

2021 Parsnip Arctic Grayling Critical Habitats and Abundance: Towards an Effective Habitat Stewardship Framework.

John Hagen¹ and Mike Stamford²

March 31, 2022

Prepared for:



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

FWCP Project No. PEA-F22-F-3407

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.



¹ John Hagen and Associates, 330 Alward St., Prince George, BC, V2M 2E3; hagen_john2@yahoo.ca

² Stamford Environmental; 877 West Bay Road, Gambier Island, BC, V0N 1V0; stamford@telus.net

Suggested citation:

Hagen, J., and M. Stamford. 2022. 2021 Parsnip Arctic Grayling critical habitats and abundance: towards an effective habitat stewardship framework. Report prepared for the Fish and Wildlife Compensation Program – Peace Region, Prince George, BC. FWCP Project No. PEA-F22-F-3407.

EXECUTIVE SUMMARY

Because of conservation concern with hydroelectric development and high value for humans, the Arctic Grayling is a priority species for the Fish and Wildlife Compensation Program – Peace Region (FWCP) and collaborators BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD) and McLeod Lake Indian Band (MLIB). Over the 1995-2007 period, FWCP periodically monitored adult Arctic Grayling abundance and trend in the Parsnip River watershed using replicated snorkeling surveys, during the month of August, in two index reaches of the Table River and four index reaches of the Anzac River. Abundance and trend are the two most important indicators of a fish population's conservation status, i.e., whether it still exists and how likely it is to become extinct in the future.

In 2018, after an 11-year hiatus, the snorkeling study in these long-term index sections was resumed. At the same time an important new study component was added: single-pass snorkeling surveys to estimate critical summer rearing habitat and adult grayling abundance in other sub-basins of the Parsnip River watershed. This report details results from the fourth consecutive year of this five-year study program, which addresses Action #9 of FWCP's *Rivers, Lakes, and Reservoirs Action Plan* (p. 12):

Conduct research and monitoring of Arctic Grayling to obtain data related to conservation status, critical habitats, and key limiting factors.

In 2021, snorkeling surveys in the Parsnip River watershed were conducted over the August 11-18 period consistent with past surveys. During snorkeling surveys, two independent, three-person crews were utilized. In long-term index sections in the Table and Anzac Rivers, counts were replicated by both crews. Single-pass surveys were conducted in 5 sections of Reynolds Creek and 3 sections of Colbourne Creek.

A key area of focus for our study since 2019 has been the application of models that analyze replicated count data to estimate detection probability and abundance in snorkeling reaches. Over the 1995-2021 period, a total of 42 surveys have taken place in the six long-term index sections of the Anzac and Table rivers in which at least two replicate counts were made. In 2021, variation among replicate counts at individual sites were analyzed to estimate the accuracy of snorkeling counts using a binomial-likelihood model framework. The best model included two predictors of detection probability: site width and horizontal underwater visibility. Detection probability estimates ranged from 0.54-0.74 among long-term index sections, with highest estimates associated with the smaller reaches at the top of the Arctic Grayling distribution in each system.

After adjusting snorkeling counts in long-term index sections to account for variable detection probability, analysis of population trend using a linear mixed-effects model indicated significant population growth ($P < 0.001$) over the 1995-2021 period. The linear mixed effects model output suggested an annual population growth rate of 4.1% for the Parsnip River population as a whole,

which equates to an increase of approximately 103% over a 25-year time frame. The total number of Arctic Grayling counted in long-term index sections in 2021 was the highest ever recorded.

Single-pass reconnaissance snorkeling surveys have now been completed in several potential Arctic Grayling streams outside of the Table and Anzac rivers: the Missinka River surveyed in 2019, the Hominka River and Wichcika Creek surveyed in 2020, and Reynolds and Colbourne creeks surveyed in 2021. Among surveyed reaches in these streams, the most productive summer rearing habitats for adult Arctic Grayling are distributed from 36-29 km of the Missinka River and from 48-32 km of the Hominka River. Wichcika, Reynolds, and Colbourne creeks provide summer rearing habitat for very few adult Arctic Grayling.

We conclude our report by recommending a habitat stewardship and monitoring framework to ensure that investments in Arctic Grayling conservation in the Parsnip River watershed are effective. Key conservation and monitoring actions for the short term are:

1. Share study results and critical habitat information with FLNRORD and First Nations whose territories overlap the Parsnip River watershed, in forms that are useful to them for land use planning and stewardship.
2. Watershed-scale land use objectives to protect against water temperature increases and hydrological hazards, e.g., Fisheries Sensitive Watershed designations, in watersheds that provide summer rearing habitat for adult Arctic Grayling.
3. Studies to improve knowledge of limiting factors, e.g., the roles of water temperature and other physical habitat variables in limiting Arctic Grayling distribution and abundance now and in the future.
4. Effectiveness monitoring to evaluate whether watershed-scale land use objectives and other stewardship actions are adequate for the long-term conservation of Arctic Grayling in the Parsnip River watershed.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i

LIST OF TABLES iii

LIST OF FIGURES iv

1.0 INTRODUCTION 1

2.0 GOALS AND OBJECTIVES 4

3.0 STUDY AREA 4

4.0 METHODS 7

 4.1 Survey Conditions 7

 4.2 Snorkeling Methods 8

 4.3 Environmental DNA Sampling 16

 4.4 Analyses 16

 4.4.1 *Detection probability and abundance.* 16

 4.4.2 *Population trend.* 17

5.0 RESULTS 18

 5.1 Survey Conditions 18

 5.2 Snorkeling Detection Probability 21

 5.3 Population Trend 24

 5.4 Critical Summer Habitats in Reynolds and Colbourne Creeks 25

 5.4.1 *Reynolds Creek.* 25

 5.4.2 *Colbourne Creek.* 28

 5.5 Other Species 31

6.0 DISCUSSION 35

 6.1 Scientific Information Needs for Arctic Grayling Conservation 35

 6.1.1 *Monitoring data requirements* 35

 6.1.2 *Conservation status and risk* 35

 6.1.3 *Critical habitats.* 37

 6.1.4 *Limiting factors* 38

 6.1.5 *Effectiveness of conservation actions.* 39

 6.2 Recommendations Towards an Arctic Grayling Stewardship Framework 39

 6.2.1 *Conservation vision and principles.* 39

 6.2.2 *Recommended stewardship and monitoring actions.* 40

7.0 ACKNOWLEDGMENTS 42

8.0 REFERENCES 42

LIST OF TABLES

Table 1. Biophysical characteristics of sub-basins potentially utilized by Arctic Grayling within the Parsnip River watershed..... 7

Table 2. Horizontal underwater visibility in snorkeling survey sections of the Parsnip River watershed, August 2021.....	21
Table 3. Replicated snorkeling counts of Arctic Grayling >20 cm in long-term index sites of the Anzac and Table rivers, 1995-2021.	22
Table 4. Comparison among predictors of detection probability p estimated within a binomial-probability model framework (see text) from replicated count data in the Parsnip River watershed. Symbols K , $\text{Log}(L)$, AIC_c , Δ_i , $L(g_i x)$, and w_i , denote 1) the number of estimable parameters, 2) model log-likelihoods, 3) the Akaike information criterion values adjusted for small sample size, 4) the difference in AIC_c values between each model and the model with the lowest AIC_c score, 5) the likelihood that the candidate model is the best among the set, and 6) Akaike weights, respectively.	23
Table 5. Predictions of mean detection probability p at long-term index sections of the Parsnip River watershed, computed at average values of wetted width (WIDTH) and underwater visibility at which Arctic Grayling can be discerned (FISH_VIS).	24
Table 6. Snorkeling counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish >20 cm in reconnaissance sections of the Parsnip River watershed, 2019-2021.	27
Table 7. Unadjusted mean counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish in long-term index sections of the Table and Anzac rivers, 1995-2021.	34

LIST OF FIGURES

Figure 1. Sub-basins of the Parsnip River watershed (Parship mainstem, Misinchinka, Colbourne, Reynolds, Firth, Anzac, Bill's, Table, Hominka, Missinka, Wichcika, Arctic Lake, Upper Parsnip) potentially utilized by Arctic Grayling.	6
Figure 2. Snorkeling survey of Table River section 35-31 km under conditions of good water clarity, August 2021.	8
Figure 3. Index sections of the Table River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2021. Site 22-18 km was utilized up to 2007, but was replaced by site 26-22 km in 2018 due to the presence of a clay slump at 22 km that continues to compromise visibility in the lower site.	9
Figure 4. Index sections of the Anzac River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2021.	10
Figure 5. Top boundary of Anzac River long-term snorkeling survey section 47-45 km, now accessible from the Coastal GasLink Pipeline access road crossing (background).	11
Figure 6. Reconnaissance sections of Reynolds Creek utilized for snorkeling and environmental DNA (eDNA) surveys to monitor Arctic Grayling abundance and presence, respectively, August 2021.	12
Figure 7. Reconnaissance sections of Colbourne Creek utilized for snorkeling and environmental DNA (eDNA) surveys to monitor Arctic Grayling abundance and presence, respectively, August 2021.	13

Figure 8. Three-person snorkeling team in the Parsnip River watershed.	14
Figure 9. Table River Arctic Grayling.	14
Figure 10. Black-and-white Secchi disk used to estimate horizontal underwater visibility, August 2021.	15
Figure 11. Estimated discharge (solid line) relative to long-term average discharge (dashed line) in the lower Parsnip River before and during the August 11-18 study period, Water Survey of Canada (WSC) Station 07EE007 (Parsonip River above Misinchinka River).	19
Figure 12. Rapid decline of visibility to < 2 m at Table River 22 km, the top boundary of former long-term index section Table 22-18 km, on August 13, 2021.	20
Figure 13. Unadjusted snorkeling counts of Arctic Grayling >20 cm in index sites of the Anzac River and Table River watersheds 1995-2021. Values are averages of replicate counts. *Beginning in 2018, Table River section 26-22 was substituted for 22-18 which was affected by a major clay slump at 22 km.	25
Figure 14. Holding pool utilized by adult Arctic Grayling in Reynolds Creek section 30-26 km, 2020 and 2021.	26
Figure 15. Reconnaissance sections of streams in the Parsnip River watershed surveyed using single-pass snorkeling over the 2018-2021 period.	28
Figure 16. In the distance can be seen one of several areas of streamside logging and riparian forest removal in the lower Colbourne Creek watershed, August 2021.	30
Figure 17. Channel widening and fine sediment deposits in Lower Colbourne Creek.	30
Figure 18. Counts of Bull Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.	32
Figure 19. Counts of Rainbow Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.	33
Figure 20. Counts of Mountain Whitefish >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.	33

1.0 INTRODUCTION

In the upper Peace Basin, the Arctic Grayling (*Thymallus arcticus*) is a fluvial (stream-dwelling) species. Following construction of the W.A.C. Bennett dam in 1967 and the formation of Williston Reservoir, Arctic Grayling populations were devastated in the flooded portions of the Parsnip River, Finlay River, and Peace River watersheds (Stamford et al. 2017). The Parsnip River valley upstream of the flood zone is home to one of the few surviving grayling populations. For these populations, increased land use and climate change pose new threats.

What actions are needed to conserve Parsnip Arctic Grayling for future generations? This study is designed to address this question directly, by providing abundance monitoring data to track the status of the Parsnip population, and by providing critical habitat information to help focus habitat stewardship in the watershed.

Remnant populations of Arctic Grayling in the Williston Reservoir watershed face threats both from the reservoir's footprint impacts and other human-caused ecological and physical habitat changes. Parsnip Arctic Grayling appear to be demographically and genetically isolated from other remnant populations by the reservoir, which they do not appear to migrate through (Phillipow and Langston 2002; Sebastian et al. 2003; Clarke et al. 2005). The Arctic Grayling is also a species that is sensitive to land use-related habitat degradation (Armstrong 1986; Northcote 1993; Walker 2005; USFWS 2010; Cahill 2015). In the Parsnip River watershed, major increases in industrial activities related to forestry expansion, pipeline construction, and associated roads threaten habitat suitability, as well as providing increased access for anglers to remote areas where protective regulations are difficult to enforce. Key mechanisms of habitat degradation affecting Arctic Grayling are increases in sediment transport, stream flow variation, and water temperature (de Bruyn and McCart 1974; Tack 1974; Birtwell et al. 1984; McLeay et al. 1987; Reynolds et al. 1989; Clark 1992; Deegan et al. 1999; Cowie and Blackman 2003; Hawkshaw et al. 2013; Hawkshaw and Shrimpton 2014). Situated at the southern margin of the species' range in British Columbia, Parsnip Arctic Grayling are also threatened by thermal habitat changes from climate warming (Hawkshaw and Shrimpton 2014; Stamford et al. 2017).

The Arctic Grayling is valued by First Nations of the Williston watershed as a delicacy and as a nutritious food fish (Pearce et al. 2019; Arlene Solonas, pers. comm. January 2022), and is also prized by northcentral British Columbia's recreational anglers. Because of conservation concern and high value for humans, the Arctic Grayling is a priority species for the Fish and Wildlife Compensation Program – Peace Region (FWCP), which was established to conserve and enhance fish and wildlife impacted by the creation of the Williston and Dinosaur Reservoirs (BC Hydro 2020: *Peace Region Rivers, Lakes, and Reservoirs Action Plan*). To facilitate this aim for Arctic Grayling populations, FWCP conducted a major study to evaluate the existing knowledge base relative to key strategic objectives for species conservation and enhancement. The resulting *Arctic Grayling Synthesis Report* (Stamford et al. 2017) identified key knowledge gaps limiting FWCP's ability to initiate conservation and enhancement actions (Stamford et al. 2017). Highest

priority knowledge gaps and monitoring needs were summarized in the companion document *Arctic Grayling Monitoring Framework* (Hagen and Stamford 2017).

This report documents 2021 results from the fourth year of a five-year snorkeling study initiated in 2018, which has been conducted for FWCP by consultant John Hagen and Associates in collaboration with the British Columbia Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), the University of Northern British Columbia's Freshwater Fish Ecology Laboratory (FFEL), and McLeod Lake Indian Band (MLIB). The study was designed to directly address two of the highest priority information gaps identified for Arctic Grayling in the Parsnip River watershed. The first of these was the lack of adult abundance and population growth rate (trend) data since 2007 for assessing the conservation status of the Arctic Grayling population (Table 1, ID #1 in Hagen and Stamford 2017). The conservation status of a group of organisms is an estimate of the viability of the group: whether it still exists and how likely it is to become extinct in the future (McElhany et al. 2000; IUCN 2012). Adult abundance and trend are the two most important indicators of conservation status, and therefore also the most important indicators of whether current species conservation measures are working (McElhany et al. 2000; O'Grady et al. 2005; USFWS 2010).

The second of these two key information gaps for Parsnip Arctic Grayling was the lack of information about abundance and critical adult rearing habitats outside of the Table and Anzac sub-basins (Table 1, ID #2 in Hagen and Stamford 2017). Critical habitats are those necessary for the species to persist and thrive, and in which limiting factors regulate growth and survival to the adult life stage (Rosenfeld and Hatfield 2006; Richardson et al. 2010; Hagen and Stamford 2017). Knowledge of critical habitat locations, and the relative importance of these habitats, is necessary to 1) initiate effective habitat conservation actions, 2) identify threats from human land use, other species, and climate change, and 3) identify locations for habitat restoration and enhancement actions.

In 2021, our snorkeling study had two key components to address these information gaps. The first of these was the fourth consecutive year of Arctic Grayling abundance monitoring in 6 long-term index sections of the Anzac and Table rivers, using replicated snorkeling surveys, after a hiatus of more than 10 years between 2007 and 2018. These data are utilized in this report to describe population trend over the 1995-2021 period. The second study component was comprised of single-pass snorkeling surveys to delineate critical adult/subadult rearing habitat and estimate abundance in Reynolds Creek and Colbourne Creek.

Downstream snorkeling surveys are an attractive population monitoring methodology for stream-dwelling, subadult and adult salmonids including Arctic Grayling. Relative to other methodologies such as electrofishing or seine netting, snorkeling surveys are non-invasive, relatively rapid, and can be utilized within a variety of habitats. Up to 10 km of stream habitat can be surveyed in a day (Hagen and Baxter 2005), meaning that the sampling fraction within stream reaches can be high and extrapolation errors minimized relative to other methods.

However, the accuracy of snorkeling counts may vary widely among systems, with species differences, underwater visibility, instream cover, and observer experience being potential variables that can affect snorkeling detection probability (Northcote and Wilkie 1963; Schill and Griffith 1984; Slaney and Martin 1987; Zubik and Fraley 1988; Young and Hayes 2001; Hagen and Baxter 2005; Mollenhauer and Brewer 2017). A key area of focus for our study since 2019 has been the application of models that analyze replicated count data to estimate detection probability and abundance in snorkeling reaches (Olkin et al. 1981; Royle 2004; Mollenhauer and Brewer 2017), thereby improving the accuracy of estimates of total abundance and trend. These advances in the analysis of the snorkeling count data have been made in collaboration with the University of Northern British Columbia's Freshwater Fish Ecology Laboratory (FFEL) as an in-kind FFEL contribution to this study (e.g., Dowd 2021).

Fausch et al. (2002) pointed out that the typical focus on a limited number of index sites within a stream network, such as our surveys of 6 index sections in two streams of the Parsnip River watershed, may leave many key features affecting the distribution of critical habitats out of view. Examples of potential features affecting Arctic Grayling distribution and abundance are waterfalls or high gradient sections limiting access, unsuitable thermal regimes, or key geomorphology attributes affecting habitat suitability. They argue that a more continuous view of the entire, spatially-heterogeneous river environment, which they term the 'riverscape,' is essential for effective research and conservation of fishes and other aquatic biota (Fausch et al. 2002).

The second component of the proposed study, which is designed to delineate critical summer rearing habitats for adult/subadult Arctic Grayling in the Parsnip River watershed and identify potential limiting factors, utilizes the same snorkeling crew format but sacrifices replication of index reaches for the sake of more spatially-continuous coverage of the stream network. In 2021, we applied single-pass snorkeling surveys in sections of the Reynolds Creek and Colbourne Creek watersheds, where adult/subadult Arctic Grayling have not been previously documented (Stamford et al. 2017). Since 2018, single-pass surveys have been utilized to delineate critical habitat and estimate abundance in the Anzac River (Hagen et al. 2019), Missinka River (Hagen and Gantner 2020), Hominka River (Hagen and Stamford 2021), and Wichcika Creek (Hagen and Stamford 2021). Beginning in 2020, the single-pass snorkeling surveys have been augmented with environmental DNA (eDNA) sampling (e.g., Stamford et al. 2022) to increase the spatial coverage further and identify the potential presence of other life history types.

A landscape-scale habitat stewardship framework is urgently needed for the Parsnip River watershed, given the expected sensitivity of Arctic Grayling at the southern margin of their British Columbia range and given new threats from land use and climate change. We conclude our 2021 report by discussing the state of knowledge about Parsnip Arctic Grayling conservation status and identify remaining information needs, and also by making recommendations towards an effective fish habitat stewardship and monitoring framework for the watershed.

2.0 GOALS AND OBJECTIVES

The FWCP is partnership between BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations and public stakeholders. In the Peace Region, FWCP's aim is to conserve and enhance fish and wildlife impacted by the construction of the W.A.C. Bennett and Peace Canyon dams on the Peace River, and the subsequent creation of the Williston and Dinosaur Reservoirs (FWCP 2020).

The first goal of the Parsnip Arctic Grayling snorkeling study is to enable conservation actions that maintain or improve the status of the population and the productivity of its critical habitats. The second goal is to work with study collaborators FLNRORD and MLIB to achieve effective fish and fish habitat stewardship in the Parsnip River watershed. As such, these goals are aligned with overarching strategic objectives of FWCP's *Rivers, Lakes, and Reservoirs Action Plan* (FWCP 2020).

The study had the following specific objectives:

1. Conduct replicated snorkeling counts of Arctic Grayling and other species in long-term index sites located in the Anzac and Table rivers, using a snorkeling survey methodology consistent with past surveys.
2. Estimate detection probability and utilize the estimates to improve the analysis of trend for Arctic Grayling in the Parsnip River watershed.
3. Acquire counts of Arctic Grayling and other species in Reynolds Creek and Colbourne Creek using a single-pass snorkeling survey methodology, to assess relative abundance and identify critical summer rearing habitats.
4. Conduct eDNA sampling in Reynolds Creek and Colbourne Creek to i) expand the spatial scope of our sampling by including areas that we could not snorkel, and ii) indicate the potential presence of either very low densities of grayling or juvenile life stages undetectable by snorkeling.
5. Recommend a fish stewardship framework for the Parsnip River watershed which includes both habitat stewardship and monitoring actions.

These study objectives address Action #9 of the Rivers, Lakes, and Reservoirs Action Plan (FWCP 2020):

“Conduct research and monitoring of Arctic Grayling to obtain data related to conservation status, critical habitats, and key limiting factors” (p. 12).

3.0 STUDY AREA

The Parsnip River watershed lies within the traditional territory of the McLeod Lake Indian Band, and the Anzac River and Table River watersheds and their natural resources are of critical

community interest (Hagen et al. 2015; Pearce et al. 2019). The mouths of the Anzac River, Table River, Reynolds Creek, and Colbourne Creek are located approximately 40 km, 60 km, 25 km, and 15 km southeast and east of the community of McLeod Lake, respectively (Figure 1). Arctic Grayling of the Table and Anzac rivers are also prized by the recreational angling community in northcentral BC.

Historically, the Parsnip River flowed roughly 280 km along the Rocky Mountain Trench from Arctic Lake to its confluence with the Finlay River, where the two rivers joined to form the Peace River. The 183 m high W.A.C. Bennett Dam is located on the Peace River approximately 110 km downstream of this confluence (Hirst 1991). Construction of the dam was completed in 1967, which resulted in the formation of Williston Reservoir. The Reservoir reached full pool in 1972 and flooded the lower 110 km (approximately) of the Parsnip River.

The post-impoundment Parsnip River system is a 6th order stream that has a watershed area of 5,600 km² (Table 1). Major sub-basins of the Parsnip (Misinchinka, Colbourne, Reynolds, Anzac, Table, Hominka, Missinka, Upper Parsnip), range from 290 km² to 1,000 km² and drain mountainous terrain in the Hart Ranges of the Rocky Mountains, lying to the east of the trench. In contrast, smaller sub-basins on the west side of the Parsnip (95 km² to 182 km²) drain lower elevation areas of the Nechako Plateau (Figure 1; Table 1).

Streamflow is snowmelt driven, with peak discharge occurring, on average, in late-May to early-June in the Parsnip River watershed (Water Survey of Canada Station 07EE007 *Parsnip River above Misinchika River*). Much of the watershed drains higher elevation, mountainous areas. Consequently, sediment load is relatively high among sub-basins, as evidenced by turbid water flows in spring, wide channels relative to stream size, and extensive bar development (Bruce and Starr 1985). Substantial glacial influence occurs only within the Upper Parsnip sub-basin (Figure 1), however. Consequently, in most years water clarity is excellent throughout watershed sub-basins throughout much of the year, and by late summer the Parsnip mainstem itself becomes relatively clean in areas downstream of the Missinka River (Anonymous 1978).

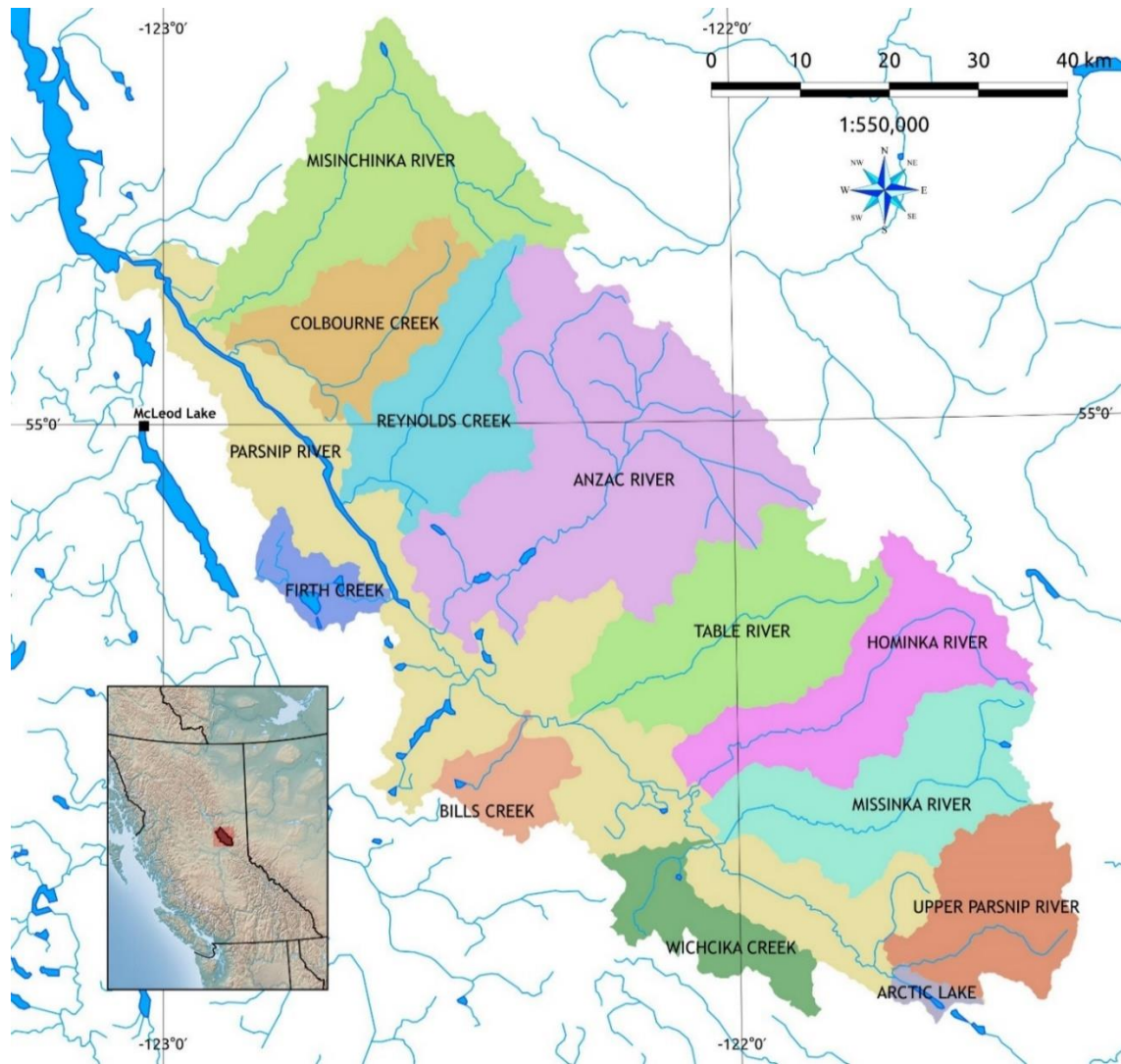


Figure 1. Sub-basins of the Parsnip River watershed (Parson mainstem, Misinchinka, Colbourne, Reynolds, Firth, Anzac, Bill's, Table, Hominka, Missinka, Wichcika, Arctic Lake, Upper Parsnip) potentially utilized by Arctic Grayling.

Table 1. Biophysical characteristics of sub-basins potentially utilized by Arctic Grayling within the Parsnip River watershed.

Watershed	Sub-basin	Watershed area (km ²)	Stream order	Fish species present
Parsnip	Parsnip total	5,612	6	GR, EB, BT, BB, KO, LKC, LT, LW, CSU, LNC, LSU, MW, NSC, PCC, CAS, PW, RB, RSC, CCG, WSU
Parsnip	Misinchinka River	595	4	GR, BT, BB, LSU, MW, RB, CCG
Parsnip	Colbourne Creek	289	4	GR, BT, CSU, LSU, MW, RB, CCG
Parsnip	Reynolds Creek	366	5	GR, BT, BB, LKC, CSU, LNC, LSU, MW, RB, RSC, CCG
Parsnip	Firth Creek	95	3	GR, BB, LKC, LW, LNC, LSU, MW, RB, CCG
Parsnip	Anzac River	1,044	5	GR, BT, BB, LKC, LT, LW, LSU, MW, PCC, CAS, RB, RSC, CCG
Parsnip	Tacheeda Lakes	95	4	BT, KO, LT, LW, LNC, LSU, MW, NSC, PCC, CAS, PW, RB, RSC, WSU
Parsnip	Bill's Creek	122	5	GR, BB, MW, RB, CCG
Parsnip	Table River	504	5	GR, BT, BB, LW, CSU, LSU, MW, NSC, RB, CCG, WSU
Parsnip	Hominka River	433	5	GR, BT, BB, LSU, MW, PCC, RB, CCG, WSU
Parsnip	Missinka River	434	5	GR, BT, BB, LKC, CSU, LNC, LSU, MW, NSC, RB, RSC, CCG
Parsnip	Wichcika Creek	182	5	GR, BT, BB, MW, RT, CCG
Parsnip	Arctic Lake	31	-	GR, BT, KO, LT, LW, LSU, MW, NSC, RB, RSC, WSU
Parsnip	Upper Parsnip	303	-	GR, BT, BB, KO, LT, LW, CSU, LSU, MW, NSC, RB, RSC, CCG, WSU

4.0 METHODS

4.1 Survey Conditions

The feasibility and safety of snorkeling surveys in mountain streams depend on good water clarity and low-to-moderate stream flows. Advance knowledge of stream flows and precipitation at the field site can help minimize unanticipated costs from aborted field days due to high, dirty water and safety concerns.

Water Survey of Canada (WSC) Station 07EE007 *Parsnip River above Misinchinka River* is located on the Parsnip River near its mouth. It is the only WSC flow monitoring station for the Parsnip River watershed. In August 2021, this WSC station provided real time stream discharge

and precipitation data that was utilized to assess the potential safety and feasibility of snorkeling surveys.

4.2 Snorkeling Methods

In 2021 we conducted replicated snorkeling surveys in five of six long-term index sections of the Parsnip River watershed, including Table River section 35-31 km (Figure 2, Figure 3) on August 13, Anzac River section 16-12 km (Figure 4) on August 11, Anzac 34-30 km (Figure 4) on August 12, Anzac 43-39 km (Figure 4) on August 17, and Anzac 47-45 km (Figure 4, Figure 5) on August 12. Table River section 26-22 km (Figure 3) received only a single snorkeling pass due to time constraints on August 13. In 2021, the planned survey of both Table River sites by both crews on August 13 was not feasible within the period of optimal visibility between 0900 and 1700 PDT, suggesting replicated surveys through 8 km of stream habitat is too much when the logistics of crew transportation in the Parsnip River watershed are factored in.



Figure 2. Snorkeling survey of Table River section 35-31 km under conditions of good water clarity, August 2021.

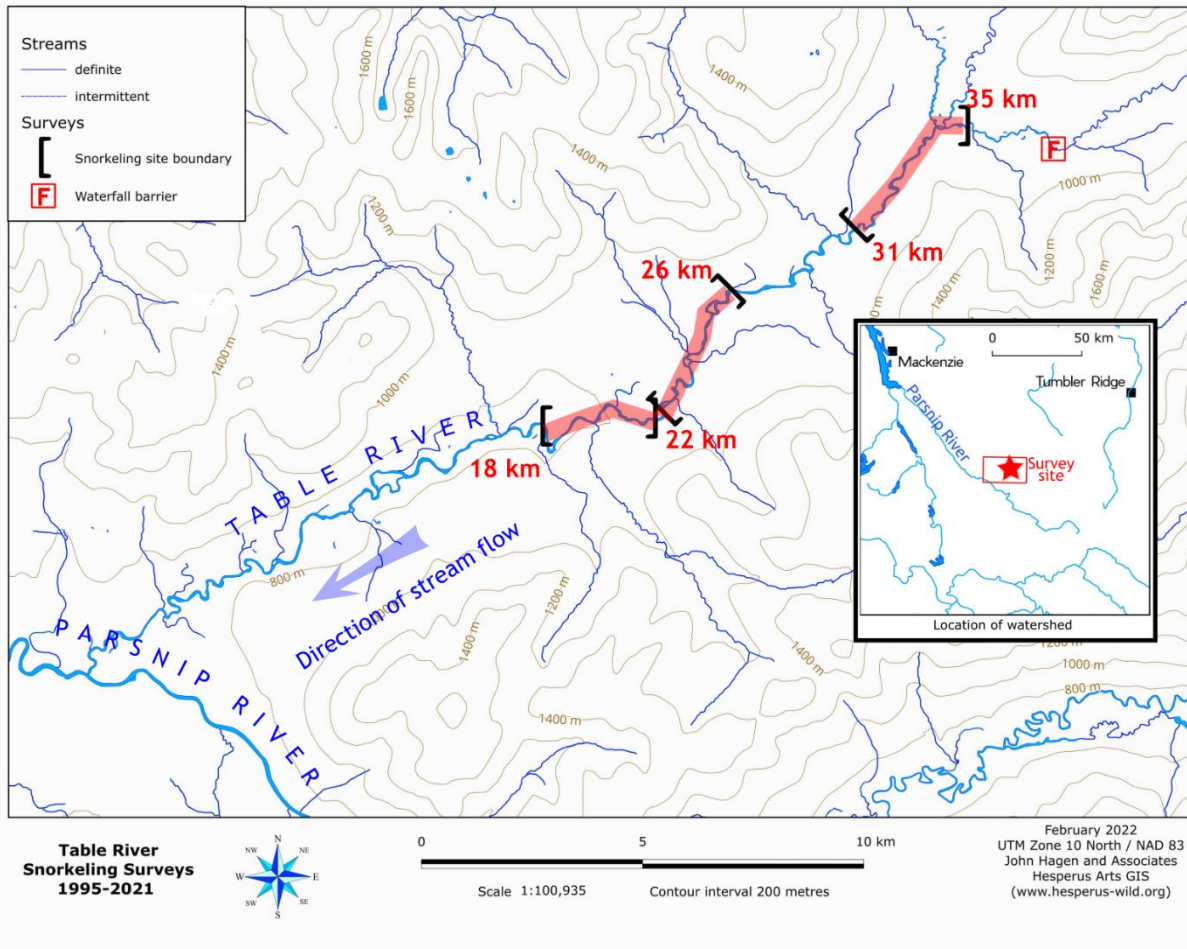


Figure 3. Index sections of the Table River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2021. Site 22-18 km was utilized up to 2007, but was replaced by site 26-22 km in 2018 due to the presence of a natural clay slump at 22 km that continues to compromise visibility in the lower site.

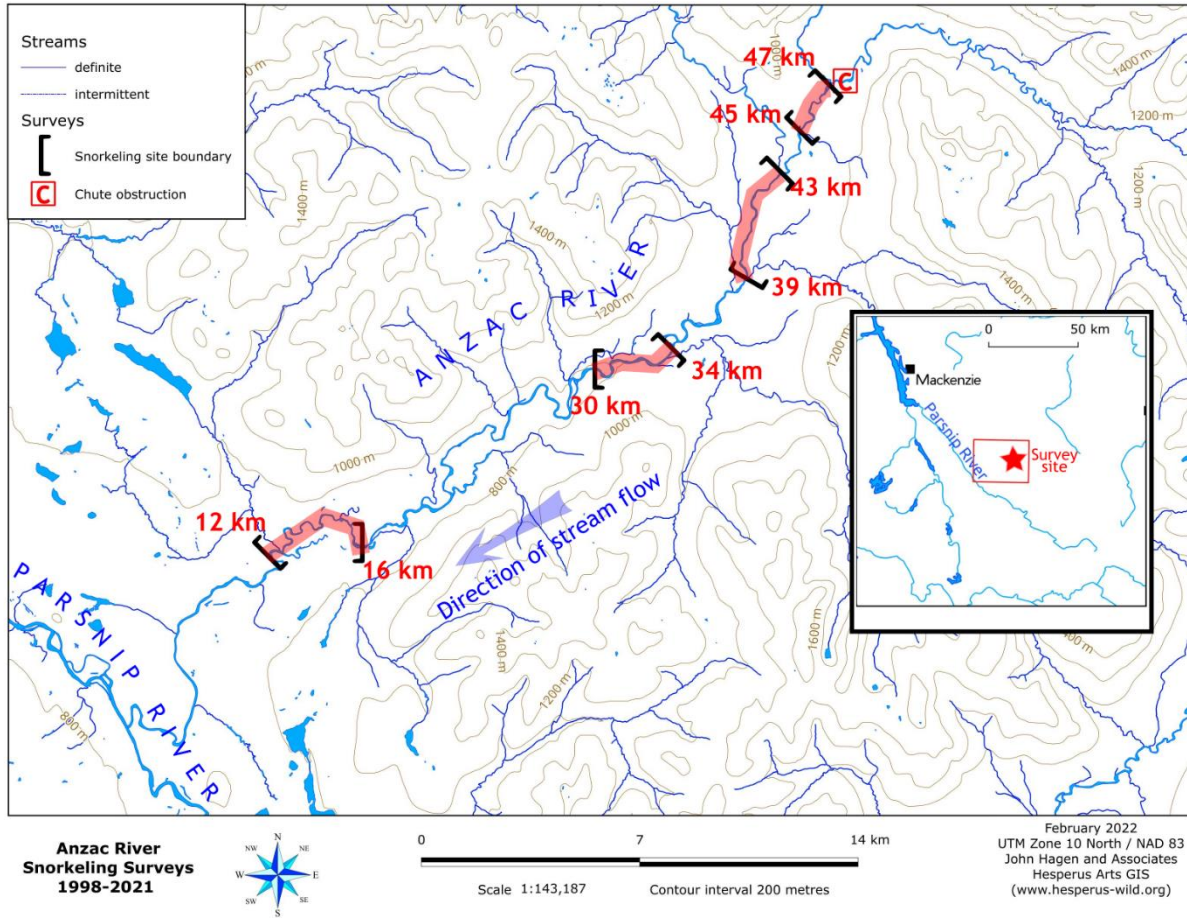


Figure 4. Index sections of the Anzac River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2021.



Figure 5. Top boundary of Anzac River section 47-45 km, now accessible from the Coastal GasLink Pipeline access road crossing (background).

Single-pass snorkeling surveys of 5 reconnaissance sections of the Reynolds Creek watershed were conducted over the August 14-15 period (Figure 6). Reconnaissance surveys of 3 sections of Colbourne Creek (Figure 7) were conducted on August 15 (3-1 km) and August 18 (17-13 km, 9-5 km).

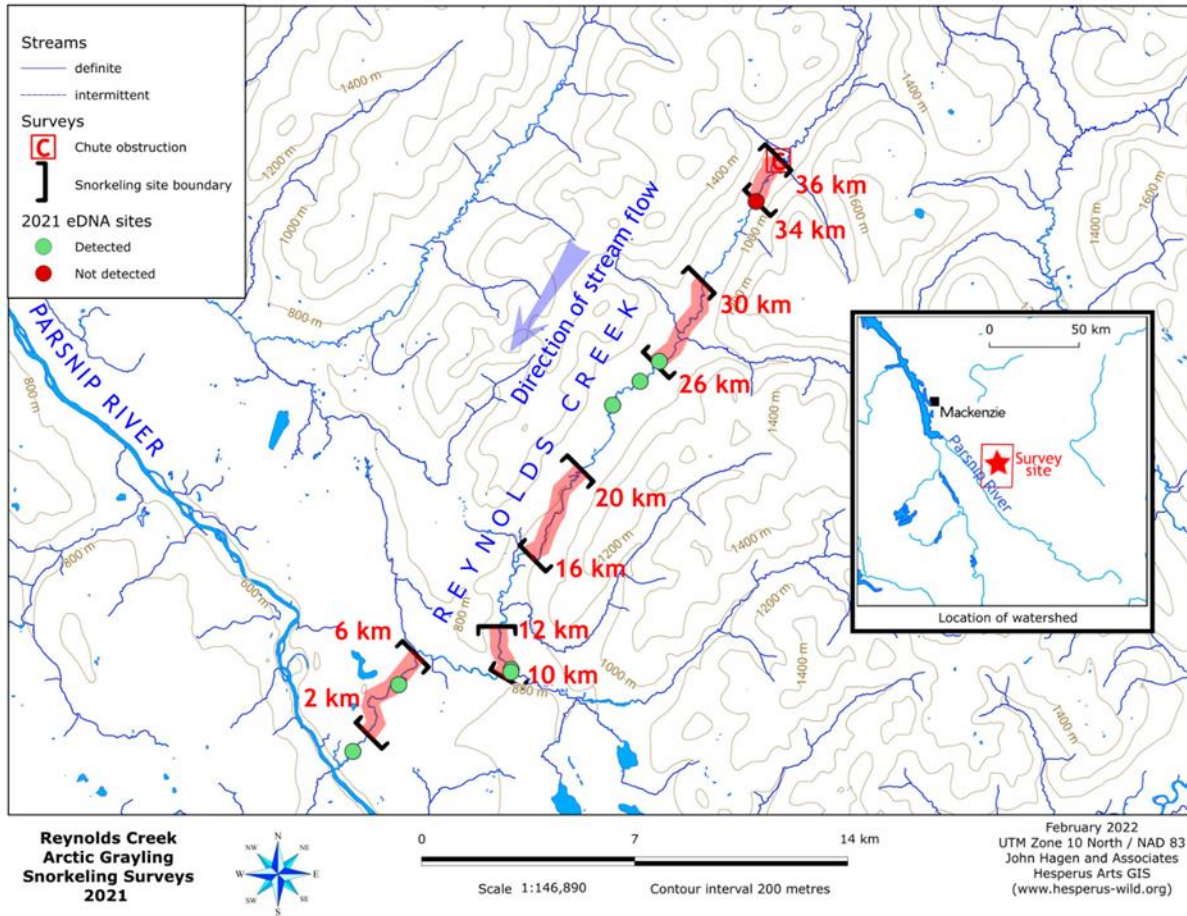


Figure 6. Reconnaissance sections of Reynolds Creek utilized for snorkeling and environmental DNA (eDNA) surveys to monitor Arctic Grayling abundance and presence, respectively, August 2021.

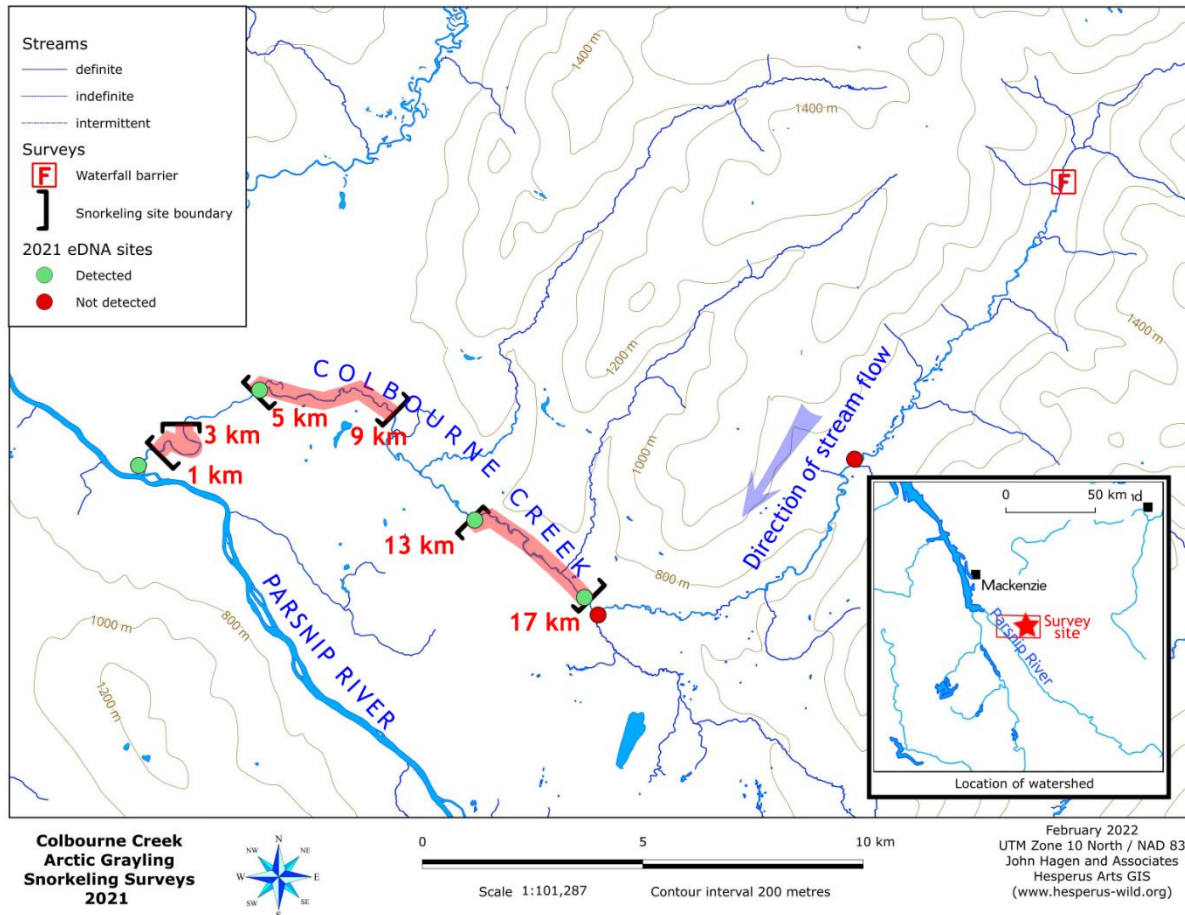


Figure 7. Reconnaissance sections of Colbourne Creek utilized for snorkeling and environmental DNA (eDNA) surveys to monitor Arctic Grayling abundance and presence, respectively, August 2021.

Replicate snorkeling surveys in the long-term index sections of the Table and Anzac rivers were conducted by two independent, three-person crews. A minimum one-hour delay was utilized between surveys to allow the sections to recover from disturbance. Single-pass reconnaissance sections in Reynolds Creek and Colbourne Creek were surveyed by just one crew, but were otherwise surveyed by the same method.

Snorkeling passes were conducted by three-person crews comprised of two observers in drysuits accompanied by a Swiftwater Rescue Technician paddling an inflatable kayak (Figure 8). During snorkeling surveys, observers surveyed lanes of width determined by underwater visibility conditions and estimated habitat suitability (usable wetted width for subadult and adult Arctic Grayling – see Blackman 2004 for microhabitat preferences of subadult/adult grayling). Where possible observers counted fish in a lane extending in front of them and to one side only. When the usable wetted width exceeded the width of 2 lanes surveyed in this manner, one or both swimmers extended their lane widths and looked both ways. If fish moved in reaction to

observers, frequent communication ensured that double counting did not occur. Observed fish (e.g., Figure 9) were classified as to species, and assigned to size categories in 10-cm increments.



Figure 8. Three-person snorkeling team in the Parsnip River watershed.



Figure 9. Table River Arctic Grayling.

Reliable counts require a disciplined effort to organize divers in lanes across the stream, and regular communication among divers to avoid overcounting or missed areas of suitable habitat (Northcote and Wilkie 1963; Schill and Griffith 1984; Slaney and Martin 1987; Hagen and Baxter 2005). In our study, this was facilitated by the use of crews led by biologists with >20 years experience with snorkeling surveys.

Two physical habitat attributes potentially affecting snorkeling detection probability were also monitored within surveyed stream sections. These were: 1) underwater visibility and 2) wetted stream width. We measured underwater visibility in snorkeling survey sections in two ways: 1) horizontal underwater Secchi disk visibility (Figure 10), and 2) horizontal underwater distance at which the species identity of a 30 cm Arctic Grayling model could no longer be discerned. We estimated wetted stream width using a laser range finder. Visibility was measured only once per reach, at the beginning of the survey, while wetted stream width was measured at approximately 10 locations in each reach.



Figure 10. Black-and-white Secchi disk used to estimate horizontal underwater visibility, August 2021.

4.3 Environmental DNA Sampling

Environmental DNA (eDNA) samples were also collected during reconnaissance snorkeling surveys in Colbourne and Reynolds creeks, as a component of FWCP Project PEA-F21-F-3198 (Stamford et al. 2022). In that study, snorkeling results were utilized to validate two eDNA sampling techniques: an instream filtering method completed in field, and a rapid bottle filling method in which filtering is completed at the completion of the day. All field, laboratory, and analysis methods for both techniques are detailed in Stamford et al. (2022).

In turn, we utilized the eDNA sampling results to i) expand the spatial scope of our sampling by including areas that we were unable to snorkel, and ii) indicate the potential presence of either very low densities of grayling or juvenile life stages undetectable by snorkeling. In snorkeling sections, eDNA was always sampled from a downstream to upstream direction and most sites received triplicate one-liter bottle sampling in the morning before snorkelers entered the water. The instream filtering method was also used in 2021 to sample 11 sites in Reynolds Creek (Figure 6) and Colbourne Creek (Figure 7), including sites where snorkeling was not conducted, and took place 24 hours after snorkel surveys were completed. The delay assumed sufficient time to clear stream reaches of eDNA contamination from the snorkelers but also assumed Arctic Grayling had not moved from previous snorkel observations.

4.4 Analyses

4.4.1 Detection probability and abundance.

Binomial-Likelihood Model. During exploratory statistical analyses in 2019 (Hagen and Gantner 2020) and 2020 (Hagen and Stamford 2021), we utilized a binomial-likelihood model to estimate detection probability and abundance (Olkin et al. 1981; Royle 2004). In this report, we update the analysis with improved estimates of covariates for detection probability collected during the 2021 field season.

We assumed for all years 1995-2021 that the population of Arctic Grayling in each index reach was closed with respect to movement, mortality, etc. between the start and finish of all replicate surveys. We further assumed that replicated counts n_{ir} were binomially-distributed random variables from the distribution

$$n_{ir} \sim \text{Binomial}(N_{it}, p)$$

where i is the site, r the replicate (among R replicated surveys), N_{it} the population size at index site i and year t and p is the detection probability. The likelihood statement for data from a site is detailed in Royle (2004), and represented in simplified form here as:

$$L(N_{it}, p | \{n_{i1}, \dots, n_{iR}\}) = \prod_{r=1}^R \text{Binomial}(n_{ir}; N_{it}, p)$$

Joint likelihood across all sites of interest is given by the product of the site-specific likelihoods (Royle 2004). In 2021, we estimated the N_{it} and p by searching for parameter values that maximized the joint likelihood across all the site/year possibilities for the 1995-2021 period, (e.g., a site with replicated count data in four separate years would yield four site/year-specific likelihoods conditional on the four N_{it} and one p).

Covariate effects on detection probability. A question of key interest to us has been whether predictions of abundance and detection probability p could be improved through the use of logistic regression models for p , for use within the binomial-likelihood model framework described above. Our a priori expectation was that two factors in particular would affect snorkeling detection probability: 1) the stream wetted width in index reaches, which is related to the cross-sectional area to be searched by snorkelers, and 2) horizontal underwater visibility. During some years over the 1995-2007 period, snorkeling crews were comprised of 3 swimmers rather than 2. We therefore defined a third variable of interest: number of observers.

To update the exploratory analysis of 2020 (Hagen and Stamford 2021), we identified a series of candidate models representing different hypotheses about the effects of these 3 factors on p , then compared these models using an information-theoretic approach (Burnham and Anderson 2002). Unfortunately, stream width data have been extremely sparse among years (Cowie 2021). In 2021, we were able to substantially improve our knowledge of index section widths, by basing our estimates in all snorkeling reaches on 10 systematically-spaced measurements. Because of our concern for unreliable or missing estimates prior to 2021, stream width values used in our analysis are average values and are not year-specific.

Model selection was performed using replicated count data from all years 1995-2021. We used the Akaike information criterion corrected for small sample size (AIC_c) for the comparisons among models. We computed the strength of evidence for each candidate model being the best in the set by computing the likelihood of each model given the data $L(g_i|x)$, then normalizing these likelihoods as a set of Akaike weights w_i (Burnham and Anderson 2002).

4.4.2 Population trend

We assessed the trend in Arctic Grayling abundance over time for the Parsnip River watershed using model estimates of abundance in preference to raw count data, to account for the effects of variable detection probability. Binomial-Likelihood Model estimates of N_{it} (see preceding paragraphs) were analyzed within a linear mixed effects analysis, performed using the Stata statistical analysis program (StataCorp, 2009) and the 'xtmixed' function (Rabe-Hesketh and Skrondal 2008). The N_{it} were entered into the model as a fixed effect, along with observation year. As random effects, we had intercepts for sites nested within streams.

Trend, i.e., population growth rate, is a key indicator of conservation status and risk, and of potential effects of limiting factors (see Section 1.0). From the linear mixed effects model output, we computed population growth rate using the formula:

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

Where N_0 is the predicted initial population size and N_t is the predicted population size after time interval t years.

5.0 RESULTS

5.1 Survey Conditions

We target the August 10-24 period each year for snorkeling surveys in long-term index sections of the Parsnip River watershed. This period is thought to correspond to the completion of upstream migrations from spawning areas to preferred adult/subadult rearing areas in tributaries, and is prior to emigration to the Parsnip River when water temperatures drop (Blackman 2002a).

August 2021 was well-suited to snorkeling surveys. As a result of an early spring runoff and dry weather, discharge in the Parsnip River watershed was below long-term average levels for the beginning of fieldwork on August 11 (Figure 11, Figure 2, Figure 5). A substantial, short-term spike in stream discharge, resulting from heavy rain the night of August 14-15 (Figure 11), resulted in cancellation of surveys on the afternoon of August 15 and on August 16. Fortunately, water clarity returned rapidly in tributary reaches, and completion of the snorkeling study on August 17 and 18 was possible under suitable visibility and safe swimming conditions.

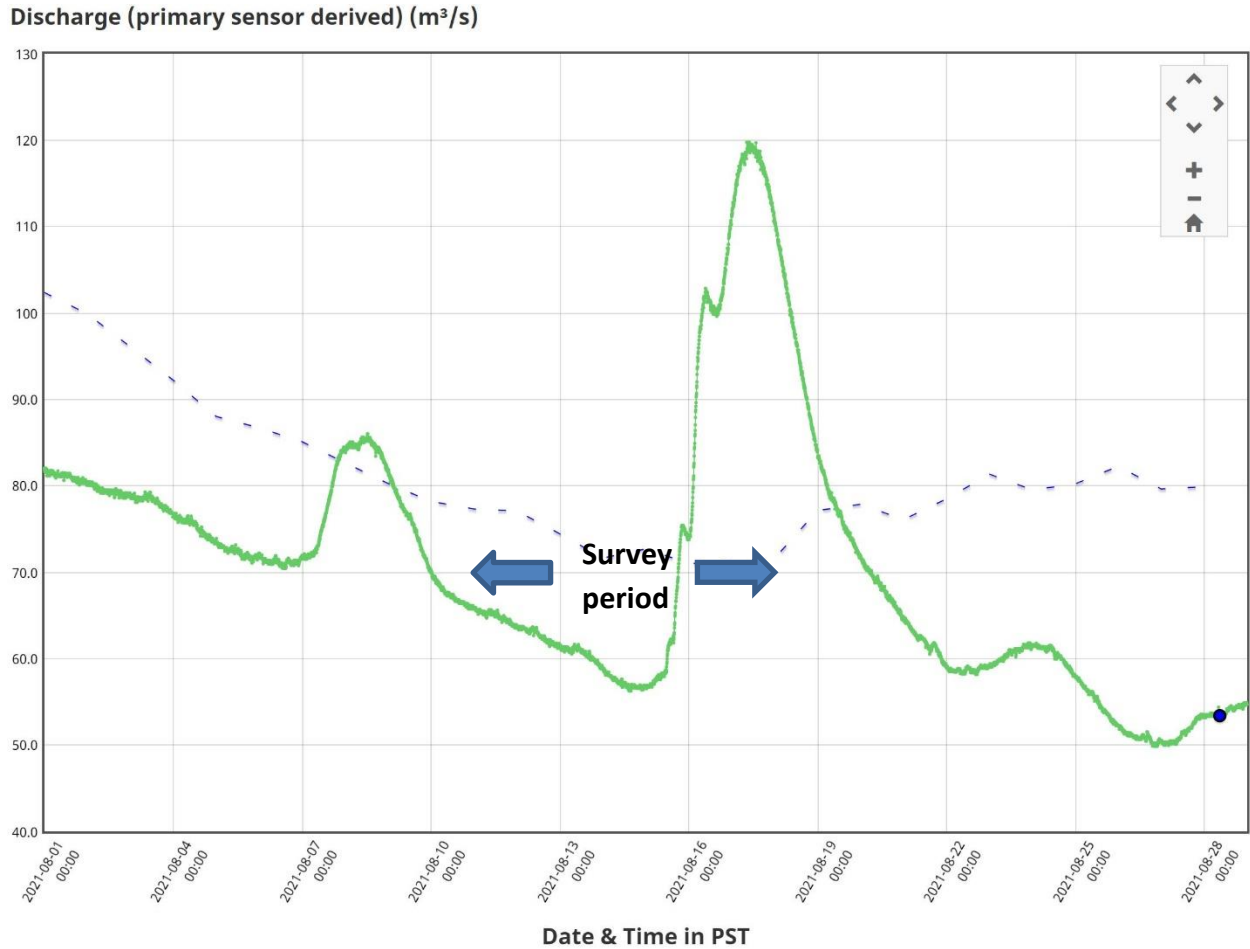


Figure 11. Estimated discharge (solid line) relative to long-term average discharge (dashed line) in the lower Parsnip River before and during the August 11-18 study period, Water Survey of Canada (WSC) Station 07EE007 (Parson River above Misinchinka River).

Table River site 26-22 km was a replacement for the previous long-term index site 22-18 km in the Table River, due to a major natural clay slump into the river at 22 km, for the fourth consecutive year. The extensive nature of the slump indicates that visibility in the formerly-surveyed reach may be compromised for years to come (Figure 12).



Figure 12. Rapid decline of visibility to < 2 m at Table River 22 km, the top boundary of former long-term index section Table 22-18 km, on August 13, 2021.

Secchi disk visibility in August, 2021 ranged from 7.6 m to 7.8 m in the two long-term index sections of the Table River, from 7.9-8.8 m in four long-term index sections of the Anzac River, from 4.8 m to 12 m in five reconnaissance sections of Reynolds Creek, and from <2 m to 6.2 m in three reconnaissance sections of Colbourne Creek (Table 2). The Colbourne 3-1 km section was surveyed under rapidly declining visibility from 6 m Secchi visibility to < 2 m as the river blew out on August 15.

Visibility for discernment of Arctic Grayling models ranged from 5.6 m to 6.5 m in Table River index sections, from 4.8-7.0 m in the four long-term index sections of the Anzac River, from 4.6-7.2 m in reconnaissance sections of Reynolds Creek, and from <2-5 m in three reconnaissance sections of Colbourne Creek (Table 2).

Table 2. Horizontal underwater visibility in snorkeling survey sections of the Parsnip River watershed, August 2021.

	Table River		Anzac River				Reynolds Creek					Colbourne Creek		
Snorkeling section (km)	35-31	26-22	47-45	43-39	34-30	16-12	36-34	30-26	20-16	12-10	6-2	17-13	9-5	3-1
Date	13-Aug	13-Aug	21-Aug	18-Aug	18-Aug	21-Aug	14-Aug	14-Aug	14-Aug	15-Aug	15-Aug	18-Aug	18-Aug	15-Aug
Secchi disk visibility (m)	7.6	7.8	8.8	7.9	8.1	8.5	12	11	7.4	4.8	7	6.2	6	6.0 to <2
Fish model visibility (m)	6.5	5.6	6.6	5.7	4.8	7.0	7.2	7	5.2	4.6	5	4.8	5	4.1 to <2
1995-2020 range (fish)	3.5-7	3.0-7.7	3.0-6.6	4.3-5.7	3.0-9.5	3.8-7.0	-	-	-	-	-	-	-	-

5.2 Snorkeling Detection Probability

Over the 1995-2021 period, a total of 42 surveys have taken place in the six long-term index sections of the Anzac and Table rivers in which at least two replicate counts were made (Table 3). These data were analyzed within the Binomial-Likelihood Model framework described in Section 4.4.1, which estimates site-specific abundance N_{it} and snorkeling detection probability p conditional on the replicated count data (Section 4.3). Detection probability is a parameter of key interest to us given the logistical challenges and investment required to estimate p by other means (e.g., mark-resight studies). In the update to exploratory statistical analysis in 2021, we were interested in three variables potentially influencing p and subsequent inferences about population status: 1) site wetted width $WIDTH$, 2) horizontal underwater visibility at which Arctic Grayling could be discriminated $FISH_VIS$, and 3) and the number of observers OBS (Table 3).

Within the Binomial-Likelihood Model framework, we evaluated a candidate set of 6 logistic regression models for p using AIC_c (Table 5). The best model contained both $WIDTH$ and $FISH_VIS$ as predictor variables with the expected signs (negative for $WIDTH$, positive for $FISH_VIS$), and resulted in a significant improvement in model likelihood relative to the constant- p model (Chi-square $P < 0.001$). The logistic model was:

$$p = \frac{1}{1 + \exp \{-(1.918 - 0.0645 * WIDTH + 0.0221 * FISH_VIS)\}}$$

The probability of this model being the best, as indicated by its Akaike weight w_i , was 0.421 (Table 5). Support for other models with $WIDTH$ as a predictor was also high, particularly the $WIDTH$ -only model with marginally-lower $w_i = 0.371$. The $WIDTH$ logistic model was:

$$p = \frac{1}{1 + \exp \{-(2.022 - 0.0643 * WIDTH)\}}$$

Table 3. Replicated snorkeling counts of Arctic Grayling >20 cm in long-term index sites of the Anzac and Table rivers, 1995-2021.

Replicate Counts of Arctic Grayling >20 cm									
Site	Year	R1	R2	R3	R4	FISH_VIS	WIDTH	No. of swimmers	Predicted N_{it}
Table 22-18	1998	54	79			5.5	20.7	3	104
	2000	39	30	40	38	4	20.7	2	62
	2001	35	48			3	20.7	2	65
	2003	75	62	72		4.5	20.7	2	115
	2007	39	57	42		4	20.7	3	75
Table 26-22	2018	75				7.7	22.6	2	115
	2019	116				4	22.6	2	183
	2020	67				3.8	27.8	2	121
	2021	171				5.6	23.2	2	270
Table 35-31	1995	107	115			5	15.2	2	145
	1998	137	135			5.5	15.2	2	164
	2000	101	111	136	145	7	15.2	2	167
	2001	80	102			3.5	15.2	2	124
	2003	139	138	134		3.5	15.2	2	171
	2005	96	104	94		3.6	15.2	2	122
	2007	124	103	112		3.7	15.2	2	142
	2018	191	230	209		5.7	15.2	2	264
	2019	188				3.5	15.2	2	256
	2020	139	164			4.7	22.0	2	187
	2021	221	235			6.5	14.8	2	319
Anzac 16-12	1998	13	3			6.5	28.7	3	19
	2001	6	15			4	28.7	2	23
	2003	18	30	22		4.5	28.7	3	53
	2005	26	31			4.5	28.7	3	59
	2007	44	50			3.8	28.7	3	94
	2018	22				7.7	28.7	2	39
	2019	40				4.4	28.7	2	74
	2021	46	53			7.0	30.3	2	98
Anzac 34-30	1998	116	96			9.5	29.2	3	191
	2001	48	55			3	29.2	2	95
	2003	54	68	41		3.5	29.2	2	107
	2005	98	56	82		4	29.2	3	154
	2007	34	83	67		3.7	29.2	3	124
	2018	138	93	111		6	29.2	2	238
	2019	82	67	68		5	29.2	2	139
	2021	149	154			4.8	33.1	2	321
Anzac 43-39	1998	167	114	127		4.5	26.6	2	224
	2001	73	96			4.5	26.6	2	133
	2003	144	181	172		4.5	26.6	2	269
	2005	99	83			4.3	26.6	3	148
	2018	173	187	185		4.6	26.6	2	294
	2019	140	149	167		5.1	26.6	2	246
	2021	135	128			5.7	25.6	2	218
Anzac 47-45	1998	157	171			4.5	15.0	2	272
	2000	69	67			3	16.9	2	115
	2001	15	25			3	16.9	2	39
	2003	62	80	92		3.5	16.9	2	127
	2018	194				5.5	16.9	2	269
	2019	110	85	77		4.4	16.9	2	150
	2021	140	152			6.6	20.8	2	224

Support for models without *WIDTH* as a predictor was almost non-existent (Table 4). Counter-intuitively, the predictor *OBS* was negatively-related to estimated detection probability (i.e., adding a swimmer reduced the accuracy of the counts), and it was dropped from consideration in more complex models.

Along with p , abundance N_{it} (population size N at site i in year t) is a parameter of the Binomial-Likelihood model. The N_{it} for the 42 replicated sites 1995-2021 are presented in (Table 3) along with count data and physical site attributes. In Table 3, the N_{it} for the 8 sites without replicated counts were predicted using the *WIDTH + FISH_VIS* logistic regression model for p .

Table 4. Comparison among predictors of detection probability p estimated within a binomial-probability model framework (see text) from replicated count data in the Parsnip River watershed. Symbols K , $\text{Log}(\mathcal{L})$, AIC_c , Δ_i , $\mathcal{L}(g_i|x)$, and w_i , denote 1) the number of estimable parameters, 2) model log-likelihoods, 3) the Akaike information criterion values adjusted for small sample size, 4) the difference in AIC_c values between each model and the model with the lowest AIC_c score, 5) the likelihood that the candidate model is the best among the set, and 6) Akaike weights, respectively.

Model	K	$\text{Log}(\mathcal{L})$	AIC_c	Δ_i	$\mathcal{L}(g_i x)$	w_i
<i>WIDTH+VIS</i>	4	-597.244	1203.74	0.00	1	0.421
<i>WIDTH</i>	3	-598.63	1203.99	0.25	0.88269225	0.371
<i>WIDTH+VIS+WIDTH*VIS</i>	5	-596.607	1205.15	1.41	0.493731772	0.208
<i>OSERVERS</i>	3	-823.389	1653.51	449.77	2.15854E-98	9.08E-99
Constant-only	2	-872.02	1748.40	544.66	5.3572E-119	2.25E-119
<i>VIS</i>	3	-871.54	1749.80	546.06	2.6561E-119	1.12E-119
	Min AIC_c		1203.74			
	n	37				

Estimated detection probability among long-term index sections of the Table and Anzac rivers can be compared by applying the *WIDTH + FISH_VIS* model for p to mean wetted width and visibility data for each section (Table 5). Detection probability estimates show a consistent pattern of highest detection probability in the smaller reaches at the top of the Arctic Grayling distribution in each system. Mark-resight data to validate the detection probability estimates exist for just a single index section in one year. In 2019, 12 of 15 acoustic-tagged Arctic Grayling present in Table River section 35-31 km were observed by the snorkeling team, equating to a detection probability estimate of 0.80 (80% confidence interval: 0.61-0.92). This suggests that the relatively high model estimate for this section of 74% (Table 5) is plausible. In Table River section 35-31 km, two swimmers can easily cover the entire wetted width in most locations.

Table 5. Predictions of mean detection probability p at long-term index sections of the Parsnip River watershed, computed at average values of wetted width ($WIDTH$) and underwater visibility at which Arctic Grayling can be discerned ($FISH_VIS$).

	Site	Table River		Anzac River			
		35-31	22-18	47-45	43-39	34-30	16-12
$WIDTH$		15.2	22.6	16.9	26.6	29.2	28.7
$FISH_VIS$		4.7	4.7	4.4	4.7	4.9	5.3
Binomial-Likelihood Model estimated p		0.74	0.64	0.72	0.58	0.54	0.55

5.3 Population Trend

Counts of Arctic Grayling >20 cm in long-term index sections over the 1995-2021 period, averaged across replicates for each year, are depicted in Figure 13. In the Table River, counts over the 2018-2021 period are higher than counts up to 2007, notwithstanding the change from 22-18 km to 26-22 km for the lower site location. In the Anzac River, counts over the 1998-2021 time series also indicate an increasing trend, which is most clear in the lower 2 sites 34-30 km and 16-12 km. In the upper, canyon sections of the Anzac River 47-45 km and 43-39 km, variability among years is higher, particularly for 47-45 km which is located above a 2-km section of rapids that may affect upstream movements in some years. In 2021, more Arctic Grayling were counted in total than in any other year to date.

To account for the unwanted effects of variable detection probability, we utilized model estimates of abundance (see previous section) in our estimates of trend in preference to raw count data. The site- and year-specific population estimates N_{it} from the Binomial-Likelihood Model (Table 3), analyzed using a linear mixed-effects model in which N_{it} and $YEAR$ were utilized as fixed effects and $STREAM$ and $SITE$ as nested random effects, statistically confirm that a significant increase in the abundance of Arctic Grayling >20 cm has occurred in the Parsnip River watershed ($P < 0.001$) over the 1995-2021 period. A benefit of the linear mixed-effects model framework was that it could account for missing site data which occurs in nearly half of the sampling years.

The linear mixed effects model output suggests an annual population growth rate of 4.1% for the Parsnip River population as a whole, which equates to an increase of approximately 103% over a 25-year time frame.

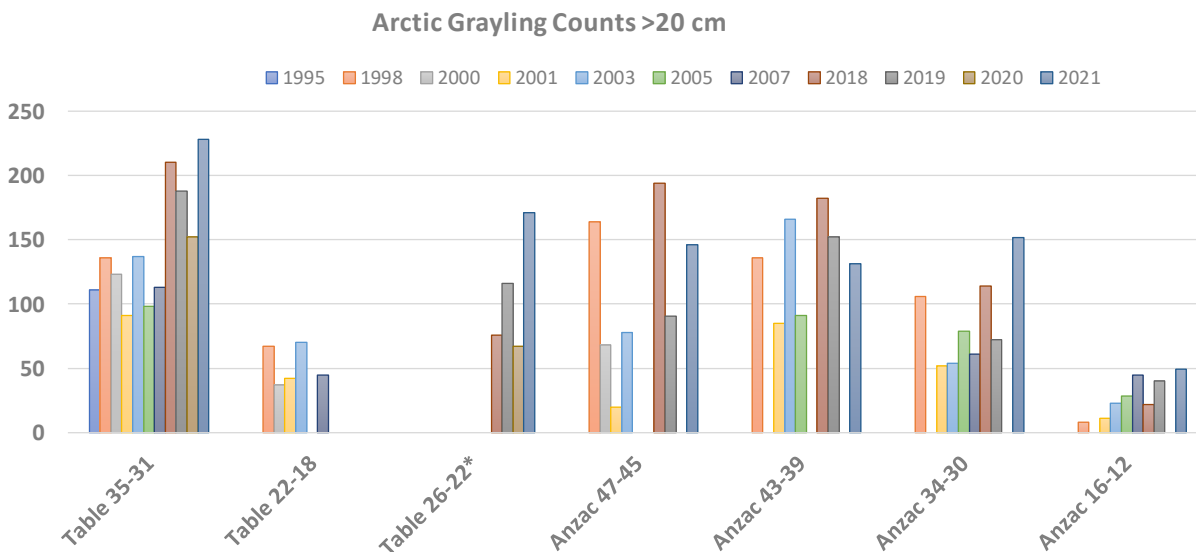


Figure 13. Unadjusted snorkeling counts of Arctic Grayling >20 cm in index sites of the Anzac River and Table River watersheds 1995-2021. Values are averages of replicate counts. *Beginning in 2018, Table River section 26-22 was substituted for 22-18 which was affected by a major clay slump at 22 km.

5.4 Critical Summer Habitats in Reynolds and Colbourne Creeks

5.4.1 Reynolds Creek

The use of the Reynolds Creek by adult and subadult Arctic Grayling >20 cm was confirmed in Reynolds Creek section 30-26 km as part of this study in 2020 (Hagen and Stamford 2021). Prior knowledge of Arctic Grayling presence in Reynolds Creek was limited to unpublished fry (young-of-year)-oriented sampling conducted by FWCP in 2005 (Hagen et al. 2015; Stamford et al. 2017) and from juvenile-oriented sampling conducted by Hawkshaw and Shrimpton (2014) suggesting that a self-sustaining population utilizes the watershed.

In 2021, a chute obstruction at approximately 36 km of Reynolds Creek was assessed from the air and on the ground, and was considered the upstream limit of potential Arctic Grayling migration (Figure 6). On August 14 and 15 we conducted single-pass snorkeling surveys in 5 sections below this barrier totaling 16 km of stream habitat (Figure 6). Water samples for eDNA analysis were collected using both the bottle-filling method (Section 4.3), which occurred prior to snorkeling surveys, and using the instream filtering method on August 18, 3 days after the completion of the snorkeling surveys.

Single-pass snorkeling surveys in 2021 confirmed the presence of adult/subadult Arctic Grayling in Reynolds Creek distributed from the mouth to 30 km (Figure 6). However, snorkeling counts of grayling >20 cm were very low relative to other tributaries in the Parsnip River watershed (Table 6) and especially relative to long-term index sections in the Table and Anzac rivers (Table 3), suggesting that Reynolds Creek provides marginally-important habitat for the subadult/adult life stage. Environmental DNA assays at all sites downstream of 30 km were positive (Figure 6),

including at the mouth of tributary Chuyazega Creek (10 km) where no snorkeling took place, and at the bottom of the 12-10 km section where no Arctic Grayling >20 cm were observed during snorkeling (Figure 6).

It is noteworthy that 12 young-of-year were observed in the 6-2 km section, confirming the use of the system for spawning and early rearing. The presence of juvenile life stages is a plausible explanation for negative snorkeling results conflicting with positive detection using eDNA, and highlights the importance of other sampling methods to learn about critical habitat use throughout the life cycle.

Estimated 2021 abundance N_{it} for each reconnaissance section, based on estimated detection probability from the *WIDTH + FISH_VIS* model (Section 5.2), and measurements of wetted width and underwater visibility, are also presented in Table 6.



Figure 14. Holding pool utilized by adult Arctic Grayling in Reynolds Creek section 30-26 km, during both 2020 and 2021.

Snorkeling observations in section 30-26 km of Reynolds Creek corroborated previous aerial redd count data identifying a substantial population of large-bodied, migratory Bull Trout spawners (Table 6). Rainbow Trout were much more abundant in lower sections of Reynolds Creek than in other stream reaches surveyed during this study (Figure 15), and Mountain Whitefish were also abundant (Table 6).

Table 6. Snorkeling counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish >20 cm in reconnaissance sections of the Parsnip River watershed, 2019-2021.

Stream	Section	Arctic Grayling	Bull Trout	Rainbow Trout	Mountain Whitefish	WIDTH	FISH_VIS	Arctic Grayling N_{it}
Missinka River* 2019	33-29	34	5	11	211	19.0	5	49
	25-22	3	0	1	84	22.3	4.8	5
	8-4	1	6	0	28	28.0	4.4	2
Hominka River 2020	60-56	0	14	0	162	15.0	8	0
	56-53	0	10	0	150	19.4	10.2	0
	53-48	2	26	0	220	24.7	10.2	3
	48-44	42	30	0	381	16.3	11.6	56
	44-41	23	2	0	144	20.8	8.5	34
	39-35	29	5	1	343	25.2	4	49
	32-29	4	3	0	28	37.0	2.6	10
Wichcika Creek 2020	10-7	1	1	0	41	26.2	4.5	2
	27.5-24	1	0	1	16	13.9	3.5	1
	22.5-20.5	2	3	8	62	15	3.6	3
	15-11	5	0	17	65	17.7	4.6	7
	10-7	0	0	4	9	16.3	3.9	0
Reynolds Creek 2021	5-1	1	2	14	4	18.4	4.6	1
	36-34	0	3	2	0	11.8	7.2	0
	30-26	2	42	70	79	10.5	7	2
	20-16	0	5	24	0	16.6	5.2	0
	12-10	0	2	39	0	14.5	3.4	0
Reynolds 2020	6-2	6	9	39	9	22.2	5	9
Colbourne Creek 2021	30-26	6	0	1	121	16.6	2.7	8
	17-13	0	0	22	3	14.1	4.8	0
	9-5	0	9	31	326	14.3	5	0
	3-1	0	1	0	0	14.3	3	0

* Missinka River widths are based on visual estimates

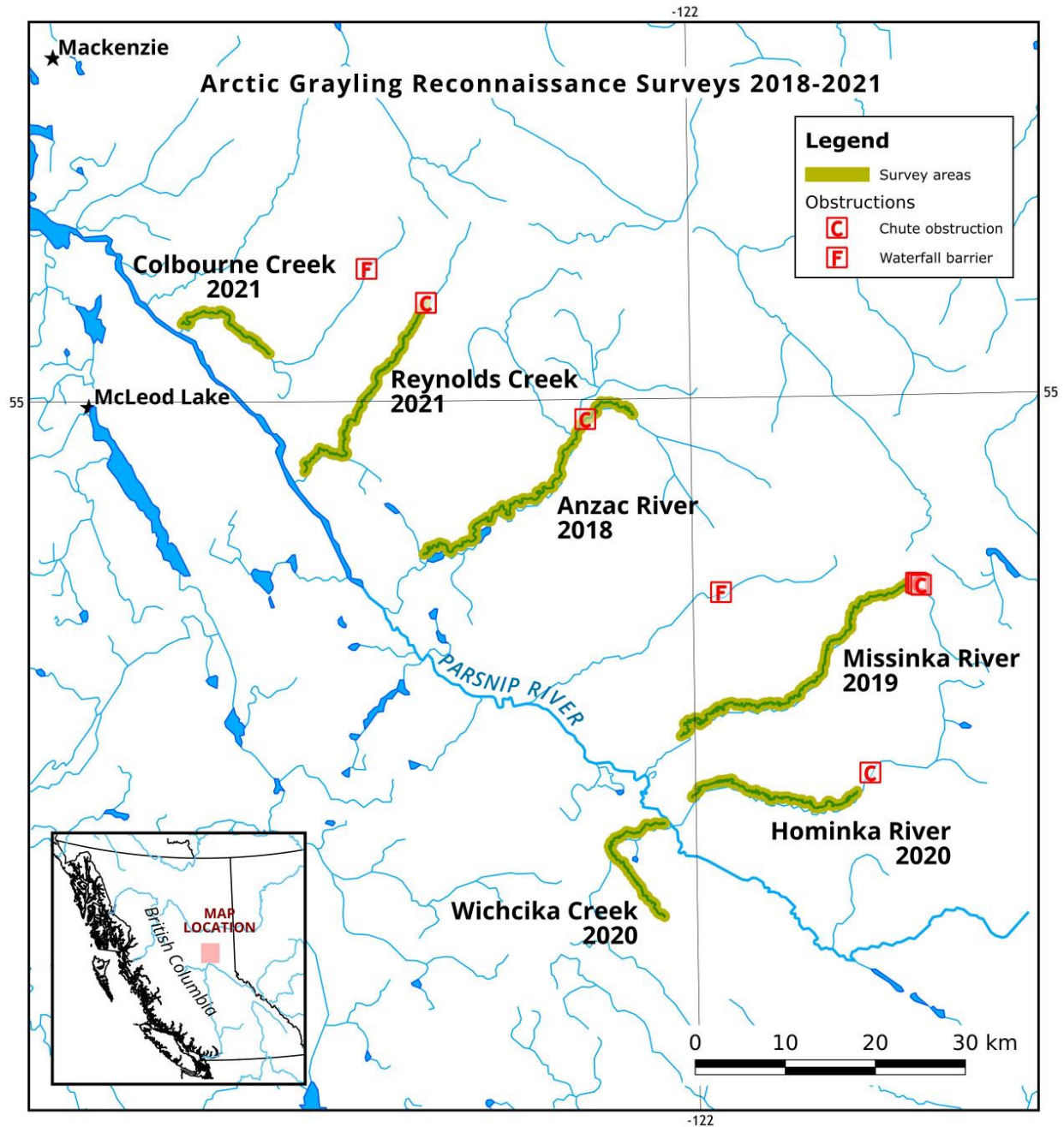


Figure 15. Reconnaissance sections of streams in the Parsnip River watershed surveyed using single-pass snorkeling over the 2018-2021 period.

5.4.2 Colbourne Creek

No juvenile Arctic Grayling were captured in Colbourne Creek during prior surveys that specifically targeted juvenile life stages (Hawkshaw and Shrimpton 2014; Hagen et al. 2015), although a generalized 1977 record in the BC Geographic Warehouse has previously suggested grayling presence (Hagen et al. 2015).

A waterfall at approximately 38 km of Colbourne Creek was assessed from the air and considered an impassable migration barrier for all species (Figure 7). On August 15 and 18 we conducted single-pass snorkeling surveys in 3 sections below this barrier totaling 10 km of stream habitat (Figure 7). The survey of the 3-1 km section was conducted as the river was rapidly rising on August 15. Visibility declined to < 2 m forcing us to stop before reaching the stream mouth, suggesting the count from that section is not reliable.

No Arctic Grayling of any life stage were observed during snorkeling surveys of Colbourne Creek reconnaissance sections 17-13 km and 9-5 km, which were conducted under suitable visibility and flow conditions (Table 6). It is interesting, therefore, that all four eDNA assays located within or below the snorkeling index sections were positive for Arctic Grayling presence (Table 7). As suggested in Section 5.4.1, the positive assays may indicate the presence of juvenile life stages undetected by snorkeling. Therefore, we were unable to fully assess the importance of this stream to the Parsnip River grayling population, and alternative methods (e.g., electrofishing or beach seining) are necessary to identify potential use by juveniles. Rainbow Trout and Mountain Whitefish are the dominant fish species of lower Colbourne Creek (Table 6).

Upper Colbourne Creek is a very small stream where snorkeling surveys would require much walking. The single eDNA assay in the upper Colbourne system, which was negative, was located in a planned reconnaissance survey section that was not swum due to the high-water event midway through August 15 and rapidly-declining underwater visibility.

Although it is not the only system exhibiting signs of historic habitat degradation related to human activity, Colbourne Creek appears to have been seriously impacted. Primary riparian forests have been stripped along the lower Colbourne system as a result of kilometers of streamside logging as well as a railway right-of-way (Figure 16). Our survey sections were characterized by extensive fine sediment deposits and rapid lateral movement of the channel into streamside second-growth forests (Figure 17). Currently, intensive forestry is ongoing in the upper Colbourne Creek watershed, which has the potential to increase fine sediment, stream temperature, peak flow, and riparian hazards in this system if watershed-scale objectives to protect water quality are not established and adhered to.



Figure 16. In the distance can be seen one of several areas of streamside logging and riparian forest removal in the lower Colbourne Creek watershed, August 2021.



Figure 17. Channel widening and fine sediment deposits in Lower Colbourne Creek.

5.5 Other Species

In our study, Arctic Grayling were the first priority for snorkeling observations and also our focus for analyses of abundance and trend. However, Bull Trout, Rainbow Trout, and Mountain Whitefish were also counted simultaneously in long-term index sections of the Anzac and Table rivers (Figure 18, Figure 19, Figure 20; Table 7).

Bull Trout

Bull Trout counts in index sites are highly variable among years (Figure 18, Table 7). It has been previously noted that this may potentially indicate an effect of stream conditions on pre-spawning migration and staging behaviour. For example, counts of Bull Trout in 2018 were above long-term averages at most index sites, but this may be an artefact of record low water conditions reducing the suitability of spawning tributaries for staging prior to spawning (Hagen et al. 2019). A more reliable methodology for monitoring Bull Trout abundance in the Parsnip River watershed is through counts of gravel nests, or ‘redds’ following the completion of spawning (Hagen et al. 2015). However, Bull Trout spawner abundance monitoring using redd counts occurs only infrequently in the Table and Anzac rivers, which contain some of the most important critical habitat for the species within the Parsnip River watershed (Hagen et al. 2015). Although imprecise, Bull Trout snorkeling count data may be of increasing value in future if redd count surveys are not conducted to monitor the effects of increased forestry and pipeline development in the Table and Anzac systems on this sensitive species. Therefore, Bull Trout counts should remain a priority during snorkeling surveys. Their abundance is generally low, and reliable counts can be made without sacrificing counts of Arctic Grayling, our target species. Reliable snorkeling counts of Bull Trout in August also indicate vulnerable pre-spawning aggregations of fish. Knowledge of these staging areas can be incorporated during the planning of Bull Trout habitat conservation.

Rainbow Trout

Snorkeling counts of Rainbow Trout (Figure 19, Table 7) are also highly variable among years. The time series of snorkeling count data indicates that Rainbow Trout have rarely been abundant at index sites, but the 2021 counts are relatively high in index sites of the Table River and in the lowest Anzac River site (Figure 19). Rainbow Trout counts are of interest because of potential interspecific competition among Rainbow Trout, Arctic Grayling, and Bull Trout, with Rainbow Trout expected to become increasingly more prevalent as systems warm (Parkinson and Haas 1996; Parkinson et al. 2012; Hawkshaw and Shrimpton 2014). Currently, Arctic Grayling are numerically dominant over Rainbow Trout throughout most of the Table and Anzac long-term index sections, and there is not obvious evidence for a fish community shift at this point in time.

Mountain Whitefish

Counts of Mountain Whitefish (Figure 20, Table 7) are especially high and variable. Mountain Whitefish are far too numerous to count reliably and for this reason have always been assigned

the lowest priority during our snorkeling surveys. Therefore, Mountain Whitefish counts should be considered of low precision and accuracy relative to the other three species. This prioritization was obviously in place during previous surveys also: Mountain Whitefish counts for 2005 are missing altogether. Given their imprecise nature, Mountain Whitefish counts may not be a good indicator of conservation status for the species. However, high abundance of the species in the mountainous Parsnip River watershed do not currently indicate cause for conservation concern. Despite the challenge in acquiring them, Mountain Whitefish counts are important as potential indicators of watershed health, changing ecological conditions, and levels of interspecific competition with Arctic Grayling.

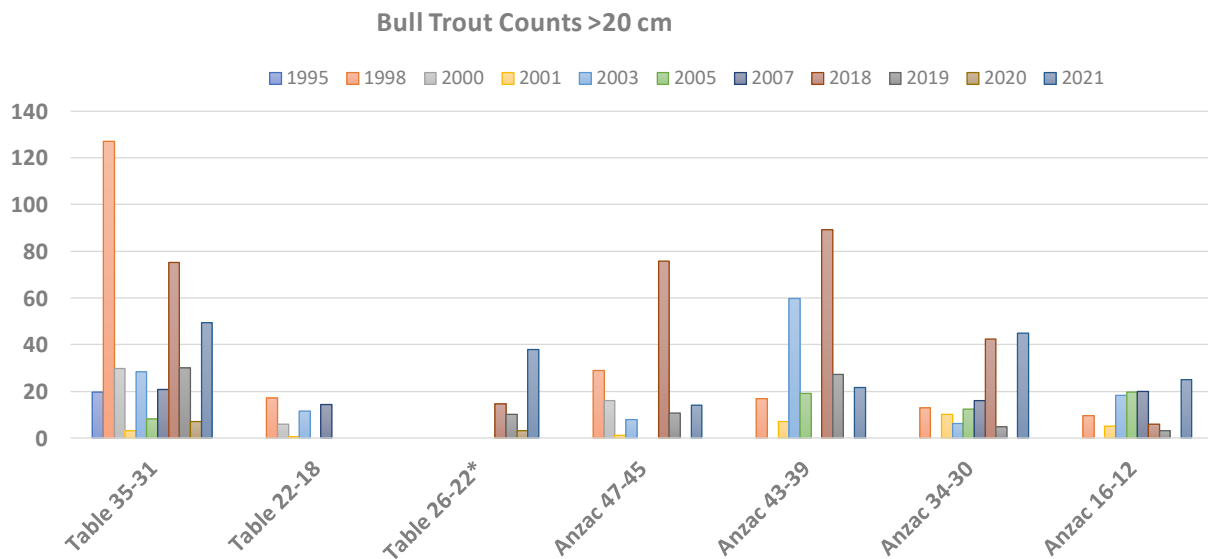


Figure 18. Counts of Bull Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.

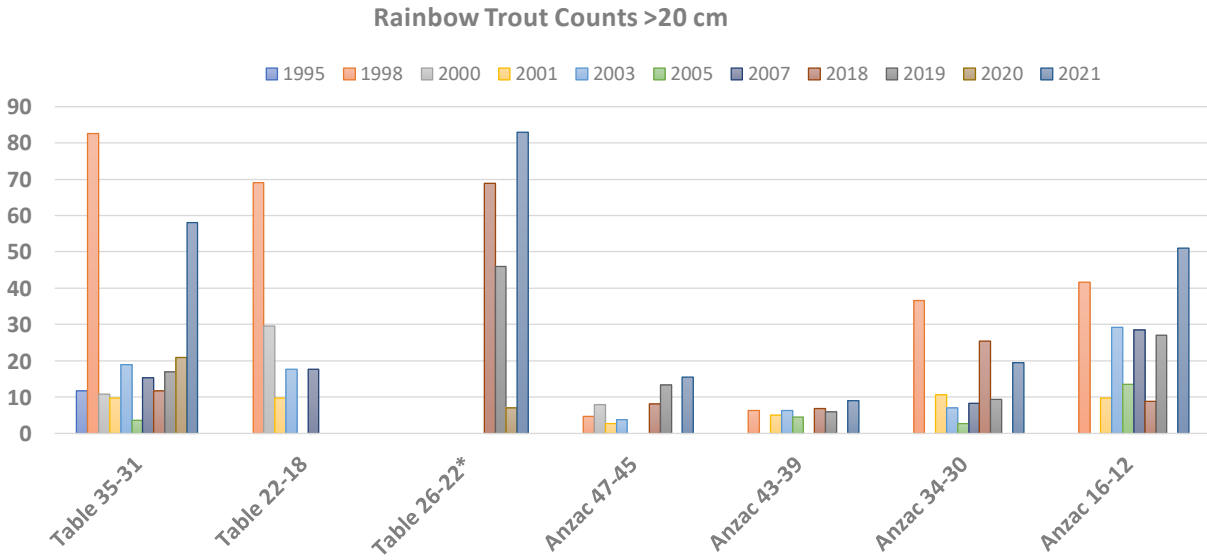


Figure 19. Counts of Rainbow Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.

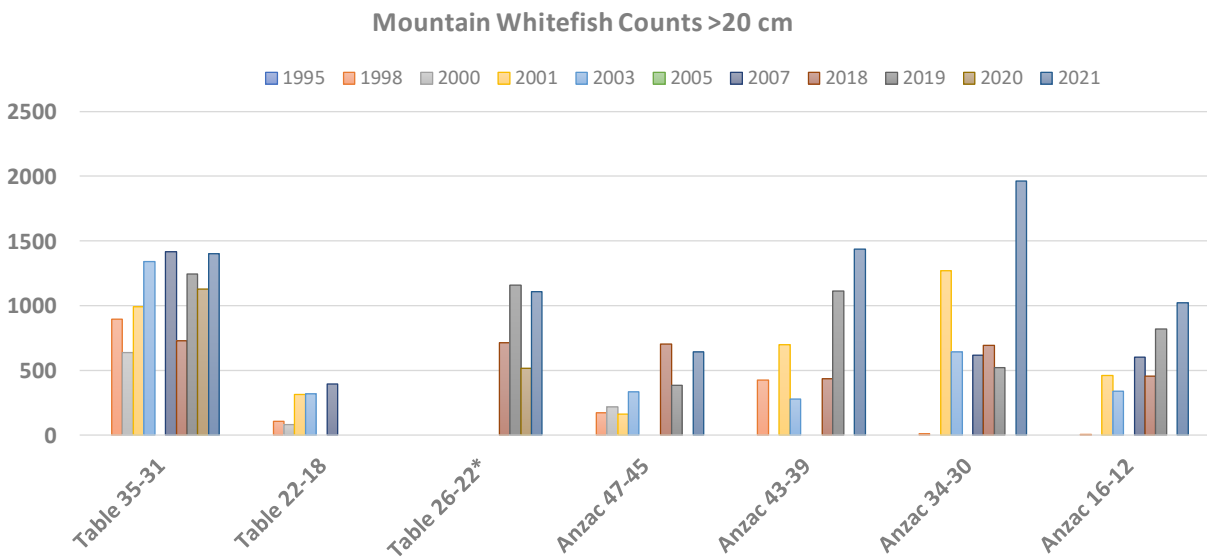


Figure 20. Counts of Mountain Whitefish >20 cm in sections of the Anzac and Table River watersheds, 1995-2020. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.

Table 7. Unadjusted mean counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish in long-term index sections of the Table and Anzac rivers, 1995-2021.

Year	Species	Table River Sites			Anzac River Sites			
		Table 35-31	Table 22-18	Table 26-22*	Anzac 47-45	Anzac 43-39	Anzac 34-30	Anzac 16-12
<u>1995</u>	GR	111						
	BT	20						
	RB	12						
	MW							
<u>1998</u>	GR	136	67		164	136	106	8
	BT	127	17		29	17	13	10
	RB	83	69		5	6	37	42
	MW	894	105		170	426	8	1
<u>2000</u>	GR	123	37		68			
	BT	30	6		16			
	RB	11	30		8			
	MW	636	82		217			
<u>2001</u>	GR	91	42		20	85	52	11
	BT	3	1		1	7	10	5
	RB	10	10		3	5	11	10
	MW	991	315		161	700	1272	458
<u>2003</u>	GR	137	70		78	166	54	23
	BT	28	12		8	60	6	18
	RB	19	18		4	6	7	29
	MW	1341	320		333	277	641	340
<u>2005</u>	GR	98				91	79	29
	BT	8				19	12	20
	RB	4				5	3	14
	MW							
<u>2007</u>	GR	113	45				61	45
	BT	21	14				16	20
	RB	15	18				8	29
	MW	1415	394				616	600
<u>2018</u>	GR	210		76	194	182	114	22
	BT	75		14	76	89	42	6
	RB	12		69	8	7	25	9
	MW	730		711	705	433	692	458
<u>2019</u>	GR	188		116	91	152	72	40
	BT	30		10	11	27	5	3
	RB	17		46	13	6	9	27
	MW	1246		1160	383	1111	522	821
<u>2020</u>	GR	152		67				
	BT	7		3				
	RB	21		7				
	MW	1128		516				
<u>2021</u>	GR	228		171	146	132	152	50
	BT	50		38	14	22	45	25
	RB	58		83	16	9	20	51
	MW	1404		1109	645	1438	1962	1021

*replacement for Table River section 22-18 beginning in 2018.

6.0 DISCUSSION

6.1 Scientific Information Needs for Arctic Grayling Conservation

6.1.1 Monitoring data requirements

In 2021/2022, during our community outreach activities, we have heard on multiple occasions about the importance of turning improvements in scientific understanding in to improvements in Arctic Grayling stewardship in the Parsnip River watershed. In Section 1.0, we posed the question: What actions are needed to conserve Parsnip Arctic Grayling for future generations? We cannot definitively answer this question in 2022. Instead, in this Discussion section we address it obliquely by proposing a framework for conservation action and for additional learning, to ensure that our investments in conservation are effective. In the two sections of our Discussion, we break this question in to two sub-questions: 1) what additional information is necessary to guide stewardship actions and evaluate whether they are effective in conserving Arctic Grayling? (Section 6.1 Scientific Information Needs for Arctic Grayling Conservation) and 2) what is the most effective route to habitat conservation? (Section 6.2 Recommendations for a Stewardship Framework).

The Fish and Wildlife Compensation Program – Peace Region has made several important investments in compiling and synthesizing background information on Arctic Grayling biology, conservation status, critical habitat locations, limiting factors, and potential enhancement measures (Northcote 1993; Blackman 2002b; Clarke and Shrimpton 2005; Ballard and Shrimpton 2009; Hawkshaw and Shrimpton 2014; Stamford et al. 2017). Additional information needs beyond these syntheses are classified in FWCP’s Arctic Grayling Monitoring Framework document (Hagen and Stamford 2017) in to four types:

1. Population data indicating conservation status and risk.
2. Information delineating critical habitats.
3. Information indicating potential limiting factors.
4. Information about the effectiveness of conservation actions.

Our study results can potentially be utilized to improve the knowledge base in each of these categories (Sections 6.1.2-6.1.5). However, to get the most out of FWCP’s investment in the snorkeling study, additional monitoring and analysis steps are also required (Section 6.2).

6.1.2 Conservation status and risk

Improved understanding of the conservation status of Parsnip Arctic Grayling has been a primary objective of this study. Adult abundance and trend are the two most important indicators of conservation status (McElhany et al. 2000; O’Grady et al. 2005; USFWS 2010). Extirpation risks posed by demographic stochasticity, inbreeding depression, and long-term genetic losses/genetic drift are magnified greatly at very small adult population sizes (Franklin 1980; Nunney and Campbell 1993). Caughley (1994) has suggested that population trend should be considered an even more important indicator of population viability. Unless the external factors driving

negative population growth in the first place (often overharvest and habitat destruction in salmonid populations) can be identified and corrected, extirpation may be a likely outcome.

The distribution and diversity of a group of organisms are also indicators of its conservation status (McElhany et al. 2000; IUCN 2012). Widely distributed groups of organisms consisting of multiple, connected sub-populations are generally thought to be more resilient to environmental stochasticity (variability in environmental conditions) and forces driving population declines, because of greater genetic and habitat diversity (Simberloff 1988; McElhany et al. 2000; IUCN 2012).

As we have pointed out in Section 1.0, acquiring these population data at spatial scales relevant to human activities has been a challenge for scientists. The typical focus on a limited number of index sites within a stream network may fail to identify key landscape attributes, both natural and human-caused, affecting the distribution and abundance of organisms (Schlosser 1991; Fausch et al. 2002; Lowe 2002; Jacobs et al. 2021). In this study, we have addressed this challenge by dividing our snorkeling effort into monitoring at a restricted spatial scale but long temporal scale in long-term index sections, and also watershed-scale monitoring using the more rapid method of single-pass snorkeling surveys. The former addresses the need for trend information, and the latter addresses the need for total abundance and distribution information. In our view, this approach has been effective at improving our knowledge of Arctic Grayling conservation status indicators within the Parsnip River watershed.

With respect to the population trend, snorkeling data from the 6 long-term index sections has provided fairly solid evidence of a positive trend in Arctic Grayling abundance over the 1995-2021 period. This is of course encouraging, and has important implications for recreational fishing management which are discussed below (Section 6.1.4 Limiting factors). However, as discussed in Section 6.1.4, rapidly increasing land use in the Parsnip River watershed is a potentially serious threat to Arctic Grayling going forward.

Following completion of single-pass surveys in the Misinchinka River in 2022, we will be in position to estimate total abundance and summer distribution of subadult/adult Parsnip Arctic Grayling for the first time and to describe the relative importance of each sub-basin. This will be an objective of the year 5 final report.

The Parsnip snorkeling study has been effective in improving our understanding of Arctic Grayling conservation status in the watershed. While annual monitoring of abundance is not necessary to evaluate changes in population status, it cannot be assumed that the current level of population health and ecosystem productivity will be maintained, as discussed in the following sections. Rapid increases in industrial activity and angler access in the Parsnip River watershed, associated with forestry and pipeline initiatives, are potential threats to Arctic Grayling population viability. Therefore, we recommend a long-term role for the snorkeling study within a stewardship framework for the Parsnip River watershed (Section 6.2).

6.1.3 Critical habitats

In addition to the objective of learning about adult abundance in the Parsnip River watershed, a primary objective of the reconnaissance snorkeling surveys has been to identify stream habitat that is critical for the summer rearing of subadult and adult Arctic Grayling. Adult rearing habitat is known to be limiting for Arctic Grayling populations and its productivity can be strongly affected by land use-related habitat degradation and increased angler access (Stamford et al. 2017 and references therein).

At the time of the 2017 FWCP Arctic Grayling information synthesis (Stamford et al. 2017), there was a great deal of uncertainty about the distribution and abundance of adult and subadult Arctic Grayling in the Parsnip River watershed outside of the Table and Anzac sub-basins. The single-pass, reconnaissance snorkeling surveys have been effective at addressing this information gap. We now know that Arctic Grayling are present and widely distributed in other parts of the Parsnip River watershed, particularly upstream of the Table River (Table 6). Adult Arctic Grayling utilize at least 34 km of the Missinka River (Hagen and Gantner 2020), 48 km of the Hominka River (Hagen and Stamford 2021), 27.5 km of Wichcika Creek (Hagen and Stamford 2021), and 30 km of Reynolds Creek (Table 6). Wichcika Creek and Reynolds Creek appear to be somewhat marginal for adult Arctic Grayling, with very low densities numerically-dominated by Rainbow Trout (Table 6). The most productive summer rearing habitats for adult Arctic Grayling outside of the Table and Anzac rivers are in the upper Parsnip River watershed distributed from 36-29 km of the Missinka River (Hagen and Gantner 2020) and from 48-32 km of the Hominka River (Hagen and Stamford 2021). Most importantly, these critical habitats are now candidates for stewardship actions, as discussed in Section 6.2.

Although reconnaissance surveys will not be complete until 2022, it is already clear that the most important of the Parsnip River's sub-basins are the Anzac and Table systems. Given the disproportionate importance of these two systems, reconnaissance in the Table River watershed similar to the spatially-continuous survey of the Anzac River in 2018 (Hagen et al. 2019) is warranted. The Table River has not been a target for reconnaissance surveys during this study mostly because of poor visibility below the slump at 22 km. The potential recovery of water clarity downstream of this slump should be investigated during fieldwork in 2022, and other methods (e.g., eDNA combined with adult capture methods) could also be considered for application in the lower Table River.

It is important to recognize Arctic Grayling have a complex life history and critical habitats for adult rearing, spawning, overwintering, and juvenile rearing are often in distinct locations that may be separated by long migration distances (Armstrong 1986, Northcote 1993, Stamford et al. 2017). Therefore, critical summer rearing locations for adult Arctic Grayling identified during this study do not comprise a complete picture of the distribution of critical habitats for the species in the Parsnip River watershed. Fortunately, a substantial amount of past FWCP sampling targeting juvenile life stages of Arctic Grayling has occurred in the Parsnip watershed (Hawkshaw and Shrimpton 2014; Stamford et al. 2017 and references therein). These data have

previously been interpreted to delineate critical habitats for other life stages (Hagen et al. 2015; Stamford et al. 2017) and the results should also be taken into account when identifying targets for stewardship actions (Section 6.2).

6.1.4 Limiting factors

Limiting factors regulate Arctic Grayling growth and survival. Knowledge of how physical habitat attributes limit Arctic Grayling distribution can be used to identify the conditions that need to be maintained within critical habitats to ensure long-term conservation, or to set targets for restoration and enhancement of unproductive habitats (Hagen and Stamford 2017). FWCP and its collaborators have made important investments in directly investigating limiting factors for Arctic Grayling in the Williston watershed, including investigations of 1) the effects of reservoir creation on adult migration and gene flow (Clarke et al. 2005), 2) the effects of stream nutrient enrichment (Wilson et al. 2008) on adult abundance, 3) the roles of physical habitat attributes in defining the range of juvenile Arctic Grayling (Hawkshaw and Shrimpton 2004), and 4) the roles of water temperature and other factors on adult Arctic Grayling movements in the Parsnip River watershed (Martins et al. 2020).

Snorkeling data indicating the distribution and abundance of adult Arctic Grayling can be used to evaluate potential limiting factors. For example, Arctic Grayling are thought to be highly susceptible to angling exploitation (Stamford et al. 2017). In the Parsnip River watershed, it appears that human use of Arctic Grayling in catch-and-release sport fisheries and First Nations subsistence fisheries has been sustainable over the 1995-2007 period, as evidenced by the positive trend in abundance.

Snorkeling results from across the Parsnip River watershed indicate strong contrast in adult Arctic Grayling abundance among tributary sub-basins, with the Anzac River being the most productive. Field observations made during this study and prior work by FWCP have suggested several stream habitat attributes to investigate as potential factors driving this pattern. These are:

1. Water temperature and its variation: Adults can show higher growth rates during years when summer water temperatures are lower (e.g., approaching 10°C; Lohr et al. 1996; Deegan et al. 1999). Juvenile Arctic Grayling are more likely to be present in large watersheds with cool, stable summer temperatures (Hawshaw and Shrimpton 2014).
2. Watershed size: Included in best models of juvenile Arctic Grayling presence for Hawkshaw and Shrimpton (2014). The Anzac River is the Parsnip watershed's largest sub-basin and has the strongest population size.
3. Stream gradient: Sub-basins of the Parsnip River watershed with extensive sections of low-gradient meander have fewer adult grayling.
4. Hydrological variables: E.g., peak flows, sediment delivery. Known to affect productivity for juvenile and adult life stages (Stamford et al. 2017 and references therein).
5. Past land use: The Anzac River has until recently had a pristine upper watershed.

6. Distance from the reservoir: Included in best models of juvenile Arctic Grayling presence for Hawkshaw and Shrimpton (2014).
7. Stream channel geomorphology: E.g., Anzac River adult Arctic grayling occupy the deepest water at or near the edge of the thalweg, usually where the river is narrow (Blackman 2004).
8. Site-level physical habitat attributes: e.g., pool depth, bed material particle size, e.g., Blackman 2004 found preferred adult grayling depth is 1.36 m and 0.36 m/sec velocity.

In 2022 we will collaborate with the FFEL-led FWCP Project PEA-F23-F-3652 to incorporate Arctic Grayling snorkeling survey data into a more detailed assessment of the roles of water temperature and other limiting factors in defining critical habitats.

6.1.5 Effectiveness of conservation actions

A substantial conservation action for Parsnip Arctic Grayling was the introduction of the no-harvest angling regulation beginning in 1995 (Hawkshaw and Shrimpton 2014). As described in Section 6.1.4, this study has documented a positive trend in abundance since that time, suggesting that existing recreational fisheries are sustainable. Fish and aquatic habitat conservation measures in the Parsnip River watershed have only recently been proposed or implemented into law (Section 6.2), and our data would not indicate yet whether they are enough to conserve Arctic Grayling. Conservation and enhancement actions are necessarily and should be based on our current knowledge about limiting factors, but there may be substantial uncertainty about whether they will be effective. Therefore, effectiveness monitoring is a key component of our habitat stewardship recommendations in Section 6.2.

6.2 Recommendations Towards an Arctic Grayling Stewardship Framework

6.2.1 Conservation vision and principles

Chapin et al. (2015) defined environmental stewardship as: “a framework that guides society to actively shape pathways of ecological and social change to enhance both ecosystem resilience and long-term human wellbeing.” Our use of the term stewardship in this section is deliberate and sets the intention to better integrate conservation and community goals in the Parsnip River watershed, which we feel will ultimately be more effective. Our use of the term framework implies our stewardship recommendations will be guided by a vision and supporting principles.

Our vision is for the long-term conservation of Arctic Grayling in the Parsnip River watershed at abundance levels that support continued recreational and subsistence fisheries.

In support of this vision, we recommend implementation of six principles:

1. Local communities and First Nations whose territories overlap with the Parsnip River watershed should have a central role in stewardship of watersheds they are close to, care about, and depend on for subsistence needs and livelihoods (Bennett et al. 2018). The Parsnip watershed is of critical community interest to McLeod Lake Indian Band in particular.

2. Achieving FWCP strategic objectives for conservation, sustainable use, and community engagement will require collaboration with BC Government agencies, First Nations, and communities of the Williston Reservoir watershed. This is because critical habitats for Arctic Grayling exist on Crown land and First Nations territories where FWCP itself may have limited opportunities for habitat conservation.
3. Conservation of critical habitats in good ecological condition and expected to be resilient to future climate change is more urgent and cost-effective than restoration and enhancement of already-degraded habitat (Roni et al. 2002; Chapin et al. 2015).
4. More productive sub-basins in the Parsnip River watershed supporting higher abundances of Arctic Grayling are candidates for greater investments in habitat preservation. These populations are likely to have the highest long-term viability.
5. Watershed-scale land use objectives will have a greater chance of conserving habitat productivity for both adult and juvenile life stages.
6. Application of the Precautionary Principle implies that when scientific confidence is lacking, decisions should be sufficiently risk averse to avoid serious or irreversible harm.

6.2.2 *Recommended stewardship and monitoring actions*

Restoration of degraded habitats and enhancements to boost the productivity of small or declining Arctic Grayling populations may one day be necessary in the Parsnip River watershed as a part of a stewardship plan. However, at present critical habitats in the core of the Arctic Grayling distribution in the Anzac and Table remain productive, as indicated by the positive abundance trend. Therefore, we recommend conservation of habitats currently in good ecological condition as the most reliable and cost-effective stewardship approach (Roni et al. 2002).

Highest-priority recommendations for the near term are:

1. *Share study results and critical habitat information with First Nations whose territories overlap the Parsnip River watershed.* First Nations share with FWCP and other collaborators the goal of long-term Arctic Grayling conservation, and have personnel and programs dedicated to land use stewardship. Representatives of these Nations have identified that sharing of spatial layers depicting critical fish habitat would be an especially valuable outreach product. Critical fish habitat layers for the Parsnip River watershed are being prepared in collaboration with Ecosystems Section, Omineca Region. Following completion, they will be available from Sandra Sulyma, Ecosystems Section Omineca Region FLNRORD, Prince George.

In 2021, we improved the accessibility of the study results and increased the scope of our outreach through the production of a video, which was distributed to First Nations, project supporters in the recreational angling community, and study collaborators Freshwater Fisheries Society of BC (FFSBC) and FLNRORD. The video featured both

the snorkeling study and the Parsnip, Peace, and Dinosaur eDNA study (FWCP Project No. PEA-F21-F-3198; Stamford et al. 2022), with a focus on the Parsnip River watershed where our filming was conducted.

2. *Watershed-scale land use objectives to protect against water temperature increases and hydrological hazards, in watersheds that provide summer rearing habitat for adult Arctic Grayling.* Watershed-scale habitat protection measures designed to protect against changes in hydrology and water temperature are necessary, because Arctic Grayling are vulnerable to increased peak flows, increased fine sediment in streams, and increased water temperature (Stamford et al. 2017 and references therein). These objectives should include limits to watershed disturbance (equivalent clearcut area – ECA) to protect against elevated peak flows, wider buffers on all stream reaches to protect against fine sediment inputs and water temperature increases, and road building practices that maintain fish passage at stream crossings, reduce fine sediment inputs, and avoid easy angler access to vulnerable aggregations of fish. Design and implementation of watershed-scale land use objectives may be led by McLeod Lake Indian Band’s Land Stewardship in consultation with licensees and their own forestry operators, and by the BC Government. The key tool for establishing watershed-scale land use objectives within British Columbia’s *Government Actions Regulation* (GAR) is the ‘Fisheries Sensitive Watershed’ (FSW) designation (GAR Section 14). The Fisheries Sensitive Watershed initiative in the Parsnip River watershed has been led by Sandra Sulyma, Ecosystems Section, Omineca Region, and has already resulted in FSW legislation for the Anzac, Table, Hominka, and Missinka sub-basins. Further FSWs are planned and will involve consultation with community interests and First Nations (Sandra Sulyma, pers. comm. March 2022).
3. *Studies to improve knowledge of limiting factors.* A multi-scale modeling study of current and future water temperatures in the Williston Reservoir watershed is needed, and has been conditionally funded for 2022 (FWCP project no. PEA-F23-F-3632). Increases in water temperature would threaten cold water-adapted Arctic Grayling and also Bull Trout populations.

A study to better define the roles of water temperature and other physical habitat attributes in limiting adult Arctic Grayling in the Parsnip River watershed is also needed, and has been conditionally funded (PEA-F23-F-3652). This study will be conducted in collaboration with the snorkeling study in 2022, and study outcomes will also be complementary to the water temperature modeling study mentioned above.

4. *Effectiveness monitoring.* The watershed-scale land use objectives and other stewardship actions have been or will be designed to protect against hydrological and water temperature changes in critical habitats, but uncertainty will remain about whether they

are enough to ensure long-term conservation of Arctic Grayling. Therefore, periodic monitoring of abundance using snorkeling surveys in index sections will be necessary to evaluate their effectiveness. During future surveys, it may be desirable to add index sections from other watersheds (e.g. Hominka, Missinka) to the program to increase the spatial replication of the effectiveness monitoring. The most efficient long-term strategy for monitoring Arctic Grayling population status and the effectiveness of conservation actions at the scale of the entire Williston Reservoir watershed may be to alternate between periodic snorkeling in the Parsnip River watershed and snorkeling in tributaries to the west shore of Williston Reservoir (i.e., Ingenika, Mesilinka).

7.0 ACKNOWLEDGMENTS

The authors would like to thank the Fish and Wildlife Compensation Program – Peace Region for their long-term (since 1995) financial support of Arctic Grayling monitoring in the Parsnip River watershed. This project has been conducted in collaboration with BC’s Ministry of Forests, Lands, Natural Resource Operations, and Rural Development and UNBC’s Freshwater Fish Ecology Laboratory. McLeod Lake Indian Band and the Polar Coachman Flyfishers are gratefully acknowledged for their long-standing support of this study. Dawn Cowie, Cody Haggard, Austin Roberts, Ciara Sharpe, and Julia Tuininga provided assistance in the field. Morgan Dowd, Benita Kaytor, and Eduardo Martins provided assistance and/or advice related to the statistical analyses. Morgan Hite produced the maps used in the report. Our pilot for the 2021 study was Nick Herbert of Yellowhead Helicopters Ltd. Additional funding for outreach video editing was provided by the Freshwater Fisheries Society of British Columbia. The video was shot by Benita Kaytor of Kaytor Ecologica and Nick Herbert, directed by Benita Kaytor, and edited by Jake Daly of Tiny Life Media, with additional footage from the field crew and Nikolaus Gantner. Randy Zemlak reviewed an earlier version of this report.

8.0 REFERENCES

- Anonymous. 1978. Report on environmental studies for the McGregor Diversion Project. Report prepared by Reid, Crowther, and Partners, Ltd. for BC Hydro and Power Authority.
- Armstrong, R.H. 1986. A review of the Arctic grayling studies in Alaska, 1952-1982. Biol. Paper Univ. Alaska No. 23:3-17.
- Ballard, S and J.M. Shrimpton. 2009. Summary Report of Arctic Grayling Management and Conservation 2009. A synopsis of the information available on Arctic grayling in the Omineca region of northern British Columbia and identification of additional information needs. Peace/Williston Fish and Wildlife Compensation Program Report No. 337. 66 pp plus appendices.

- Bennett, N.J., T.S. Whitty, E. Finkbeiner, J. Pittman, H. Bassett, S. Gelcisch, and E.H. Allison. 2018. Environmental stewardship: a conceptual review and analytical framework. *Environmental Management* 61: 597-614.
- Birtwell, I.K., Hartman, G.F., Anderson, B., McLeay, D.J., and Malick, J.G. 1984. A brief investigation of Arctic grayling (*Thymallus arcticus*) and aquatic invertebrates in the Minto Creek drainage, Mayo, Yukon Territory: an area subjected to placer mining. *Can. Tech. Rep. Fish. Aquat. Sci.* 1287: xi + 57 p.
- Blackman B.G. 2004. 1997 Arctic grayling habitat use in the Table and Anzac rivers with ancillary information on other associated species. Peace/Williston Fish and Wildlife Compensation Program Report No. 296. 34 pp plus appendices.
- Blackman, B.G. 2002a. Radio telemetry studies of Arctic grayling migrations to overwinter, spawning and summer feeding areas in the Parsnip River watershed. Peace/Williston Fish and Wildlife Compensation Program, Prince George, B.C.
- Blackman, B.G. 2002b. An Information Summary on Arctic Grayling from the Williston Reservoir Watershed with Data Gap Analysis and Recommendations. PFWWCP Report No. 258.
- Bruce, P.G., and P.J. Starr. 1985. Fisheries resources and fisheries potential of Williston Reservoir and its tributary streams, volume II: fisheries resources potential of Williston Lake tributaries - a preliminary overview. BC Government Fisheries Technical Circular No. 69.
- Burnham, K.P., and D.R. Anderson. 2002. Model selection and inference: an information-theoretic approach. Springer-Verlag, New York.
- Cahill, C.C. 2015. Status of the Arctic Grayling in 2015: update 2015 Report prepared for Alberta Environment and Parks and Alberta Conservation Association. Alberta Wildlife Status Report no. 57 (Update 2015).
- Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* 63: 215-244.
- Chapin, F.S., M. Sommerkorn, M.D. Robards, and K. Hillmer-Pegram. 2015. Ecosystem stewardship: a resilience framework for Arctic conservation. *Global Environmental Change* 34: 207-217.
- Clark, R.A. 1992. Influence of stream flows and stock size on recruitment of Arctic grayling (*Thymallus arcticus*) in the Chena River, Alaska. *Can. J. Fish. Aquat. Sci.* 49:1027-1034.
- Clarke, A.D., K. Telmer and J.M. Shrimpton. 2005. Population structure and habitat use by Arctic grayling (*Thymallus arcticus*) in tributaries of the Williston Reservoir using natural elemental signatures. Peace/Williston Fish and Wildlife Compensation Program Report No. 300. 62p. + 1 Appendix.

Cowie, D.M. 2021. Data Compilation and Summary of Reports Related to Arctic Grayling Studies in the Table, Anzac and Parsnip Rivers, 1995-2007. Data report prepared for the Fish and Wildlife Compensation Program – Peace Region and BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, Prince George, BC.

Cowie D.M. and B.G. Blackman. 2012. An Overview and Summary of Methodologies of Arctic grayling (*Thymallus arcticus*) Projects Conducted in the Parsnip, Table, and Anzac Rivers from 1995 to 2007. Fish and Wildlife Compensation Program – Peace Region Report No. 349. 24 pp. plus appendices.

Cowie D.M. and B.G. Blackman. 2003. 2001-2002 Arctic grayling (*Thymallus arcticus*) Fry Surveys in the Omineca and Osilinka Rivers. Peace/ Williston Fish and Wildlife Compensation Program Report No. 276. 18 pp plus appendices.

de Bruyn, M., and P. McCart. 1974. Life history of the grayling (*Thymallus arcticus*) in Beaufort Sea drainages in the Yukon Territory. In P.J. McCart [ed.] Arctic Gas Biological Report Series, Vol. 15, Chapter 2, 41p.

Deegan, L.A., H.E. Golden, C.J. Harvey, and B. J. Peterson. 1999. Influence of Environmental Variability on the Growth of Age-0 and Adult Arctic Grayling. Trans, Am. Fish. Soc. 128(6): 1163-1175.

Dowd, M. 2020. Estimating abundance for Arctic Grayling and Bull Trout in the Parsnip River watershed. Honours thesis, Department of Ecosystems Science and Management, University of Northern British Columbia.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to Riverscapes: Bridging the gap between research and conservation of stream fishes. BioScience 52 (6): 483-498.

Franklin, I.A. 1980. Evolutionary changes in small populations. Pages 135–150 in M. Soule and B. A. Wilcox, editors. Conservation biology: an evolutionary perspective. Sinauer Associates, Sunderland, Massachusetts.

FWCP. 2020. Fish and Wildlife Compensation Program – Rivers, Lakes, and Reservoirs Action Plan. BC Hydro, Prince George, BC.

Hagen, J. and J.S. Baxter. 2005. Accuracy of diver counts of fluvial rainbow trout relative to horizontal underwater visibility. North American Journal of Fisheries Management 25:1367-1377.

Hagen, J., and N. Gantner. 2020. Abundance and Trend of Arctic Grayling (*Thymallus arcticus*) in Index Sites of the Parsnip River Watershed, 1995-2019. Report prepared for the Fish and

Wildlife Compensation Program – Peace Region, Prince George, BC. FWCP project no. PEA-F20-F-2959.

Hagen, J., R. Phillipow, and N. Gantner. 2019. Trend in Abundance of Arctic Grayling (*Thymallus arcticus*) in Index Sites of the Parsnip River Watershed, 1995-2018. Report prepared for the Fish and Wildlife Compensation Program – Peace Region, Prince George, BC. FWCP project no. PEA-F19-F-2625.

Hagen, J., and M. Stamford. 2017. FWCP Arctic Grayling Monitoring Framework for the Williston Reservoir Watershed. Prepared for Fish and Wildlife Compensation Program, Peace Region. http://fwcp.ca/app/uploads/2017/07/FWCP-Arctic-Grayling-Monitoring-Framework_Final.pdf

Hagen, J., and M. Stamford. 2021. Arctic Grayling Abundance and Trend in the Parsnip River Watershed, 1995-2020. Prepared for Fish and Wildlife Compensation Program - Peace Region, Prince George, BC. FWCP Project No. PEA-F21-F-3203.

Hagen, J., Williamson, S., Stamford, M.D., and R. Phillipow. 2015. Critical Habitats for Bull Trout and Arctic Grayling within the Parsnip River and Pack River watersheds. Report prepared for: McLeod lake Indian Band, McLeod Lake Indian Band, Sekani Drive, McLeod Lake, BC.

Hawkshaw, S.C.F. and J.M. Shrimpton. 2014. Temperature preference and distribution of juvenile Arctic grayling (*Thymallus arcticus*) in the Williston Watershed, British Columbia, Canada. Fish and Wildlife Compensation Program – Peace Region Report No. 366. 40 pp plus appendices.

Hawkshaw, S.C.F., Gillingham, M.C. and J.M. Shrimpton. 2013. Habitat characteristics affecting occurrence of a fluvial species in a watershed altered by a large reservoir. Ecology of Freshwater Fish, 12pp.

Hirst, S.M. 1991. Impacts of the operations of existing hydroelectric developments on fishery resources in British Columbia, Volume II: inland fisheries. 91. Canada. Department of Fisheries and Oceans. Canadian Manuscript Report of Fisheries and Aquatic Sciences.

IUCN. (2012). *IUCN Red List Categories and Criteria: Version 3.1*. Second edition. Gland, Switzerland and Cambridge, UK: IUCN (International Union for Conservation of Nature). iv + 32pp.

Jacobs, G.R., R.F. Thurow, J.M. Buffington, D.J. Isaak, and S.J. Wenger. 2021. Climate, fire regime, geomorphology, and conspecifics influence the spatial distribution of Chinook Salmon redds. Transactions of the American Fisheries Society 150: 8-23.

Joseph, L.N., C. Elkin, T.G. Martin, and H.P. Possingham. 2009. Modeling abundance using *N*-mixture models: the importance of considering ecological mechanisms. *Ecological Applications* 19: 631-642.

Lohr, S., T. Cummings, W. Fredenberg, and S. Duke. 2000. Listing and recovery planning for Bull Trout. Pages 80-87 in Schill, D., S. P. Moore, P. Byorthe, and B. Hamre, editors. *Wild Trout VII, Management in the new millennium: are we ready? Proceedings of the Wild Trout VII Symposium, 1-4 October 2000, Yellowstone National Park, WY*. Trout Unlimited, Arlington, VA.

Lowe, W.H. 2002. Landscape-scale spatial population dynamics in human-impacted stream systems. *Environmental Management* 30 (2): 225-233.

Martins, E., O'Connor, B., Bottoms, J., Clevenger, I., Auger-Methe, M., Power, M., Patterson, D., Shrimpton, M., Cooke, S., 2020. Spatial Ecology of Arctic Grayling in the Parsnip Core Area. Report prepared for the Fish and Wildlife Compensation Program – Peace Region, Prince George, BC. Project Number: PEA-F20-F-2961.

McElhany, P., M.H. Ruckelhaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42.

McLeay B. J., Birtwell I. K., Hartman G. F., and G. L. Ennis. 1987. Responses of Arctic grayling (*Thymallus arcticus*) to acute and prolonged exposure to Yukon placer mining sediment. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 658-673.

Mollenhauer, R., and S.K. Brewer. 2017. Multinomial *N*-mixture models improve the applicability of electrofishing for developing population estimates of stream-dwelling Smallmouth Bass. *North American Journal of Fisheries Management* 37: 211-227.

Northcote, T.G. 1993. A review of management and enhancement options for the Arctic grayling (*Thymallus arcticus*) with special reference to the Williston Reservoir watershed in British Columbia. Province of British Columbia, Ministry of Environment Lands and Parks, Fisheries Branch. Fisheries Management Report No. 101: 69pp.

Northcote, T.G., and D.W. Wilkie. 1963. Underwater census of stream fish populations. *Transactions of the American Fisheries Society* 92:146-151.

Nunney, L., and K.A. Campbell. 1993. Assessing minimum viable population size: demography meets population genetics. *Trends in Ecology and Evolution* 8: 234-239.

O'Grady, J.J., D.H. Reed, B.W. Brook, and R. Frankham. 2004. What are the best correlates of predicted extinction risk? *Biological Conservation* 118: 513–520

- Olkin, I., A.J. Petkau, and J.V. Zidek. 1981. A comparison of N estimators for the binomial distribution. *Journal of the American Statistical Association* 76: 637-642.
- Parkinson, E., and G. Haas. 1996. The role of macrohabitat variables and temperature in defining the range of bull trout. Province of British Columbia Fisheries Project Report 51.
- Parkinson, E.A., E. Lea, and M.A. Nelitz. 2012. A framework for designating “Temperature Sensitive Streams” to protect fish habitat, Part 2: Identifying temperature thresholds associated with fish community changes in British Columbia, Canada. Province of BC, Ministry of Environment, Ecosystem Protection & Sustainability Branch, Fisheries Technical Report No. RD111.
- Pearce, T., Lieske, S., Morgan, J., A. Solonas. 2019. First Nations Information Gathering on Kokanee, Bull Trout and Arctic Grayling. Project Number: PEA-F19-F-2866. Prepared for Fish and Wildlife Compensation Program and Tse’Khene Nation (McLeod Lake Indian Band).
- Pillipow R.A., and A.R. Langston. 2002. Williston Reservoir fish assessments 2000, pelagic netting summary. Report prepared for the Peace-Williston Fish and Wildlife Compensation Program, Prince George, BC. PFWWCP Report No. 261.
- Rabe-Hesketh, S., and A. Skrondal. 2008. *Multilevel and Longitudinal Modelling Using Stata*. 2nd Ed. Stata Press, College Station, TX.
- Reynolds, J.B., Simmons, R.C., and A.R. Burkholder. 1989. Effects of placer mining discharge on health and food of Arctic grayling. *Journal of the American Water Resources Association* 25(3): 625–635.
- Richardson, J.S., E.B. Taylor, D. Schluter, M. Pearson, and T. Hatfield. 2010. Do riparian zones qualify as critical habitat for endangered freshwater fishes? *Canadian Journal of Fisheries and Aquatic Sciences* 67: 1197-1204.
- Roni, P., T.J. Beechie, R.E. Bilby, F.E. Leonetti, M.M. Pollock, and G.R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. *North American Journal of Fisheries Management* 22(1):1-20.
- Rosenfeld, J.S, and T. Hatfield. 2006. Information needs for assessing critical habitat of freshwater fish. *Canadian Journal of Fisheries and Aquatic Sciences* 63 (3): 683-698.
- Royle, J.A. 2004. *N*-Mixture models for estimating population size from spatially replicated counts. *Biometrics* 60: 108-115.
- Schill, D.J. and J.S. Griffith. 1984. Use of underwater observations to estimate cutthroat trout abundance in the Yellowstone River. *North American Journal of Fisheries Management* 4:479-487.

Schlosser, I.J., 1991. Stream fish ecology: a landscape perspective. *BioScience* 41 (10): 704-712.

Sebastian D.C., G.H. Scholten, and P.E. Woodruff. 2003. Williston Reservoir fish assessment: results of hydroacoustic, trawl and gill net surveys in August 2000. Report prepared for the Peace-Williston Fish and Wildlife Compensation Program, Prince George, BC. PFWWCP Report No. 274.

Simberloff, D.S. 1988. The contribution of population and community biology to conservation science. *Annual Reviews in Ecology and Systematics* 19:473-511.

Skoglund, H., K.W. Wollset, R. Lennox, O. Skaala, and B.T. Barlaup. 2021. Drift diving: a quick and accurate method for assessment of anadromous salmonid spawning populations. *Fisheries Management and Ecology* 2021; 00:1-8.

Slaney, P.A. and A.D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. *North Am. J. Fish. Manage.* 7:117-122.

Stamford, M.D., Hagen, J. and S. Williamson. 2017. FWCP Arctic Grayling Synthesis Report: Limiting Factors, Enhancement Potential, Conservation Status, and Critical Habitats for Arctic Grayling in the Williston Reservoir Watershed, and Information Gaps Limiting Potential Conservation and Enhancement Actions. Prepared for Fish and Wildlife Compensation Program, Peace Region.

http://fwcp.ca/app/uploads/2017/07/FWCP_Grayling_Synthesis_Final.pdf

Stamford MD, Strohm J., Euchner T, Pitt C, and B Murray. 2022. Williston Grayling distribution: Parsnip, Peace, Dinosaur. FWCP Project Number: PEA-F21-F-3198.

StataCorp. 2009. *Stata Longitudinal-data/Panel-data Reference Manual*, Release 11. Stata Press, College Station, TX.

Tack, S.L. 1974. Distribution, abundance, and natural history of Arctic grayling in the Tanana River drainage. Alaska Department of Fish and Game, Juneau, Alaska. Federal Aid in Fish Restoration, Annual Performance Report Project F-9-6.

United States Fish and Wildlife Service (USFWS). 2010. Endangered and Threatened Wildlife and Plants; Revised 12-Month Finding to List the Upper Missouri River Distinct Population Segment of Arctic Grayling as Endangered or Threatened. *Federal Register* / Vol. 75, No. 173 / Wednesday, September 8, 2010 / Proposed Rules.

Walker, J. 2005. Status of the Arctic grayling in Alberta. Prepared for Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association. *Wildlife Status Report* No. 57.

Wilson, G.A., K. I. Ashley, P.A. Slaney and R.W. Land. 2008. Williston Reservoir River Fisheries Restoration: The Mesilinka River Fertilization Experiment, 1992-99. Peace/Williston Fish and Wildlife Compensation Program Report NO. 319. 95 pp + appendices.

Young, R.G., and J.W. Hayes. 2001. Assessing the accuracy of drift-dive estimates of brown trout (*Salmo trutta*) abundance in two New Zealand Rivers: a mark-resighting study. New Zealand Journal of Marine and Freshwater Research 35:269-275.

Zubik, R.J., and J.J. Fraley. 1988. Comparison of snorkel and mark-recapture estimates for trout populations in large streams. North American Journal of Fisheries Management 8:58-62.