Ingenika River Arctic Grayling 2004-2020

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Executive Summary

The Arctic Grayling (*Thymallus arcticus*) is an especially coveted and sought-after sustenance species for the Tsay Keh Dene Nation. Since flooding, Arctic Grayling appear to have disappeared from many of the direct tributaries to Williston Reservoir. Self-sustaining populations are known only from the larger Parsnip, Nation, Omineca, Mesilinka, Finlay, and Ingenika watersheds. The Ingenika River watershed is of critical interest to the nearby community of Tsay Keh Dene. In this report, we present results of a snorkeling survey study designed to monitor Arctic Grayling population status and the distribution of critical summer rearing habitat along the Ingenika River mainstem.

In 2017, The Fish and Wildlife Compensation Program (FWCP) identified two key knowledge gaps limiting the program's ability to initiate conservation and enhancement actions for Ingenika River Arctic Grayling: 1) the lack of monitoring data indicating the conservation status of the population, and 2) the lack of monitoring data indicating critical habitats for key life stages. By addressing high-priority knowledge gaps of the Arctic Grayling monitoring program, our study is aligned with FWCP's *Streams Action Plan* priority action *1b-3*:

"*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 two most important indicators of conservation status are the total abundance of adult individuals, and the population trend. In August 2020, we investigated population trend in the Arctic Grayling population by conducting the third consecutive year of snorkeling surveys in long-term index sites distributed along the accessible length of the Ingenika River. Surveys in the 2018-2020 period followed a hiatus of 14 years since the first and only other survey was conducted in 2004. Counts of Arctic Grayling >20 cm in 13 long-term index sites in 2020 were low relative to other survey years. However, analysis of unadjusted count data from 2004, 2018, 2019, and 2020 using a linear mixed-effects model, in which counts of Arctic Grayling >20 cm

and survey year were utilized as fixed effects and site ID as a random effect, did not indicate a significant decline.

To estimate the total abundance of Arctic Grayling >20 cm in the Ingenika River in 2020, we first estimated snorkeling detection probability, using two independent approaches, to enable expansion of the raw count data into abundance estimates. In the first approach, we estimated detection probability by conducting a mark-resight study in a 5-km section of the Ingenika River. Arctic Grayling detection probability p was estimated directly by comparing replicated counts of marked fish observed by snorkelers to the number of marks deployed in the reach. Following three replicate surveys, the resultant maximum likelihood estimate was $p = 0.59$ (95% confidence interval = 0.43-0.73). In the second approach, we adapted a no-mark modeling approach developed for Arctic Grayling surveys in the Parsnip River watershed, which utilizes the variability in replicated count data to estimate detection probability and abundance based on expectations for the binomial distribution. In this approach, model predictors of p are site width and underwater visibility. The model estimate of $p = 0.58$ exhibits good agreement with the estimate for the same reach derived from the mark-resight study. Using this latter approach, we utilized stream width and underwater visibility estimates to model detection probability at all index sites surveyed in 2020, and expand the snorkeling observations into a total abundance estimate of 354 Arctic Grayling >20 cm for the Ingenika River.

Patterns of Arctic Grayling abundance in index sites over the 2004-2020 period have also allowed us to estimate the distribution of critical summer rearing habitat for adult and subadult Arctic Grayling in the Ingenika River. Arctic Grayling densities in index sites exhibit a consistent pattern among years, with sharp changes in density evident among four reaches. Sites above a chute obstruction located 95 km from the mouth were inhabited by very low densities of Arctic Grayling, suggesting this upper reach is relatively unimportant to the species for summer rearing. The highest densities of Arctic Grayling were found in the 5-km, single-channel reach located below this chute obstruction. The core of the Arctic Grayling summer distribution along the Ingenika River includes this reach and the more braided, middle reach extending from 90-41 km from the mouth. This critical summer rearing section is currently in pristine ecological condition, and should be considered a top-priority candidate for habitat conservation and enhancement actions along with critical fry rearing habitat (identified in a previous electrofishing study) extending from 57-28 km. The lower reach of the Ingenika is utilized by very low densities of Arctic Grayling >20 cm in summer, and lacks the channel stability and habitat complexity exhibited by upstream reaches.

During the mark-resight study, captured fish were also sampled for aging structures. The Ingenika River Arctic Grayling population contains large and old individuals up to 450 mm fork length and 11 years of age (fin ray age), suggesting relatively good annual survival for adults. Ingenika Arctic Grayling have a similar size-at-age to other Williston Reservoir watershed populations up to age-5. For older ages, however Ingenika size-at-age is larger and most comparable to Finlay River Arctic Grayling.

Our specific recommendations for future monitoring of Ingenika River Arctic Grayling are:

1. Conduct future snorkeling surveys of the Ingenika River index sites on a periodic basis, e.g. 3 out of every 10 years.

2. Conduct replicated snorkeling surveys (3 replicates) in 3-4 index sections each year, to enable application of no-mark models of detection probability and abundance.

3. Utilize genetic and other methods (e.g. otolith microchemistry) to evaluate the degree of genetic and demographic isolation of the Ingenika core area from the nearby Lower Finlay core area.

4. Replicate electrofishing surveys in the watershed to confirm critical fry rearing habitat locations and the importance of this habitat for recruitment to the Ingenika River Arctic Grayling population.

5. Conduct reconnaissance snorkeling surveys in tributaries potentially utilized by adult/subadult Ingenika River Arctic Grayling, e.g. Swannell River, Wrede Creek.

6. Co-ordinate with Arctic Grayling abundance monitoring elsewhere in the Williston Reservoir watershed (e.g. FWCP project no. PEA-F21-F-3203*: 2020 Parsnip Arctic Grayling Abundance and Critical Habitats*) to explore opportunities to improve knowledge about limiting factors.

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1 Introduction

In their lifetimes, members of the Tsay Keh Dene Nation born before the completion of the W.A.C. Bennett Dam in 1967 have seen incredible physical and ecological changes in their traditional territory. Williston Reservoir, which reached full pool in 1972 (Hirst 1991), flooded approximately 110 km of the lower Finlay River valley, with profound effects on fish and wildlife communities. The Arctic Grayling (*Thymallus arcticus*) is an especially coveted and sought-after sustenance species for the Nation. Since flooding, Arctic Grayling appear to have disappeared from many of the direct tributaries to Williston Reservoir. Self-sustaining populations are known only from the larger Parsnip, Nation, Omineca, Mesilinka, Finlay, and Ingenika watersheds (Stamford et al. 2017). The Ingenika River watershed is of critical interest to the nearby community of Tsay Keh Dene (Hagen et al. 2018). In this report, we present results of a snorkeling survey study designed to monitor Arctic Grayling population status and the distribution of critical summer rearing habitat along the Ingenika River mainstem.

In 2017, a major study was conducted by the Fish and Wildlife Compensation Program – Peace Region (FWCP) to evaluate the existing knowledge base relative to conservation objectives for Arctic Grayling. The resulting Arctic Grayling synthesis report (Stamford et al. 2017), along with the Arctic Grayling monitoring framework presented in a companion summary document (Hagen and Stamford 2017), identify key knowledge gaps limiting the ability of FWCP to initiate conservation and enhancement actions for Arctic Grayling.

The most important information gap identified for the Ingenika River Arctic Grayling population was the lack of monitoring data for assessing the "conservation status" of the population (Stamford et al. 2017). Conservation status can be defined as an assessment of the overall population viability, or health. The two most important indicators of conservation status are the total abundance of adult individuals, and the population trend (McElhany et al. 2000; O'Grady et al. 2004). The reason that total abundance is so important is that at very small population sizes, the extirpation risks posed by environmental and demographic stochasticity, and genetic processes (inbreeding depression and long-term genetic losses and genetic drift) are greatly magnified (Simberloff 1988; Nunney and Campbell 1993). Guidelines for minimum viable population sizes for sensitive fish species may be based on quantitative models, or on the commonly cited "50/500" rule in conservation biology, where 50 is the minimum effective population size required to avoid immediate risk of extirpation through inbreeding and 500 is the minimum needed for sufficient genetic diversity to enable adaptation to long-term environmental change (Franklin 1980). Empirical studies of extinction in mammals and birds have generally suggested that an adult census population size of $N<50$ is clearly insufficient for a population's long-term persistence, populations of $50<N<200$ are marginally secure, and those of $N>200$ are secure at least over time frames as limited as those used in the studies (reviewed in Boyce 1992). With respect to population trend, a sustained population decline obviously threatens a population's viability, if threats cannot be identified and mitigated (Caughley 1994). Trend needs to be evaluated at appropriate time scales, often decadal. The recommended minimum guideline for evaluating trend from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), for example, is 3 generations (COSEWIC 2010).

A second, key information gap limiting the ability to initiate conservation actions for Ingenika River Arctic Grayling was the lack of information indicating critical habitats for key life stages (Stamford et al. 2017). Critical habitats 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 an Arctic Grayling population, they must target limiting factors operating within critical habitats for that population.

For subadult and adult Arctic Grayling of the Ingenika River watershed, FWCP-led monitoring of abundance and critical summer rearing habitats was conceived and implemented for the first time in 2004 (Cowie and Blackman 2012). Low fish densities observed in 2004, and the presumed isolation of the population due to flooding (Clarke et al. 2005), have previously raised concern for Ingenika River Arctic Grayling status (Stamford et al. 2017). Given this concern, the resumption of monitoring in the watershed was a recommendation of the FWCP Arctic Grayling synthesis report which was considered to be of high urgency (Stamford et al. 2017; Hagen and Stamford 2017).

After a hiatus of 14 years, in 2018 FWCP funded the resumption of snorkeling surveys in the Ingenika River. In 2020, we completed the third consecutive year of snorkeling surveys to complete the three-year study plan.

In 2020, we added an important new element to our study, which was a study of our snorkeling detection probability p, i.e. the proportion of fish actually present that are seen and counted by observers. This information is necessary for expanding raw count data into abundance estimates. Results from published accounts suggest that p 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 p 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). In this report, we present results from a mark-resight study conducted in a section of the Ingenika River in August, 2020.

Mark-resight studies however are frequently difficult to implement and/or costly, resulting in inadequate replication of detection probability estimates (Royle 2004). Alternative, no-mark methods of estimating Arctic Grayling snorkeling p and population size N have also been explored in the Williston Reservoir watershed (FWCP Project No. PEA-F21-F-3203: Hagen and Stamford 2021). These are based on variability among counts at a location that are repeated in time, relative to expectations for binomially-distributed count data at various levels of p and N. In this report, we adapt a model of p, developed as part of FWCP Project No. PEA-F21-F-3203 *2020 Parsnip Arctic Grayling Abundance and Critical Habitats* (Hagen and Stamford 2021), apply it to physical site conditions in the Ingenika River, and compare the result to our mark-resight estimate of p to explore potential future utility of each approach.

The most important results presented in this report are the comparisons of Arctic Grayling abundance and habitat use over the 2004-2020 period. For the first time, we estimate both total abundance and trend for Ingenika River Arctic Grayling, key indicators of the conservation status of this valued population.

Age and growth of fish are also potentially important indicators of population health and can identify effects of limiting factors such as overfishing (Walters and Martell 2005) or habitat degradation (Birtwell et al. 1984; McLeay et al. 1987; Reynolds et al. 1989). Among the hard structures used to estimate ages for Arctic grayling, otoliths are considered the most accurate structures for estimating ages for older and slow growing species but involve lethal sampling. Fin ray cross sections have shown similar ages to otoliths (Sikstrom 1983) and are therefore an important, non-lethal alternative. Scales, on the other hand, underage Arctic grayling increasingly after age five (Blackman and Hunter 2001). This report presents fin ray age, scale age, and body size estimates from Ingenika River Arctic Grayling sampled in 2020 and compares them to the results of previous sampling in 2004 and to other populations in the Williston Reservoir watershed.

We conclude this final report with recommendations for future monitoring of Arctic Grayling in the Ingenika River watershed.

2 GOALS AND OBJECTIVES

Within the Peace Region, FWCP’s goal is to conserve and enhance fish and their habitat in order to support the maintenance of thriving fish populations in watersheds that are functioning and sustainable (FWCP 2014a: *Peace Basin Plan*).

By addressing high-priority knowledge gaps of the Arctic Grayling monitoring program (Stamford et al. 2017; Hagen and Stamford 2017), we also aimed to align our study with FWCP’s *Streams Action Plan* (FWCP 2014b) priority action *1b-3*:

> *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 (FWCP 2014b).

In support of these goals, the 2020 study in the Ingenika River watershed had the following specific objectives:

1. To acquire counts of Arctic Grayling and other species in established index reaches of the Ingenika River watersheds, using a snorkeling survey methodology consistent with surveys in 2004, 2018, and 2019.

2. To estimate snorkeling detection probability *p* by conducting a mark-resight study in index sections of the Ingenika River.

3. To replicate snorkeling counts in a portion of the survey area, to facilitate estimation of *p* using an alternative, no-mark modeling approach.

4. To evaluate changes in Arctic Grayling abundance and distribution since 2004 by comparing counts in index sections.

5. To characterize age and growth of Ingenika River Arctic Grayling by sampling individuals during fish capture and tagging.

3 STUDY AREA

The Ingenika River watershed lies within the traditional territory of the Tsay Keh Dene Nation and is of critical interest to the community of Tsay Keh Dene, which is located approximately 20 km from the lower Ingenika River at the head of Williston Reservoir's Finlay Reach. The Ingenika River watershed has played a central role in Tsay Keh Dene culture and heritage and is still used today for traditional hunting, gathering, fishing and other cultural activities. Many Tsay Keh Dene citizens grew up in the community of Grassy Bluff that is located adjacent to the Ingenika River, and consequently the river and its resources hold special significance to them.

The post-impoundment Ingenika River is a 7^{th} order stream with a watershed area of 5,491 km^2 (Cowie and Blackman 2012). The Ingenika originates in the McConnell Range of the Omineca Mountains and flows east for approximately 140 km to the Rocky Mountain Trench and Williston Reservoir. Major, accessible tributaries of the Ingenika River include Swannell River, Pelly Creek, Wrede Creek, and Frederikson Creek. The mainstem Ingenika has been divided into 4 basic reaches based on habitat similarities (Table 1). It should be noted, however, that the 'Headwater' reach above Km 109 is further divided into sections that are 1) accessible to fish migrating from the lower River or Williston Reservoir, and 2) isolated above an impassable waterfall at 9 V 661477 6302342, located at approximately Km 117.

Table 1: Reach descriptions for the mainstem Ingenika River (adapted from Cowie and Blackman 2012).

Reach ID	Length (km)	River km	Snorkeling sites	Sampling fraction*	Habitat description	Substrate** (dominant/ subdominant	Gradient %
Lower	40.6	0 to 40.6	13-17	28%	Mean wetted width: 49m; slow velocity; single channel	Fines**	0.2%
Mid	48.9	40.6 to 89.5	6-12	42%	Mean wetted width: 40m; braided multi-channel; frequent log jams	Gravel Fines/cobble	0.3%
Upper	19.5	89.5 to 109	4-5 (d/s chute) 1-3 (u/s chute)	100% 54%	Mean wetted width: 41m; boulder/riffle; single channel	Boulder Cobble	1.0%
Headwater	36	109 to 143.4	None	0%	Mean wetted width: <25m; bedrock step-pool; entrenched	Bedrock Boulder/cobble	1.5%

*Stream channel length snorkeled as a proportion of the total channel length in the reach
**Fines <2mm, gravel 2-64 mm, cobble 64-256 mm, boulder >256mm.

Streamflow in the Ingenika River watershed is snowmelt driven, with peak discharge usually occurring in early June (Water Survey of Canada, data on file: https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=07EA004). Much of the watershed drains higher elevation, mountainous areas, but glaciers are not present in tributary watersheds. Consequently, in most years water clarity is excellent throughout watershed sub-basins throughout most of the year, and by August the mainstem Ingenika River is clear (Cowie and Blackman 2012).

The most significant factor affecting fish populations in the Ingenika River watershed has been the flooding of the river’s lower 12 km caused by the construction of W.A.C. Bennett Dam, which resulted in loss of habitat and connectivity with the Finlay River (Stamford et al. 2017 and references therein). Land use and related habitat degradation in the unflooded portion of the Ingenika River watershed is restricted to the Swannell River watershed, and the lower 40 km of the Ingenika River watershed downstream of Pelly Creek. The Ingenika’s headwaters and major tributaries Pelly Creek, Wrede Creek, and Frederikson Creek remain largely pristine.

A previous study, using the technique of otolith microchemistry, has suggested that following flooding Arctic Grayling in the Williston Reservoir watershed do not make significant use of the reservoir (Clarke et al. 2005), meaning that Ingenika River Arctic Grayling are likely to be isolated from other populations. Alternatively, more recent study using the technique of environmental DNA (eDNA) has indicated the presence of Arctic Grayling in more tributaries to Williston Reservoir than previously suspected, suggesting the possibility of movements through the reservoir, or the presence of previously-undetected remnant populations (Stamford et al. 2020). Until uncertainty about demographic and genetic connections between Ingenika Arctic Grayling and other populations can be resolved, the Ingenika River watershed should continue to be classified as a separate conservation unit or 'core area.' A core area is defined as a group of populations that are demographically linked and genetically similar (Stamford et al. 2017),[1] and is thus conceptually similar to the widely known concept of the 'metapopulation' (Levins 1969; Hanski and Gilpin 1991). In the Williston Reservoir watershed, the distribution of Arctic Grayling is comprised of the Ingenika, Parsnip, Nation, Omineca, Lower Finlay, Upper Finlay, Williston, and Upper Peace core areas (Stamford et al. 2017).

In addition to Arctic Grayling (*Thymallus arcticus*), native salmonids inhabiting the Ingenika River watershed include Bull Trout (*Salvelinus confluentus*), Dolly Varden (*Salvelinus malma*) Rainbow Trout (*Oncorhynchus mykiss*), Mountain Whitefish (*Prosopium williamsoni*), Lake Whitefish (*Coregonus clupeaformis*), kokanee (*Oncorhynchus nerka*), and possibly Pygmy Whitefish (*Prospium coulteri*). Burbot (*Lota lota*), Peamouth (*Mylocheilus caurinus*), Lake Chub (*Couesius plumbeus*), Largescale Sucker (*Catostomus macrocheilus*), Longnose Sucker (*Catostomus catastomus*), White Sucker (*Catostomus commersoni*), Slimy Sculpin (*Cottus cognatus*), Prickly Sculpin (*Cottus asper*), and Longnose Dace (*Rhinichthys cataractae*) are also present (Bruce and Starr 1985; Cowie and Blackman 2012; BCGW 2019).

[1] Although a core area may also comprise a single population.

4 METHODS

4.1 Study Design

Cowie and Blackman (2012) stratified the Ingenika River into 4 reaches (Lower = 5 sites, Mid = 7 sites, Upper = 5 sites, Headwaters = 0 sites; Table 1), three of which were sub-sampled using single pass snorkeling surveys in 2004. The sampling fraction for each of these reaches was positively related to the expected densities of Arctic Grayling (Table 1). In our study, we retained the same site locations and stratification scheme. A new distribution of sampling sites would potentially introduce a large degree of uncertainty into the comparison between years, related to spatial variation in fish density. We introduced one minor modification of the study design beginning in 2018 to improve analysis of the snorkeling count data. This included dividing the Upper reach into two sections, one upstream and one downstream of a chute obstruction (u/s chute, d/s chute; Table 1). We observed a strong effect from this chute on Arctic Grayling distribution and abundance.

Although the high sampling fraction among reaches is a benefit of the study design, the large effort required to swim all 17 sites means that additional effort directed at mark-resight studies and/or replication of swim counts constitutes a logistical challenge. A plan to replicate snorkeling swims three times in 3-4 sites was included for the design of the 2019 study, but this could not be accomplished due to high flows throughout the month of August in that year. In 2020, both mark-resight and replication methods to investigate detection probability were approved for funding, but the spatial extent of these studies was limited to 2 of 17 sites.

4.2 Survey Conditions

Water Survey of Canada (WSC) Station 07EA004 is located on the Ingenika River upstream of the Swannell River confluence. It is the only WSC flow monitoring station for the Ingenika 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 2020. These data were also utilized to compare flow conditions in the Ingenika River watershed among survey years.

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 4.1), 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.

Figure 4.1. Estimating horizontal underwater visibility in the exceptionally clear Ingenika River, August 2020.

4.3 Biological sampling and tagging

Arctic Grayling capture and tagging was conducted over the August 8-9 period, 2020, by angling with artificial flies and lures in sites 4 and 5 of the Mid reach of the Ingenika River (Table 1). Added together, these sites have a stream channel length of approximately 5.3 km, which was thought to be the maximum distance that could be swum twice in a single day.

Captured fish were not anaesthetized to minimize potential effects of capture and handling on their subsequent behaviour. All captured fish were netted in order to facilitate handling, then tagged with a two, orange T-anchor tags (Floy Tag & Manufacturing, Inc., Seattle, WA) which were inserted one-per-side into the fish' s back near the posterior insertion of the dorsal fin (Figure 4.2). Biological sampling included measurements of fork length (mm) and mass (g), a visual assessment of sex, a tissue sample for future genetic analysis, a sample of approximately 5 scales removed from the fish' s side (2-3 scale rows above the lateral line, posterior the dorsal fin but anterior to the anal fin), and a sample of a single pelvic fin ray.

Figure 4.2. Tagged Ingenika River Arctic Grayling ready for release, August 2020.

As the first step in pelvic fin ray aging, fin rays were embedded in epoxy and three perpendicular cross sections were removed using a slow speed diamond saw (Isomet, Beuler Inc.). Polished sections were mounted onto labelled slides and polished further with wet dry sandpaper until growth increments were visible with transmitted light viewed at about 90X magnification using a stereo microscope. Information from all three sections were used to distinguish the summer and winter growth bands that constitute annuli.

Cross sections were examined twice blind (i.e. no knowledge of fish length or previous counts; Casselman 1983) and those fish with unequal annulus counts were examined a third time. Age estimates were determined by two equal annulus counts among trials or the average among three different counts. Calibrated digital images of fin ray cross sections were collected and labelled after age determination was completed under the microscope (Figure 1).

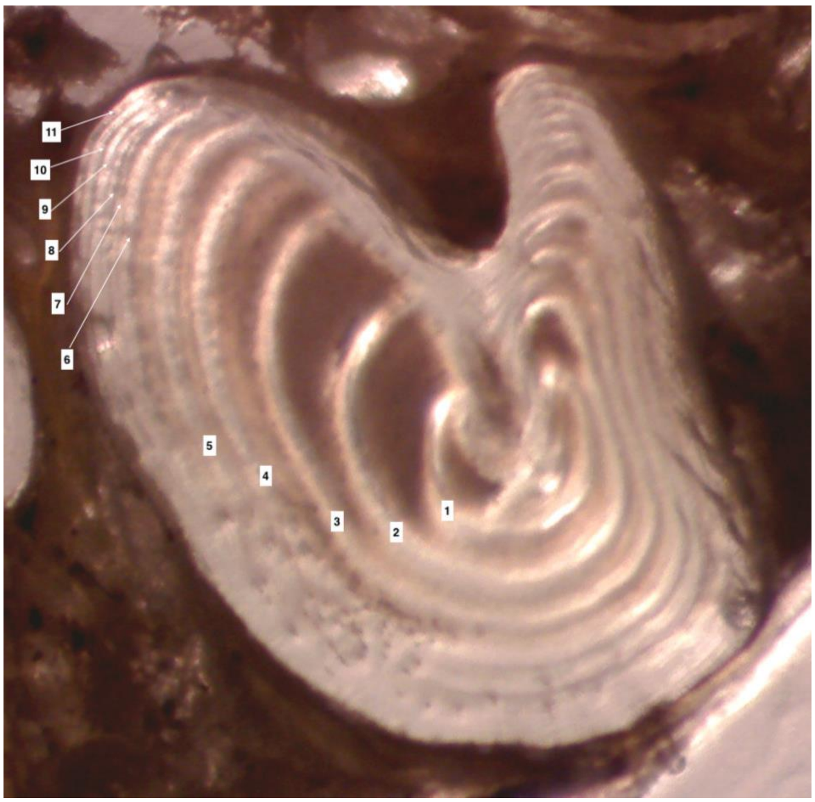

Figure 4.3. Pelvic fin ray cross section from 11-year-old Arctic grayling sampled from the Ingenika River in August, 2020.

For comparative purposes with paired fin ray ages, scale samples were also analyzed. Up to six scales showing the smallest focus (i.e. no evidence for regeneration) were cleaned with water then mounted onto labelled slides and examined with transmitted light at about 30X magnification under a stereo microscope. All scales on the slide were examined to ensure growth band counts and patterns were consistent among scales collected from each fish. Annuli were identified blind using both microscope and digitized images with no knowledge of previous counts or fish length. Live microscope view provided the option of focussing on close details while the digitized images provided a broader view of growth patterns across the whole scale, which improved annulus identification.

4.4 Snorkeling Methods

In 2020 we conducted snorkeling surveys in 13 of 17 index sites along the Ingenika River (Figure 4.3: upper Ingenika River; Figure 4.4: lower Ingenika River) over the five-day period between August 7-13th, similar to the original August 10-13 period surveyed in 2004. Four sites were excluded from the survey in 2020 for time and budgetary constraints: Site 10 in the Mid reach (Figure 4.3, Table 1) because of a time constraint, and Sites 13, 16, and 17 in the Lower reach because of budgetary constraints (Figure 4.4, Table 1). Sites 13, 16, and 17 are isolated necessitating a helicopter drop off and pick up for each site, and are the furthest distance from the helicopter base at the Kemess Mine. It was not feasible in 2020 for the helicopter to remain with the snorkeling crew which would have facilitated surveys of these sites. Surveys of sites 4 and 5, which together comprised the reach utilized for the mark-resight experiment, were replicated three times in succession over the August 10-11 period. All other sites were surveyed with a single pass.

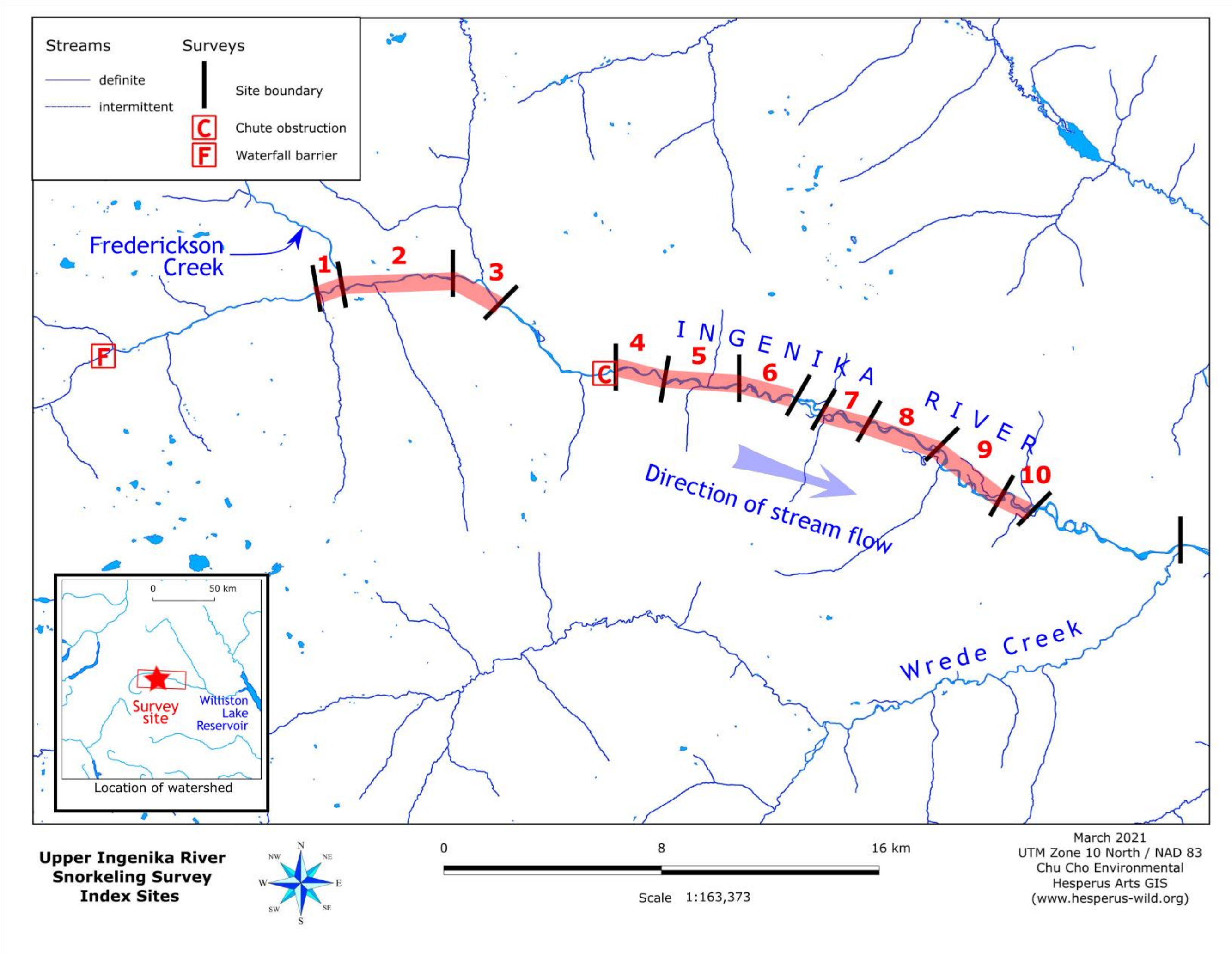

Figure 4.4. Stream sections (sites) of the upper Ingenika River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 2004 and 2018-2020. Site 10 was not surveyed in 2020 due to a time constraint.

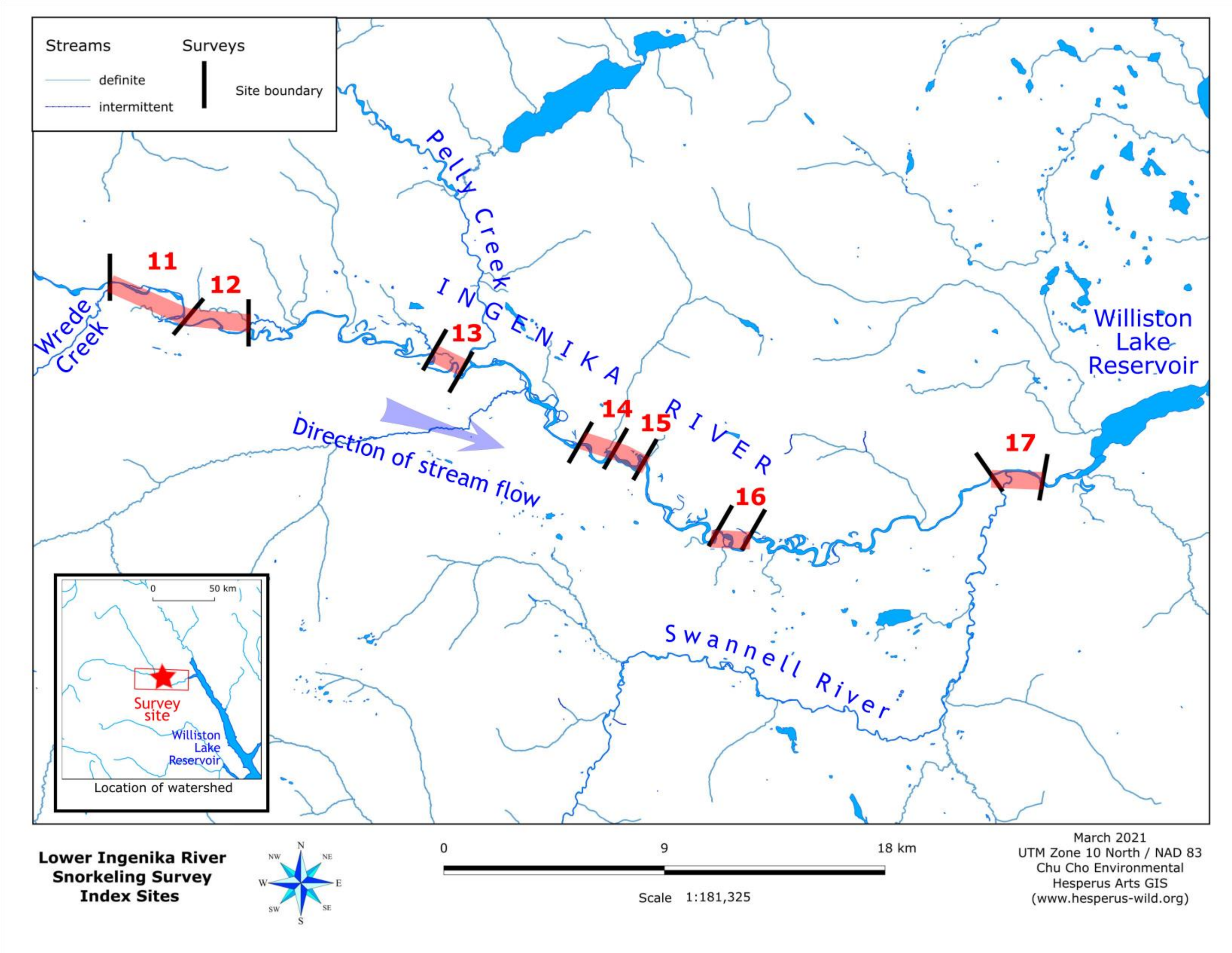

Figure 4.5. Stream sections (sites) of the lower Ingenika River utilized for snorkeling surveys to monitor Arctic Grayling abundance, 2004 and 2018-2020. Sites 13, 16, and 17 were not surveyed in 2020 due to time and budgetary constraints.

Consistent with methods in 2004 (Cowie and Blackman 2012), snorkeling surveys were conducted by a crew of 3 observers (Figure 4.5), organized in lanes of width determined by horizontal underwater visibility and estimated habitat suitability (usable wetted width for subadult and adult Arctic Grayling). All observers were experienced in snorkeling and had worked together on a minimum of one prior snorkeling survey study. A fourth crew member was a trained Swiftwater Rescue Technician in charge of safety, who followed the line of snorkelers in an inflatable kayak. Where possible observers counted fish in a lane extending in front and to one side only. When the usable wetted width exceeded the width of 3 lanes surveyed in this manner, one or more observers would extend their lane widths and look both ways. In areas where the usable width was less than the sum of the lane widths, one snorkeler would drift through behind the others and temporarily stop counting. Observed fish 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. All Arctic Grayling were also inspected for the presence of tags (Figure 4.6).

Figure 4.6. Snorkeling survey in the 'Upper d/s chute' reach of the Ingenika River, August 2020.

Figure 4.7. Underwater view of tagged and untagged Arctic Grayling, Ingenika River 2020.

Reliable counts require a disciplined effort to organize divers in lanes across the stream, and regular communication among divers to avoid overcounting or missing areas of suitable habitat (Northcote and Wilkie 1963; Schill and Griffith 1984; Slaney and Martin 1987; Hagen and Baxter 2005). To avoid double counting fish, observers attempted to count only fish that were in their lane as they passed by. However, because fish moved in reaction to the survey team, frequent communication was necessary to ensure that double counting did not occur.

4.5 Analyses

Detection probability

We utilized two approaches to estimate detection probability p of Arctic Grayling in the Ingenika River: 1) directly from mark-resight data, and 2) using replicated count data and the Binomial-Likelihood Model described in Royle (2004).

Mark-resight estimate of p

Arctic Grayling detection probability p was estimated directly by comparing replicated counts of marked fish m_t (for t=1…,t=3) observed by snorkelers to the number of marks deployed in the reach (M). The estimate of p was derived as the value maximizing the likelihood of the observations, assuming counts of marked fish were binomially-distributed random variables from the distribution

$$m_t \sim \text{Binomial}\ (M, p)$$

Limits of 95% confidence for the maximum likelihood estimate of p were estimated using a deterministic approximation to the method of likelihood profile. Expected log-likelihoods for confidence limits for p are given in Haddon (2001) by:

$$LL(p)_{95\%CL} = LL(p)_{max} - \frac{\chi^2_{1,1-\alpha}}{2}$$

where $\chi^2_{1,1-\alpha}$ is the (1-α)th quantile of the χ^2 distribution with 1 degree of freedom (i.e. for 95% confidence limits α = 0.95, 1-α = 0.05, and $\chi^2_{1,1-\alpha}$ = 3.84). Limits of 95% confidence for p were derived as the values of p that generated log-likelihoods equal to the log-likelihood of the maximum likelihood estimate minus half the required χ^2 value (1.92).

Royle (2004) Binomial-Likelihood Model of detection probability and abundance

This modeling approach first assumes that the population of Arctic Grayling in each location is closed with respect to movement, mortality, etc. between the start and finish of all replicate surveys. It further assumes that replicated counts n_{ir} are 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:

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

(1)

Joint likelihood across all sites of interest is given by the product of the site-specific likelihoods (Royle 2004). Estimates of the N_{it} and p are derived by searching for parameter values that maximized the joint likelihood across all the site/year possibilities (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).

Stable estimates of N_{it} and p are are not possible from replicated count data at a single location in the Ingenika River in just one year. To enable a trial application of the method, we first adapted the model produced for replicated index locations in the Parsnip River watershed as part of FWCP Project PEA-F21-F-3203 (Hagen and Stamford 2021) to be a generalized model for the Williston Reservoir watershed. We did this by pooling Parsnip and Ingenika data, and re-fitting the best model (as indicated by AIC_c) of Hagen and Stamford (2021) to the pooled dataset. Although the Ingenika data have only a limited influence on the model parameter estimates, being sparse, the best model includes two predictors of p, site width and underwater visibility, which facilitate its adaptation to the generally wider and clearer Ingenika River. To assess the potential of this approach for application to the Ingenika River watershed in future, the model estimate of p, computed using this generalized model and estimates of width and underwater visibility, was compared to the empirical estimate derived from the mark-resight experiment.

Abundance and trend

As the first step in estimating total abundance of Arctic Grayling >20 cm in the Ingenika River, we expanded raw count data into site-specific abundance estimates utilizing model predictions of p based on site width and underwater visibility, as described in the preceding paragraph. Resulting population densities were averaged across all sites in a reach, then applied to the entire length of the reach to estimate total abundance in the reach.

We assessed the trend in Arctic Grayling abundance over time for the Ingenika River Arctic Grayling population within a linear mixed effects analysis, performed using the Stata statistical analysis program (StataCorp, 2009) and the 'xtmixed' function (Rabe-Hesketh and Skrondal 2008). Square root-transformed count data from 2004-2020 period were entered into the model as a fixed effect, along with observation year. As a random effect, we entered sites.

5 RESULTS AND DISCUSSION

5.1 Survey Conditions

August 2020 was wet, and Ingenika flows were above long-term average levels (Figure 5.1). The timing of the 2020 study, over the August 7-13 period, however, appears to have been optimal relative to other potential periods in early August (Figure 5.1).

In contrast to August 2019 (Strohm et al. 2020), underwater visibility remained highly suitable for snorkeling surveys throughout the study period. Horizontal underwater visibility to the Secchi disk ranged from 7.0-16.3 m, with the range in the Mid and Upper reaches ranging from 10.0-16.3 m. Horizontal underwater visibility at which the Arctic Grayling models could be discerned ranged from 6.4-12.8 m, with the range in the Mid and Upper reaches ranging from 6.9-12.8 m.

The Ingenika River watershed appears to be well-suited to long-term abundance monitoring, given the exceptional water clarity during above-average flows. In contrast, in August 2020 conditions in long-term snorkeling index sites of the Parsnip River watershed (FWCP Project PEA-F21-F-3203; Hagen and Stamford 2021) were much worse. In the Anzac River, where four of the Parsnip watershed's six long-term index sites are located, it does not appear that underwater visibility was suitable for snorkeling surveys at any point during summer 2020. Industrial sources appear to have contributed to the poor visibility conditions in that system (Hagen and Stamford 2021).

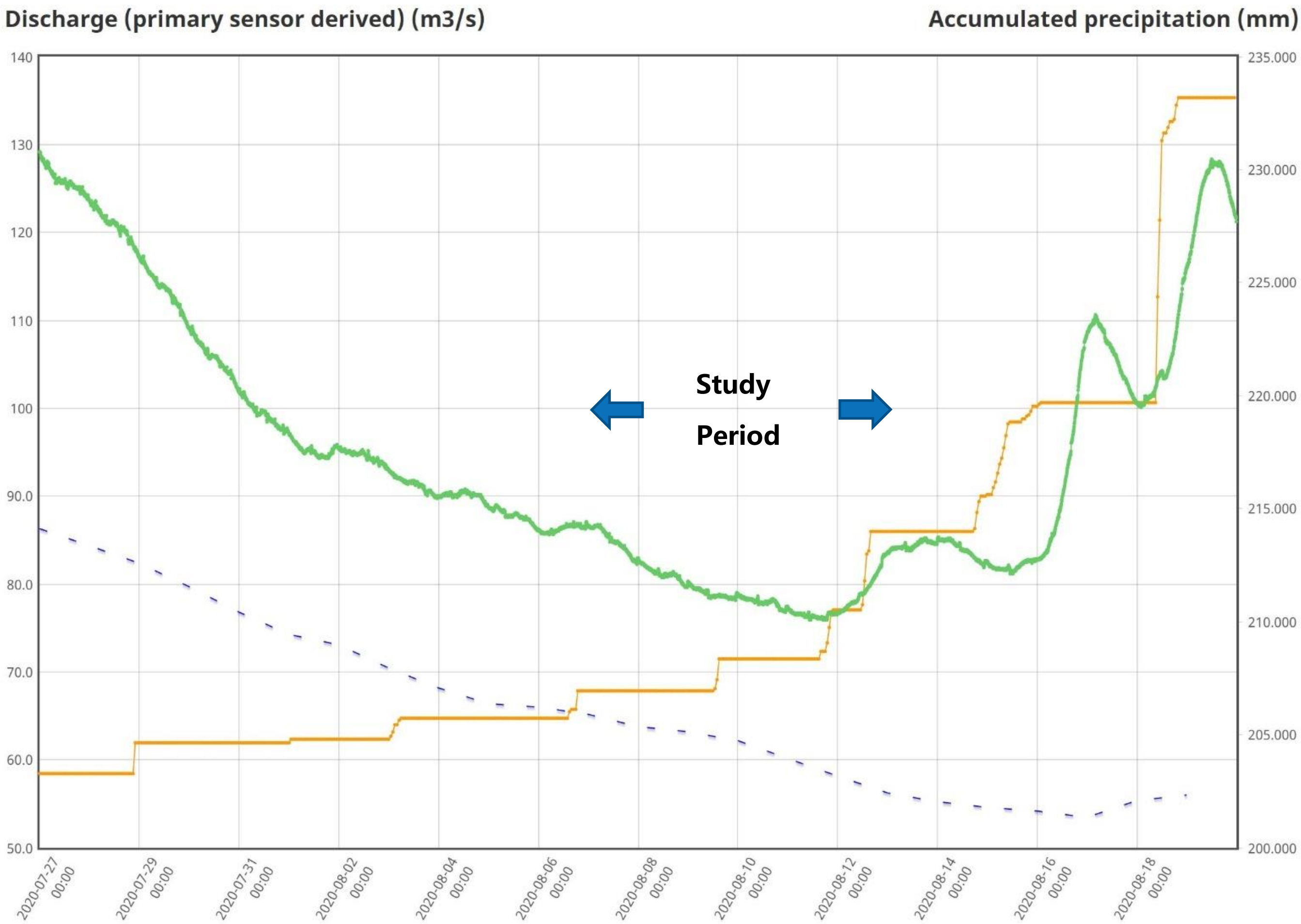

Figure 5.1. Daily discharge (green line) and cumulative precipitation (orange line) at Water Survey of Canada Station 07EA004 (*Ingenika River above Swannell River*), early August 2020. The study period was August 7-13.

5.2 Critical Summer Rearing Habitat for Subadult/adult Arctic Grayling

Arctic Grayling densities (Figure 5.2; unadjusted for detection probability <1) and raw counts in index sites (Table 2) exhibit a consistent pattern among years, with relatively distinct breaks evident between reaches. The most important feature along the Ingenika River affecting the distribution of Arctic Grayling appears to be the chute obstruction located approximately 95 km from the mouth, which divides the Upper reach into 'd/s chute' and 'u/s chute' sections (Figure 5.2, Table 2). Sites above this chute were surveyed in all years and were inhabited by very low densities of Arctic Grayling <2 fish/km (Figure 5.2), suggesting the Upper reach between 95 km and 109 km is relatively unimportant to the species for summer rearing. Arctic Grayling have not been observed upstream of Frederikson Creek.

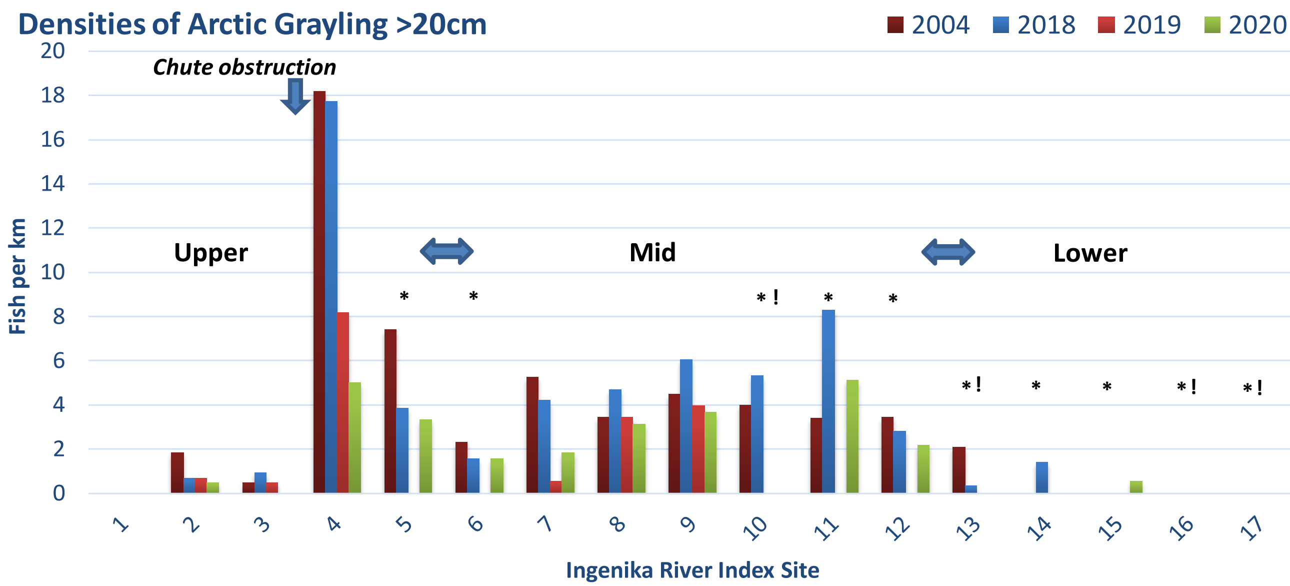

Figure 5.2. Unadjusted densities (fish/km) of Arctic Grayling >20 cm in index sites along the Ingenika River, 2020 (green bars), 2019 (red bars), 2018 (blue bars) and 2004 (burgundy bars). Asterisks denote index sites that were not surveyed in 2019 due to poor visibility. Exclamation marks denote sites not surveyed in 2020 due to time and budgetary constraints.

Table 2. Unadjusted, August snorkeling counts of Arctic Grayling, Bull Trout, Rainbow Trout, and Mountain Whitefish (GR, BT, RB, MW, respectively) >20 cm in index sites along the Ingenika River, 2004 and 2018-2020. Empty cells in 2019 and 2020 denote index sections that were not surveyed.

		Length	2004 Counts >20 cm*				VIS	2018 Counts >20 cm				VIS	2019 Counts >20 cm				VIS	2020 Counts >20 cm				VIS
Site	Reach	(km)	GR	BT	RB	MW	(m)	GR	BT	RB	MW	(m)	GR	BT	RB	MW	(m)	GR	BT	RB	MW	(m)
1	Upper	1.1	0	0	3	28	7+	0	11	5	46	9	0	14	0	32	8.7	0	6	5	70	10.5
2	Upper	4.4	8	1	2	60	7+	3	42	23	266	10	3	14	6	109	8.7	2	19	16	116	10.5
3	Upper	2.2	1	3	1	26	7+	2	8	17	115	10	1	1	4	46	7.5	0	2	6	57	10.5
4	Upper	2.2	40	0	1	46	7+	39	41	3	121	9	18	8	9	72	6.8	11	26	10	105	11.8
5	Upper	3.1	23	3	0	58	7+	12	4	1	102	9						10	7	11	115	11.5
6	Mid	2.6	6	0	0	84	7+	4	0	2	98	7.5						4	6	1	134	12.8
7	Mid	1.9	10	1	1	56	7+	8	8	2	175	9	1	7	5	63	6.2	7	5	5	135	6.9
8	Mid	3.2	11	1	0	90	7+	15	6	0	34	9	11	4	7	84	6.4	10	2	4	85	6.9
9	Mid	3.8	17	1	1	81	7+	23	15	1	108	7.5	15	7	7	132	6.4	14	5	5	175	8.7
10	Mid	1.5	6	0	0	33	7+	8	8	1	17	7.5										
11	Mid	4.1	14	4	2	55	7+	34	70	23	216	6						21	54	9	343	8.7
12	Mid	3.2	11	1	0	47	7+	9	18	2	173	6						7	6	1	263	8.7
13	Lower	2.9	6	1	1	157		1	20	1	407	6.5										
14	Lower	2.1	0	2	0	79		3	15	1	34	6.5						0	1	0	13	6.4
15	Lower	1.8	0	3	0	0		0	9	0	79	6.5						1	2	0	9	6.4
16	Lower	2.3	0	1	0	0		0	7	0	54	5.2										
17	Lower	2.3	0	1	0	76	4	0	10	0	153	4.5										
Total	*All*	*44.7*	*153*	*23*	*12*	*976*		*161*	*292*	*82*	*2198*		*49*	*55*	*38*	*538*		*87*	*141*	*73*	*1620*	

*From Cowie and Blackman (2012).

The core of the subadult/adult Arctic Grayling distribution in the Ingenika River in August appears to lie over a 54 km section between the 95 km chute and the top of the Lower reach at 41 km (Figure 5.2, Table 2). We consider this section to be critical summer rearing habitat for the adult/subadult life stage. In the winter of 2021, this information was presented to BC’s Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), where it was incorporated into an Arctic Grayling critical habitat spatial layer. This layer will be used in a BC-led *Fisheries Sensitive Watershed* initiative to establish watershed-scale land use objectives that protect water quality (Zsolt Sary, FLNRORD Ecosystems Section, pers. comm. 2021), and in the *Environmental Stewardship Initiative* (ESI) engagement between the Tsay Keh Dene Nation and the Government of British Columbia (Hagen et al. 2021 in prep.) to help identify key areas for biodiversity conservation. Arctic Graying critical habitat information for the Ingenika River has also been shared with TKDN to identify watersheds for special habitat management within the nation’s *Forest Stewardship Framework* document (Chu Cho Environmental 2021), which is under development and lays out expectations for industry operating on TKDN territory.

In 2004, 2018, and 2019, the highest Arctic Grayling densities observed were for Site 4, located immediately downstream of this chute (Figure 5.2). In 2004 and 2018, observed densities in this site were two-fold higher or greater than observed in other sites. Sites 4 and 5 were characterized by Cowie and Blackman (2004) as being part of the Upper reach, based on larger bed material, higher gradient, and a single-channel morphology relative to the more braided Mid reach (Table 1; Figure 5.3). The abrupt change in fish density downstream of the chute may indicate that it is a migration obstruction for most Arctic Grayling, as suggested by Strohm et al. (2020). Alternatively, it may be the reach characteristics (e.g. Figure 5.3) that attract subadult and adult Arctic Grayling.

Figure 5.3. Chute obstruction and confined reach of the Ingenika River located 95 km from the mouth.

The contrast in Arctic Grayling density between Site 4 and sites 5-12 (other sites in the 'Upper d/s chute' and 'Mid' reaches) is not nearly as strong in 2019 and especially 2020, relative to 2004 and 2018. The two years 2019 and 2020 were wet with above-average levels of stream discharge (Section 5.1) (Strohm et al. 2020). In contrast, 2004 and 2018 were of near-average and below-average flows, respectively (Water Survey of Canada data on file) (Hagen et al. 2019). Elsewhere, in the Parsnip River watershed, differences in flow conditions among years appear to affect Arctic Grayling distribution. Over the 1995-2020 period, researchers have observed that adult grayling become more concentrated in the upper reaches as water levels drop in late summer, but if water levels do not drop, more adults remain in the lower and middle reaches (Blackman 2002; Blackman 2004; Blackman et al. 2012; Zemlak and Langston 1998; Hagen and Gantner 2020). These patterns may indicate a shift in fish habitat use in an attempt to balance energy expenditures and foraging success. For example, as water velocities increase, the percentage of detected prey that Arctic Grayling can capture decreases (Hughes and Dill 1990). Under higher flow conditions, the higher gradient, confined reach downstream of the chute may not be as advantageous as it is during lower flow periods, and the energy expenditure necessary to reach this location may not be worth it.

In all years, the Lower reach of the Ingenika River mainstem did not appear to be utilized by substantial numbers of Arctic Grayling. An obvious reduction in summer foraging habitat quality is evident, with bed material shifting to unstable gravel and sand and water clarity reduced relative to upstream areas (Table 2). Downstream migration to this reach may nonetheless comprise an important part of the Ingenika River Arctic Grayling life history, during the overwintering, juvenile rearing, and possibly also spawning periods of the life cycle. For example, the Parsnip River mainstem and lower reaches of its tributaries provide critical habitat for rearing young-of-year and older juveniles, for overwintering adult and subadult Arctic Grayling, and for spawning (Blackman 2002; Blackman et al. 2012). The identification of critical habitats for these other life stages was beyond the scope of this study and would require different study techniques, such as radio or acoustic telemetry (Blackman 2002), juvenile-oriented sampling (e.g. electrofishing, seine netting; Blackman et al. 2012), or environmental DNA (eDNA: e.g. FWCP project no. PEA-F21-F-3198, Stamford et al. 2020).

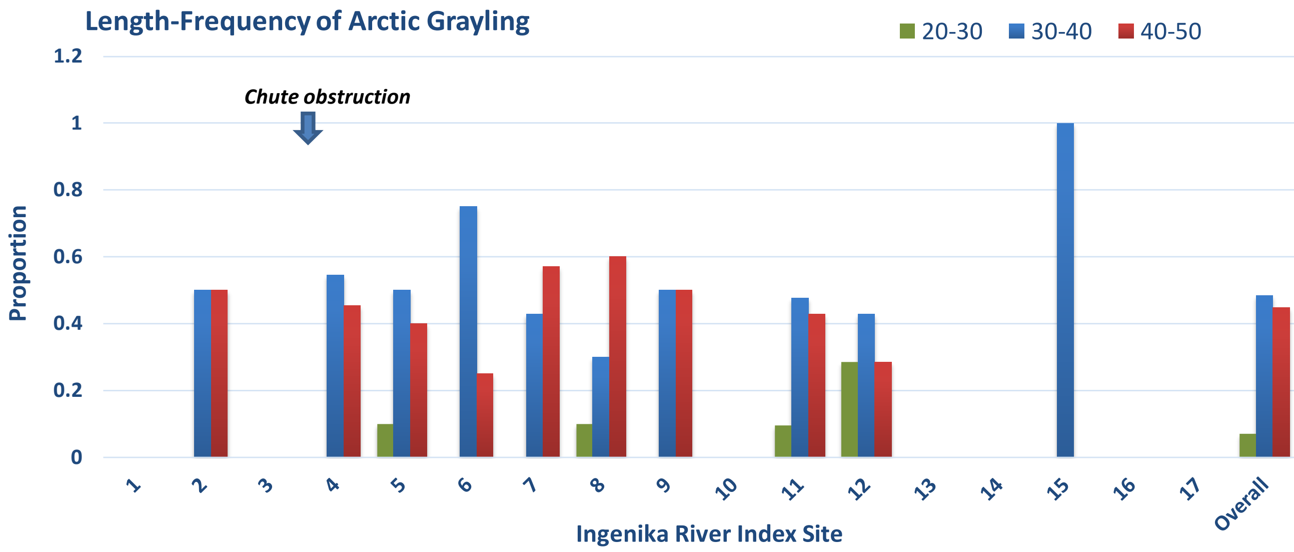

Figure 5.4. Proportion of observed Arctic Grayling in size classes 20-30 cm (green bars), 30-40 cm (blue bars), and >40 cm (red bars) among sites and overall, Ingenika River snorkeling surveys 2020. Size estimates are based on visual estimates by snorkelers.

In 2018, Arctic Grayling observations in the Ingenika River (Hagen et al. 2019) indicated a classic size distribution with a generally higher proportion of larger individuals (30 cm and larger) in sites located further upstream (e.g. Hughes and Reynolds 1994; Baccante 2010). In 2020, this pattern is not strongly evident (Figure 5.4), perhaps for a similar reason to that discussed above for the reduced importance of the Upper reach in Site 4.

In 2020, for the second consecutive year there was a striking lack of observations of smaller Arctic Grayling, with only five seen in the 20-30cm size class (Figure 5.5). For the third consecutive year, no Arctic Grayling were observed <20cm (Figure 5.5). The absence of observations from the <20cm size class over the 2018-2020 period is in strong contrast to results from the 2004 survey, in which a total of 27 Arctic Grayling <20cm were observed (Cowie and Blackman 2012). This may indicate that downstream snorkeling surveys are a poor method for assessing these juveniles (age one or two), which find distinct habitat types relative to the larger size classes (Blackman and Hunter 2001; Blackman 2002). Although the reason for the discrepancy between periods is not clear, juvenile salmonids <20cm are highly susceptible to predation and known to exhibit daytime concealment (Cunjak et al. 1988; Hillman et al. 1992; Thurow and Schill 1996), and a major increase in the presence of Bull Trout predators in the 2018-2020 period relative to 2004 (up to 10-fold greater: Table 2, Section 5.6) is a plausible factor potentially triggering a shift in the type of habitat they use. As a second alternative, the rarity of juvenile Arctic Grayling over the 2018-2020 period may indicate successive year-class failures resulting from environmental stochasticity, which has for example been observed elsewhere following a severe flood event (Tack 1974). An intriguing third alternative hypothesis is that Ingenika River Arctic Grayling spawning and juvenile rearing now occurs elsewhere, either within the nearby Finlay River watershed or in tributaries to the Ingenika River.

This last alternative hypothesis for missing observations of juvenile Arctic Grayling <20 mm has implications for the status assessment for Ingenika Arctic Grayling, and therefore should be explored further. In 2003, an extensive electrofishing study of Arctic Grayling fry distribution in the Ingenika River watershed was conducted (Cowie and Blackman 2004). Key results were that Arctic Grayling fry were only found in the Ingenika River mainstem, and the core fry rearing zone was a multi-channel zone of the Ingenika River extending from 57.3-28.0 km.[2] Surveys of index sites in this zone could be replicated to evaluate whether it remains an important source of recruitment for the Ingenika River Arctic Grayling population. Furthermore, alternative sources of recruitment in the nearby Finlay River watershed could be investigated using the technique of otolith microchemistry as recommended in Section 6 (e.g. Clarke et al. 2005; Stamford et al. 2019).

5.3 Snorkeling Detection probability

Mark-Resight Estimate

Over the August 8-9 period, 2020, we captured and tagged 13 Arctic Grayling, ranging from 295-450 mm (mean = 373 mm, SD = 48.5 mm), in sites 4 and 5 of the Ingenika River. To reduce unwanted variance in observations of marked fish related to small numbers of marks in each site,

[2] This critical fry rearing habitat segment has also been forwarded to FLNRORD and TKDN for incorporation into the Arctic Grayling critical habitat spatial layer and related *Fisheries Sensitive Watershed*, *Environmental Stewardship Initiative*, and *Forest Stewardship Framework* initiatives as described above (Hagen et al. 2021 in prep.).

we pooled snorkeling observations for these two sites for the purpose of estimating detection probability *p*.

Snorkeling observations of marked fish were 5, 9, and 9 for replicates 1-3, respectively, which took place on August 10 and 11. The assumption of site closure appears to have been met for the mark-resight study, based on the complete absence of marked fish in sites 6-9 and in the 1.3-km gap separating sites 6 and 7, which was also surveyed. These observations equate to a maximum likelihood estimate of p = 0.59 (95% confidence interval = 0.43-0.73).

Binomial-Likelihood Model

The best Binomial-Likelihood Model of Hagen and Stamford (2021), as determined by AIC_c for replicated count data, was one with two predictors of detection probability p : wetted stream width *WIDTH* and underwater visibility *FISH_VIS* (at which an Arctic Grayling model can be discerned). When re-fit to combined data from the Parsnip River watershed (n = 37) and Ingenika River watershed (n = 1), the maximum likelihood model for p was

$$p = \frac{1}{1 + \exp\{-(1.0953 - 0.0398 * WIDTH + 0.0460 * FISH\_VIS)\}}$$

(2)

Note that in our analysis, count data from sites 4 and 5 were first pooled together to permit direct comparison to mark-resight study results which were also based on pooled data (see preceding paragraph). Mean estimated values for *WIDTH* and *FISH_VIS* for the combined Ingenika site were 32.6 m and 11.6 m, respectively. These equate to model estimates of p = 0.58 and abundance N_{it} = 38 in the combined site (see Section *4.5*). The estimate of p is in close agreement with the estimate of 0.59 derived from the mark-resight study.

A key result of our analyses was that estimated detection probability p was relatively high for Arctic Grayling in the Ingenika River, despite above-average flow conditions and the relatively wide sites in which p was evaluated. Species differences in behaviour may mediate the effect of underwater visibility, or other physical habitat features such as stream width, on p. Our observation of good snorkeling detection probability for Arctic Grayling is corroborated by Binomial-Likelihood Model estimates of p for the same species in the Parsnip River watershed, which have ranged from 0.56-0.73 among long-term index sites despite relatively lower levels of underwater visibility (Hagen and Stamford 2021). Westslope Cutthroat Trout are another species associated with high snorkeling detection probability across a range of underwater visibility levels (e.g. p = 74% at 3 m visibility for Slaney and Martin 1987; p = 79%, 81% at 12.9 m, 12.2 m, respectively for Hagen and Baxter 2005). We have observed that Arctic Grayling appear to be highly similar to Westslope Cutthroat in their behaviour, often holding station and continuing to feed immediately in front of the masks of the approaching divers. In contrast, Rainbow Trout appear to react more strongly to the presence of divers and can move out of the range of detection at low levels of underwater visibility, resulting in a stronger relationship between visibility and p (Northcote and Wilkie 1963; Korman et al. 2002; Hagen and Baxter 2005). High levels of snorkeling p for Arctic Grayling are encouraging and support use of the method for estimating critical habitats and abundance in other locations.

We are also encouraged that it was possible to estimate Arctic Grayling snorkeling detection probability by applying models to replicated count data, and that the model result compared favourably to a more traditional mark-resight estimate in the Ingenika River. Mark-resight methods may be relatively costly compared to replication of snorkeling counts, and are invasive. The Royle (2004) Binomial-Likelihood Model we applied to replicated count data in the Ingenika River is conceptually-simple, but has limitations. Most importantly, the model is known to produce unstable results if replicated count data are sparse or abundance very low (Olkin et al. 1981; Royle 2004), conditions that exist in index sites along the Ingenika River. Our ability to generate estimates of detection probability p and site-specific abundance N_{it} depends strongly on the incorporation of abundant replication data from the Parsnip River watershed. This is likely to bias model outcomes until sufficient count data from outside the Parsnip can be incorporated into a truly generalized model. An alternative, Poisson-Mixture Model conditional on p, site-specific abundance N_{it}, and integration over a prior distribution (Poisson) on mean annual abundance N_t (Royle 2004) addresses these limitations and may be a better solution for areas outside of the Parsnip River watershed in future. Application of this modeling approach, however, requires replication at more independent locations in each year (ideally, 3-4; Dowd 2000) which was not feasible in the Ingenika River in 2020.

5.4 Abundance and Trend

The detection probability model of equation (2), along with estimates of underwater visibility and site width acquired in 2020, provides for the first time a basis for expanding raw count data into an estimate of total Arctic Grayling abundance in the mainstem Ingenika River. Site-specific estimates of visibility, wetted width, detection probability, and Arctic Grayling abundance are presented in Table 3. Average densities for the Lower, Mid, Upper Below Chute, and Upper Above Chute reaches, based on the site-specific abundance estimates, are 0.24, 7.07, 5.98, and 1.31 Arctic Grayling/km, respectively, which equate to total abundance estimates of 3, 35, 293, and 54 for these same respective reaches (Table 3). Total abundance of Arctic Grayling >20 cm in the mainstem Ingenika River in August, 2020 is estimated to be 385. This estimate is consistent with the categorical estimate of 250-1,000 adult individuals presented in Hagen et al. (2019), and corroborates their assessment that abundance of adult individuals is likely to be at the low margin of this range.

Table 3. Estimated abundance of Arctic Grayling in the Ingenika River watershed, 2020.

Reach	Site	Length (km)	Count >20 cm	*WIDTH*	*FISH_VIS*	Predicted *p*	Site Abundance *N*	Density (per km)
Upper Above Chute	1	1.1	0	26	10.5	0.63	0	0
Upper Above Chute	2	4.4	2	26	10.5	0.63	3	0.7
Upper Above Chute	3	2.2	0	26	10.5	0.63	0	0
Upper Below Chute	4	2.2	11	35	11.8	0.56	20	8.9
Upper Below Chute	5	3.1	10	29	11.5	0.62	16	5.2
Mid	6	2.6	4	27	12.8	0.65	6	2.4
Mid	7	1.9	7	27	6.9	0.58	12	6.3
Mid	8	3.2	10	27	6.9	0.58	17	5.4
Mid	9	3.8	14	44	8.7	0.44	32	8.4
Mid	10	1.5						
Mid	11	4.1	21	33	8.7	0.55	38	9.4
Mid	12	3.2	7	33	8.7	0.55	13	4.0
Lower	13	2.9						
Lower	14	2.1	0	68	6.4	0.21	0	0
Lower	15	1.8	1	68	6.4	0.21	5	2.6
Lower	16	2.3						
Lower	17	2.3						

Reach and Total Abundance (*N*)

Reach	Reach Density	Reach Length (km)	Reach *N*
Upper Above Chute	0.24	14	3
Upper Below Chute	7.07	5	35
Mid	5.98	49	293
Lower	1.31	41	54
Total *N*			**385**

A visual inspection of Arctic Grayling densities in long-term index sites, unadjusted for detection probability <1 (Figure 5.4), suggests a declining trend but also that declines have occurred primarily since 2018. Analysis of unadjusted count data from 2004, 2018, 2019, and 2020 (Table 2) using a linear mixed-effects model, in which counts of Arctic Grayling >20 cm and survey year were utilized as fixed effects and site ID as a random effect, did not indicate that the decrease of Arctic Grayling >20 cm over the 2004-2020 period was significant (P = 0.132). A benefit of the linear mixed-effects model framework was that it accounts for missing site data which occurred in both 2019 and 2020.

To reliably estimate trend, a significant effort applied at the decadal scale is required to acquire the necessary population data. Although the 2004-2020 count data span a meaningful period >2 generations, 2020 represents only the fourth year of snorkeling surveys in index sites in the Ingenika River. With this level of replication, the ability to estimate the change in the population over time is obviously limited, and the apparent decline over the 2018-2020 period may merely represent inter-annual variability. Periodic resumption of the Ingenika River snorkeling program, e.g. in 3 out of every 10 years (Section 6), will improve our ability to resolve the conservation status of this valued population, especially if accompanied by continued efforts to account for variable snorkeling detection probability as discussed in the previous section.

It may be possible to identify sources of interannual variability in Arctic Grayling counts in the Ingenika River, in addition to variable detection probability, and improve the population estimation procedure in future. For example, the potential use of tributaries to the Ingenika River by adult and subadult Arctic Grayling has not been resolved. Environmental DNA samples collected in 2019 from Wrede Creek and Swannell River have indicated the presence of Arctic Grayling (Stamford et al. 2020), although it is unknown for which life stage. Reconnaissance snorkeling surveys in future may resolve whether adult and subadult Arctic Grayling use these systems in summer, and improve our estimates of total abundance and trend.

5.5 Age and growth

Arctic Grayling captured over the 2018-2020 period (Table 4) averaged 381 mm fork length (SD = 44 mm, n = 18). This is larger than the mean of 367 mm (SD = 367 mm, n = 20) for fish captured in 2004 (Table 4), although the difference is not significant (t = -1.109, df = 36, P= 0.14). The most notable difference is the increased prevalence of fish >400 mm in the 2018-2020 sample.

Table 4. Estimated age of Arctic Grayling sampled from the Ingenika River watershed, 2004-2020.

ID	Year	Date	Fork Length (mm)	Weight (g)	Sex	Otolith Age	Scale Age	Fin Ray Age
1	2004	10-Aug	336	470		6	5	
2	2004	10-Aug	279	258				
3	2004	12-Aug	333	377		5	5	
4	2004	12-Aug	397	722			6	
5	2004	12-Aug	369	523			5	
6	2004	12-Aug	366	534		7	6	
7	2004	12-Aug	384	634		6	6	
8	2004	11-Aug	392	694				
9	2004	11-Aug	355	255		6	5	
10	2004	11-Aug	376	630		7	7	
11	2004	11-Aug	386	677		11	7+	
12	2004	11-Aug	387	590		7		
13	2004	11-Aug	391	590				
14	2004	11-Aug	356	545			5	
15	2004	11-Aug	394	636				
16	2004	11-Aug	400	681			7	
17	2004	11-Aug	414	726			8	
18	2004	11-Aug	340	454			6	
19	2004	12-Aug	393	590			6	
20	2004	12-Aug	285	227			4	
21	2018	12-Aug	410					
22	2018	12-Aug	435					
23	2018	12-Aug	378					
24	2018	12-Aug	385					
25	2018	12-Aug	405					
26	2020	08-Aug	415	650	M		6	6
27	2020	08-Aug	320	350	F		4	4
28	2020	08-Aug	295				4	4
29	2020	08-Aug	430	875	M		7	9
30	2020	08-Aug	450	900	M		8	11
31	2020	08-Aug	375	600	F		6	6
32	2020	08-Aug	378	625	F			7
33	2020	08-Aug	395	625	M		6	8
34	2020	08-Aug	425	875	M		6	7
35	2020	08-Aug	340	525	M		5	5
36	2020	08-Aug	338	450	M		5	5
37	2020	09-Aug	320	400	F		5	5
38	2020	09-Aug	368	550	M		na	7

Scale ages are in good agreement with otolith ages (2004; *n* = 8) or fin ray ages (2020; *n* = 13) only up to age-5, with scale ages being underestimates for older Arctic Grayling (Table 4). This is consistent with the prior observation of Blackman and Hunter (2001) for Arctic Grayling of the Williston Reservoir watershed. Fin ray and otolith ages cannot be directly compared, but exhibit a similar maximum age of 11 years which is exceptional within the Williston Reservoir watershed (Table 5).

Ingenika River Arctic Grayling are large. They have a similar size-at-age to other Williston Reservoir watershed populations up to age-5 (Table 5). For older ages, however Ingenika size-at-age is larger and most comparable to Finlay River Arctic Grayling. Populations at the southern margin of the species range (Anzac, Table, Nation) have smaller size-at-age for ages >5 years. The presence of 11-year-old fish in the Ingenika River sample is unique among streams of the Williston Reservoir watershed, and indicates relatively good annual survival.

Table 5. Mean ages derived from fin rays or otoliths collected from the Williston Reservoir watershed, derived from data compiled in Table 9 of Ballard and Shrimpton (2009).

		Fin Ray or Otolith Age							
Stream	*n*	4	5	6	7	8	9	10	11
Ingenika	21	308	333	373	385	395*	430*		418
Anzac	38	336	333	345	353	363	369		
Table	24	301	320	343	345	353	350		
Nation	8	240*	325*	344	350*				
Omineca	22	313	325	355	374	375*	410*		
Finlay	46	313	320	372	384	392	413		

* based on a single individual

5.6 Other Species

Although Arctic Grayling were the first priority for snorkeling observations, Bull Trout (Figure 5.8, Table 2), Rainbow Trout (Figure 5.9, Table 2), and Mountain Whitefish (Figure 5.10, Table 2) were also counted during snorkeling surveys of the Ingenika River index sites. Because Mountain Whitefish were too numerous in many locations to count reliably, counts (Table 2) and estimated densities should be considered of low precision and accuracy relative to the other 3 species, and the comparison between years may not be reliable.

Similar to 2018 and 2019 (in sites that could be surveyed in 2019), in 2020 we observed that the mouths of Frederikson Creek (Sites 1 and 2) and Wrede Creek (Site 11), along with the chute obstruction at 95km (Site 4) were features associated with higher concentrations of adult Bull Trout, potentially indicating an effect of pre-spawning migration and/or staging behaviour. The Ingenika River watershed is one of the most important Bull Trout systems identified anywhere in the Williston Reservoir watershed, and Frederikson and Wrede Creek are its two most important spawning tributaries (Hagen and Spendlow 2017). In 2018, we noted that counts of Bull Trout in that year were higher by 10-fold than those in 2004, but suggested this may be an artefact of differing stages of pre-spawning migration. With two additional years of Bull Trout count data to examine, however, it is clear that Bull Trout densities in the 2018-2020 period are much higher than in 2004.

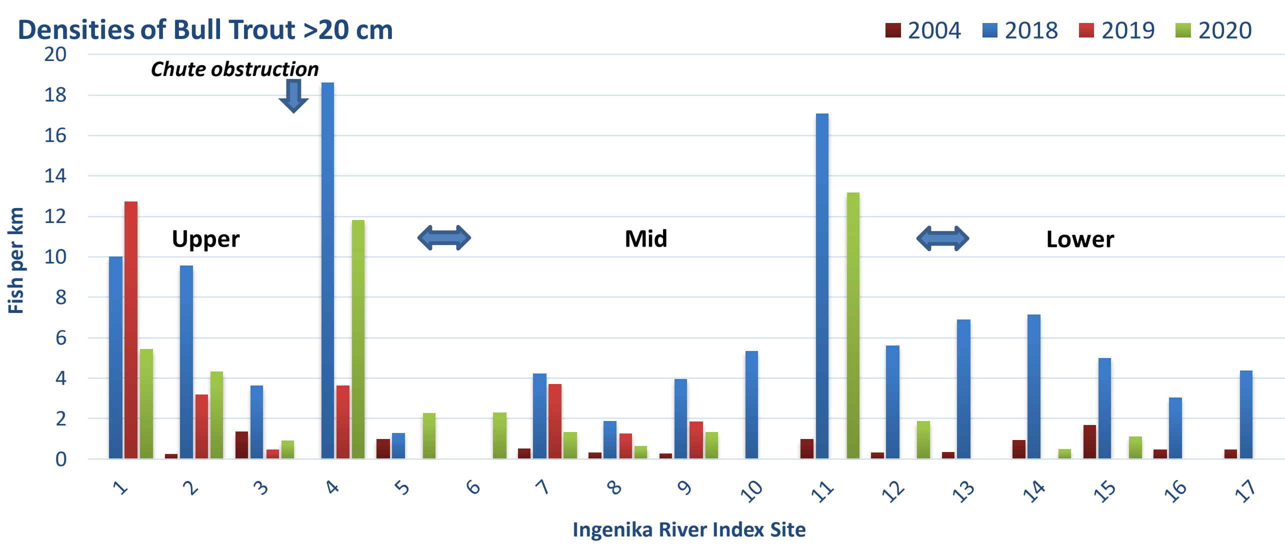

Figure 5.5. Densities (fish/km) of Bull Trout >20 cm in index sites along the Ingenika River, 2020 (green bars) 2019 (red bars), 2018 (blue bars), and 2004 (burgundy bars). Surveys downstream of Site 9 were not conducted in 2019.

A more reliable methodology for monitoring Bull Trout abundance is through counts of gravel nests, or "redds," following the completion of spawning. Currently, long-term trend in Bull Trout abundance is monitored at just one location in Finlay Reach: the Davis River on the reservoir's eastern shore. Positive population growth in the Davis River, along with observations of major populations in other tributaries to Finlay Reach, suggest that the reach is a stronghold for Bull Trout within the Williston Reservoir watershed (Hagen et al. 2021). Our snorkeling observations of increased Bull Trout abundance in the Ingenika River since 2004 appear to corroborate the assessment of strong conservation status for the species in Finlay Reach.

The distribution of Rainbow Trout among index sites exhibits substantial variability among years (Table 2, Figure 5.9). In 2018, higher densities of Rainbow Trout were observed in the vicinity of Frederickson Creek (Sites 1-3), and in Site 11 downstream of Wrede Creek (Figure 5.9). In 2019, Rainbow Trout were observed at much lower densities above the chute barrier, and at higher densities in the middle index sections where they were almost absent in 2018. The pattern observed in 2020 is intermediate, with higher densities observed in the Upper reach both upstream and downstream of the Site 4 chute obstruction, and lower densities downstream.

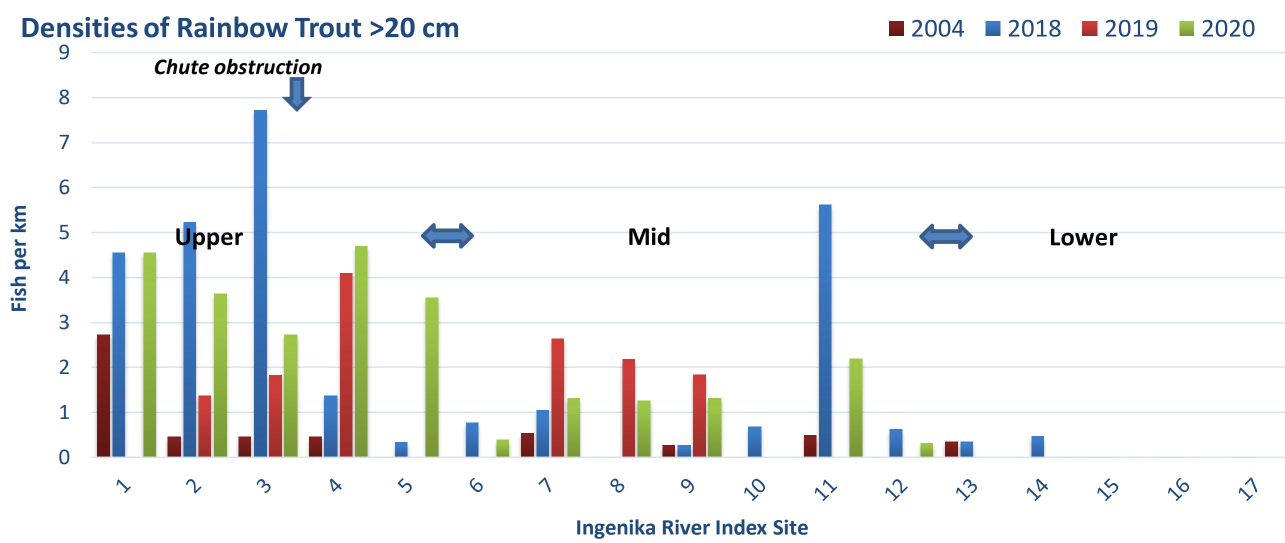

Figure 5.6. Densities (fish/km) of Rainbow Trout >20 cm in index sites along the Ingenika River, 2020 (green bars) 2019 (red bars), 2018 (blue bars), and 2004 (burgundy bars). Surveys downstream of Site 9 were not conducted in 2019.

Over the longer term, Rainbow Trout abundance will be of interest because of potential competitive interactions 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). Densities of Rainbow Trout observed over the 2018-2020 period are generally higher than those observed in

2004 (Figure 5.9, Table 2). However, Rainbow Trout densities remain low among index sites, less than 5 fish/km in all sites in 2020 (Figure 5.9), which does not indicate a significant threat to Arctic Grayling at this time.

In all years of the study 2004-2020, Mountain Whitefish were by far the most numerous salmonid observed during snorkeling surveys (Table 2, Figure 5.10). In 2020, Mountain Whitefish were present in every site surveyed and were at highest densities in sites 11-12 downstream of Wrede Creek. It should be noted however that Site 13, which has held peak densities of Mountain Whitefish in past years, was not surveyed in 2020 because of budgetary constraints. Mountain Whitefish densities in the Ingenika River appear generally to have increased in the Ingenika River watershed. Low significance should perhaps be placed on this point, however, because of large discrepancies in counts of this species evident among observers in 2004, possibly indicating that Mountain Whitefish counts were not prioritized because of potential interference with counts of Arctic Grayling.

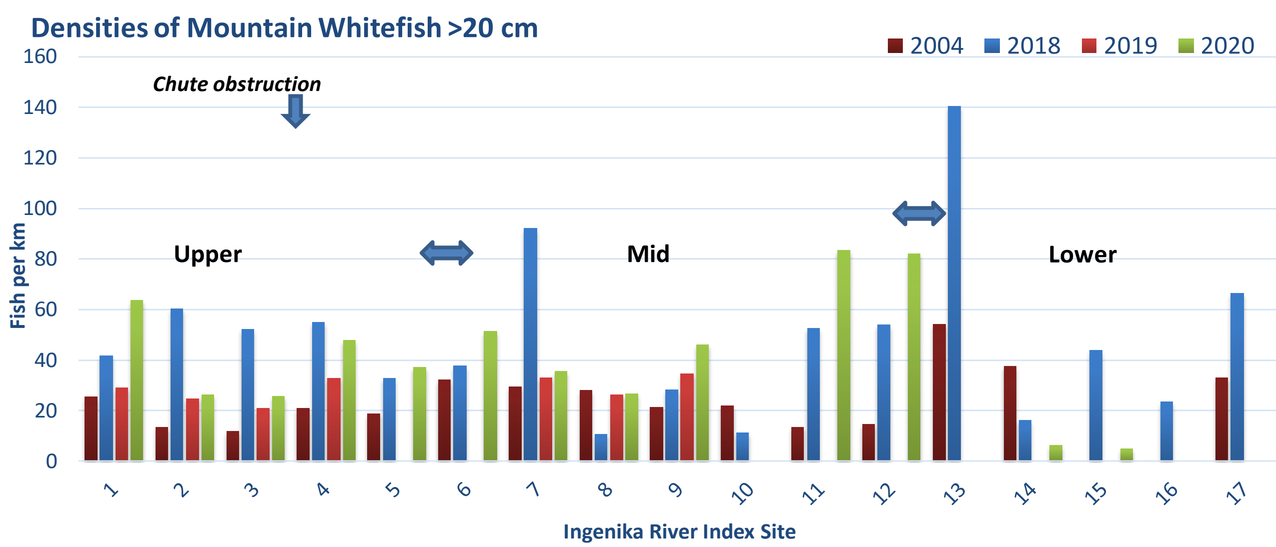

Figure 5.7. Densities (fish/km) of Mountain Whitefish >20 cm in index sites along the Ingenika River, 2020 (green bars) 2019 (red bars), 2018 (blue bars), and 2004 (burgundy bars). Surveys downstream of Site 9 were not conducted in 2019.

6 CONCLUSIONS AND RECOMMENDATIONS

The first key information gap addressed by this study was the lack of population data since 2004 indicating conservation status of Ingenika River Arctic Grayling (see Section 1.0). As we have suggested in the pages of this report, population data are still too sparse to reliably estimate status (i.e. future viability) of this valued population. We can state categorically, however, that the Ingenika continues to support a small but potentially stable population of large, long-lived Arctic Grayling. The small adult population size (~350), limited geographic distribution, and potential isolation of Ingenika Arctic Grayling by flooding remain of concern, however. Degradation of the conservation status because of a declining trend, a decrease in adult population size below 250, or an increase in threats would elevate this concern greatly, and continued monitoring is therefore necessary.

A second information gap limiting the ability to initiate conservation actions for Ingenika River Arctic Grayling has been the lack of information indicating critical habitats for key life stages. Critical habitats limit or have the potential to limit the number of Arctic Grayling surviving to adulthood in the population, and are key targets for conservation and enhancement actions. Our study was focused on critical summer rearing habitats for the adult/subadult life stage, which must be maintained in good ecological condition for Arctic Grayling populations to thrive (Stamford et al. 2017 and references therein). We have learned that summer rearing habitats used by subadult and adult Arctic Grayling have remained consistent over the 2004-2020 period. Critical summer rearing habitats are distributed along 50+ km of stream from 41 km to a chute obstruction at 95 km. This information augments knowledge gained from a previous electrofishing study of Arctic Grayling fry distribution in the Ingenika River watershed, which identified a critical fry rearing zone extending from 28 km to 57 km (Cowie and Blackman 2004).

These sections of the watershed, and the total catchment area affecting them, are currently in good ecological condition. This is also likely to be a factor behind the excellent water clarity that permits the snorkeling survey methodology. Human land use has the potential to negatively affect the productivity of these critical habitats. Given the special place that the Ingenika River and Arctic Grayling have for the Tsay Keh Dene Nation, and given the potential sensitivity of this small and isolated population, stringent land use objectives are necessary to protect water quality and minimize potential effects on stream hydrology. The sharing of this critical habitat information from this study with the governments of British Columbia and the Tsay Key Dene Nation, as discussed in Section 5.2, will facilitate the necessary planning for habitat conservation through a BC-led *Fisheries Sensitive Watershed* initiative, through TKDN's *Environmental Stewardship Initiative* engagement with British Columbia, and through the Tsay Keh Dene Nation's *Forest Stewardship Framework* document (Chu Cho Environmental 2021).

Although population data remain sparse after just four years of monitoring, we have nonetheless advanced our understanding of abundance and trend by exploring new analytical approaches. Our mark-resight study in 2020 has demonstrated that Ingenika Arctic Grayling have relatively high detection probability, which increases confidence in estimates of abundance and trend. Importantly, we have demonstrated that an alternative, no-mark method for estimating detection probability and abundance can also be applied to replicated count data and produce plausible results. We are hopeful that future development of this model will enable us to account for unwanted effects of variable detection probability among sites and among years, and improve estimates of abundance and trend.

We recommend continued monitoring of the Ingenika River Arctic Grayling population until reliable estimates of conservation status can be established. More specifically:

1. Conduct future snorkeling surveys of the Ingenika River index sites on a periodic basis, e.g. 3 out of every 10 years, to build a time series for estimating population growth rate.

2. Conduct replicated snorkeling surveys (3 replicates) in 3-4 index sections each year, to enable application of no-mark models of detection probability and abundance.

3. Utilize genetic and other methods (e.g. otolith microchemistry) to evaluate the degree of genetic and demographic isolation of the Ingenika core area from the nearby Lower Finlay core area, to evaluate whether 1) Williston Reservoir is an ecological barrier to movements and gene flow, or alternatively 2) movements through the reservoir provide demographic and genetic connections between the Ingenika River and other Arctic Grayling streams.

4. Replicate electrofishing studies of Arctic Grayling fry abundance to confirm the distribution of critical fry rearing habitat and the importance of this habitat for recruitment to the Ingenika River population.

5. Conduct reconnaissance snorkeling surveys in tributaries potentially utilized by adult/subadult Ingenika River Arctic Grayling, e.g. Swannell River, Wrede Creek.

6. Co-ordinate with Arctic Grayling abundance monitoring elsewhere in the Williston Reservoir watershed (e.g. FWCP project no. PEA-F21-F-3203: *2020 Parsnip Arctic Grayling Abundance and Critical Habitats*) to explore opportunities to improve knowledge about limiting factors.

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