Abundance and Trend of Arctic Grayling (*Thymallus arcticus*) in Index Sites of the Parsnip River Watershed, 1995-2019.

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March, 2020

Prepared for:

Fish and Wildlife Compensation Program – Peace Region
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FWCP Project No. PEA-F20-F-2959

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.

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EXECUTIVE SUMMARY

Over the 1995-2007 period, the Fish and Wildlife Compensation Program – Peace Region (FWCP) consistently monitored Arctic Grayling abundance and trend in the Parsnip River watershed using snorkeling surveys during the month of August in two index reaches of the Table River and four index reaches of the Anzac River. In 2017, FWCP identified the ten-year hiatus in the monitoring program since 2007 as a high priority knowledge gap for Arctic Grayling. The most important component of our study, which was initiated in 2018, has been to address this information gap by resuming snorkeling surveys in these long-term index reaches. This report presents snorkeling survey results from August 2019, the second consecutive year of surveys in these locations. A second component of our study addresses another high-priority knowledge gap for FWCP: the lack of information delineating critical habitats and abundance in other sub-basins of the Parsnip River watershed. In 2019, we utilized single-pass snorkeling surveys to identify critical summer rearing habitats and count Arctic Grayling in the Missinka River in the upper Parsnip River watershed.

In 2019, snorkeling surveys were conducted over the August 12-17 period, with August 12 being dedicated to site layout and safety reconnaissance. During snorkeling surveys, three independent, three-person crews were utilized. Each crew was comprised of two observers wearing drysuits and a safety boater with appropriate swiftwater rescue equipment and training. Snorkeling counts were replicated by all three crews in three long-term index reaches of the Anzac River: 47-45 km, 43-39 km, and 34-30 km. For the second consecutive year, repeatability of snorkeling counts of Arctic Grayling >20 cm was relatively high. The coefficient of variation (*CV*) ranged from 9.0% to 19.0% among the three locations averaging 13.2% (±3.0%). The remainder of the long-term index reaches (Anzac 16-12 km, Table 35-31 km, Table 26-22 km) received a single snorkeling pass.

Replicated count data exist for all years of the Arctic Grayling snorkeling program in the Parsnip River watershed. We conducted an exploratory statistical analysis in which we estimated population size N and snorkeling detection probability p at index sites based on the variability among replicated counts over the 1995-2019 period. In our approach, observed counts were assumed to be from a Binomial (N_{it}, p) distribution, where each N_{it} signifies population size N at site i and time t. Values for the N_{it} and p, given the count data, were then estimated using maximum likelihood methods. The best model among several alternatives was one which included SITE as a stratified predictor variable for p, i.e. p was site-specific. Resulting maximum likelihood estimates for p were 0.77 and 0.62 for Table River sites 35-31 km and 26-22 km, respectively, and 0.64, 0.65, 0.52, and 0.51 for Anzac River sites 47-45 km, 43-39 km, 34-30 km, and 16-12 km, respectively. Values for p may be related to the stream size in index sites. At the time of writing, however, stream width data were not available for a quantitative analysis of this potential association.

Through collaboration with the University of Northern BC (UNBC)-led telemetry study *Spatial ecology of Arctic grayling in the Parsnip core area* (FWCP project PEA-F21-F-3178), we were able to acquire an independent, mark-resight estimate of detection probability for the Table 35-31 km index section. The mark-resight estimate of 0.80 detection probability

(12 of 15 marked fish observed) exhibited relatively good agreement with the maximum likelihood estimate of 0.77 that was based on the replicated count data for 1995-2019.

In our analysis of population trend, we accounted for the effects of varying detection probability among sites by utilizing the N_{it} estimates in place of the raw snorkeling count data. Application of the linear mixed-effects model, in which N_{it} and *YEAR* were utilized as fixed effects and *STREAM* and *SITE* as nested random effects, indicated a significant increase in the abundance of Arctic Grayling >20 cm in the Parsnip River watershed (P <0.001) over the 1995-2019 period. Model results suggest that since 1998 when monitoring was initiated in all six long term index sites in the Parsnip River watershed, the N_{it} have increased by roughly 60%.

At this point in time, we consider estimates of the N_{it} and trend to be provisional. This is because improved models for estimating detection probability and abundance, based on replicated count data, are currently being developed and evaluated using simulation data. These efforts are being led by the Freshwater Fish Ecology Laboratory (FFEL) at UNBC, and are likely to be incorporated in to this study following the 2020 field season.

In contrast to the Anzac and Table Rivers, the Missinka River does not appear to be utilized by a large population of Arctic Grayling in August. Estimated mean densities for the three single-pass snorkeling survey sections were just 8.5, 1.0, and 0.25 Arctic Grayling >20 cm per km (based on unadjusted raw counts) for 33-29 km, 25-22 km, and 8-4 km, respectively. Even the best of these estimates is less than a third of the overall mean density for the Anzac River of 26.6 per km. Furthermore, critical summer rearing habitat for Arctic Grayling appears to have a limited distribution in the upper watershed below the migration barrier. In contrast to the Anzac and Table rivers, which are utilized by relatively high numbers in their middle reaches in August, Arctic Grayling had declined to negligible densities by approximately the 24 km point on the Missinka River mainstem. This point corresponds to the beginning of low gradient meanders extending downstream to a point just above the 8-4 km index section, which contrasts the riffle-pool channel morphology of the Anzac and Table rivers in which Arctic Grayling reach their highest densities. Based on these results, this habitat in the Missinka River should be considered a lower priority for habitat conservation and enhancement actions, relative to critical summer rearing habitats in the Table and Anzac sub-basins.

For the 2020-21 study, we recommend: 1) continued monitoring of Arctic Grayling abundance in long-term index sites of the Anzac and Table rivers, using replicated snorkeling surveys, 2) continued collaboration with UNBC's FFEL lab on improved models for estimating detection probability and abundance, 3) co-ordination with the crew of the FFEL-led acoustic telemetry study to acquire mark-resight detection probability data in at least 2 additional sites, 4) application of single-pass, reconnaissance snorkeling surveys in previously-unsurveyed reaches of the Hominka River watershed, and 5) continued dialogue with McLeod Lake Indian Band to identify opportunities for information exchange, training, and employment.

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1.0 INTRODUCTION

Following construction of the W.A.C. Bennett dam in 1967 and the formation of Williston Reservoir, Arctic Grayling (*Thymallus arcticus*) populations were devastated in the flooded portion of the Parsnip River watershed. Impoundment resulted in the permanent loss of over 110 km of critical Arctic Grayling habitats in the Parsnip River mainstem, and the loss of local populations that depended on these habitats (Stamford et al. 2017; Pearce et al. 2019). The remnant distribution of Arctic Grayling in the Williston Reservoir watershed appears to be restricted to stream habitat only, suggesting that populations at the southern edge of their range in British Columbia lack the phenotypic diversity present in more northern populations where lake-dwelling populations are common (Stamford et al. 2017).

Arctic Grayling are also sensitive to habitat degradation from forestry, mining, and pipeline developments (Stamford et al. 2017 and references therein), meaning that even those populations that survived flooding may be under threat from current resource extraction activities. Given this conservation concern, along with the high value of the species for First Nations subsistence fishers and BC recreational anglers, the Arctic Grayling is a priority fish species for FWCP. Our study addresses key indicators of conservation status for Arctic Grayling populations in the Parsnip River watershed upstream of the reservoir influence and identifies critical habitats for potential future conservation actions.

Abundance and population growth rate (trend) are the two most important indicators of conservation status and risk for vertebrate populations (Franklin 1980; Nunney and Campbell 1993; Caughley 1994; McElhany et al 2000; O'Grady et al. 2004). Extirpation risks posed by demographic stochasticity, inbreeding depression, and long-term genetic losses/genetic drift are magnified greatly at very small 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.

Over the 1995-2007 period, FWCP monitored Arctic Grayling abundance and trend in the Parsnip River watershed using August snorkeling surveys in two index reaches of the Table River and four index reaches of the Anzac River (Cowie and Blackman 2012). In 2017, the ten-year hiatus in the monitoring program since 2007 was identified as a high priority knowledge gap in FWCP's Arctic Grayling synthesis report (Stamford et al. 2017). The most important component of our study has been to address this information gap by resuming snorkeling surveys in Anzac River and Table River index reaches beginning in 2018 (Hagen et al. 2019). This report presents snorkeling survey results from August 2019, the second consecutive year of surveys in these locations.

The accuracy and precision of snorkeling counts as indices of fish abundance are affected by snorkeling detection probability, i.e. the proportion of fish actually present that are seen and counted by observers. Results from published accounts suggest that snorkeling detection probability can vary substantially from system to system. Correlated factors have included species differences, underwater visibility, instream cover, stream size, and observer experience (Northcote and Wilkie 1963; Schill and Griffith 1984; Slaney and Martin 1987; Zubik and Fraley 1988; Young and Hayes 2001; Korman et al. 2002; Hagen and Baxter 2005). A common method of estimating detection probability in snorkeling surveys has been through mark-resight studies (Slaney and Martin 1987; Zubik and Fraley 1988; Young and Hayes 2001; Korman et al. 2002; Hagen and Baxter 2005). Mark-resight studies however may be difficult to implement and/or costly, resulting in inadequate replication of detection probability estimates (Royle 2004). Mark-resight estimates of snorkeling detection probability have been attempted previously in index sites of the Parsnip River watershed and not considered reliable because of evidence for post-tagging movements out of index sites prior to the snorkeling surveys (Cowie and Blackman 2012 and references therein). In this report, we present a mark-resight estimate of snorkeling detection probability from a single index site of the upper Table River, in which the abundance of fish marked during a concurrent movement study (FWCP project PEA-F21-F-3178: *Spatial ecology of Arctic grayling in the Parsnip core area*) was known from the telemetry record.

An alternative, no-mark method for estimating detection probability and abundance has been implemented in circumstances where counts of animals at a geographic location are repeated over time. Replicated snorkeling count data exist for 9 years of Arctic Grayling snorkeling surveys in the Parsnip River watershed over the 1995-2019 period. In this alternative approach, observed counts are assumed to be from a Binomial (N, p) distribution, where N and p are abundance (i.e. number of trials) and detection probability, respectively. Using maximum likelihood methods, values for N and p can then be found that maximize the binomial probability of the count data (Olkin et al. 1981; Royle 2004). In practice, this simple method has resulted in unstable maximum likelihood estimates when data suggest p is low or counts are sparse (Olkin et al. 1981; Royle 2004). These limitations are not present in the time series of Arctic Grayling snorkeling count data from the Parsnip River watershed. Therefore, in this report we present results from an exploratory statistical analysis of N and p for index sites in the Table and Anzac rivers. We also incorporate estimates of N into the analysis of trend, to account for the effects of variable detection probability.

Arctic Grayling are known or suspected to be present in other sub-basins of the Parsnip River watershed in addition to the Anzac and Table rivers (Hagen et al. 2015). The lack of monitoring data indicating Arctic Grayling abundance and critical habitat locations for these populations comprises a second, high-priority information gap identified in the Arctic Grayling synthesis document (Stamford et al. 2017). Critical habitats are those which limit or have the potential to limit the number of Arctic Grayling surviving to adulthood in the population. For conservation actions to be effective in maintaining a population, they must target limiting factors operating within critical habitat for that population (Hagen and Stamford 2017). In 2019, an additional component our study was to utilize single-pass snorkeling surveys to sub-sample the accessible length of the Missinka River, which has been identified as a potential hub of Arctic Grayling abundance in the upper Parsnip River watershed (Stamford et al. 2017). These surveys allowed us to provide estimates of critical summer rearing habitats for Arctic Grayling and other species in the Missinka River, and assess the relative importance of these habitats within the Parsnip River watershed as a whole.

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.

Our study has been designed specifically to address two high-priority recommendations of FWCP's *Arctic Grayling Monitoring Framework for the Williston Reservoir Watershed* (Hagen and Stamford 2017), using the methodology of snorkeling surveys in the Parsnip River watershed. The study therefore is aligned with *Streams Action Plan* priority action *1b-3* (FWCP 2014):

> Action *1b-3*: Undertake Arctic Grayling monitoring as per recommendations of the monitoring program and develop specific, prioritized recommendations for habitat-based actions which correspond to the monitoring results.

The study had the following specific objectives:

1. Acquire counts of Arctic Grayling and other species in established index sites located in the Anzac and Table rivers, using a snorkeling survey methodology consistent with past surveys.

2. Conduct replicated snorkeling counts of Arctic Grayling within three index reaches using three independent crews, to investigate the repeatability of counts across a realistic range of crew experience levels.

3. Estimate detection probability and population size at sites where snorkeling counts have been replicated and utilize these estimates in an analysis of trend for Arctic Grayling in the Parsnip River watershed.

4. Acquire counts of Arctic Grayling and other species in the Missinka River using a single-pass snorkeling survey methodology, to assess relative abundance and identify critical summer rearing habitats.

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). The mouths of the Anzac, Table, and Missinka rivers are located approximately 40 km, 60 km, and 80 km southeast of the village of McLeod Lake, respectively (Figure 1). These rivers also enjoy high popularity amongst 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. Construction of the 183 m high W.A.C. Bennett Dam, which was completed in 1967, resulted in the formation of Williston Reservoir, which reached full pool in 1972 (Hirst 1991) and flooded the lower ~110 km of the Parsnip River.

The post-impoundment Parsnip River system is a 6th order stream that has a watershed area of 5,600 km^2 (Table 1). Major sub-basins of the Parsnip (Misinchinka, Colbourne, Reynolds, Anzac, Table, Hominka, Missinka, Upper Parsnip), range from 290 km^2 to 1,000 km^2 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 km^2 to 182 km^2) 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, https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=07EE007). 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). 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).

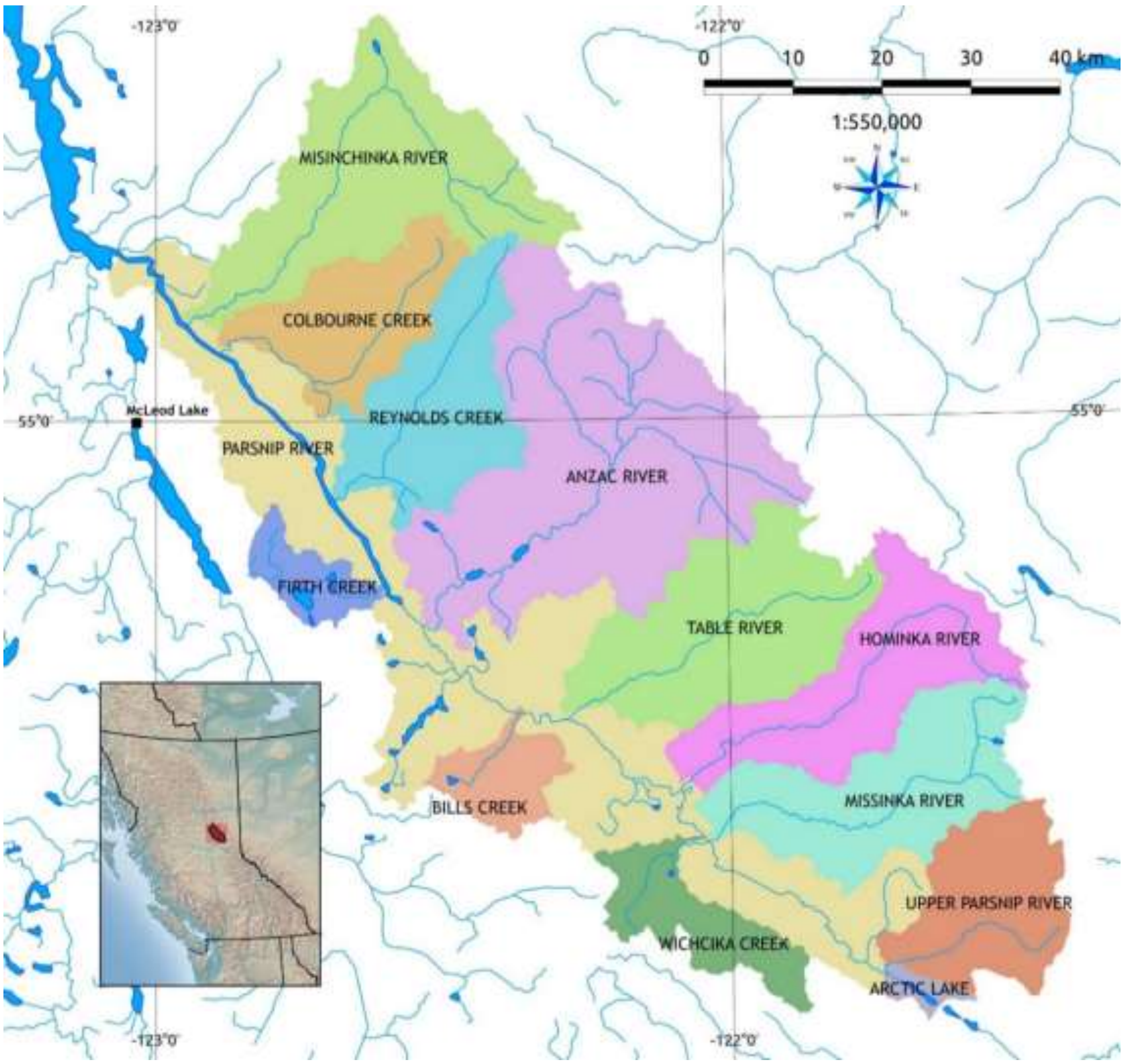

Figure 1. Sub-basins of the Parsnip River watershed (Parsnip mainstem, Misinchinka, Colbourne, Reynolds, Firth, Anzac, Bill's, Table, Hominka, Missinka, Wichcika, Arctic Lake, Upper Parsnip) potentially utilized by Arctic Grayling.

Table 1. Biophysical characteristics of sub-basins potentially utilized by Arctic Grayling within the Parsnip River watershed (adapted from Hagen et al. 2015).

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

*From records in databases linked to the BC Geographic Warehouse, accessed January 2015

4.0 METHODS

4.1 Survey Conditions

Water Survey of Canada (WSC) Station 07EE007 is located on the Parsnip River near its mouth. It is the only WSC flow monitoring station for the Parsnip River watershed. This WSC station provided real time stream discharge data which was utilized to assess the potential safety and feasibility of snorkeling surveys in August 2019. These data were also utilized to compare flow conditions in the Parsnip River watershed in 2019 to long-term average conditions.

A primary factor affecting detection probability in streams is underwater visibility (Hagen and Baxter 2005). In our study, we measured underwater visibility at index sites in two ways: 1) horizontal underwater Secchi disk visibility (Figure 2), and 2) horizontal distance at which the species identity of a 30 cm Arctic Grayling model could no longer be discerned.

Figure 2. Estimating horizontal underwater visibility in the Anzac River, August 2019.

4.2 Snorkeling Methods

In 2019 we conducted snorkeling surveys in six index reaches of the Anzac and Table rivers (Figure 3: Anzac River; Figure 4: Table River) and three new index reaches of the

Missinka River (Figure 5). Surveys were conducted over the August 12-17 period, with August 12 being dedicated to site layout and safety reconnaissance.

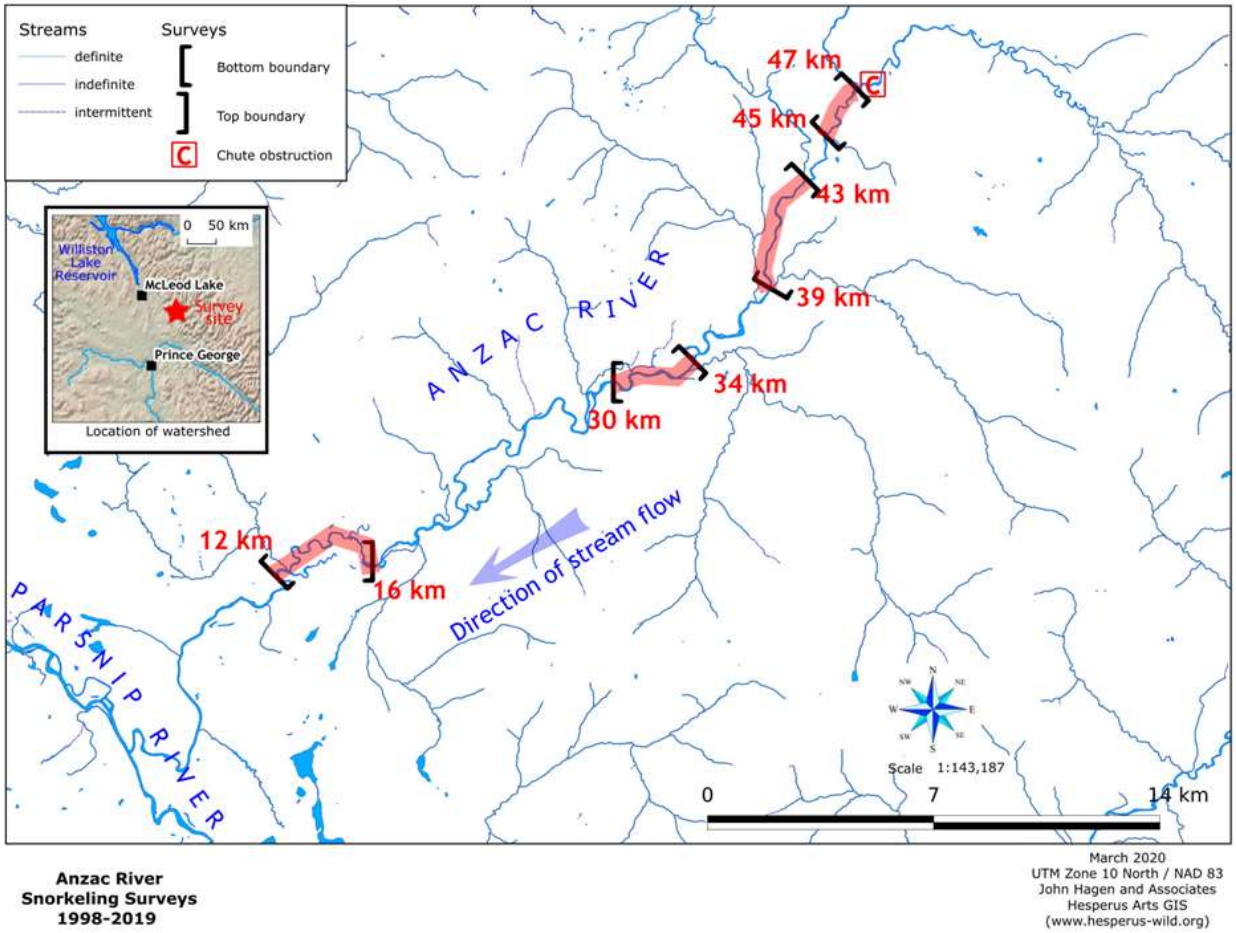

Figure 3. Stream sections of the Anzac River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2019.

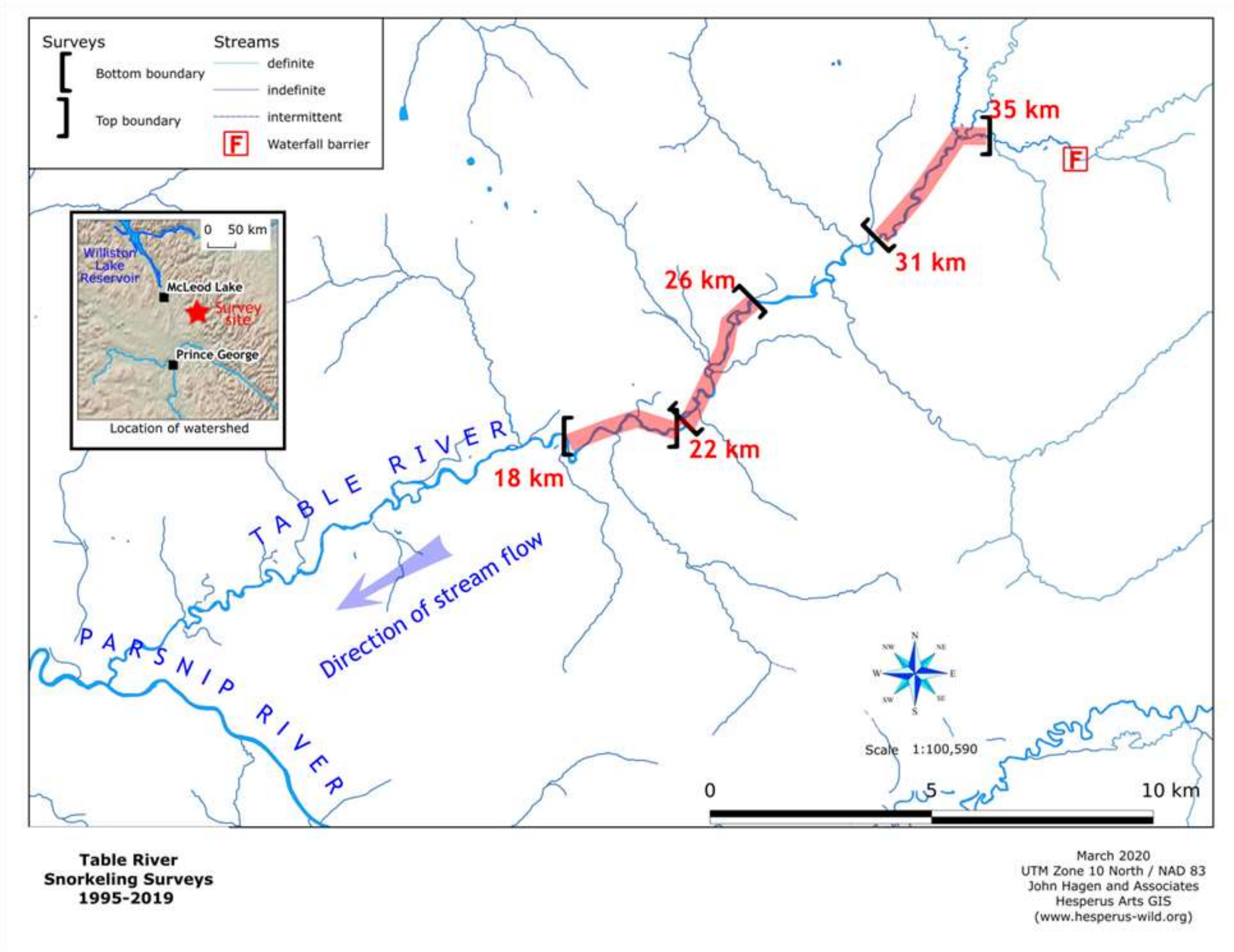

Figure 4. Stream sections of the Table River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 1995-2019. Site 22-18 km was utilized up to 2007, however, was replaced by site 26-22 km in 2018 due to the presence of a clay slump at 22 km compromising underwater visibility in the lower site.

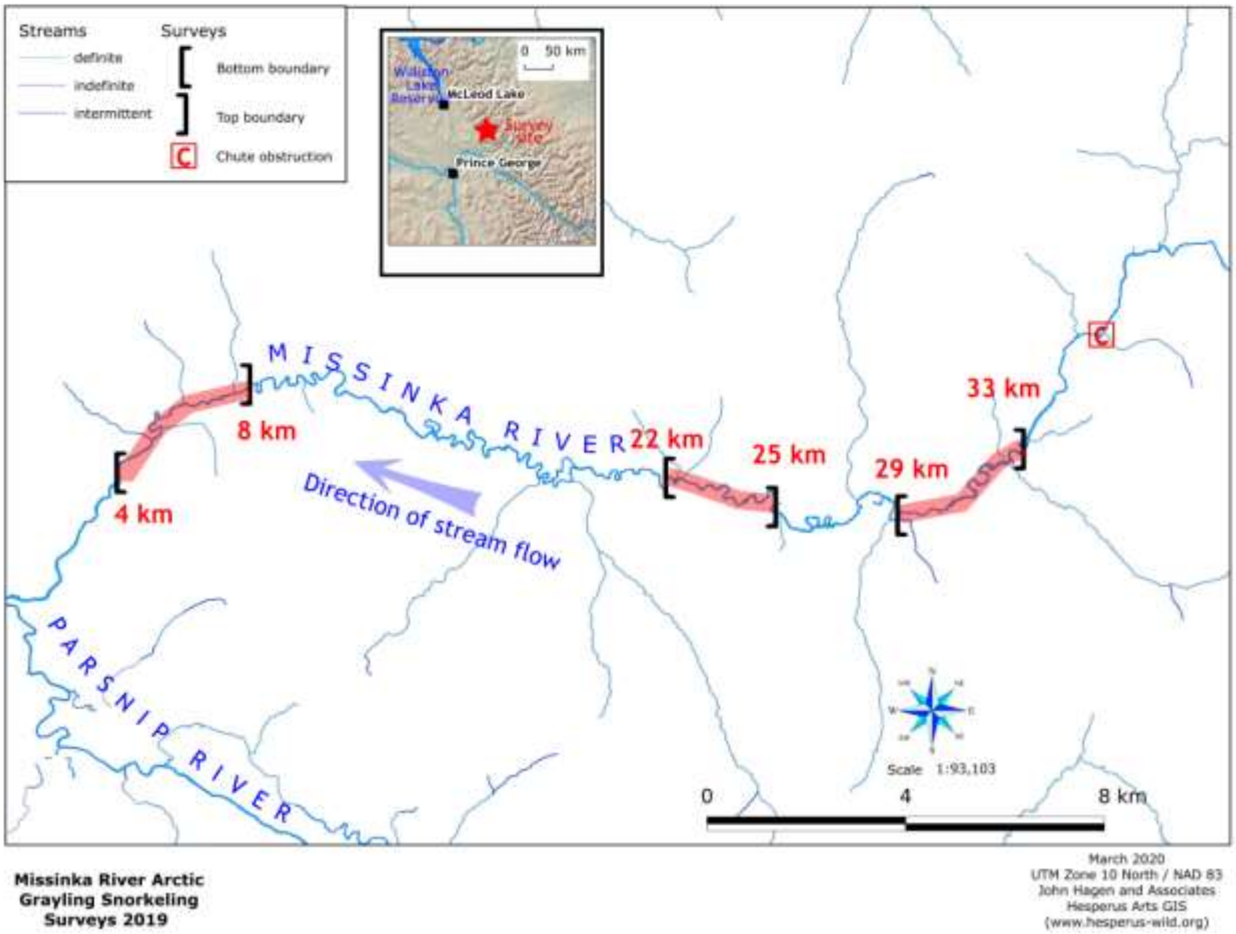

Figure 5. Stream sections of the Missinka River utilized for snorkeling surveys to monitor Arctic Grayling abundance, August 2019.

During snorkeling surveys, three independent, three-person crews were utilized. Two crews were comprised of contract personnel coordinated by consultant John Hagen and Associates, while the third crew was comprised of in-kind personnel of BC's Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD).

Consistent with methods utilized up to 2007 (Cowie and Blackman 2012), snorkeling counts were made by two observers in drysuits (Figure 6), organized in lanes of width determined by horizontal underwater visibility and estimated habitat suitability for Arctic Grayling (see Blackman 2001 for subadult/adult Arctic Grayling habitat use). All observers had experience in at least one other snorkeling study and had received in-the-water training with the study protocol prior to the survey period. During snorkeling surveys, typically observers surveyed adjacent lanes on either side of the thalweg and scanned the water ahead of them and to the right or left depending on which side of the stream they were responsible for. Observers attempted to count only fish that were in their lane. If fish moved in reaction to observers, frequent communication ensured that double counting did not occur. In areas where the usable width of the stream was greater than the width of two lanes surveyed in this manner, one or both observers would extend their lane width and look both ways. Observed fish (Figure 6) were classified to species, and tallied in one of five size categories: 0-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, and 50+ cm.

The third member of each crew was a safety boater with appropriate swiftwater rescue training and equipment (as per FLNRORD Snorkel Drift Safety Work Procedure, 2019). The safety boater paddled behind the line of snorkelers in an inflatable kayak that could navigate the range of stream features encountered and that could be stowed deflated in the basket of the helicopter (Figure 7).

At the start of each survey, size estimation was practiced under water using Arctic Grayling models (laminated, trimmed photographs).

In index sections that received replicated surveys by all three crews, a minimum one-hour delay was enforced between surveys to allow the site to recover from disturbance.

Figure 6. Snorkeling team in the upper Anzac River watershed, August 2019.

Figure 7. Table River Arctic Grayling, August 2019.

4.3 Analyses

In 2019, our statistical analysis of Arctic Grayling snorkeling count data had two areas of focus. The first was an exploratory analysis of the potential benefits of using replicated count data to estimate detection probability p and abundance N. The second was an analysis of trend with estimates of N in index reaches substituted for raw count data, to account for unwanted variation in detection probability.

We assumed for all years 1995-2019 that the population of Arctic Grayling in each index reach was closed with respect to movement, mortality, etc. over the period when replicated surveys were conducted. We further assumed that counts were binomially-distributed random variables from the distribution ~Binomial (N_{it}, p), where N_{it} is the population size at index site i and year t and p is the detection probability. In our exploratory analysis, we estimated the N_{it} and p parameters simply by searching for parameter values that maximized the binomial likelihood of the count data (Olkin et al. 1981; Royle 2004) using the 'Solver' iterative routine (Frontline Systems, Inc.) available as an add-in for Microsoft Excel.

A question of key interest to us in this exploratory analysis was whether predictions of N_{it} and p could be improved through the use of logistic regression models. To do this, we defined a series of candidate models representing different hypotheses about the effects of site (*SITE*), year (*YEAR*), and visibility (*FISH_VIS*) on p, then compared these models using an information-theoretic approach (Burnham and Anderson 2002). Model selection was performed using replicated count data from three years 1998, 2001, and 2003, the only years for which there were no missing data for *SITE* and *FISH_VIS*, and all counts were replicated at least twice. 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). Following model selection, the best model was then re-fit to all replicated count data 1995-2019 to estimate p and the N_{it}, the key parameters of interest for assessing conservation status for Parsnip River Arctic Grayling.

Limits of 95% confidence for p were estimated using the deterministic approximation to the method of likelihood profile presented in Haddon (2001):

$$LL(N_i, p) = LL(N_i, p)_{max} - \frac{\chi^2_{1,1-\alpha}}{2}$$

where $\chi^2_{1,1-\alpha}$ is the (1-α)th quantile of the χ^2 distribution with 1 degree of freedom (e.g. for 95% CL's α = 0.95, 1-α = 0.05, and $\chi^2_{1,1-\alpha}$ = 3.84).

We assessed the trend in Arctic Grayling abundance over time for the Parsnip River watershed as a whole within a linear mixed effects analysis, performed using the Stata statistical analysis program (StataCorp, 2009) and the 'xtmixed' function (Rabe-Hesketh and Skrondal 2008). To account for variability in detection probability, we entered the maximum likelihood estimates of N_{it} (see preceding paragraph) rather than raw count data into the model as a fixed effect, along with observation year. As random effects, we had intercepts for sites nested within streams. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality, following square root-transformation of the N_{it}.

5.0 RESULTS

5.1 Survey Conditions

August 2019 was wet, with several significant rain events recorded on the Water Survey of Canada's gauge in the lower Parsnip River. A visual inspection of graphs of accumulated precipitation and discharge at the station suggests that rainfall preceded flow increases by roughly 25-30 hours (Figure 8).

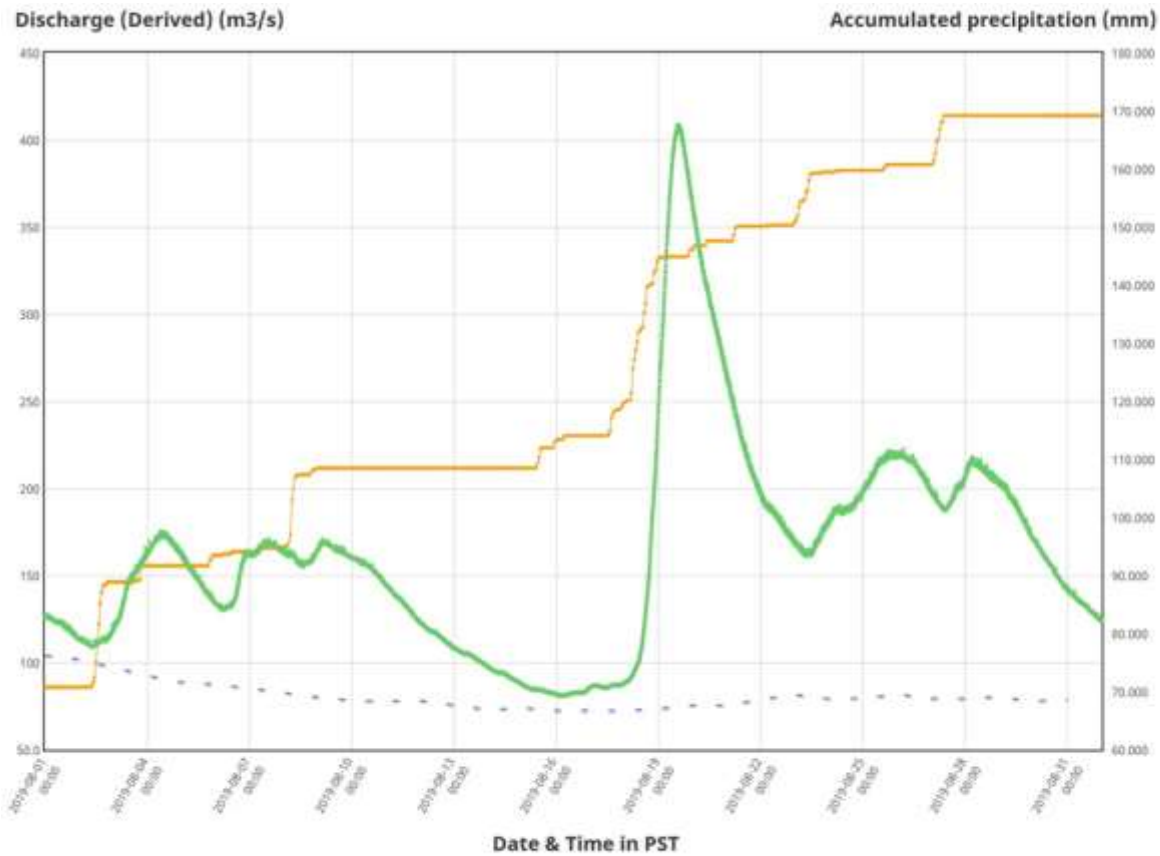

Figure 8. 2019 Discharge (green line), long-term average discharge (dashed line), and 2019 accumulated precipitation (orange line) estimated for the lower Parsnip River (WSC gauge 07EE007), August 2019.

To accommodate the rainy weather forecast, the target start date of the 2019 study was advanced from August 15 to August 12. Daily average discharge in the Parsnip River over the August 13-17 snorkeling survey period ranged from 82.4-103.5 m^3/s at WSC Station 07EE007, which were above WSC's estimated long-term averages (Figure 8, Table 2). Fortunately, this was a period of declining discharge and all planned snorkeling surveys in the Anzac and Table rivers could be completed under suitable conditions. Not all surveys planned for the Missinka River could be completed however, due to high water unsuitable for snorkeling surveys beginning with the August 18 spike (Figure 8).

Table 2. Average daily flow at Water Survey of Canada Station 07EE007 (lower Parsnip River), August 13-17, 2019.

Date	13-Aug	14-Aug	15-Aug	16-Aug	17-Aug
Long-term average discharge (m^3/s)	75.7	72.9	74.1	72.5	72.6
2019 average discharge (m^3/s)	103.5	92.8	84.2	82.4	86.5

Secchi disk visibility in 2019 ranged from 5.1 to 5.8 m in two index sites on the Table River, from 6.5 to 7.5 m in Anzac River index sites (Figure 2), and from 6.5 to 7.0 m in three index sites in the Missinka River. Visibility for discernment of Arctic Grayling models ranged from 3.5 m to 5.1 m among index sites, within the historical ranges of fish visibility previously recorded (Table 3). The long-term index site extending from 22-18 km in the Table River, located below a clay slump into the river at 22 km, was the exception and had unsuitable visibility <3.0 m for the second consecutive year. The extensive nature of the slump indicates that visibility in the reach may be compromised for years to come. In order to retain a desirable index reach in the middle section of the Table River, since 2018 we have surveyed a 4-km reach (26 km-22 km) immediately upstream of the slump instead, and use the resulting count data in the comparison with count data for 22 km-18 km over the 1995-2007 period (section *5.3*)

Table 3. Horizontal underwater visibility in index sites of the Parsnip River watershed, August 13-17, 2019. Historical estimates before 2018 are assumed to be fish visibility, but this has not been confirmed.

	Table River		Anzac River				Missinka River		
Site	**35-31**	**26-22**	**47-45**	**43-39**	**34-30**	**16-12**	**33-29**	**25-22**	**8-4**
Secchi disk visibility (m)	5.1	5.8	6.5	7.5	7.5	6.5	7.0	7.0	6.5
Fish model visibility (m)	3.5	4.0	4.5	5.1	5.0	4.4	5.0	4.8	4.6
Historical range (fish)	3.5-5.7	3.3-5.5	3.5-7	3.5-7	3.5-12	3.5-7.7			

5.2 Precision and Accuracy of Snorkeling Counts

In 2019, snorkeling counts were replicated by three independent crews in three index reaches of the Anzac River: 47-45 km, 43-39 km, and 34-30 km (Figure 3). For the second consecutive year, repeatability of snorkeling counts of Arctic Grayling >20 cm was relatively high. The coefficient of variation (*CV*) ranged from 9.0% to 19.0% among the three locations averaging 13.2% (±3.0%). Among replicates at these sites, there was no consistent pattern evident related to crew composition or order of crew deployment (Figure 9). Replicate swim data for the 1995-2007 period (Table 4) are less precise on average (mean CV = 19.6% ±3.2%). This may be related to less replication (n=2) at some sites, or reduced detection probability (see following paragraphs).

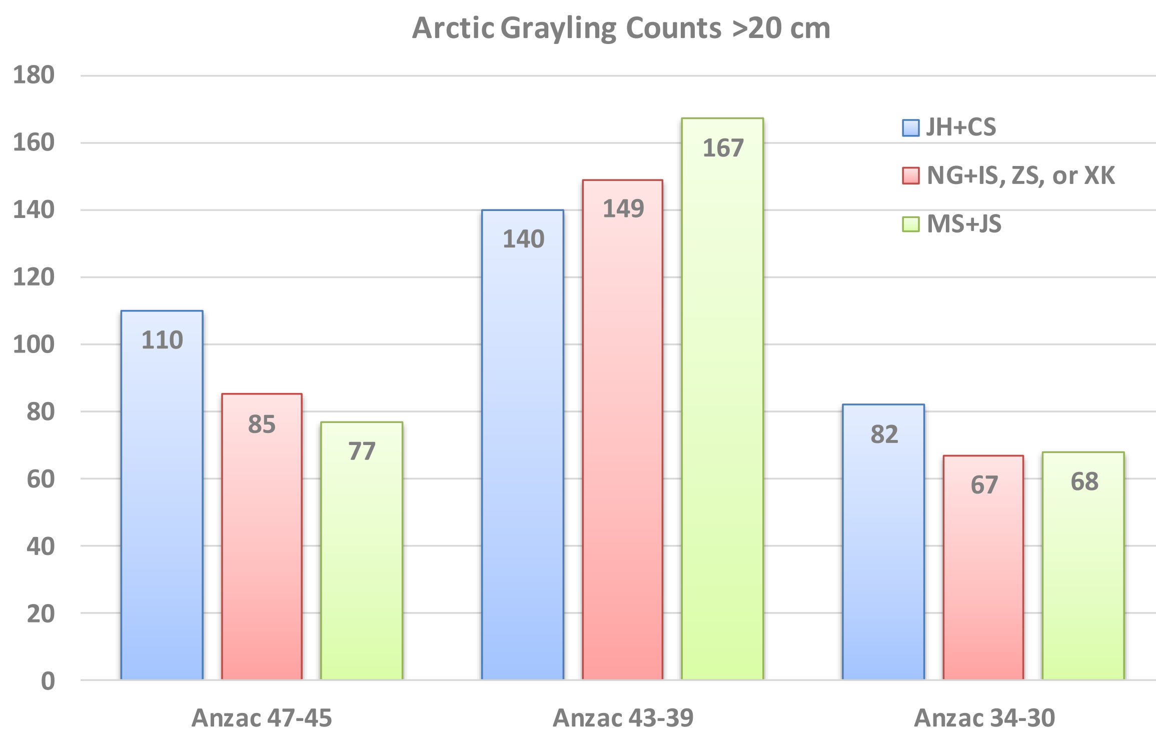

Figure 9. Replicated snorkeling counts of Arctic Grayling >20 cm in three index sections of the Anzac River watershed, August 2019. Site numbers correspond to stream distances from the mouth of the stream to the upper and lower site boundaries. Counts are presented in the same order as crew deployment.

Table 4. Replicated snorkeling counts of Arctic Grayling >20 cm in index sites of the Anzac and Table rivers, 1995-2019.

		Replicate Counts of Arctic Grayling >20 cm						
SITE	**YEAR**	**R1**	**R2**	**R3**	**R4**	**Coefficient of Variation**	**FISH_VIS (m)**	**Predicted *N***
Table 22-18	1998	54	79			26.6%	5.5	92
	2000	39	30	40	38	12.4%		60
	2001	35	48			22.2%	3.5	70
	2003	75	62	72		9.8%	4.5	117
	2007	39	57	42		21.0%	4	78
Table 26-22	2018	72				na	7	116
	2019	116				na	4.0	187
Table 35-31	1995	107	115			5.1%	5	148
	1998	137	135			1.0%	5.5	182
	2000	101	111	136	145	16.8%		168
	2001	80	102			17.1%	3.5	133
	2003	139	138	134		1.9%	3.5	153
	2005	96	104	94		5.4%		130
	2007	124	103	112		9.3%	3.8	148
	2018	191	230	209		9.3%	5.7	276
	2019	188				na	3.5	245
Anzac 16-12	1998	13	3			88.4%	7	19
	2001	6	15			60.6%	3.5	23
	2003	18	30	22		26.2%	4.5	48
	2005	26	31			12.4%		57
	2007	44	50			9.0%	3.8	85
	2018	22				na	7.7	44
	2019	40				na	4.4	79
Anzac 34-30	1998	116	96			13.3%	12	205
	2001	48	55			9.6%	3.5	99
	2003	54	68	41		24.9%	3.5	115
	2005	98	56	82		26.9%		161
	2007	34	83	67		40.7%	3.7	130
	2019	82	67	68		11.6%	5.1	153
Anzac 37-31.8	2018	168	113	136		19.9%	6	220
Anzac 43-39	1998	167	114	127		20.3%	7	216
	2001	73	96			19.2%	3.5	135
	2003	144	181	172		11.6%	4.5	257
	2005	99	83			12.4%		140
	2019	140	149	167		9.0%	5.1	235
Anzac 45-41.8	2018	183	198	195		4.1%	4.6	280
Anzac 47-45	1998	157	171			6.0%	7	256
	2000	69	67			2.1%		106
	2001	15	25			35.4%	3.5	34
	2003	62	80	92		19.4%	3.5	124
	2018	194				na	5.5	304
	2019	110	85	77		19.0%	4.4	142

Precision and accuracy of snorkeling counts are affected by p, the snorkeling detection probability (see section *1.0*). In our exploratory statistical analysis in 2019, we were interested in three variables potentially influencing p and subsequent inferences about population status: 1) SITE, 2) YEAR, and 3) FISH_VIS (underwater visibility). Complete data for all three of these variables were available for the years 1998, 2001, and 2003 (Table 4), so initial model selection was restricted to these data.

Improved prediction of p and N_{it} (population size N at site i in year t) over the years 1998, 2001, and 2003 was indeed possible through the use of logistic regression models including these three variables. The global model containing all three predictors SITE, YEAR, and FISH_VIS resulted in a significant increase in the likelihood of the predictions relative to the constant-only model (Chi-square P <0.001).

In addition to the global model, we evaluated a candidate set of 7 simpler models using AIC_c (Table 5). The best model contained only the stratified predictor variable SITE. The likelihood of this model being the best, as indicated by the ratios of its Akaike weight w_i to those of other candidate models, was very high (Table 5). The level of empirical support for all other models was far less, and models containing YEAR and FISH_VIS had essentially no support (Δ_i >10; Table 5).

Table 5. Summary of comparison among candidate models of detection probability and N estimated in index sites of the Parsnip River watershed during 1998, 2001, and 2003. Symbols K, Log (L), AIC_c, Δi, 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	Log($\mathcal{L}$)	AIC_c	Δ_i	$\mathcal{L}(g_i\|x)$	w_i
1 MEAN_P (constant only)	19	-334.27	326.53	13.41	0.001223222	0.001215802
2 SITE	24	-218.27	313.12	0.00	1	0.993934494
3 YEAR	21	-331.58	474.15	161.03	1.07769E-35	1.07115E-35
4 FISH_VIS	20	-324.16	408.31	95.19	2.13699E-21	2.12403E-21
5 SITE+FISH_VIS (same slopes)	25	-218.16	323.81	10.69	0.004762576	0.004733689
6 SITE+YEAR	27	-214.28	331.35	18.23	0.000109866	0.0001092
7 YEAR+FISH_VIS (same slopes)	24	-305.18	486.94	173.82	1.80022E-38	1.7893E-38
8 SITE+YEAR+FISH_VIS (same slopes) (global	28	-214.27	336.90	23.78	6.85691E-06	6.81532E-06
$MinAIC_C$			313.12			
n	18					

Following model selection, the logistic regression model incorporating the stratified SITE variable was re-fit to all the replicated count data 1995-2007 to estimate the N_{it} (Table 4) and site-specific p_i (Table 6) (Figure 10). Results indicate a strong pattern of declining detection probability in downstream sites (Table 6), with the narrow, upper Table River 35-31 km site having the highest estimated detection probability and wide sites from the Anzac River downstream of its canyon (34-30 km, 16-12 km) having the lowest. The lower Table River site 22-18 km and sites in the Anzac River's canyon (47-45 km, 43-39 km) exhibit intermediate detection probability.

Table 6. Maximum likelihood estimates of site-specific mean detection probability in index reaches of the Table and Anzac rivers, given replicated count data 1995-2019.

	Table River		Anzac River			
Site	**35-31**	**22-18**	**47-45**	**43-39**	**34-30**	**16-12**
Detection probability *p*	0.77	0.62	0.64	0.65	0.52	0.51
LCL	0.75	0.59	0.61	0.64	0.50	0.46
UCL	0.78	0.65	0.66	0.67	0.54	0.55

Mark-resight data to validate the detection probability estimates exist for just a single site in one year. In 2019, telemetry data from fixed receivers in the upper Table River suggest that 15 acoustic-tagged Arctic Grayling were likely present between 35-31 km on the date of the snorkeling survey (Joe Bottoms, UNBC, pers. comm. February 2020). On that date (August 15), 12 tagged fish were observed equating to a detection probability estimate of 80%. This estimate exhibits good agreement with the maximum likelihood estimate of 77% (Table 6).

5.3 Population Trend

Average values for replicated snorkeling counts of Arctic Grayling >20 cm over the 1995-2019 period are depicted in Figure 10. In the Table River, counts over the 2018-2019 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 also appear to exhibit an increasing trend, although variability is high among years. Variability is especially high for the furthest Anzac River site upstream (Anzac 47-45; Figure 10), located above a 2-km section of rapids that may limit upstream movements in some years.

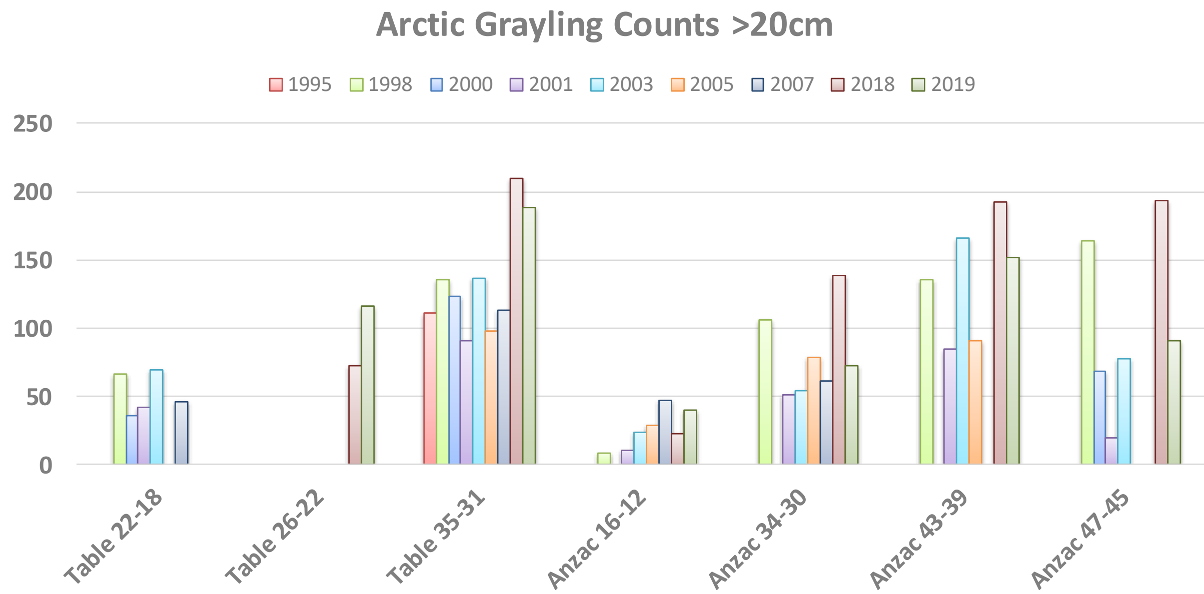

Figure 10. Snorkeling counts of Arctic Grayling >20 cm in index sites of the Anzac River and Table River watersheds 1995-2019. Values are averages of replicate counts. Beginning in 2018, Table River section 26-22 was substituted for 22-18 which was affected by a clay slump.

Unadjusted snorkeling counts were not however used as the dependent variable in our analysis of population trend. Instead, we accounted for the effects of varying detection probability among sites by utilizing N_{it}, the maximum likelihood estimate of population size N at site i in year t (see preceding section) in place of the raw count data. Prior to analysis, the N_{it} were square root transformed to better meet assumptions of normality and homoscedasticity. Application of the linear mixed-effects model, in which N_{it} and *YEAR* were utilized as fixed effects and *STREAM* and *SITE* as nested random effects, indicated a significant increase in the abundance of Arctic Grayling >20 cm in the Parsnip River watershed (P <0.001) over the 1995-2019 period. Model results suggest that since 1998 when monitoring was initiated in all six long term index sites in the Parsnip River watershed, the N_{it} have increased by roughly 60%.

5.4 Critical Summer Rearing Habitat in the Missinka River

The chute obstruction at 36.4 km (Figure 5, Figure 11) of the Missinka River has previously been assessed and considered to be a barrier to Arctic Grayling migration (Triton 1999). In 2019, we conducted single-pass snorkeling surveys in three sections below this barrier totaling 11 km stream habitat (Figure 5).

Figure 11. Aerial view of a ~2 m chute at 36.4 km of the Missinka River, previously assessed as a migration barrier for Arctic Grayling (Triton 1999).

In contrast to the Anzac and Table Rivers, the Missinka River does not appear to be utilized by a large population of Arctic Grayling in August. Arctic Grayling were not abundant in any of the three index sections, and snorkeling counts were extremely low in middle and lower reaches of the system (Figure 12, Table 7) despite appropriate viewing conditions (section *5.1*). Mean densities for the three index sections were just 8.5, 1.0, and 0.25 Arctic Grayling >20 cm per km (Table 7) for the 33-29 km, 25-22 km, and 8-4 km index sections, respectively. These are much lower than the overall mean density (unadjusted raw counts) for the Anzac River watershed of 26.6 per km (Hagen et al. 2019).

Furthermore, critical summer rearing habitats for Arctic Grayling appear to have a limited distribution in the upper watershed below the migration barrier. In contrast to the Anzac and Table rivers, which are utilized by relatively high numbers in their middle reaches in August (Figure 10), Arctic Grayling had declined to negligible densities by approximately the 24 km point on the Missinka River mainstem. This point corresponds to the beginning of low gradient meanders extending downstream to a point just above the 8-4 km index section, which contrasts the riffle-pool channel morphology of the Anzac and Table rivers in which Arctic Grayling are much more abundant.

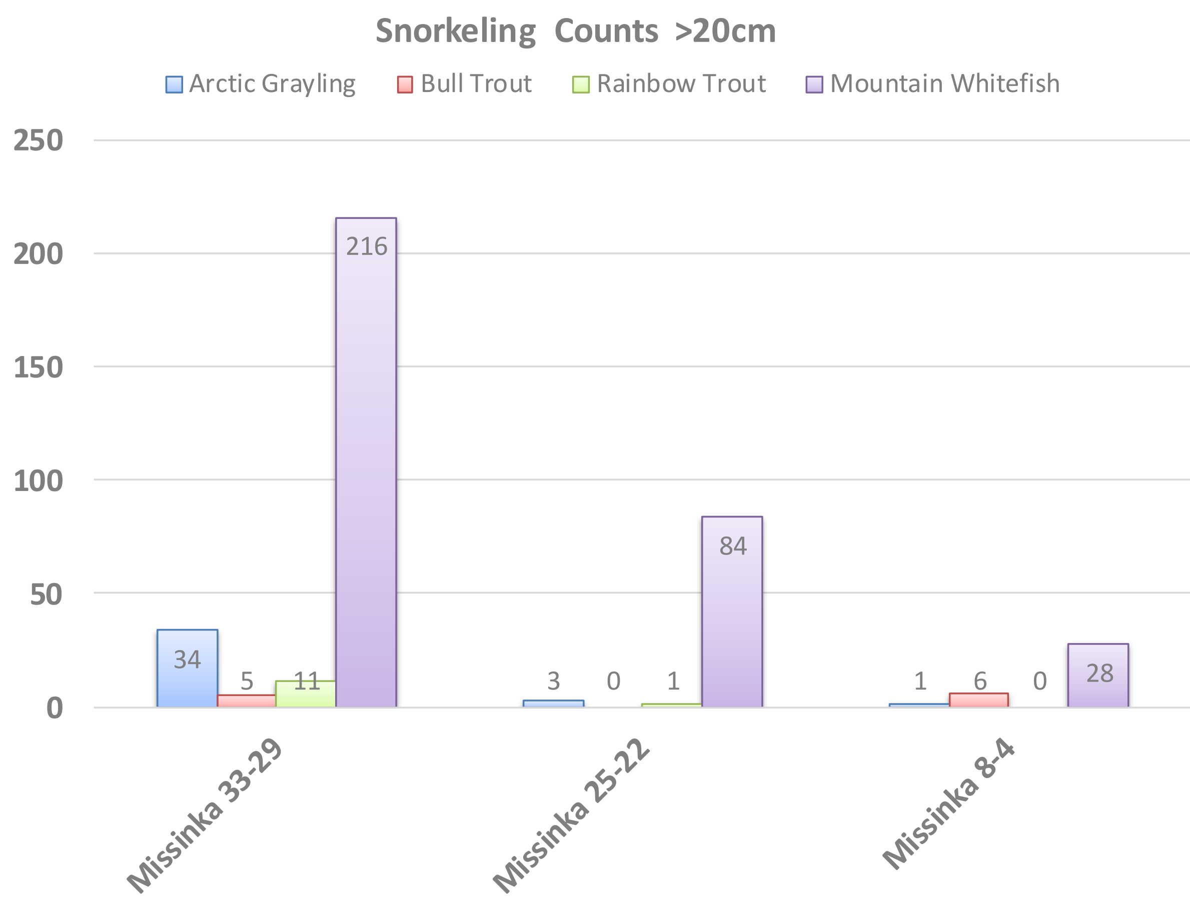

Figure 12. Counts of Arctic Grayling (blue bars), Bull Trout (red bars), Rainbow Trout (green bars), and Mountain Whitefish (purple bars) >20 cm in sections of the Missinka River watershed, 2019. Stream section labels correspond to the distance along the stream from the mouth of the Missinka River to the upstream and downstream boundaries of the surveyed reach.

Table 7. Snorkeling counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish in sections of the Missinka River, August 2019 (densities per km in parentheses).

Species	Missinka 33-29 km	Missinka 25-22 km	Missinka 8-4 km
Arctic Grayling	34 (8.5)	3 (1.0)	1 (0.25)
Bull Trout	5 (1.3)	0 (0)	6 (1.5)
Rainbow Trout	11 (2.8)	1 (0.33)	0 (0)
Mountain Whitefish	216 (54)	84 (28)	28 (7.0)

In 2019, the core of the August Arctic Grayling distribution in the Missinka River likely would have included good-looking habitat between the 33-29 km index section and the 36.4 km migration barrier, as well as habitat downstream of km 29. As mentioned previously (section *5.1*), additional reconnaissance surveys were planned for these stream sections, but could not be completed due to high water conditions beginning August 18.

The patterns of distribution for other species Bull Trout, Rainbow Trout, and Mountain Whitefish are similar to that for Arctic Grayling (Figure 12, Table 7), with higher densities present in the furthest upstream reach 33-29 km. Although Bull Trout appear to be the exception, counts of Bull Trout in the upper and lower index sites belong to different life stages and are not directly comparable. Six fish counted in the lowest reach 8-4 km were exclusively subadult individuals 20-30 cm in length, while five fish counted in the 33-29 km reach were maturing adults mostly >50 cm in length. Unnamed tributary 236-614900-52600, which has previously been identified as a spawning stream utilized by a small population of large-bodied, migratory Bull Trout (Hagen et al. 2015), enters the Missinka River in this upper reach.

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 index sections of the Anzac and Table rivers (Figures 13-15; Table 8). As the design of our study is not optimized for monitoring abundance of other salmonid species, our ability to assess changes in population sizes for these species is likely to be compromised. However, count data from index sites may be of interest over the longer term, particularly to assess potential fish community shifts resulting from habitat degradation or climate change.

Bull Trout counts in index sites are highly variable among years potentially indicating an effect of stream conditions on pre-spawning migration and staging behaviour (Figure 13, Table 8). 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).

Snorkeling counts of Rainbow Trout (Figure 14, Table 8) are also highly variable among years. The time series of snorkeling count data indicates that Rainbow Trout are rarely abundant at index sites (Figure 15). Low 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 et al. 2013; Hawkshaw and Shrimpton 2014). Although we did not conduct an analysis of trend for Rainbow Trout abundance, visual inspections of the time series of count data do not indicate obvious increases during the observed period.

Counts of Mountain Whitefish (Figure 15, Table 8) are especially variable. Mountain Whitefish are far too numerous to count reliably and were 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. Irrespective, visual inspections of the time series of counts at index sites do not indicate obvious cause for conservation concern (i.e. low abundance, declining trend) for this species.

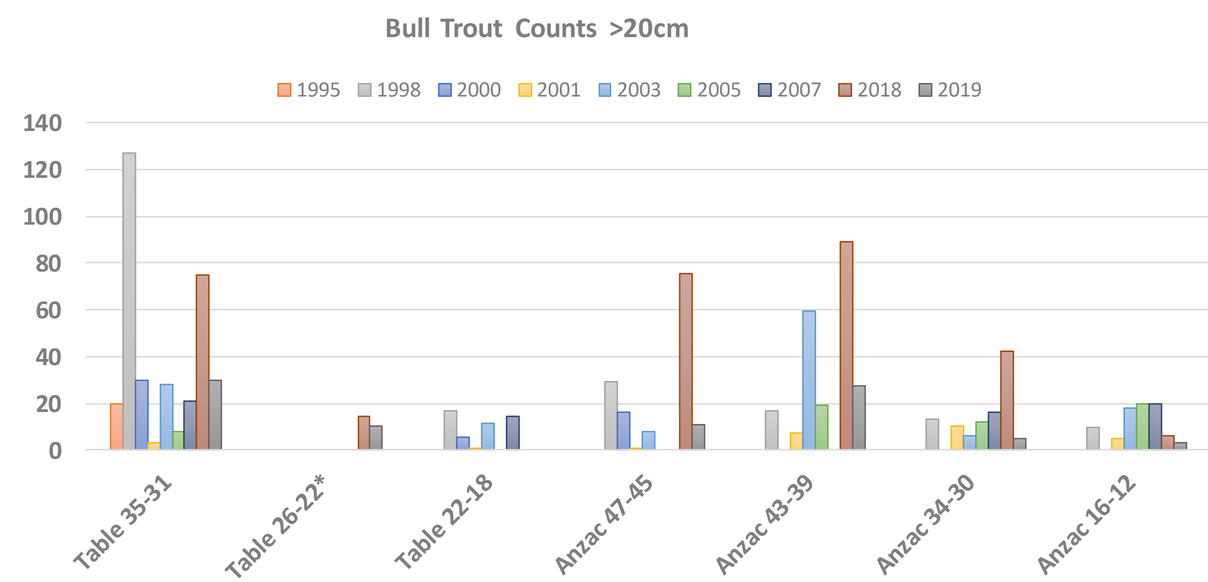

*Figure 13. Counts of Bull Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2019. Stream section labels correspond to the distance along the stream from the mouth to the upstream and downstream boundaries of the surveyed reach. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.*

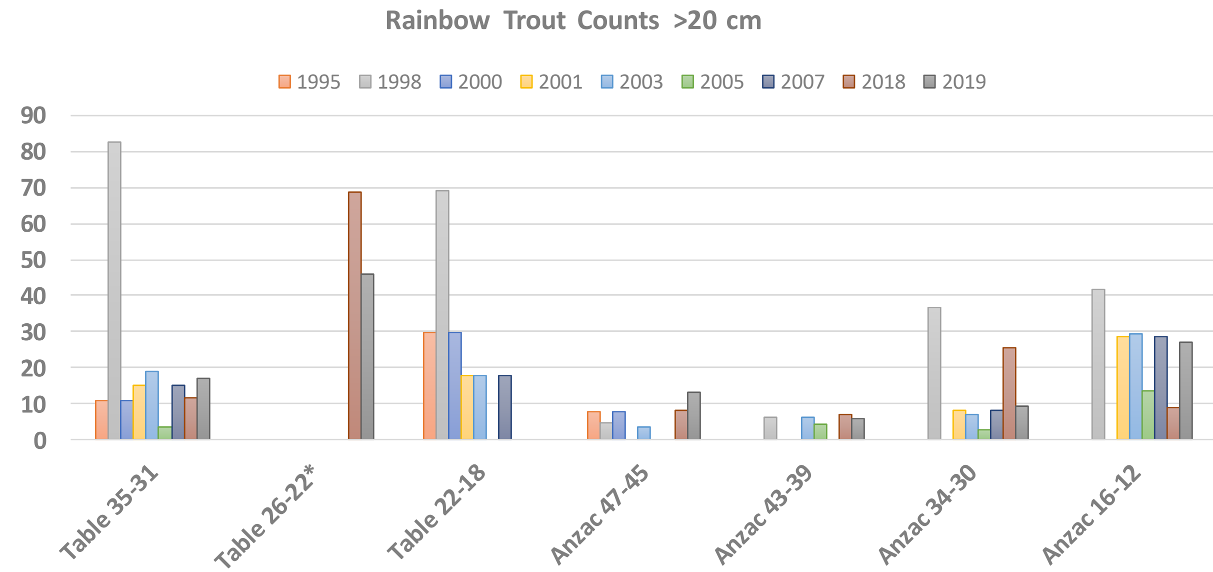

*Figure 14. Counts of Rainbow Trout >20 cm in sections of the Anzac and Table River watersheds, 1995-2019. Stream section labels correspond to the distance along the stream from the mouth to the upstream and downstream boundaries of the surveyed reach. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.*

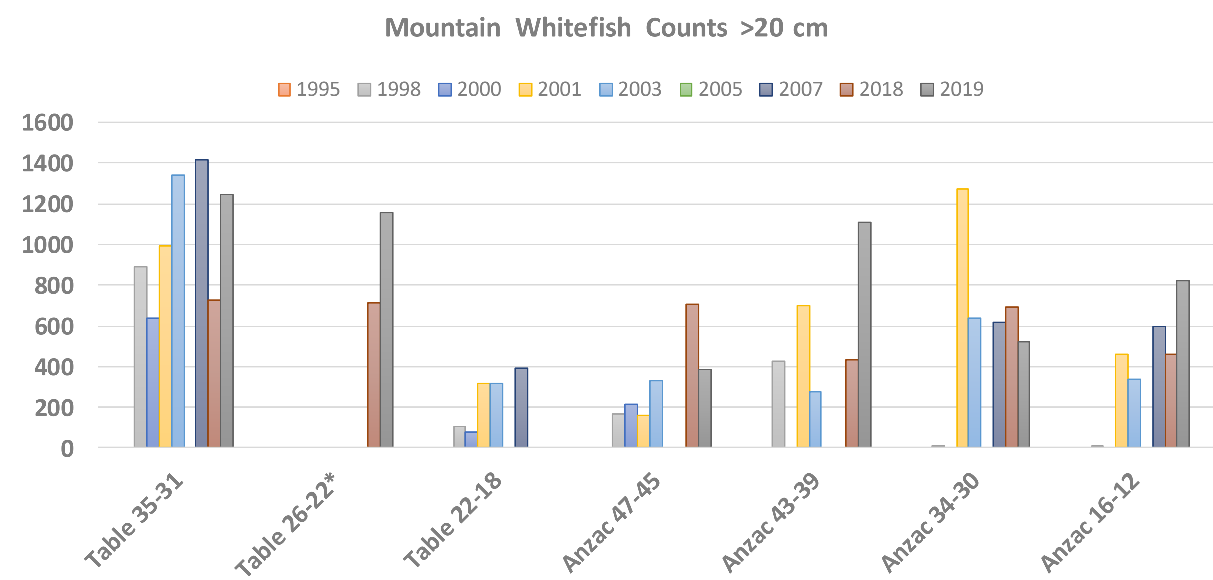

*Figure 15. Counts of Mountain Whitefish >20 cm in sections of the Anzac and Table River watersheds, 1995-2019. Stream section labels correspond to the distance along the stream from the mouth to the upstream and downstream boundaries of the surveyed reach. *Table 26-22 is a replacement for Table 22-18 beginning in 2018.*

Table 8. August snorkeling counts of salmonids >20 cm in index sites of the Parsnip River watershed, 1995-2019. Counts are averages if more than one replicate swim occurred.

		Table River Sites			Anzac River Sites			
Year	Species	Table 35-31	Table 26-22*	Table 22-18	Anzac 47-45	Anzac 43-39	Anzac 34-30	Anzac 16-12
1995	GR	111						
	BT	20						
	RB	12						
	MW							
1998	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
2000	GR	123		37	68			
	BT	30		6	16			
	RB	11		30	8			
	MW	636		82	217			
2001	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
2003	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
2005	GR	98				91	79	29
	BT	8				19	12	20
	RB	4				5	3	14
	MW							
2007	GR	113		45			61	45
	BT	21		14			16	20
	RB	15		18			8	29
	MW	1415		394			616	600
2018	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
2019	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

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

5.6 First Nations engagement in 2019-20

First Nations engagement and communications for this project were led by FLNRORD. The project goals and objectives were provided to four First Nations (McLeod Lake Indian Band, Saulteau, West Moberly First Nations, and Prophet River First Nations) in spring of 2019 to FWCP-provided contacts via email memorandum followed up with phone calls to offer opportunity to discuss the planned project. At that time, we jointly agreed with representatives of McLeod Lake Indian Band that the best opportunity for

First Nations outreach would be at the Annual General Assembly (AGA) of McLeod Lake Indian Band on August 9, 2019.

Representatives from our team were particularly pleased to be able to attend the 2019 AGA. During this meeting, our objectives were: 1) to showcase FLNRORD-led fisheries work to the band membership, 2) make personal connections leading to opportunities for training and employment for band members, and 3) to share study findings in an open and transparent manner. Important strides were made towards our long-term objective of including a MLIB member on our survey team. The highly-technical nature of the fieldwork precluded this possibility in 2019, but planning is already underway to facilitate this in 2020.

Formal presentation of the 2019 study results, along with their implications for Arctic Grayling conservation, occurred following a community dinner in McLeod Lake on the evening of March 3, 2020. Results of the UNBC-led acoustic telemetry study, also funded by FWCP, were presented on the same evening. McLeod Lake Indian Band members asked a broad range of questions and appreciated being able to hear about study results in person. As a follow up to the meeting, we discussed the potential for MLIB to highlight the availability of the project reports in their MLIB community newsletter, as well as a potential 2nd visit at the AGA in 2020. These activities are currently pending the developments of the COVID-19 pandemic (https://www.who.int/emergencies/diseases/novel-coronavirus-2019) and associated limitations to interact with vulnerable populations.

6.0 DISCUSSION

6.1 Accounting for Detection Probability in Estimates of Abundance and Trend

Maximum likelihood estimates of site-specific detection probability, generated from the 1995-2019 replicated count data, are plausible. The primary supporting evidence for this plausibility is the negative association between subjective estimates of stream size and detection probability. Site-specific detection probability estimates are higher in the smaller Table River, and in both streams decrease in wider downstream reaches. This is a logical potential relationship given that two-person crews are utilized in all index reaches regardless of stream size. In the Thompson River watershed, for example, cross-sectional area of sites has been found to be the most important physical habitat variable affecting snorkeling detection probability of two-person crews for juvenile Steelhead Trout (Hagen et al. 2010).

Although results are promising, we consider our analysis of detection probability at this point to be exploratory. A primary reason for this is that validation data, while supportive, are limited to a single site (Table River 35-31) where a mark-resight estimate of detection probability was available to corroborate the maximum likelihood estimate based on replicated count data. Furthermore, the simple approach to estimating detection probability from replicated count data presented in this report has previously been evaluated by other authors, and found wanting because: 1) the likelihood function utilized is conditional on a large number of abundance N_{it} parameters, and 2) maximum likelihood estimates of the abundance and detection probability parameters have been unstable under some conditions, e.g. sparse counts and low detection probability (Olkin et al. 1981; Carroll and Lombard 1985 as cited in Royle 2004; Royle 2004).

The process of refining and validating the statistical approach to estimating detection probability and abundance, based on replicated Arctic Grayling count data in the Williston Reservoir watershed, is already underway. It is being led by the Freshwater Fish Ecology Laboratory (FFEL) at UNBC, and will be incorporated in to this study following the 2020 field season. A key step in development of the statistical approach will be the evaluation of potential models using simulation data (Morgan Dowd, UNBC, pers. comm. March 2019). The modeling approach will likely have the flexibility to estimate detection probability, population size, and trend within a single analysis (e.g. N-mixture models; Royle 2004; Joseph et al. 2009). Our team is supporting FFEL by searching for previously-recorded site habitat information that may function as predictors in models of detection probability (e.g. wetted stream width, underwater visibility, stream discharge). Site habitat cards containing this information are thought to be archived on BC Hydro property, however, had not been located at the time of writing (Chelsea Coady, pers. comm. March 2020).

In our analysis of population trend, we utilized for the first time estimates of N_{it} (abundance N at site i and time t) in place of raw count data. By incorporating detection probability as a variable in our analysis, our confidence has increased that variability in the N_{it} reflects true variation in population abundance and not just false variation caused by variable detection probability (Joseph et al. 2009). Our results suggest a significant, positive trend in abundance for Arctic Grayling in index sites of the Parsnip River watershed. We now have increased confidence that the increasing trend is not merely an artefact of improved viewing conditions in sites. We had proposed this possibility following the 2018 field season, which had been conducted under record low flow conditions (Hagen et al. 2019) and high underwater visibility.

Given that the analysis methods for estimating detection probability and abundance are still under development, we consider this estimate of increasing trend to be provisional. For this same reason, we have not generated estimates of total abundance for populations of Arctic Grayling in the Parsnip River watershed in this report, even though population size is a key indicator of conservation status in addition to trend (Franklin 1980; McElhany et al. 2000; O'Grady et al. 2004). A second reason for this omission was that long-term index sites are low in number and have not been systematically- or randomly-distributed spatially. Therefore, estimation error related to spatial variation in abundance would likely compromise abundance estimates unless it was explicitly accounted for in the analysis. Prior distributions describing patterns of abundance can be incorporated into the modeling approach being developed by the FFEL at UNBC. At that time, single-pass snorkeling count data from previously-unsurveyed sections of the Anzac River in 2018 (Hagen et al. 2019) and Missinka River in 2019 will be particularly valuable for estimating spatial variation in abundance and total population size.

A second reason we consider the estimate of increasing trend to be provisional is that the time series of monitoring data remain unbalanced. Given that the two highest estimates of abundance at many sites were for 2018 and 2019 after an 11-year hiatus, data points for these years have high leverage in the linear mixed-effects model. Additional surveys are therefore warranted in the next several years to confirm the estimated trend.

The provisional nature of the estimate notwithstanding, the increasing trend of Arctic Grayling in index reaches of the Parsnip River watershed is obviously encouraging. Assuming this trend is confirmed with additional monitoring data, there are important implications for British Columbians. Most importantly, it appears that human use of Parsnip Arctic Grayling in catch-and-release sport fisheries and First Nations subsistence fisheries has been sustainable. The introduction of the catch-and-release regulation in the late 1990s is a plausible potential factor behind the population increase. Physical habitat conditions also appear to have remained suitable for Table River and Anzac River Arctic Grayling populations. Recently increased land use in the Table River and Anzac River watersheds, associated with forestry and pipeline developments, increases the risk of habitat degradation and increases angler access. The impacts from both of these potential limiting factors may therefore be about to change, and continued monitoring is necessary to identify if and when thresholds of sustainability have been crossed.

6.2 Critical Habitats, Limiting Factors, and Conservation Actions

Hagen et al. (2015) speculated that the Missinka River may be a second hub of Arctic Grayling abundance in the Parsnip River watershed, in addition to a known, major population centered around the Anzac and Table rivers. Results of our study in 2019 do not support this speculation. Instead, we found the Missinka River to be utilized by much lower densities of Arctic Grayling, and the spatial extent of critical adult rearing habitats in August to be more limited relative to the Table and Anzac sub-basins.

Of index sections surveyed in the Missinka River in 2019, only the uppermost (Missinka 33-29 km) held a sizeable population of Arctic Grayling. We speculate that important summer rearing habitat in the Missinka River system likely extends from the migration barrier at 36.4 km to 29 km, the bottom of this upper index section. Arctic Grayling densities had declined to negligible levels just 4 km downstream. Based on these results, it is not clear whether additional FWCP effort is warranted to refine critical habitat boundaries in this system. It is also not clear whether these habitats should be considered a top priority for habitat conservation and enhancement actions.

At this point in time, higher prioritization is warranted for critical summer rearing habitats in the Table and Anzac sub-basins, based on much higher Arctic Grayling abundance and higher apparent habitat suitability relative to the Missinka system. Critical summer rearing habitats in the Anzac River are reasonably well understood based on results from our August, 2018 study, during which continuous snorkeling surveys were conducted along the length of the system (Hagen et al. 2019). Critical summer habitats of the Table River are less well known, however, particularly in the lower Table River. Reconnaissance surveys outside of existing index sections, therefore, are warranted to refine estimates of critical habitat and total abundance in the Table River system. The principal challenge would be reduced underwater visibility downstream of a clay slump at 22 km. Feasibility of surveys in the lower Table River should be assessed during fieldwork in August 2020, through a systematic evaluation of underwater visibility at points downstream of the slump.

The sharp contrast in Arctic Grayling distribution and abundance between the Missinka River and the Table and Anzac systems may be valuable for identifying limiting factors affecting the productivity of these populations. To facilitate future analyses of limiting factors, our team has begun the processes of identifying relevant data types and acquiring data. Potential factors include for example: 1) water temperature (Ballard and Shrimpton 2009; Hawkshaw and Shrimpton 2014; Hawkshaw et al. 2013), 2) abundance of competitors/predators (Clark 1992; Buzby and Deegan 2004) 3) stream gradient and other fluvial geomorphology variables (Blackman 2004; Lamothe and Magee 2004), 4) stream nutrients (Wilson et al. 2008; Deegan and Peterson 1992), 5) distance from overwintering and spawning locations (Blackman 2002), 6) land use and related habitat degradation (Birtwell et al. 1984; McLeay et al. 1987), and 7) watershed hydrology (Tack 1974; Clark 1992). The most appropriate timing for this analysis would be following fieldwork to identify abundance and critical habitats in the rest of the Parsnip River watershed, but exploratory analyses can begin earlier. In assessing limiting factors, estimates of abundance and critical habitats from our study will be complemented by estimates of movement and water temperature generated as part of the UNBC-led acoustic telemetry study *Spatial ecology of Arctic grayling in the Parsnip core area* (FWCP project PEA-F21-F-3178). With reliable knowledge of critical habitats and limiting factors, FWCP will be better able to identify and prioritize potential conservation, restoration, and enhancement actions (Hagen and Stamford 2017).

7.0 RECOMMENDATIONS

Our study addresses two high-priority knowledge gaps identified in FWCP's Arctic Grayling Synthesis Report (Stamford et al. 2017): 1) the lack of monitoring data indicating Arctic Grayling abundance and trend since 2007, and 2) the lack of monitoring data delineating critical habitats.

With respect to the first of these two information deficiencies, we consider the six long-term snorkeling index sites located in the Anzac and Table rivers to be key to identifying changes in population abundance over time in the Parsnip core area. Population abundance and trend are key indicators of the sustainability of remnant populations of Williston Arctic Grayling following flooding. To improve the ability of the snorkeling program to detect changes in abundance, we have the following recommendations for the 2020 study, which at the time of writing has been conditionally approved:

1. Continue monitoring of Arctic Grayling abundance in long-term index sites of the Anzac and Table rivers, using replicated snorkeling surveys. Snorkeling surveys in all long-term index sites (6) should be replicated at least twice, to improve estimates of detection probability derived from the replicated count data.

2. Continue collaboration with UNBC's FFEL on improved models for estimating detection probability and abundance.

3. Co-ordinate with the crew of the FFEL-led acoustic telemetry study *Spatial ecology of Arctic grayling in the Parsnip core area* (FWCP project PEA-F21-F-3178) to ensure that a sample of tagged fish are present at a minimum of 2 index sites during snorkeling counts in 2020. Mark-resight estimates of snorkeling detection probability will provide important validation data for the model-derived estimates.

4. Maintain dialogue with McLeod Lake Indian Band to identify opportunities for information exchange, training, and employment.

In both 2018 and 2019, single-pass snorkeling surveys were an effective tool for rapid identification of 1) critical summer rearing habitats and 2) patterns of Arctic Grayling abundance at the scale of whole watersheds. For August 2020, we recommend application of the methodology over a two-day period in eight, 4-km index sections spaced along the accessible length of the Hominka River watershed. The Hominka is also a system with a known Arctic Grayling population. However, the relative importance of the system is unknown within the Parsnip River watershed as a whole, nor have critical habitats been described (Stamford et al. 2017) Should negligible densities of Arctic Grayling be encountered in major sections of the lower Hominka River, a portion of this effort could be re-directed at unsurveyed sections of the Table River. To evaluate whether snorkeling surveys in the lower Table River are feasible, we recommend that underwater visibility be assessed downstream of the clay slump at 22 km. For efficiency, this assessment should be conducted concurrently with the snorkeling surveys of long-term index sites in the Table River watershed.

To facilitate habitat-based conservation planning for the entire Parsnip River watershed, we also recommend future application of the single-pass snorkeling methodology to other potential Arctic Grayling streams as well. Reynolds Creek for example is known to be utilized by Arctic Grayling for summer rearing. Summer rearing of Arctic Grayling may also be occurring in the Wichcika, Colbourne, and Misinchinka systems, however this has not been confirmed (Stamford et al. 2017).

8.0 ACKNOWLEDGMENTS

The Freshwater Fisheries Society of B.C. provided additional study funding enabling the replicated swims in the Anzac River. Dawn Cowie, Xena King, Benjamin Knapp, Duncan McColl, Lauren Phillips, Zsolt Sary, Ciara Sharpe, Ian Spendlow, Mike Stamford, and Jeff Strohm provided assistance in the field. Dawn Cowie compiled historical snorkeling data and entered 2019 data in to a searchable database. 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 2019 study was Tom Halbert of Bailey Helicopters Ltd.

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