting factors, and aid in the creation of conservation actions or habitat enhancements targeted at specific watersheds (i.e., populations). This is a critical next step for FWCP and the CEMPRA model can support effective decision making given its structured assessment framework, and ability to evaluate different scenarios of limiting factors (i.e., varying stressor magnitude). Lastly, the use of cumulative effects modeling also extends beyond Bull Trout and can be used for any aquatic species by adjusting the stressor reponses for a given species preferences, thereby addressing Action 1 *Assess cumulative effects on aquatic ecosystems* of the Rivers, Lakes, and Reservoirs Action Plan (FWCP 2020).

6.4 Conservation of Critical Habitats

The key management action necessary to sustain large-bodied, migratory Bull Trout in the Williston watershed is to protect the critical habitats they depend on to grow and survive. Critical spawning and early rearing habitats are known to be limiting for Bull Trout populations, and the productivity of this key habitat element is extremely sensitive to human land use (Hagen et al, 2023). Therefore, these stream segments, along with the catchment area affecting them, are the highest priority for habitat conservation and actions to protect Bull Trout from human disturbance (Section 4.5.2).

Hagen and Sary (2023) outlined recommendations for conservation planning for Bull Trout in the Williston Reservoir watershed which were described in Hagen et al. (2023). The prioritization of critical habitats for habitat conservation described in Hagen and Sary (2023) and data provided by this study are being directly used in collaborative stewardship forums (i.e., Environmental Stewardship Initiative [ESI]) between First Nations whose traditional territories lie within the footprint of the Williston Reservoir, and WLRS. Currently a reprioritized package of critical habitats in conservation categories 1, 1a and 2 (outlined in Hagen et al. 2023) has been recommended for immediate protection under the TKDN/BC ESI. In addition, increases to riparian buffers have been recommended across the Nation's entire territory. The recommendation is aligned with TKDN rights, title and interest in conserving their territory, and the guiding principles described in FWCP's recommended sequence of monitoring actions for Bull Trout (Hagen and Weber 2019). This recommendation would not have been possible without the data collected by this study. Protecting critical habitats in good ecological condition is more cost-effective than restoration activities and has been shown to provide a buffer against population declines across the species range (Roni et al. 2002; Chapin et al. 2015; Isaak et al. 2016). This study has made the creation of proposed conservation actions possible.

The data collected by this project also informs another important regional conservation effort through the BC Hydro Upper Peace River Fish Entrainment Strategy (FES). Data from this project is directly used in the effects assessment conducted under the FES. The ensuing mitigation and habitat offsetting efforts will be aided by the data collected under the aerial redd survey program and the genetic population structure study (Hagen et al. 2024; PEA-F24-F-3847). We recommend collaboration between FWCP and the FES technical committee on implementation of enhancement ("offset") actions. Following the effects assessment, a list of potential habitat offsets (enhancements) will be created based on input from the FES committee. These offsets are intended to meet the requirements of BC Hydro under a Fisheries Act Authorization to overcome the loss of fish through entrainment which cannot be mitigated. Habitat enhancements while being developed under the FES will directly address Action 3 *Implement stream conservation, restoration, and/or enhancement actions*, and 14 *Implement high priority habitat- and species-based actions for bull trout* of the Rivers, Lakes, and Reservoirs Action Plan (FWCP 2020). FWCP should be included in the creation of habitat offsets or enhancements given the investment made in acquiring the required data to design and implement those conservation actions.

7 Conclusion and Recommendations

This program has been effective at advancing through FWCP's recommended sequence of monitoring actions for Bull Trout (Hagen and Weber 2019). Following completion of the 2014-2022 aerial redd survey component of this study, critical habitat layers have been created by study collaborator WLRS. Critical habitat layers have been instrumental in the design of Bull Trout habitat conservation actions in the region. Coalescence with other FWCP funded projects is facilitating the evaluation of limiting factors for Bull Trout using novel modeling tools. Furthermore, information on spawner distribution and abundance has allowed for an improvement of the spatial scope of abundance monitoring, and development of projects investigating and refining our knowledge of population structure (Hagen et al. 2024).

This study is now able to shift focus to step #3 in the recommended sequence of monitoring actions for Bull Trout (Hagen and Weber 2019) which corresponds to *Action 13 Conduct monitoring actions that build on the work conducted to date to address data gaps limiting understanding of conservation status, critical habitats, and limiting factors for bull trout* (PEA.RLR.S04. RI.13) in the *Rivers, Lakes, and Reservoirs Action Plan* (FWCP 2020). Ongoing abundance monitoring should therefore focus on new index sites to complement the existing long-term data while ensuring all data series are maintained at 75% completion or greater over the generation timing of Bull Trout (i.e., 8 years).

Moving forward we recommend a focused effort on the evaluation of limiting factors for Bull Trout, and subsequent creation of potential on-the-ground enhancement actions targeted to specific critical habitats (i.e., local populations) as advised by the population structure study (Hagen et al. 2024). The prioritization of enhancement and conservation actions would be advised by the results of cumulative effects modeling following the next steps (below) which will be completed in winter 2024-2025. These next steps in the evaluation of limiting factors for Bull Trout using the CEMPRA modeling tool (or equivalent methodologies not reviewed here) include:

1. Define high-level objectives of cumulative effects modeling, and modeling framework which can meet those objectives (i.e., Joe Model or Population Model);
2. Define theoretical system capacity for the spatial layer over which the model is applied (adult spawning basins, or juvenile rearing basins);
3. Complete an assessment of habitat suitability curves for Bull Trout in the Williston Reservoir to refine stressor-response relationships in coordination with regional experts;
4. Gather biotic and abiotic data related to the stressor-response relationships which can be used in cumulative effects modeling (guided by the limiting factors presented here in Appendix 1 and those suggested by regional experts):
    a. Distribution data on sympatric species as a proxy for compeition;
    b. Re-run the WHOPR tool on the entire Bull Trout critical habitats geodatabse;
    c. Extract continuous temperature predictions where available and improve estimation of MWMT in critical habitats.

By conducting cumulative effects assessments on all critical habitat polygons with updated data, a future analysis can provide the evaluation of limiting factors and prioritization of on the ground enhancement actions within discrete population units.

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Appendices

Appendix 1. Potential covariates in an analysis of limiting factors for Bull Trout in the Williston Reservoir watershed.

Covariate Class	Variable Description	Rationale	Supporting Reference	Current Availability (Y/N)	Spatial Scope
Demographic/ habitat geometry	Accessible stream length > 900 m elevation	I.e., patch size; based on empircical observations in Williston, could be refined up or down (min 800 m, max 1000 m)	Dunham, J.B., and B.E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical and geometrical landscape characteristics. Ecological Applications 9:642-645.	Y	Spawning habitat
	Distance from reservoir	Migration distance from adult rearing environmment (few redds > 100 km from reservoir)	Hagen, J., Sary, Z., and B. O'Connor. 2022. Williston Bull Trout Monitoring Study 2021: How Effective Stewardship of Critical Habitats can be Achieved in the Basin. Report prepared for Fish and Wildlife Compensation - Peace Region. FWCP Project No. PEA-F22-F-3424	Y	Spawning habitat
	Stream distance to nearest population	Isolation metric from Dunham and Rieman 1999; Isaak et al. 2022	Isaak, D.J., M.K. Young, D.L. Horan, D. Nagel, M.K. Schwartz, K.S. McKelvey. 2022. Do metapopulations and management matter for relict headwater bull trout populationions in a warming climate? Ecological Applications DOI: 10.1002/eap.2594; Dunham and Rieman (1999)	Y	Spawning habitat
	Population size within 100 km (stream network)	Metapopulation source-sink dynamics; distance is arbitrary for now (needs to account for distance to reservoir and distance among stream mouths)	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
Physical habitat characteristics	Mean reach elevation	Proxy for climate	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	Mean reach slope	Index of habitat suitability	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	Reach km < 5 % slope	Index of high habitat suitability	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	% alluvial channel type	Key attribute of groundwater, high	Baxter, C.V., C.A. Frissel, and F.R. Hauer. 1999. Geomorphology, logging roads, and the distribution of bull trout (Salvelinus confluentus) spawning in a	Y	Spawning habitat

		spawning suitability	forested river basin: implications for management and conservation. Transactions of the American Fisheries Society 128: 854-867.		
	Max watershed elevation	BT distribution in BC is closely associated with moutainous areas	Hagen, J., and S. Decker. 2011. The status of Bull Trout in British Columbia: a synthesis of available distribution, abundance, trend, and threat information. BC Government Fisheries Technical Report No. FTC 110.	Y	Spawning habitat
Hydrological characteristics	Reach contributing area	Proxy for stream size	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	Water yield	Better index of stream size if feasible to estimate	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Watershed
	Runoff timing and variability	Flow monitoring	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	N	Watershed
Thermal conditions	Mean August temperature	Warm-edge thermal niche limitation	Isaak, D., M. Young, D. Nagel, D. Horan, and M. Groce. 2015. The cold-water climate shield: Delineating refugia for preserving salmonid fishes through the 21st Century. Global Change Biology. 21:2540-2553.	Y	Spawning habitat
	MWMT temp during spawning window June 15 - August 25th in spawning habitat	Warm-edge thermal niche limitation	Steel, E.A., Sowder, C., and Peterson, E.E. 2016. Spatial and Temporal Variation of Water Temperature Regimes on the Snoqualmie River Network. Jawra J Am Water Resour Assoc 52(3): 769–787. doi:10.1111/1752-1688.12423.	Y	Spawning habitat
	Reach km < 9C mean August temp	Index of high thermal suitability	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	Coefficent of Variation	Thermal variability metric	NA	Y	Spawning habitat
	Thermal exceedances of 9C	Warm-edge thermal niche limitation	Williamson, C.J. 2006. Characterization of Spawning Habitat, Incubation Environment and Early Growth and Development in Bull Trout (Salvelinus confluentus) from Pristine Streams of Northern British Columbia. Master of Science. University of Northern British Columbia. Prince George, BC. Mochnacz, M.K. Taylor, M.F. Docker, and D.J. Isaak. 2022. An ecothermal paradox: bull trout populations diverge in response to thermal landscapes across a broad latitudinal gradient.	Y	Spawning habitat

			Environmental Biology of Fishes https://doi.org/10.1007/s10641-022-01339-0		
	Max summer air temp during adult migration period	Proxy for water temperature	NA	Y	Watershed
	Thermal sensitivity	Slope of linear regression between weekly water temperature and weekly air temperature; potential index of groundwater and thermal stability	Mochnacz, M.K. Taylor, M.F. Docker, and D.J. Isaak. 2022. An ecothermal paradox: bull trout populations diverge in response to thermal landscapes across a broad latitudinal gradient. Environmental Biology of Fishes https://doi.org/10.1007/s10641-022-01339-0	Y	Spawning habitat
	Degree days to estimated emergence	juvenile rearing phenology; length of incubation and growing period	Williamson, C.J. 2006. Characterization of Spawning Habitat, Incubation Environment and Early Growth and Development in Bull Trout (Salvelinus confluentus) from Pristine Streams of Northern British Columbia. Master of Science. University of Northern British Columbia. Prince George, BC. Mochnacz, M.K. Taylor, M.F. Docker, and D.J. Isaak. 2022. An ecothermal paradox: bull trout populations diverge in response to thermal landscapes across a broad latitudinal gradient. Environmental Biology of Fishes https://doi.org/10.1007/s10641-022-01339-0	Y	Spawning habitat
	ATUs from egg deposition to onset of winter	Cold-edge thermal niche limitation	Mochnacz, M.K. Taylor, M.F. Docker, and D.J. Isaak. 2022. An ecothermal paradox: bull trout populations diverge in response to thermal landscapes across a broad latitudinal gradient. Environmental Biology of Fishes https://doi.org/10.1007/s10641-022-01339-0	Y	Spawning habitat
Wildfire disturbance	Wildfire % in reach contributing area	Indicator of climate threat	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
	Wildfire % in 100 m riparian zone	Alternative wildfire metric	Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.	Y	Spawning habitat
Cumulative effects of human land use	Road density (watershed)	General cumulative effects indicator, several time horizons possible	Kovach, R.P., R. Al-Chokhachy, D.C. Whited, D.A. Schmetterling, A.M. Dux, and C.C. Muhlfelfd. 2016. Climate, invasive species, and land use drive population dynamics of a cold-water specialist. Journal of Applied Ecology. Doi: 10.1111/1365-2664.12766.	Y	Watershed
	Road density (reach contributing area)	As above, but more focused on critical spawning and early rearing habitat	Baxter, J.S., and McPhail, J.D. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (Salvelinus confluentus) from egg to alevin. Can J Zool 77(8): 1233–1239. doi:10.1139/z99-090.; Kovach, R.P., Al-Chokhachy, R., Whited, D.C., Schmetterling, D.A., Dux, A.M., and Muhlfeld, C.C.	Y	Spawning habitat

			2017. Climate, invasive species and land use drive population dynamics of a cold-water specialist. J Appl Ecol 54(2): 638–647. doi:10.1111/1365-2664.12766.; Isaak, D.J., Young, M.K., Horan, D.L., Nagel, D., Schwartz, M.K., and Mckelvey, K.S. 2022. Do metapopulations and management matter for relict headwater bull trout populations in a warming climate? Ecological Application: e2594. doi:10.1002/eap.2594.		
	Equivalent clearcut area (ECA)	Additional cumulative effects indicator, others are available	BC MOF. 2001. Watershed assessment procedure guidebook. 2nd ed., Version 2.1. Forest Practices Board, Ministry of Forests, Victoria, BC. Forest Practices Code of British Columbia Guidebook.	Y	Spawning habitat
Adult rearing environment	Abundance of Lake Trout in Williston Reservoir	Index of interspecific competition	Donald, D.B., and D.J. Alger. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and Bull Trout in mountain lakes. Canadian Journal of Zoology 71:238-247.	N	Basin
	Estimated predator fish density in reservoir reach	Index of inter/intraspecific competition	NA	N	Basin
	Estimated Lake Trout abundance in reservoir reach	Index of interspecific competition	Donald, D.B., and D.J. Alger. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and Bull Trout in mountain lakes. Canadian Journal of Zoology 71:238-247.; Kovach, R.P., Al-Chokhachy, R., Whited, D.C., Schmetterling, D.A., Dux, A.M., and Muhlfeld, C.C. 2017. Climate, invasive species and land use drive population dynamics of a cold-water specialist. J Appl Ecol 54(2): 638–647. doi:10.1111/1365-2664.12766.	N	Basin
	Prey fish density in reservoir reach	LT-BT interspecific competition may be mediated through LT effects on prey abundance	Culling, B., T. Euchner, T. Ward, and S. Cooke. 2020. PEACE REACH LAKE TROUT MOVEMENTS FINAL REPORT - YEAR 4. Report prepared for Fish and Wildlife Compensation Project, FWCP project # PEA-F20-F-2948, Prince George, BC.	Y	Basin