The Past and Future of Arctic Grayling in the Upper Peace Basin

A Synthesis of Long-Term Learning for Recovery Planning

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EXECUTIVE SUMMARY

Rationale

Arctic Grayling of the South Beringian lineage are not considered to be at risk of extinction (yellow listed by the BC Conservation Data Centre) in their British Columbia range, but significant conservation concern remains for remnant populations in the flooded upper Peace Basin. The creation of Williston and Dinosaur Reservoirs resulted in the extirpation of an estimated 24 populations inhabiting the lower reaches of the Parsnip and Finlay rivers and upper reaches of the Peace River. Surviving populations persist in larger tributaries to Williston Reservoir and the unflooded portions of the Parsnip and Finlay rivers, all of which now face additional threats from human land use and climate change. Because of their conservation concern and high value to humans, recovering Arctic Grayling populations is a priority for the Fish and Wildlife Compensation Program - Peace (FWCP). Despite this priority, few on-the-ground recovery actions have been proposed or implemented for the species largely due to uncertainty around which options would be responsible investments with low risk to existing populations. The purpose of this study is to address this impasse with an updated synthesis of Arctic Grayling research in the Williston Reservoir and Dinosaur Reservoir watersheds, following 9 years of project implementation since the first Arctic Grayling synthesis report which was completed in 2017. Since 2017, numerous data gaps have been addressed and together inform three basic questions, which are required to design and implement effective recovery actions for Arctic Grayling in the upper Peace Basin.

What is the conservation status of remaining metapopulations, termed 'core areas' (i.e., what is the conservation urgency)?

Arctic Grayling conservation status, or population viability, was assessed using the 'Arctic Grayling Core Area Conservation Status' method, an adaptation of a rule- and point-based method previously applied in the 2017 information synthesis. Key indicators of conservation status are abundance (of mature individuals), trend, distribution, and threats. Monitoring data to assess conservation status has been a priority for FWCP since 2017. When these data were jointly analyzed with prior information since the 1990s, estimates of conservation status and risk were possible for 5 of 8 extant core areas in the upper Peace Basin (the Dinosaur Reservoir population is extirpated). The Parsnip core area was ranked C4-Low Risk because of high abundance, increasing trend, and widespread distribution, which mitigated elevated cumulative effects (threats). The Omineca core area was ranked C3-Potential Risk, due mainly to evidence of a rapidly declining trend and elevated cumulative effects. The relatively pristine Ingenika core area had low cumulative effects, but was ranked C3-Potential Risk because of small population size and limited distribution. The Williston core area, which comprises flooded portions of the Finlay and Parsnip River valleys, was ranked C2-At Risk because of drastic reductions of population size and distribution (many local extirpations), combined with high cumulative effects which are dominated by the flooding of critical, large mainstem river habitats. The Upper Peace core area was ranked C1-High Risk for similar reasons, exacerbated by the facts that Arctic Grayling distribution and abundance are so low that extirpation may have occurred or is imminent. The three remaining core areas Nation, Lower Finlay, and Upper Finlay were not ranked (CU-Unranked) because of the lack of population data indicating abundance and trend.

Where are critical habitats located within core areas (i.e., where to work)?

Work by FWCP since the 1990s, combined with new study methods such as environmental DNA, reconnaissance snorkeling surveys, and telemetry, has done much to improve understanding of the distribution of critical habitats for multiple life stages. In an updated review of this data, we delineated a total of 85 stream segments provide critical habitats for at least one Arctic Grayling life stage (fry, juvenile, subadult/adult rearing, overwintering) across seven core areas of the Williston Reservoir watershed (critical habitats have not been detected in Peace Reach [Upper Peace core area] or Dinosaur Reservoir). Most importantly, these segments identify targets for potential recovery actions including habitat conservation, restoration, and enhancements; the GIS spatial layer of critical habitat segments was the basis for defining spatial units for the analysis of limiting factors.

What are key factors currently limiting system capacity (i.e., what to do)?

Knowledge of limiting factors affecting growth and survival of Arctic Grayling identifies what kinds of recovery actions are necessary. Because uncertainty around limiting factors is a cause for low investment in recovery actions in the upper Peace Basin, in this study we prioritized the analysis of natural limiting factors and anthropogenic threats by employing a a newly-available approach: the *Cumulative Effects Modelling for Prioritizing Recovery Actions* (CEMPRA) framework. The framework makes use of explicit hypotheses about how varying magnitudes of threats (stressors) affect the productive capacity of the environment (stressor-response curves), factored together with stressor magnitude data. Outcomes, expressed in terms of remaining system capacity, are thus highly useful for identifying specific factors as targets for recovery action.

Outputs of the cumulative effects modelling were computed for two spatial scales: 1) Arctic Grayling sub-basins, as defined by the critical habitats spatial layer, and 2) 1:20,000 Watershed Assessment Units (WAUs; BC Watershed Atlas). Outcomes indicate candidate locations for habitat conservation (high system capacity scores) as well as for habitat restoration (high cumulative effects). Significant anthropogenic reductions to system capacity were indicated among sub-basins of the Parsnip, Nation, and Omineca core areas. In contrast, system capacity remains higher among sub-basins of the Ingenika, Lower Finlay, and Upper Finlay core areas. Flooding was not included as a stressor, but is known to have resulted in major effects on the Williston and Upper Peace core areas.

Recommendations

We recommend: 1) utilization of CEMPRA results to focus restoration and enhancement actions on watersheds with reduced system capacity, 2) coordination of restoration and enhancement plans at appropriate scales to address limiting factors, 3) inclusion of effectiveness monitoring in recovery planning, 4) population monitoring in the Nation, Lower Finlay and Upper Finlay core areas to identify conservation status and refine knowledge of critical habitats, 5) improving understanding about the importance of small streams to Arctic Grayling spawning and early life history, and 7) determining the feasibility and genetic implications of non habitat-based restoration levers (i.e., translocation or remote site incubation).

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1 INTRODUCTION

Arctic Grayling of the South Beringian lineage are not considered to be at risk of extinction (yellow listed) in their British Columbia range (BC CDC 2026), but significant conservation concern remains for remnant populations in the flooded upper Peace Basin. Construction of the 183-m high W.A.C. Bennett Dam was completed in 1967 and resulted in the formation of Williston Reservoir, which flooded approximately 350 km of the Peace River, Finlay River, and Parsnip River valleys (Hirst 1991). The 50-m high Peace Canyon Dam, completed in 1980 and located 23 km downstream, created Dinosaur Reservoir.[1] Flooding resulted in the extirpation of at least 24 Arctic Grayling populations inhabiting the lower reaches of the Parsnip, Finlay, and Peace Rivers including downstream in Dinosaur Reservoir (Blackman 2002a; Blackman 2002b; Stamford et al. 2017; Stamford et al. 2022). Self-sustaining populations of Arctic Grayling now appear restricted to just eight of the larger tributaries entering Williston Reservoir (Parsnip, Nation, Omineca, Osilinka, Mesilinka, Ingenika, Finlay, Toodoggone) that have substantial unflooded mainstem lengths (Hawkshaw and Shrimpton 2014; Stamford et al. 2017). Reservoir creation also facilitated widespread forestry in formerly inaccessible watersheds, which now poses additional threats to remnant populations of Arctic Grayling through land use-related habitat degradation, to which the species is highly sensitive (Armstrong 1986; AEP and ACA 2015; Federal Register 2010; Northcote 1993).

The Peace Region Fish and Wildlife Compensation Program (FWCP) was initiated in 1988, and is a partnership between BC Hydro, the Province of British Columbia, Fisheries and Oceans Canada, First Nations, and local stakeholders. The FWCP aim is to conserve and enhance fish and wildlife (including their habitats) that have been impacted by BC Hydro hydroelectric dams. The Arctic Grayling is valued by First Nations of the Williston watershed as a delicacy and as a nutritious food fish (Pearce and Abadzadesahraei 2019; Pearce et al. 2019) and is also prized by northcentral British Columbia's recreational anglers. Because of conservation concern and high value for humans, recovery of Arctic Grayling populations is a priority for FWCP (FWCP 2020).

In 2017, FWCP conducted the first major information synthesis to evaluate the existing knowledge base for Arctic Grayling in the upper Peace Basin (Stamford et al. 2017). As recommended in that document, Arctic Grayling research has since focused on information needs for Arctic Grayling recovery (also see: Hagen and Stamford 2017). Despite this, few on-the-ground recovery actions have been proposed or implemented in the upper Peace Basin (Williston and Dinosaur watersheds) largely due to uncertainty around which options would provide responsible investments and low risk to existing Arctic Grayling populations (Legault 2024). This is a recurrent issue in conservation planning; given real uncertainties and faced with an ethos of responsible investment, practitioners can struggle to decide where to begin (Buxton et al. 2022; Conroy and Peterson 2013; McDonald-Madden 2010). The purpose of this study is to provide a way through this impasse with an updated synthesis of Arctic Grayling research in the

[1] https://web.archive.org/web/20200330041958/https://www.bchydro.com/energy-in-bc/operations/our-facilities/peace.html

Williston Reservoir and Dinosaur Reservoir watersheds, paired with a new framework for identifying opportunities for effective recovery action.

Recovery actions can variously include conservation of habitat currently in good ecological condition, restoration of degraded habitats, and enhancements to boost the productivity of habitats, whether in good condition or degraded. The concept of recovery recognizes that these actions are focused on remnant populations, and that Arctic Grayling were much more widely distributed and more abundant prior to the creation of Williston Reservoir. Since 2017, stated goals for Arctic Grayling recovery in the Williston Reservoir watershed have been 1) to maintain or improve the conservation status of Arctic Grayling populations, and 2) to maintain or improve the integrity and productivity of Arctic Grayling habitats (Stamford et al. 2017). To design and implement effective recovery actions for Arctic Grayling in the Williston watershed, answers to three basic questions are required:

1. What is the conservation status of remaining populations of Arctic Grayling (conservation urgency)?
2. Where are critical habitats and what is their relative importance (where to work)?
3. What are key factors limiting system capacity currently (what to do)?

In this study, we address these questions through: 1) updated assessments of Arctic Grayling abundance, trend, distribution, and threats, which are rolled up to assess conservation status (urgency) using an adaptation of the *Core Area Conservation Status* method (Fredenberg et al. 2005), 2) updated estimates of the distribution of critical habitats for Arctic Grayling in the upper Peace Basin, which identify where recovery actions must be located to be effective (where to work), and 3) a new analysis of limiting factors using the newly-available approach: *Cumulative Effects Modelling for Prioritizing Recovery Actions* (CEMPRA; Bayly et al. 2024), which estimates what types of recovery actions are most likely to be effective for recovering Arctic Grayling in various sub-basins of the upper Peace Basin (what to do). Collectively, new study results since 2017 add to prior knowledge such that answers to questions about conservation urgency, where to work, and what to do are now tractable.

2 STUDY AREA

2.1 Conservation Units

Eight extant Arctic Grayling core areas[2] are identified for the upper Peace Basin upstream of the W.A.C. Bennet Dam: Parsnip, Nation, Omineca, Ingenika, Williston, Upper Peace, Lower Finlay, and Upper Finlay (Figure 1). Arctic Grayling in a ninth potential core area, Dinosaur Reservoir, are known to be extirpated (Stamford et al. 2022) and thus a putative Dinosaur core area is not included in this study.

Much of the Williston Reservoir watershed drains higher elevation, mountainous areas. Consequently, streamflow is snowmelt driven, with peak discharge occurring in May and June. Sediment load is naturally high during spring snowmelt, as evidenced by turbid flows and signs of bedload transport

[2] a group of populations (or subpopulations) that are demographically linked and genetically similar. The system of core areas is thus a proxy for the putative metapopulation structure (Hanski and Gilpin 1991; Dunham and Rieman 1999).

(Bruce and Starr 1985), but throughout much of the year water clarity is relatively high in most streams without glacial influence.

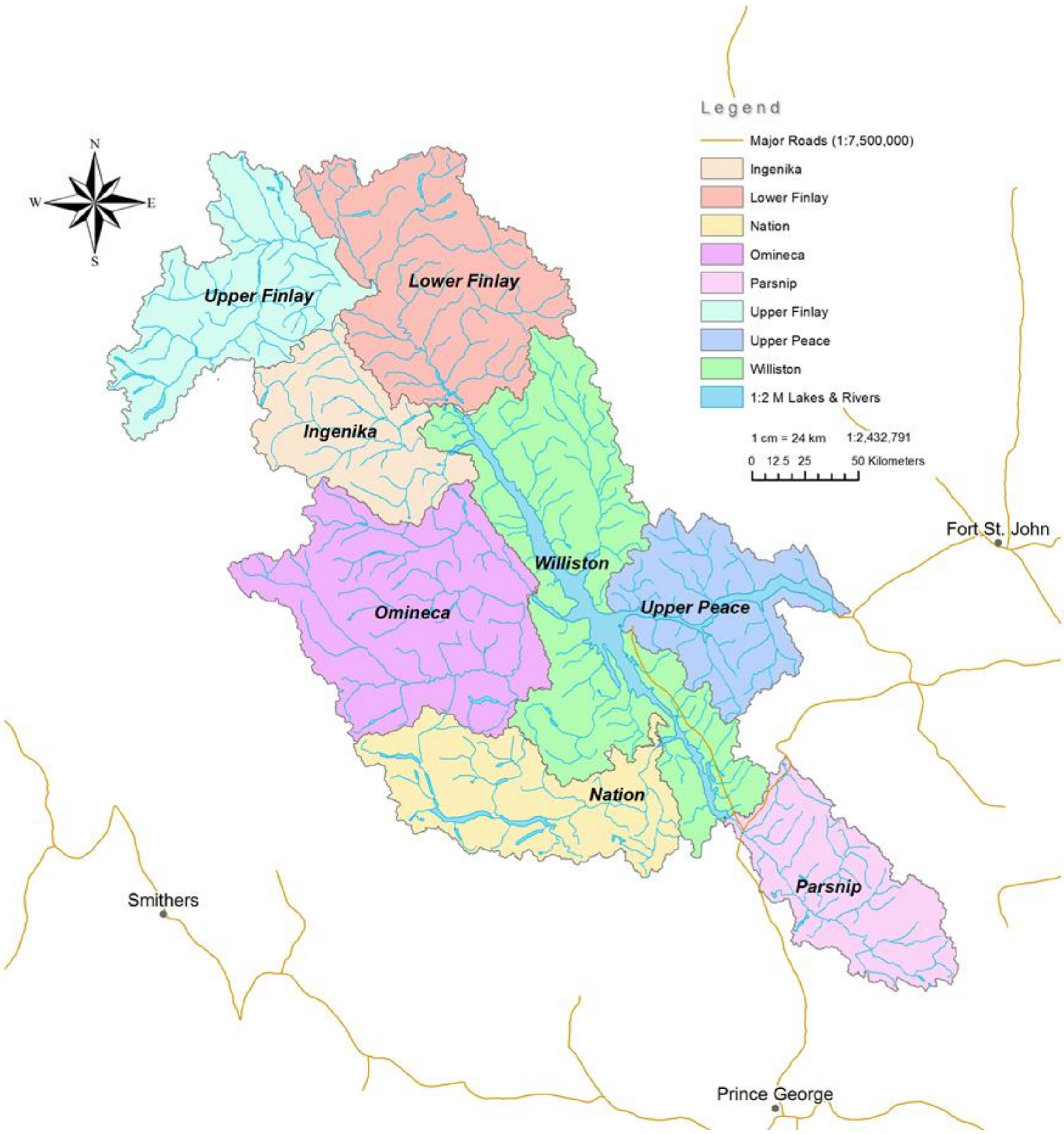

Figure 1. Arctic Grayling 'core areas' (putative metapopulations) comprising the range of Arctic Grayling in the upper Peace Basin. A potential ninth core area in the Dinosaur Reservoir watershed is known to be extirpated and not included in the study.

2.2 Parsnip Core Area

The Parsnip core area is comprised of the unflooded portion of the Parsnip River watershed. Historically, the Parsnip River flowed roughly 280 km along the Rocky Mountain Trench from near

Arctic Lake to its confluence with the Finlay River (origin of the Peace River). Major sub-basins of the Parsnip core area (Misinchinka, Colbourne, Reynolds, Anzac, Table, Hominka, Missinka, Upper Parsnip) drain mountainous terrain in the Hart Ranges of the Rocky Mountains, lying to the east of the trench, while smaller sub-basins on the west side of the Parsnip River watershed (e.g., Firth Creek, Bill's Creek, Wichcika Creek) drain lower elevation areas of the Nechako Plateau. Industrial land use is most intensive in low elevation areas and on the west side of the watershed, although rapid expansion of forestry into previously pristine upper reaches of the Rocky Mountain sub-basins is ongoing (Hagen and Stamford 2023).

2.3 Nation Core Area

The Nation core area is comprised of the Nation River watershed, which straddles the transition from the Nechako Plateau to higher elevation topography in the Omineca Mountains. Unlike other Williston core areas, the Nation core area is dominated by a series of large lakes at the source of the Nation River, which are not inhabited by Arctic Grayling. Because of these factors, the Nation River and its tributaries are substantially warmer than other watercourses inhabited by Arctic Grayling in the Williston watershed. The Nation core area has had moderately intensive industrial activity including forestry, mining, and a proposed natural gas transmission project, resulting in a widespread network of roads.

2.4 Omineca Core Area

The Omineca core area is comprised of three major stream basins draining the Omineca Mountains on the western side of the Rocky Mountain Trench: 1) Omineca River, 2) Osilinka River, which is a tributary of the lower Omineca River, and 3) Mesilinka River, which has now been separated from the rest of the Omineca core area as a result of flooding. The Omineca River watershed has had intensive land use, in the forms of forestry and placer mining, along tributaries in the lower half of the watershed (Germansen River, Discovery Creek, Fall River, Ogden Creek), but is relatively pristine in its upper reaches upstream of Ogden Creek. Substantial portions of the Mesilinka and Osilinka watersheds have been intensively logged.

2.5 Ingenika Core Area

The Ingenika core area is comprised of the large, non-glacial Ingenika River watershed draining the Omineca Mountains, which is relatively pristine upstream of the Pelly Creek confluence. Wildfire, however, is a frequent natural disturbance in the watershed.

2.6 Lower Finlay Core Area

The unflooded portion of the Finlay River watershed in the Rocky Mountain Trench, downstream of Long Canyon rapids where the Finlay cuts through from the Omineca Mountains, comprises the Lower Finlay core area. Large tributaries entering the Finlay in this section including the Akie, Kwadacha, and Fox rivers, with the Akie and Kwadacha being of glacial origin. Human land use is restricted to the Rocky Mountain Trench and low elevation areas of the major watersheds.

2.7 Upper Finlay

The Upper Finlay core area is comprised of the Finlay River watershed upstream of rapids located at Long Canyon, minus the Thutade Lake watershed at the head of the Finlay system which is isolated above Cascadero Falls (Arctic Grayling are not present above the falls). Major tributary watersheds along this section of the Finlay River are those of the Toodoggone and Firesteel rivers. The Upper Finlay core area is mostly pristine, with a small amount of watershed development related to mineral exploration and open pit mining.

2.8 Williston and Upper Peace Core Areas

The Williston and Upper Peace core areas are now comprised of the remaining direct tributaries to Williston Reservoir. All the former low gradient, large mainstem river habitat in these core areas was flooded as a result of Williston Reservoir creation. Tributaries to the eastern shores of Parsnip and Finlay reaches, which drain rugged terrain in the Rocky Mountains, have relatively short accessible lengths and moderate gradients. The most westerly tributaries of Peace Reach originate in more rugged, mountainous terrain than those tributaries lying to the east. On the western shore of Williston Reservoir, direct tributaries to the reservoir (outside of the Nation, Omineca, and Ingenika core areas) are small and thought to be relatively warm. Human land use is intensive in the eastern segment of the Upper Peace core area and of moderate-to-high intensity in areas adjacent to the reservoir in the Williston core area.

3 KEY LIFE HISTORY ATTRIBUTES

See Stamford et al. (2017) for a thorough review of Arctic Grayling life history and habitat requirements focused on the Williston Reservoir watershed. In this section, we present a brief overview of Williston Arctic Grayling life history attributes affecting their conservation status and sensitivity to natural limiting factors and anthropogenic threats.

3.1 Complex Migratory Behaviour

Northcote (1993) presented a conceptual model of Arctic Grayling life history, which is based on a cycle of potentially complex migratory behaviour involving alternation between three major habitat categories: 1) summer feeding habitat, 2) overwinter refuge, and 3) suitable spawning habitat. These movements may be at the scale of a single, relatively restricted watershed or lake system (Stewart et al. 2007), or involve long, complex migrations among critical habitats, which may traverse marginal habitat (e.g. turbid rivers, brackish estuaries) and span hundreds of kilometers between overwintering, spawning and summer feeding areas located in different systems (Armstrong 1986, Northcote 1993; Stewart et al. 2007).

Low gradient headwater areas appear to provide ecological opportunities for resident populations to differentiate from downstream migratory types and evolve locally adapted resident life histories (Buzby and Deegan 2000; Steed et al. 2010; Golden et al. 2021). Remnant Arctic Grayling populations in unflooded core areas (Parsnip, Nation, Omineca, Ingenika, Lower Finlay, Upper Finlay; Figure 1) appear to also move locally within their home streams and potentially also express locally adapted traits. In contrast, Arctic Grayling metapopulations thought to be extirpated by flooding in the Williston and

Upper Peace core areas (Figure 1) were demographically independent from surviving metapopulations and presumably adapted to the (now flooded) large river habitats (Stamford et al. 2017). Like in other salmonid species, large river-adapted ecotypes are thought to be ancestral to local populations, and express diverse life history traits that enhance resilience and promote colonization of novel habitats (e.g., long distance migration behaviour, high straying rates between natal areas and rearing habitats, phenotypic plasticity [e.g., Brennan et al. 2024; Wood et al. 2008]). Possibly, populations like these continue to survive in unflooded portions of larger rivers in the Williston watershed (e.g., Finlay, Parsnip, Omineca, Ingenika rivers).

Arctic Grayling are spring spawners. Although specific spawning locations are generally unknown for Williston Arctic Grayling, elsewhere stream reaches that warm quickly in the spring are prime habitat for spawning and early rearing. However, such reaches may also be too small and possibly warm for rearing later in the summer or for older life stages, which may explain why critical habitats for spawning and summer rearing may be in different streams (Tack 1980; Butcher et al. 1981; Ridder 1994, 1998; Stewart et al. 2007). Newly emerged Arctic Grayling fry are weak swimmers and prefer shallow areas of little or no flow close to the spawning area (Stuart and Chislett 1979; Butcher et al. 1981; Stewart et al. 1982; Armstrong 1986). As they grow through the summer, Arctic Grayling fry undergo behavioural and habitat shifts away from schooling in quiet areas and into deeper faster water along mainstem margins and side channels (Stuart and Chislett 1979; Armstrong 1986). By fall they drift or move downstream into larger streams to overwinter (Northcote 1993). These larger streams are often utilized by juvenile grayling 100-200 mm (age-1+ to age-2+) throughout the year, and the summer rearing habitats and overwintering locations may be in relative proximity to each other (Tack 1980; Butcher et al. 1981; Northcote 1993; Stewart et al. 2007). Beginning in their second or third year of life, many subadult grayling join adults in making migrations from overwintering locations (usually in an upstream direction) to summer feeding habitat and, once maturity is reached, to spawning locations (Tack 1980; Armstrong 1986; Ridder 1994; Blackman 2002a). Within the Williston watershed, Arctic Grayling probably mature around age three to five years (like in the adjacent Sukunka River, Stuart and Chislett 1979) and frequently reach age 11 (Hagen and Stamford 2021; O'Connor et al. 2026). The oldest known adult was aged 14 years from a 405 mm long Arctic Grayling captured in upper Finlay River (Stamford Environmental fin ray age data on file). Maximum body size is approximately 400-450 mm among populations and associated with adults older than eight years old (Ballard and Shrimpton 2009).

3.2 Dependence on Stream Habitats in Good Ecological Condition

Arctic Grayling in the Williston Reservoir watershed complete their life cycle in fluvial habitats and often downstream from headwater lakes (Pollard and Miller 2011; Stamford et al. 2017). The Toodoggone watershed in the Upper Finlay core area contains the only known lake inlet spawning metapopulation. Arctic Grayling do not reside in the reservoir (Clarke et al. 2005), although new results from environmental DNA (eDNA) studies and infrequent grayling encounters in tributaries to the Williston and Upper Peace core areas suggest that successful movement through the reservoir occurs more frequently than previously thought (Golder 2013; Stamford et al. 2022; Stamford and O'Connor 2022).

Arctic Grayling of all life history stages depend on good water quality. Generally, across the range of Arctic Grayling, all life history stages (young-of-year fry, age-1+ and age-2+ juveniles, subadults and adults) require clear, relatively low gradient stream reaches for rearing (deBruyn and McCart 1974; Craig and Poulin 1975; Stuart and Chislett 1979; Butcher et al. 1981; Northcote 1993; Stewart et al. 2007). Clear stream reaches appear to be critical for summer rearing of subadult and adult Arctic Grayling, likely because they are highly dependent on sight for feeding (Birtwell et al. 1984; McLeay et al. 1987; Ott et al. 1998; Stewart et al. 2007). Elevated sediment transport reduces water clarity and negatively affects Arctic Grayling populations, both through direct effects on the health and survival of individual fish, and also through degradation of habitat for feeding and reproduction (Birtwell et al. 1984; McLeay et al. 1987; Reynolds et al. 1989). Water temperature is also a key factor limiting Arctic Grayling populations, both through direct effects on survival and growth, and likely also through temperature-mediated species interactions. In the Williston Reservoir watershed, Arctic Grayling are found in streams with cool, stable water temperatures (Bottoms et al. 2023; Hawkshaw and Shrimpton 2014; O'Connor et al. 2025). Both water temperature and water clarity are affected by human land use (Macdonald et al. 2003; Meehan 1991; Moore et al. 2005), identifying the Arctic Grayling as a sensitive species.

3.3 Stream Size Requirements to Complete the Life Cycle

Flooding of roughly 350 km of the Peace River, Finlay River, and Parsnip River valleys eliminated much of the low gradient mainstem habitat that would have been used for rearing by juvenile grayling, and for overwintering for both juvenile and adult life stages. This habitat loss is the most plausible explanation for the relatively rapid extirpation of populations in the Williston and Upper Peace core areas (Stamford et al. 2017). In the Williston Reservoir watershed, a substantial amount of unflooded mainstem length appears to be necessary to complete the life cycle. The occurrence of juvenile Arctic Grayling among surviving core areas is positively related to the distance upstream from the reservoir and stream order, with occupied sites being characterized as locations in 4th order and larger tributaries with stable, cool water temperatures (Hawkshaw and Shrimpton 2014).[3]

4 ABUNDANCE AND TREND

4.1 Overview of Existing Information

The FWCP information synthesis of 2017 included assessments of conservation status and risk for the eight extant Arctic Grayling core areas of the Williston Reservoir watershed (Stamford et al. 2017). However, these were limited by a lack of population data with which to estimate adult abundance and trend, which are key indicators of conservation status (Caughley 1994; Franklin 1980; McElhany et al. 2000; Nunney and Campbell 1993; O'Grady et al. 2004; Soule and Wilcox 1980), i.e., the 'urgency' for recovery actions. At that time, Arctic Grayling abundance monitoring had not occurred anywhere in the Williston watershed since 2007. Consequently, the lack of these data was identified as a top priority

[3] Sampling in the summer may underestimate the importance of smaller tributaries which may have reduced habitat or be too warm in summer but provide conditions for rapid fry growth in spring and early summer.

information gap (Stamford et al. 2017), and studies of Arctic Grayling abundance and trend were subsequently prioritized by FWCP.

Given clear flows in stream reaches inhabited by adults, snorkeling surveys have been the primary method for monitoring abundance and trend. Recent work has built upon past FWCP snorkeling surveys, enabling comparisons among core areas and across time.

Long-term snorkeling data exist for three of the eight core areas: Parsnip, Ingenika, and Omineca. The highest frequency of monitoring has occurred in the Parsnip core area, where 11 years of monitoring data exist from the 28-year period 1995-2022 (Hagen and Stamford 2023). Snorkeling surveys have been conducted in 4 long-term index sections of the Anzac River and 3 sections of the Table River,[4] with each section's count usually being replicated at least once in the same day by a separate crew(s). Single-pass surveys in other adult summer rearing streams, to learn about total abundance for the core area and critical habitat locations (Section 5), were included in the program 2018-2022 (Hagen and Stamford 2023).

A total of 17 sections of the Ingenika River, distributed across the entire length of the mainstem known to be utilized by subadult/adult Arctic Grayling for summer rearing, were surveyed using single-pass snorkeling surveys in 2004 (Cowie and Blackman 2012). These surveys were repeated in each of three summers 2018-2020 (Hagen and Stamford 2021).

The oldest snorkeling survey data come from the Mesilinka River in the Omineca core area, where replicated snorkeling surveys in three index reaches were conducted over the 1992-1999 period related to a stream fertilization experiment (Wilson et al. 2008). These surveys were repeated in 2024, augmented by reconnaissance snorkeling surveys to delineate the distribution of Arctic Grayling in the Mesilinka watershed (Hagen et al. 2025). Elsewhere in the Omineca core area, replicated snorkeling surveys augmented by single-pass reconnaissance surveys were conducted, for the first time, in the Osilinka River watershed in 2025 (O'Connor et al. 2026).

A key area of focus for snorkeling studies since 2020 has been the application of models to estimate detection probability and abundance from replicated count data in snorkeling reaches, which has enabled population estimates that account for the fact that not all grayling that are present are counted during snorkeling surveys. Snorkel surveys in tributaries to the Williston Reservoir have been replicated within a consistent methodology since 2020, and covariates known to influence the observation process (underwater visibility and wetted width) are available within each spatiotemporal replicate (O'Connor et al. 2026). Corroboration of model results has also been conducted with mark-resight experiments in the Ingenika, Mesilinka, and Osilinka rivers (Hagen and Stamford 2021; Hagen et al. 2025; O'Connor et al. 2026). Average detection probability estimates have ranged from 0.42-0.71 among replicated long-term index sections, with highest estimates associated with the smaller reaches at the top of the Arctic

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[4] Table River site 26-22 km was a replacement for site 22-18 km beginning in 2018, due to a clay slump at 22 km reducing visibility (Hagen and Stamford 2023).

Grayling distribution in the Table and Anzac rivers (Hagen and Stamford 2021, 2022; Hagen et al. 2025; O'Connor et al. 2026).

4.2 Abundance of Mature Individuals

Work to date, particularly since 2018, indicates that Arctic Grayling abundance is highly variable among core areas of the Williston Reservoir watershed (Figure 2). Adult/subadult Arctic Grayling are found at very low average densities in long-term monitoring sites of the Ingenika River (13/km; Ingenika core area), Mesilinka River (3.8 ±1.8/km; Omineca core area), and Osilinka River (8.9 ±1.8/km; Omineca core area), for which replicated count data enable quantitative comparisons. In contrast, mean adult density estimates are higher by an order of magnitude or greater in reaches of the Table River (115 ±13/km) and Anzac River (93 ±29/km) in the Parsnip core area, identifying these adjacent streams as a major remaining hub of Arctic Grayling abundance in the Williston watershed. The Parsnip core area is the remaining, unflooded portion of the Parsnip River valley in the Rocky Mountain Trench. Current densities in this core area potentially give an indication of what was lost following flooding of >100 km of the valley.

Arctic Grayling densities are unknown elsewhere in the Williston Reservoir watershed, although Arctic Grayling are anecdotally known to be relatively abundant in parts of the Finlay River watershed. Extreme low densities present in the Williston and Upper Peace core areas are too low to enable estimates. The presence of the species is known from anecdotal reports of infrequent encounters, eDNA detections in streams draining the eastern slopes of Finlay Reach (including Ospika River), and discovery of subadults rearing in Factor Ross Creek (Golder 2013; Stamford et al. 2022; Stamford and O'Connor 2022).

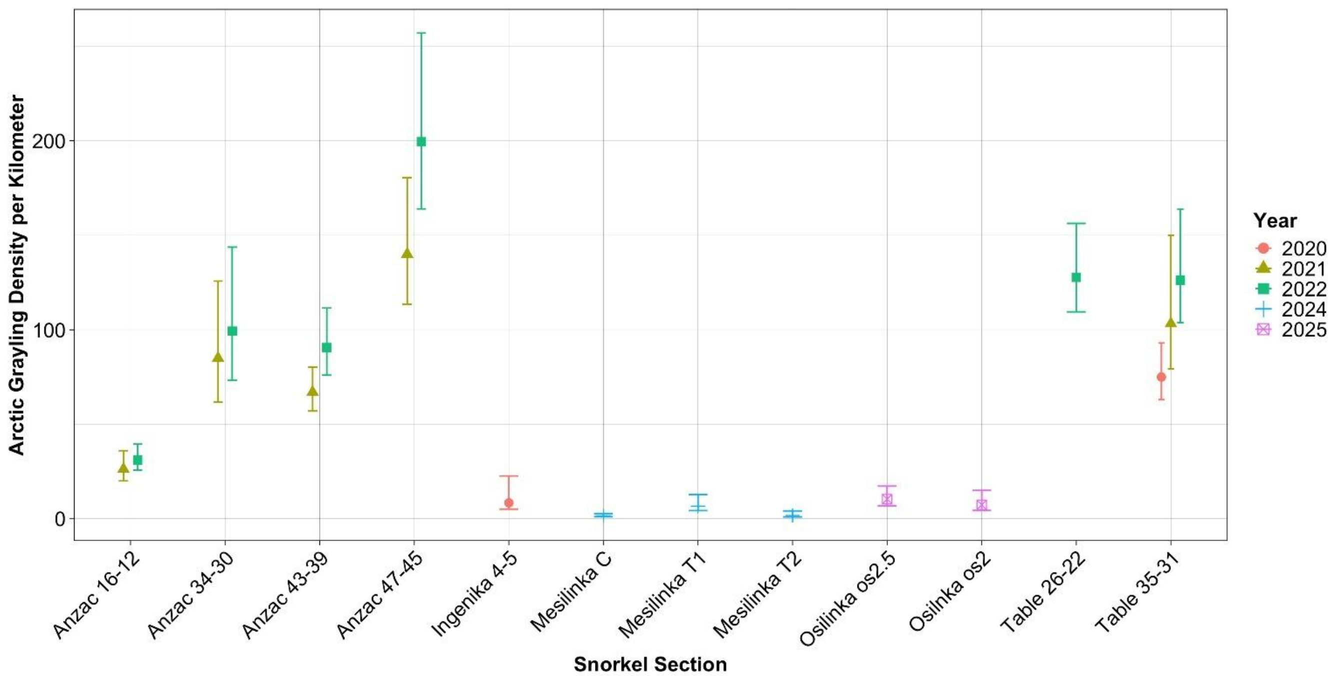

Figure 2. Estimates of Arctic Grayling density per kilometer produced by a Poisson-binomial mixture model for replicated, long-term snorkel index sections since 2020 (reprinted from O'Connor et al. 2026).

Estimates of the total abundance of mature individuals can be derived for the Parsnip and Ingenika core areas. Among Arctic Grayling streams of the Parsnip watershed, reconnaissance snorkeling surveys combined with detection probability and abundance modelling have enabled population estimates for Arctic Grayling >20 cm, which total approximately 5,600 individuals and equate to an abundance of mature individuals of at least half that (Table 1).

Total abundance of Arctic Grayling >20 cm in the mainstem Ingenika River in August, 2020 was estimated to be 385 (Table 2), with the majority thought to be mature individuals based on observed body sizes (Hagen and Stamford 2021). For the Ingenika core area, the mainstem Ingenika River probably provides the most suitable adult summer rearing, but surveys of accessible but relatively short lower reaches of Swannell River, Pelly Creek, and Wrede Creek have not occurred suggesting a somewhat larger core area population is possible.

In the Omineca core area, recent surveys of the Mesilinka River (Hagen et al. 2025) and Osilinka River (O'Connor et al. 2026) indicate low core area densities, but a substantial population has been anecdotally suggested to inhabit the yet to be surveyed Omineca River. A core area population more than 1,000 mature individuals may exist, therefore, despite very low densities observed in the Mesilinka and Osilinka rivers. Total abundance of mature individuals in the Williston and Upper Peace core areas has not been estimated but is expected to be very low and extremely low, respectively. Total abundance is unknown in the Upper Finlay, Lower Finlay, and Nation core areas, identifying a serious information gap.

Table 1. Estimated August density and total abundance (N) of Arctic Grayling >20 cm in reaches of the Parsnip River watershed during the 2018-2022 period. Count data were analyzed to estimate reach abundance within the Poisson-Binomial model framework described in Hagen and Stamford (2023).

Stream	Reach	Length (km)	Year	No. Sites	Density/km	Density 95% LCL	Density 95% UCL	*N*	*N* 95% LCL	*N* 95% UCL
Anzac	Headwater	7.9	2018	3	21.3	16.1	27.6	169	127	218
Anzac	Upper	31.1	2018	7	93.7	85.8	102	2914	2667	3175
Anzac	Lower	16.6	2018	3	37.3	29.3	46.5	619	487	772
Missinka	Upper	11.4	2019	1	13.6	7.16	22.9	155	82	261
Missinka	Lower	25.0	2019	2	0.91	0.06	3.46	23	1	86
Hominka	Headwater	12.0	2020	3	0.28	0.05	0.86	3	1	10
Hominka	Upper	16.0	2020	3	14.6	10.3	19.9	234	165	318
Hominka	Lower	32.0	2020	2	2.40	0.42	6.39	77	14	205
Wichcika	Mainstem	27.5	2020	5	0.50	0.08	1.51	14	2	41
Reynolds	Mainstem	36.0	2021	5	0.59	0.12	1.64	21	4	59
Colbourne	Mainstem	17.0	2021	2	0.00	0.00	0.34	0	0	6
Misinchinka	Upper	16.0	2022	2	0.00	0.00	0.40	0	0	6
Misinchinka	Lower	70.0	2022	3	0.28	0.05	0.85	19	3	59
Table	Upper*	15.6	2019-2021	2	69.9	57.8	83.4	1090	902	1301
Table	Lower**	22.0	1998-2007	2	13.6	8.64	20.0	299	190	441

* Table River did not receive a reconnaissance survey; upper reach estimates are based on long-term index site data from 2019-2021.
**Table River did not receive a reconnaissance survey; lower reach estimates are based on long-term index site data from 1998-2007.

Table 2. Abundance of Arctic Grayling in the Ingenika River, 2020 (Hagen and Stamford 2021).

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**

4.3 Population Trend

Like the densities, Arctic Grayling abundance trends vary among the three core areas of the Williston Reservoir watershed for which long-term abundance monitoring data exists. Counts of Arctic Grayling >20 cm in long-term index sections of the Anzac and Table Rivers exhibit a clear, increasing trend over the 1995-2022 period (Figure 3). When analyzed collectively using a linear-mixed effects model, these data suggest abundance[5] in the Parsnip core area increased significantly over the 1995-2022 period (P <0.001), equating to population growth of approximately 98% over 25 years (Hagen and Stamford 2023). The 1995 introduction of a region-wide catch-and-release regulation, as well as the possibility of successful adaptation to the new, post-flooding Parsnip River environment, are contributors to the increasing trend.

[5] Detection probability <1 was accounted for by analyzing variability among replicated counts in a binomial modelling framework with model parameters detection probability and abundance (Hagen and Stamford 2023). This was an early analog of the more advanced modelling framework utilized in O'Connor et al. (2026) to create Figure 2.

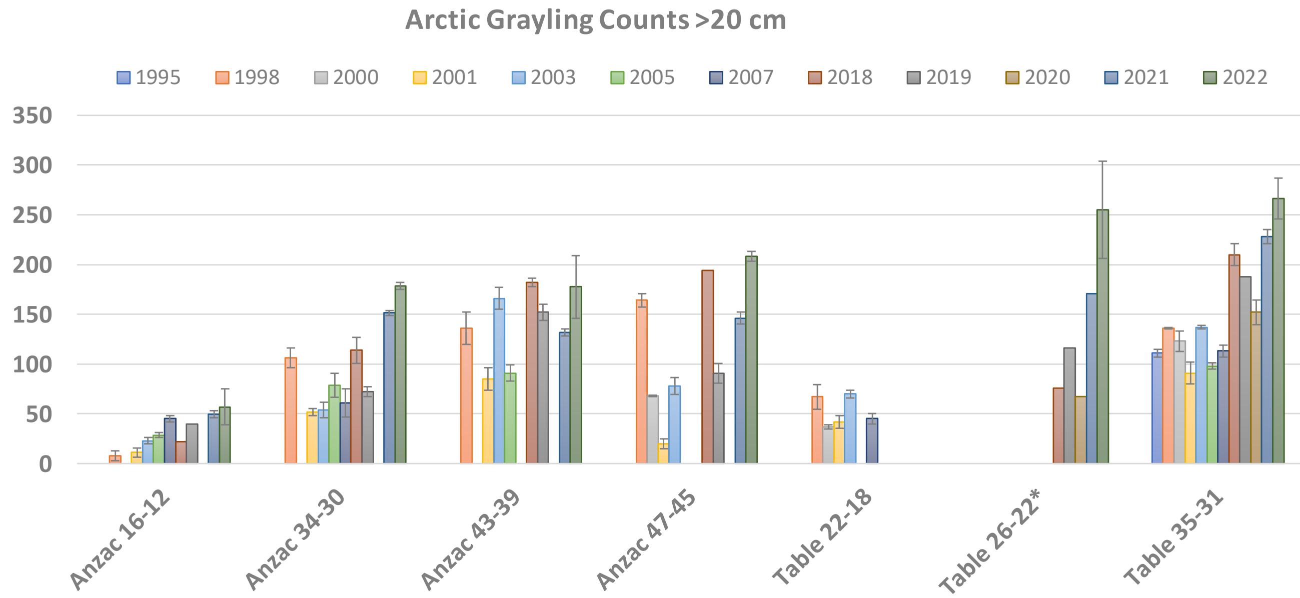

Figure 3. Unadjusted snorkeling counts of Arctic Grayling > 20 cm in index sites of the Anzac River and Table River watersheds 1995-2022. Error bars are standard errors for years with than one replicate count. Values are averages of replicate counts. Reprinted from Hagen and Stamford (2023).

In the Ingenika core area, just four years' snorkeling data from long-term index sections exist for evaluating change over time (Figure 4), although the 2004-2020 count data span a meaningful period >2 generations. Densities in index sections over the 2018-2020 period were comparable to 2004 and a significant trend was not indicated ($P = 0.132$) in a linear mixed-effects model analysis (Hagen and Stamford 2021), suggesting possibly stable abundance in this relatively pristine core area.

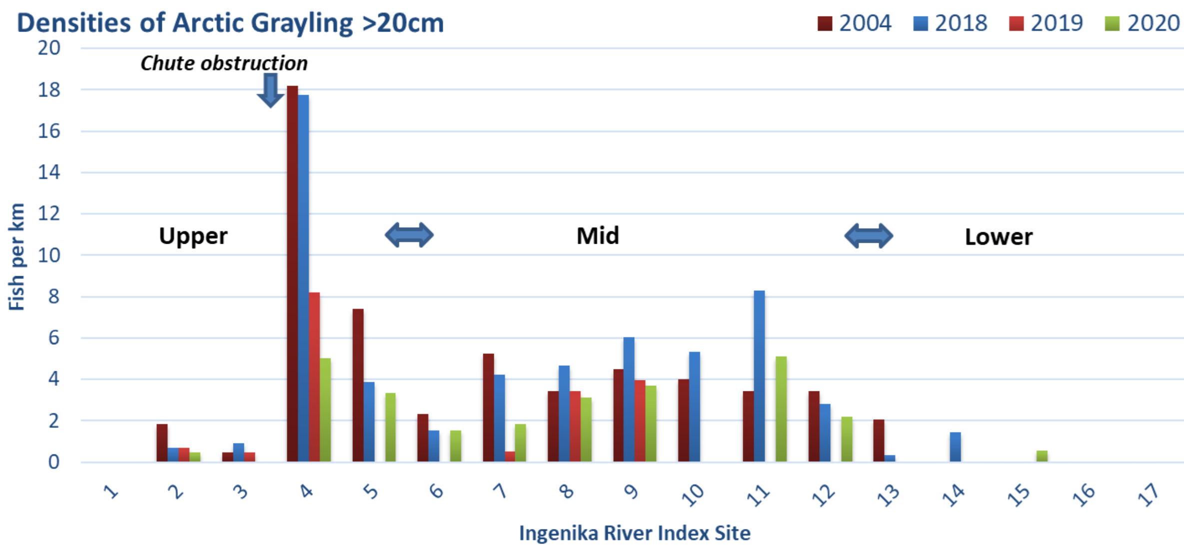

Figure 4. Unadjusted densities (fish/km) of Arctic Grayling >20 cm in index sites along the Ingenika River, 2004 (burgundy bars), 2018 (blue bars), 2019 (red bars), and 2020 (green bars). Reprinted from Hagen and Stamford (2021).

Snorkeling-based population estimates from long-term index sections of the Mesilinka River, in the Omineca core area, paint a contrasting picture of conservation concern. Mean abundance across the 1992-1999 period, estimated using two methods (mark-resight trials and an expansion method detailed in Wilson et al. [2008]), are significantly higher than abundance estimates from 2024 (Figure 5). Hagen et al. (2025) suggested that the mean mark-resight estimates and expanded counts from 1992-1999 could be seen as 'high' and 'low' estimates for the 1992-1999 period for comparing to 2024 estimates. This comparison suggests that 2024 system capacity may be as little as 20% of that observed during the 1992-1999 period.[6] A recent history of disturbance to forest cover in the Mesilinka River watershed, resulting from forestry and several large, severe fires, has been previously identified as a contributor to reduced Arctic Grayling abundance, loss of riparian forests, extensive bank erosion and mass wasting, fine sediment flows, and low availability of pools (Hagen et al. 2025).

[6] Two facts are caveats on this inference: 1) results from 2024 are a snapshot from a single year, and 2) results from 1992-1999 were collected during an enhancement experiment (Wilson et al. 2008).

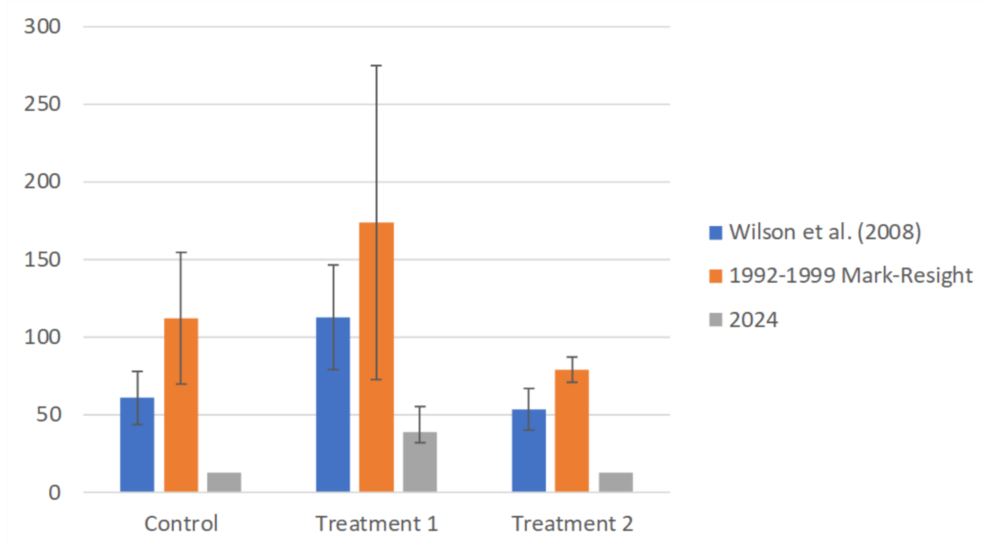

Figure 5. Mean estimated abundance of Arctic Grayling >20 cm in three long-term index sections of the Mesilinka River, for two time periods 1992-1999 and 2024. Blue and orange bars are estimates derived from the same snorkeling data 1992-1999, using separate methods (an expansion method detailed in Wilson et al. 2008, versus mark-resight trials). Reprinted from Hagen et al. (2025).

5 DISTRIBUTION AND CRITICAL HABITATS

5.1 Overview of Distribution and Critical Habitat Information

Knowledge of critical habitats and the distribution of Arctic Grayling identifies where recovery actions must be located to be effective, i.e. 'where to work'. Since 2017, FWCP has prioritized studies to identify distribution and critical habitats for Arctic Grayling using new techniques such as environmental DNA (eDNA), telemetry, and reconnaissance snorkeling surveys (e.g., Stamford et al. 2022; Hagen and Stamford 2023; Martins et al. 2022; Bottoms et al. 2023; O'Connor et al. 2026). The distribution of a species is also an indicator of conservation status, with a broader distribution suggesting increased resilience (Fredenberg et al. 2005; McElhany et al. 2000; Stamford et al. 2017).

Critical habitats were described in Stamford et al. (2017) as areas where limiting factors operate to regulate growth and survival for Arctic Grayling populations. At that time, a total of 80 stream segments providing critical habitats for at least one Arctic Grayling life stage were identified. Among these, information adequacy was estimated to be relatively high in only half the cases. Updates and improvements to the list of critical habitats, made possible because of prioritization of studies of distribution and critical habitats by FWCP since 2017, are presented in the following sub-section and detailed in Appendix A. Among 49 key references used to inform critical habitat segments for Williston Arctic Grayling (Appendix A), 17 (35%) consist of recent information collected to address high priority data gaps identified in Stamford et al. (2017).

Since 2017, multiyear, summer snorkeling surveys were paired with eDNA sampling and significantly improved the resolution of adult critical habitats in sub basins of the Parsnip, Omineca, and Ingenika core areas (Strohm et al. 2020; Hagen and Stamford 2021, 2023; Hagen et al. 2025; O'Connor et al. 2026). In these studies, eDNA samples informed the snorkel observations with presence/absence of Arctic Grayling DNA and the combined data enabled more accurate delineation of critical habitats. Snorkel observations also informed the eDNA detections with direct observations of rearing adults and enabled calibration of eDNA detection rates and detection distances in different streams (Strohm et al. 2020; Stamford et al. 2022). This paired sampling regime also enabled detection of fry/juvenile critical habitats in stream segments where adult Arctic Grayling were not observed snorkeling (e.g., Colbourne Creek; Parsnip core area).

Migratory behaviours identified critical habitats for other key life history stages and times of year. Movements were evaluated using direct observations of adult movements (acoustic telemetry) in the Parsnip core area (Martins et al. 2022; Bottoms et al. 2023) and using indirect or retrospective observations (fin ray microchemistry) from across the life cycle in the Omineca core area (O'Connor et al. 2026). Telemetry studies informed the connections between adult critical habitats across seasons, identified overwintering locations in the Parsnip River, and flagged movements into tributaries possibly for spawning. Furthermore, the analyses of acoustic telemetry data also informed detailed ecological studies that linked movement data with physical habitat parameters (e.g., stream morphology, water temperature) that define limiting factors for adults and juveniles within critical habitats of the Parsnip core area (Bottoms et al. 2023, 2025; O'Connor et al. 2025). The Parsnip core area presents a picture of complex migratory behaviour that includes spawning in the Parsnip River mainstem and small tributaries, with most adults exhibiting strong homing to the same summer rearing areas each year. A proportion of adults show less rearing site fidelity, however, and migrate to diverse summer rearing locations, possibly indicating a diversity in life history traits.

Microchemistry identified connections between juvenile rearing streams and those utilized by adult Arctic Grayling. Fin ray microchemistry analyses in Omineca core area found distinct element concentrations between adults rearing in Mesilinka River and Osilinka River that suggest adults in both streams complete their entire life history within their respective home streams (O'Connor et al. 2026). This result of demographic independence was unexpected given prior indications that adults moved between these streams (Stamford et al. 2017). Resident subpopulations like these are good candidates for displaying unique adaptive traits, a component of diversity important for long-term survival (resilience) of metapopulations. The Ingenika core area also sustains a small subpopulation, but the migratory behaviour remains less completely resolved. Possibly, the Ingenika core area is a subpopulation linked by adults that migrate among different watersheds (e.g., Lower Finlay, Fox rivers) as suggested by recent analyses of genetic and microchemistry analyses (Stamford Environmental genetic data and analyses on file).

Genetic data support the current structure that Upper Finlay Core Area is demographically independent from downstream, but a unique genotype among rearing adults in Toodoggone River also suggests demographic independence from the Finlay River. Further evaluation of population structure data is needed to substantiate the hypothesis that the Toodoggone River sustains yet another core area.

Beach seine sampling in the Upper Finlay core area found abundant fry rearing in the Finlay River mainstem but found surprisingly few yearling-sized juveniles (Chu Cho Environmental 2018). Beach seining has shown to be highly effective at capturing yearling sized juveniles that often rear in large rivers (e.g., Parsnip River, Mackay and Blackman 2012; Omineca River, Schell 2002) and their absence in the Finlay River mainstem despite significant beach seine effort suggests they prefer other habitats. Estimates of retrospective movements among the fry captured in the Finlay River mainstem, from otolith microchemistry, suggest a significant proportion (roughly 27%) originated from spawning areas outside of Finlay River (Stamford Environmental data and analyses on file). Tributaries and off channel habitats appear to provide important spawning and early rearing areas for emergent fry as well as potentially for the yearling-sized juveniles, yet these have yet to be delineated as critical habitats because of a lack of observations.

Finally, environmental DNA sampling in 28 streams draining into the Williston core area, Upper Peace core area, and Dinosaur Reservoir detected presence of Arctic Grayling DNA in seven (25%) Williston core area streams and one Upper Peace core area stream (Stamford et al. 2022). Combining these results with recent observations of rearing adults and juveniles has resulted in a significant expansion of the distribution of critical habitats in Williston core area from previous estimates of four streams to nine (Section 5.2; Appendix1). Negative eDNA results in all critical habitats previously described for Upper Peace core area and Dinosaur Reservoir suggest extirpation of populations due to flooding, and a significant range contraction for the species in the upper Peace Basin. The eDNA detections in Finlay Arm, Tony Creek, Tutu Creek (Williston core area), and Pardonet Creek (Upper Peace core area) should be considered insufficient to delineate critical habitats pending further evaluations. Critical habitats in Williston core area are supported by consistent eDNA detections across years and recent or substantial observations of adults in these streams. For instance, follow up fish sampling effort in five recurrent eDNA positive Finlay Reach streams suggest that Arctic Grayling are exceedingly rare but capture of two fry in the Ospika River indicates spawning (Stamford and O'Connor 2022). Consistent eDNA detections of Arctic Grayling presence in Finlay Reach, together with persistent observations of rearing subadults in streams (Appendix A) supports an intriguing hypothesis that Arctic Grayling continue to migrate through the reservoir to complete their life history.

In summary, the present update to the distribution of critical habitats in upper Peace Basin was informed mostly from 17 key references, which addressed data gaps identified in the 2017 synthesis (Stamford et al. 2017), and focused primarily on subadult and adult life history stages. New data and reports informed estimates of distribution and migratory behaviours in the Parsnip, Omineca, Ingenika, Lower Finlay, and Upper Finlay core areas. A new distribution of critical habitats in flooded core areas (Williston and Upper Peace) supports the hypotheses that 1) a vicariant migratory behaviour sustains critical habitats in Williston core area, 2) subpopulations in Upper Peace Core Area are extirpated or nearly so, and 3) Dinosaur Reservoir is not a viable core area. Data gaps associated with natal and juvenile critical habitats received less effort since 2017, but analyses of retrospective data (eDNA, microchemistry) suggest that small tributaries provide important natal habitats and potentially promote evolutionarily significant adaptive diversity in and among core areas. The importance of tributaries and off channel habitat use by yearling-sized juveniles also remains incompletely resolved. By refining the coordinates around critical habitats these updates provide improved focus for conservation and recovery actions.

5.2 Critical Habitats

Based on new abundance and habitat use data collected since the 2017 synthesis report (Stamford et al. 2017), as described in the preceding sections, we have been able to improve our understanding of critical habitat locations within the upper Peace Basin. Across the Williston Reservoir watershed, we delineated a total of 85 stream segments providing critical habitats for at least one Arctic Grayling life stage (fry, juvenile, subadult/adult rearing, overwintering). Descriptions and references for each critical habitat segment are presented in Appendix A. Among the 85 critical habitat segments, 23 were delineated for the Parsnip core area (Figure 6), 12 for the Nation core area (Figure 7), 13 for the Omineca core area (Figure 8), 5 for the Ingenika core area (Figure 9), 10 for the Lower Finlay core area (Figure 10), 9 for the Upper Finlay core area (Figure 11), and 13 for the Williston core area (Figure 12).

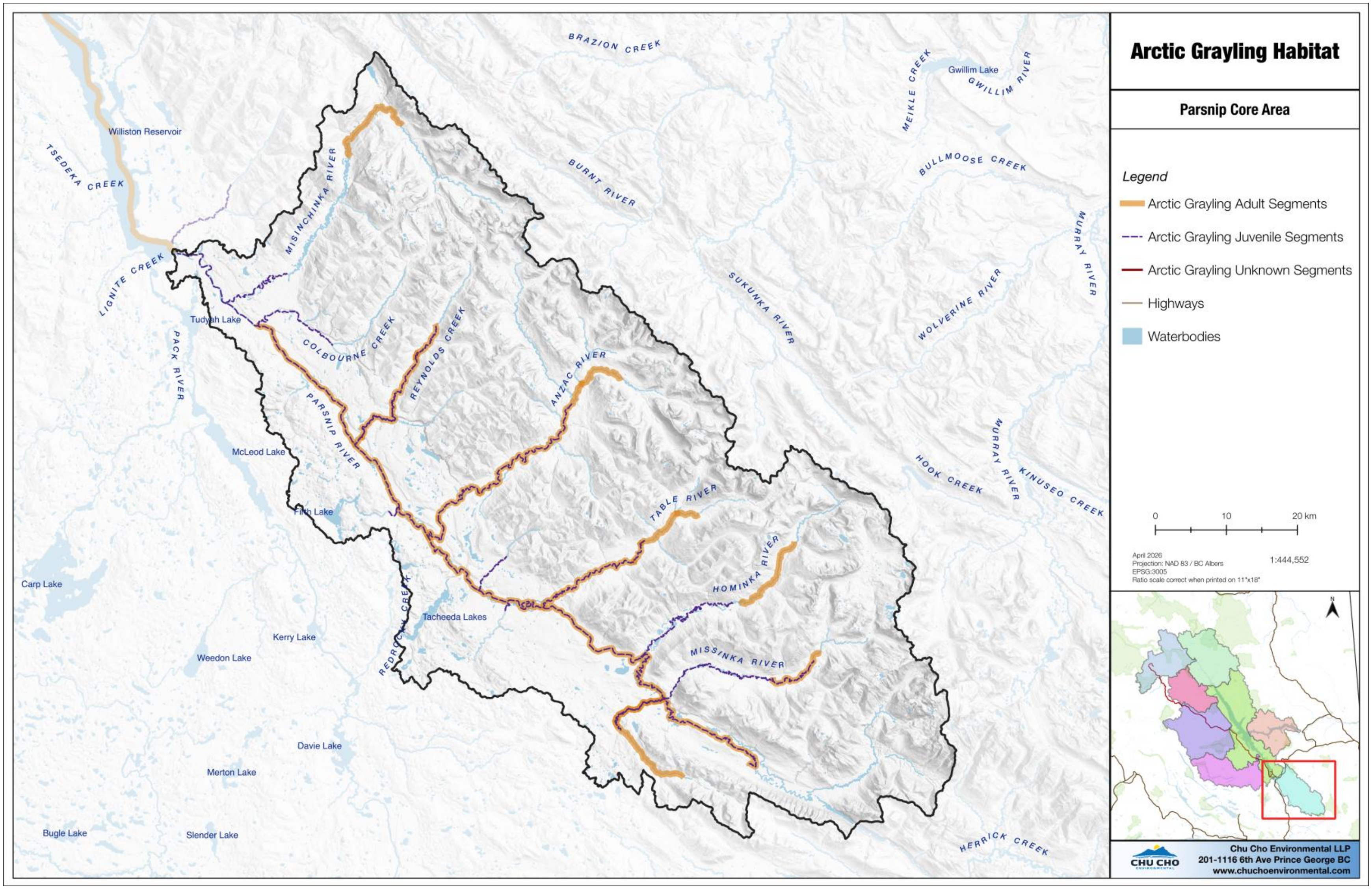

Figure 6. Critical habitat segments delineated for Arctic Grayling of the Parsnip core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping stippled over thick lines, respectively.

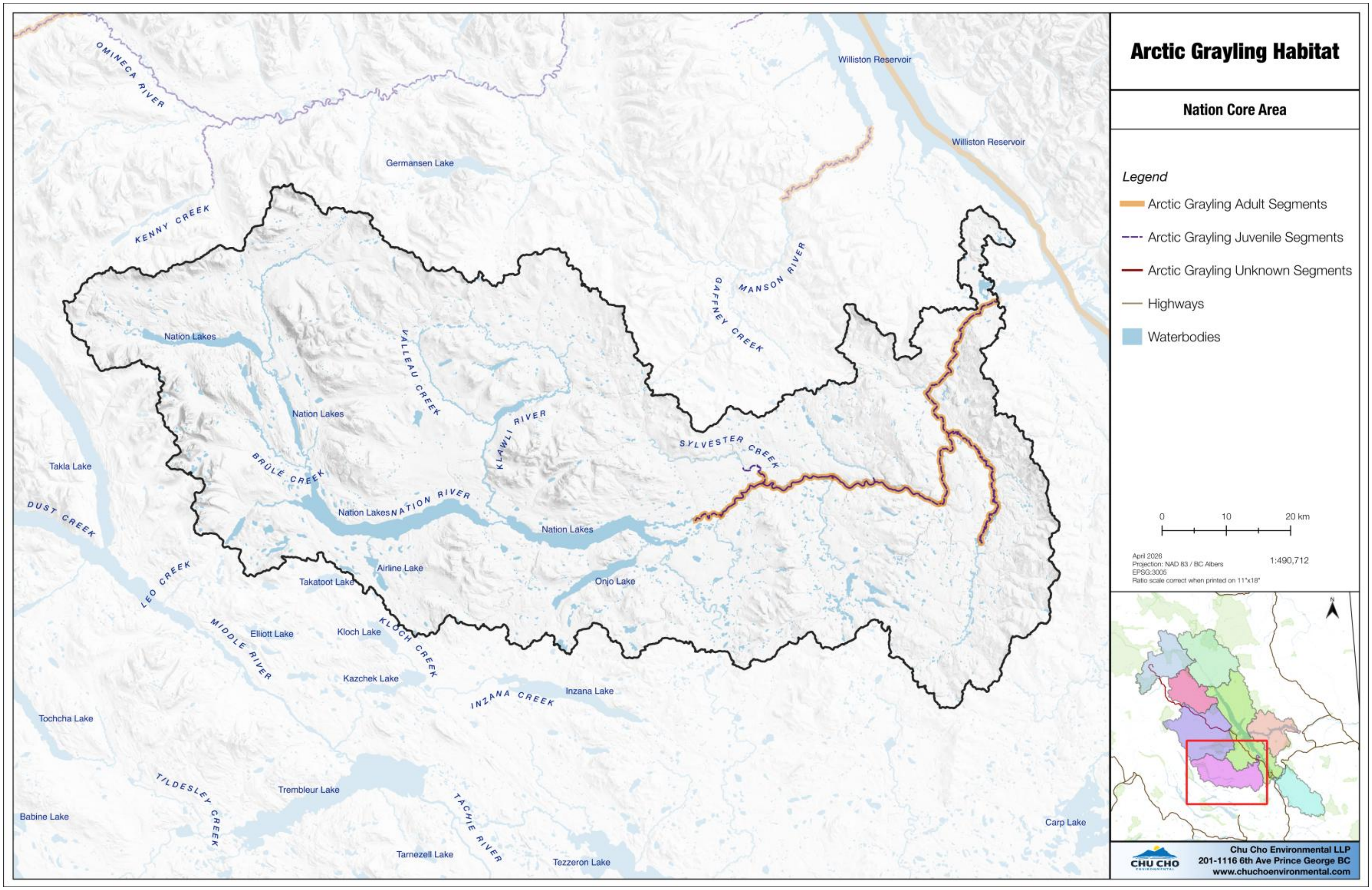

Figure 7. Critical habitat segments delineated for Arctic Grayling of the Nation core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping stippled over thick lines, respectively.

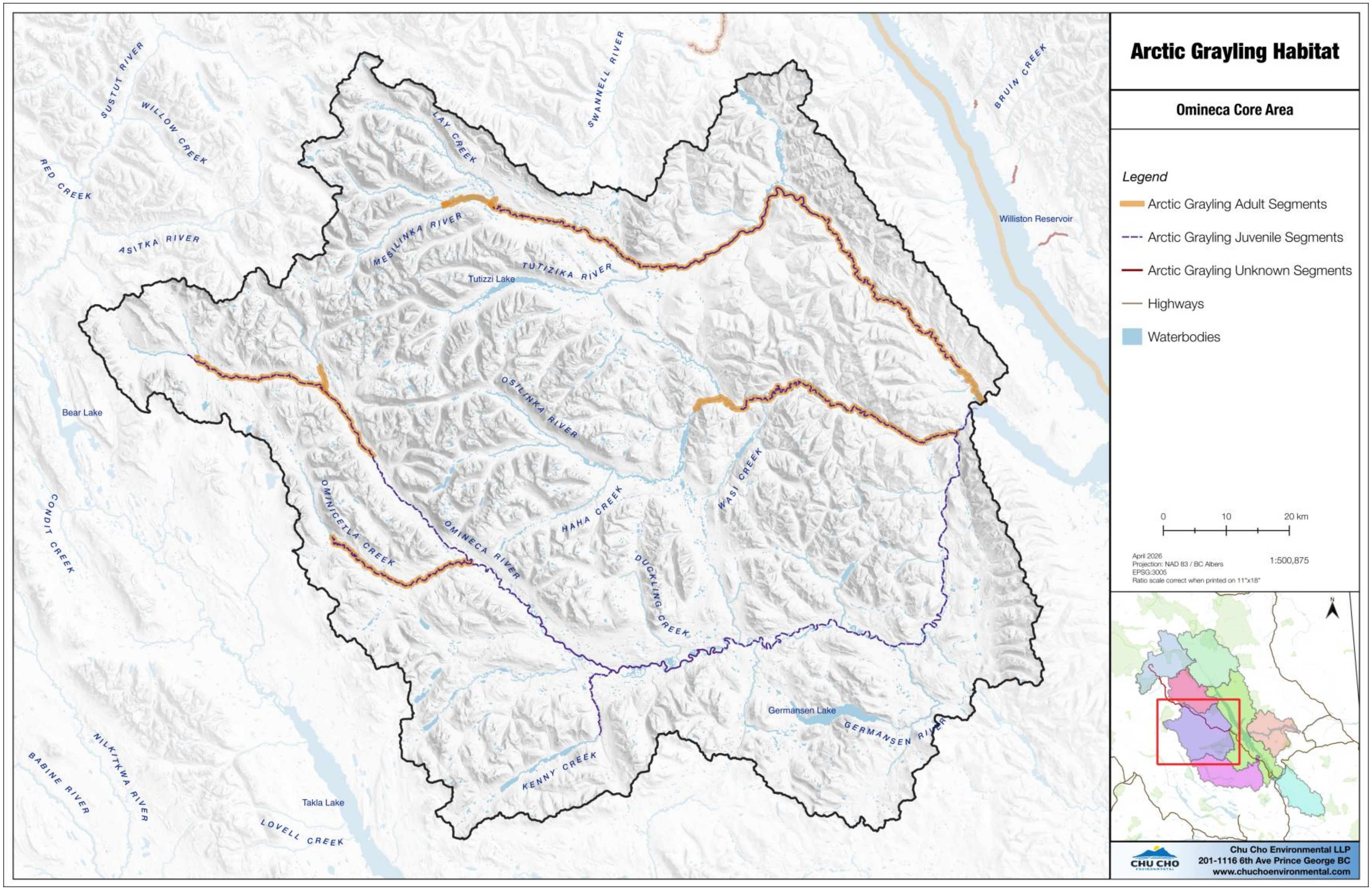

Figure 8. Critical habitat segments delineated for Arctic Grayling of the Omineca core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping stippled over thick lines, respectively.

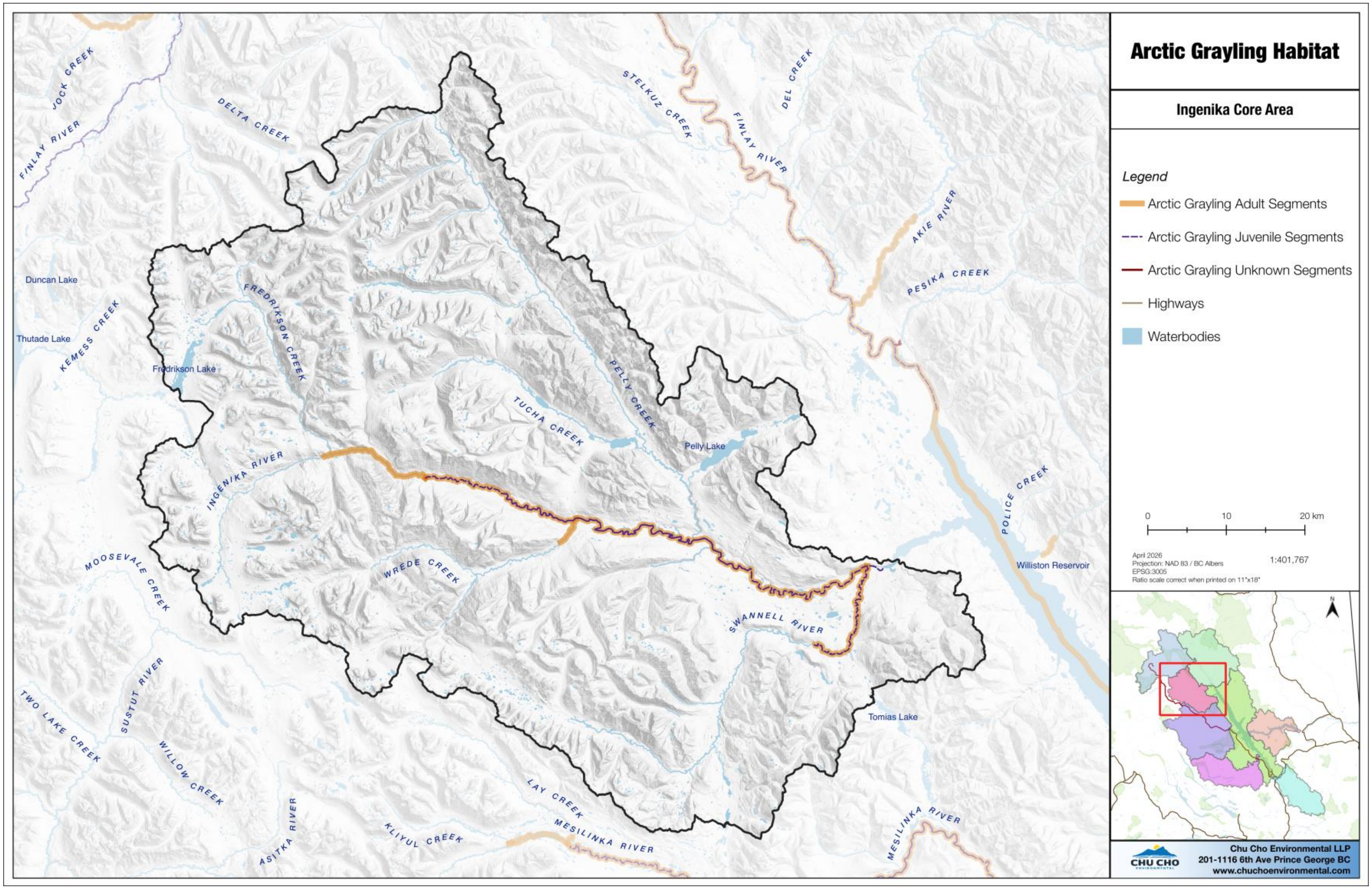

Figure 9. Critical habitat segments delineated for Arctic Grayling of the Ingenika core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping stippled over thick lines, respectively.

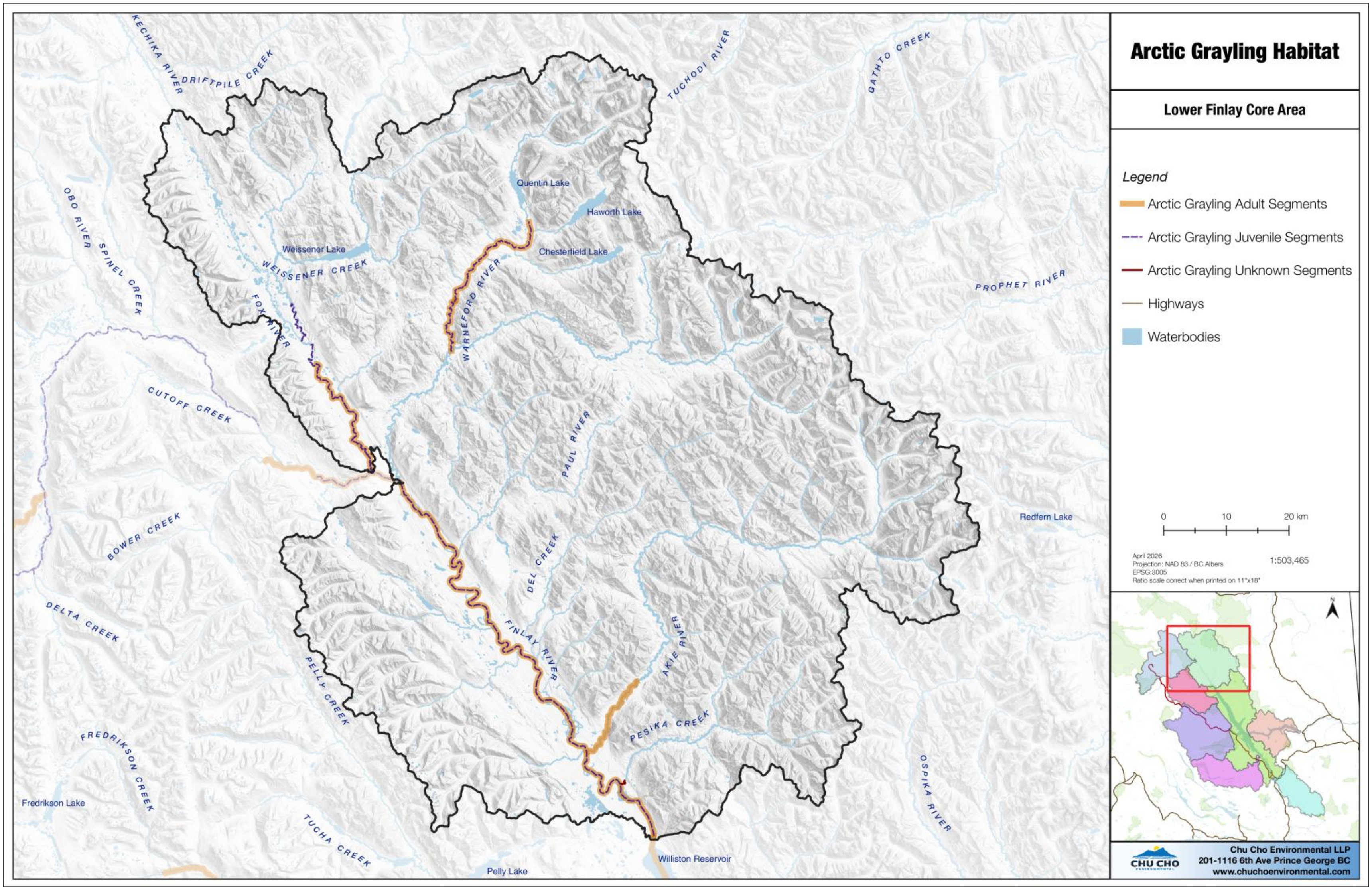

Figure 10. Critical habitat segments delineated for Arctic Grayling of the Lower Finlay core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping lines, respectively.

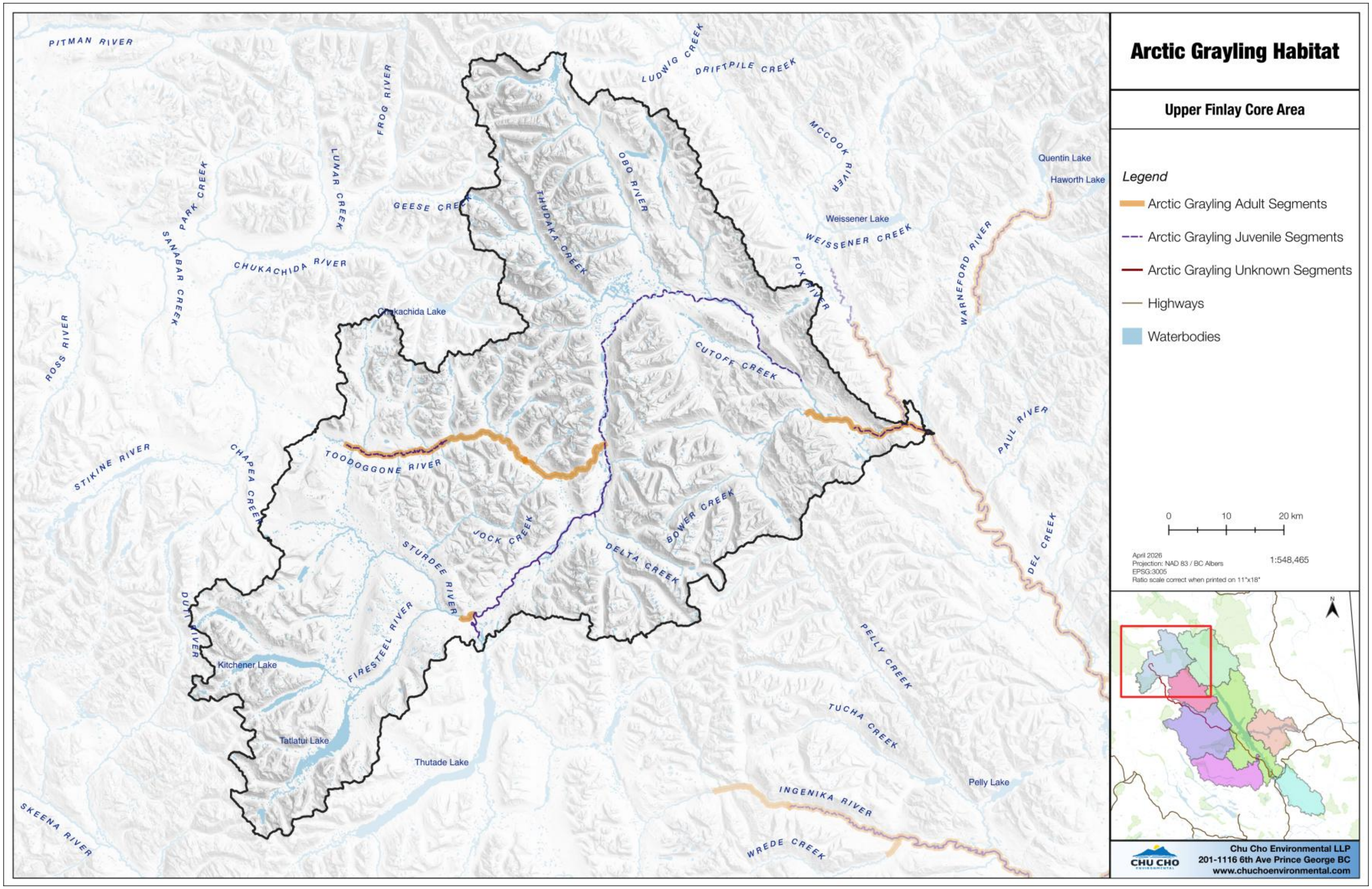

Figure 11. Critical habitat segments delineated for Arctic Grayling of the Upper Finlay core area. Segments utilized by adults/subadults, juveniles, or both life stages are thick brown lines, purple stippled lines, or overlapping stippled over thick lines, respectively (update required: adult distribution is contiguous with juvenile distribution upstream of Long Canyon rapids).

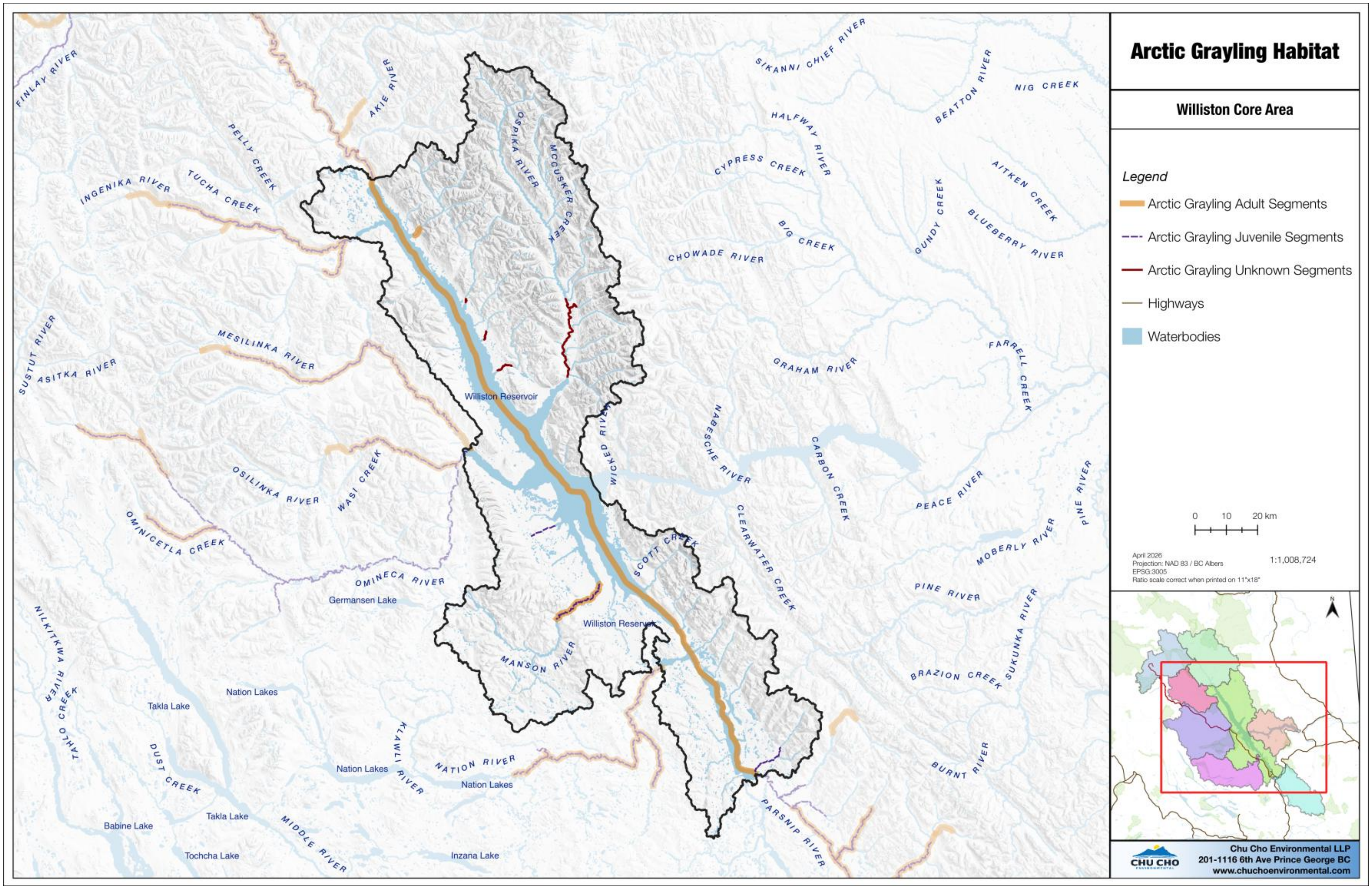

Figure 12. Critical habitat segments delineated for Arctic Grayling of the Williston core area. Segments utilized by adults, juveniles, both life stages, or unknown life stages are thick brown lines, purple stippled lines, overlapping stippled over thick lines, or thin red lines, respectively. The reservoir segment represents a putative migratory corridor for adults to access critical tributary habitats.

Among the 85 critical habitat segments, 33 (39%) describe adult summer rearing habitats, 40 (47%) describe juvenile and fry rearing areas, five (6%) describe overlapping adult and juvenile/fry habitats, and seven (8%) describe unknown life history stages (Appendix A). We did not distinguish overwintering and spawning locations, which are currently assumed to be included within or adjacent to fry and juvenile habitats. The Parsnip core area has by far the most habitat segments (23), which are in part a reflection of the accuracy of the monitoring data (Hagen and Stamford 2023), but different landscape features around watersheds also determine the types of habitats available to Arctic Grayling metapopulations. For instance, eight sub-basins support fry, juvenile and adult life history stages in the Parsnip core area, while only three or four sustain all life history stages in the other core areas (Figures 6-12). Conceivably, high abundance in the Parsnip core area (Section 4) is linked to the numerous subpopulations and associated adaptive diversity among sub-basins. Possibly, such a scenario was more widespread throughout upper Peace Basin prior to the flooding of Williston Reservoir.

Critical habitats were defined primarily by data and observations collected during August and describe habitat use by three life history stages, including fry (age 0+), juvenile (1+, 2+), and subadult and adult (age 3+ and older). Adult and juvenile life history stages often overlap in their summer rearing distributions but generally across all core areas, subadults and adults migrate upstream to find clear and cool (~12.5ºC) water and well-defined pools and riparian cover. Fry and juveniles remain downstream where low gradient river margins, small tributaries, and off channel habitats provide warmer water (~16ºC), rapid growth rates, and predator avoidance. Spawning habitats have not been precisely delineated for Williston Arctic Grayling and are currently assumed to be near fry and juvenile critical habitats due to the dispersal ability of these life stages. Overwinter habitats are also assumed to overlap with juvenile critical habitats (Section 3). Imprecise knowledge of overwintering and spawning locations remains an important information gap limiting conservation and recovery actions for these life stages, which could be addressed using relatively efficient, modern study methods (e.g., use of eDNA, retrospective analyses of microchemistry).

Generally, across all core areas, critical habitat summary comments in Appendix A provide a brief description of critical habitats (e.g., important high summer temperature refuge), convey important details about the sampling information (e.g., records include a single sampling episode), and identify key reference material. Summary comments are more detailed for Parsnip core area because more information is available to describe the habitat use and distribution. Information describing other core areas is scarcer and therefore comments are often briefer.

A folder containing geospatial data for Arctic Grayling stream segments will be uploaded to the BC Ecological Reports Catalogue (EcoCat) along with this report. Importantly, the GIS spatial files provided the basis for defining spatial units for further analysis of cumulative effects, as described in Section 6.

5.3 Distribution

The distribution (spatial extent of occurrence) of a trout species is an indicator of its conservation status within the *Core Area Conservation Status* risk assessment method (Fredenberg et al. 2005), which we have adapted for application to Arctic Grayling (Section 7). We estimated the total distribution of Arctic Grayling within core areas of the Williston Reservoir watershed based on the upstream extents of critical habitats among the core area's sub-basins, while assuming that the reservoir interface was the downstream extent (Table 3).

Table 3. Linear distribution of Arctic Grayling habitats (reservoir interface to upstream extent) within eight core areas of the Williston Reservoir watershed.

Core Area	Critical Habitat Segments	Total Distribution (km)
Parsnip	23	487
Nation	12	142
Omineca	13	494
Ingenika	5	134
Lower Finlay	10	238
Upper Finlay	9	234
Williston	13	106
Upper Peace	0	0

6 LIMITING FACTORS AND THREATS

6.1 Cumulative Effects Modelling for Prioritizing Recovery Actions

Knowledge of limiting factors affecting growth and survival of Arctic Grayling identifies what kinds of recovery actions are necessary. Because uncertainty around limiting factors is a cause for low investment in recovery actions in the upper Peace Basin (Legault 2025), in this study we prioritize the analysis of natural limiting factors and anthropogenic threats by employing a a newly-available approach. The *Cumulative Effects Modelling for Prioritizing Recovery Actions* (CEMPRA; Bayly et al. 2024) framework is a conservation tool designed to synthesize information about limiting factors and to estimate their cumulative effects on the capacity of ecosystems to support a particular species.[7]

The 'Joe Model' at the core of CEMPRA (named in honour of University of Alberta professor emeritus Joe Nelson) is a semi-quantitative, static model composed of a series of stressor-response curves that describe the relationship between aquatic 'system capacity' and the stressor variable (MacPherson et al. 2020). In this report, system capacity is defined as a unitless metric representing the capability of an environment to support Arctic Grayling, expressed as a percentage of the maximum possible capacity (Bayly et al. 2024). Anthropogenic threats and natural limiting factors both are stressors that affect system capacity.

[7] The CEMPRA (Cumulative Effects Model for Prioritizing Recovery Actions) code is publicly available on GitHub, split into two open-source components: the core R package (https://github.com/essatech/CEMPRA) and the interactive R Shiny interface (https://github.com/essatech/CEMPRAShiny).

As a high-level overview, CEMPRA integrates stressor-response functions (i.e., measures of a species' response to an environmental stressor or driver) with spatial layers of stressor distributions (i.e., stressor magnitudes) to compute a 'response score' (i.e. remaining system capacity) on a scale of 0-1 (or 0-100%). Through transparent hypotheses about limiting factors and by being spatially explicit, CEMPRA is thus able to provide a clearer picture of two of the critical prerequisites for conservation planning identified in Section 1: "where to work" and "what to do." For example, areas that are within the range of thermal suitability for Arctic Grayling would receive a score of 1, and areas that are wholly unsuitable would receive a zero. The scoring for the intermediate values between these bounds is determined by the shape of the relevant stressor-response function. Spatial layers of individual response scores are then multiplied together to compute a system capacity score. The general idea behind the multiplicative approach to cumulative effects models is that the system capacity score is throttled by the most limiting factors included in a model (e.g., ten layers of score 1 would equal one; nine layers of score 1 and one layer of score 0 would equal zero – drawing attention to the most limiting factor). Cumulative pressures along intermediate values are expressed equally as well by this method (e.g., ten layers each with a score of 0.9 would equal a system capacity of 0.9^{10}, or 0.35 [35% of maximum system capacity]).

6.2 Key Stressors for Williston Arctic Grayling

As the first step in the CEMPRA modelling process, a review of the Arctic Grayling status literature was conducted to compile a comprehensive list of limiting factors and threats hypothesized to drive patterns of abundance and distribution across the species' range. The relative importance or relevance of each these stressors for Arctic Grayling of the upper Peace Basin was then evaluated in a 3-stage expert judgement process involving six participants (including the authors) with extensive knowledge of both Arctic Grayling and the geography of the basin. In the first stage, a spreadsheet describing each stressor from the literature and potential indicators of stressor magnitude was shared, and participants were asked to 1) identify whether the stressor was relevant to the upper Peace Basin, 2) provide a categorical ranking of the importance of the stressor mechanism to Arctic Grayling in the basin, and 3) rationalize their choices through comments and literature references. Participants were also able to add new stressors for consideration. A total of 26 potential stressors were identified through this process. In the second stage, participants met online for a 3-hour discussion of the listed stressors, their potential importance for Arctic Grayling of the upper Peace Basin, whether assessing stressor magnitude was technically feasible, and whether stressors were tractable as targets for compensation actions. Finally, participants were invited to revise their original rankings. A consensus (reached March 3, 2026) of the relative importance among the 26 stressors to Arctic Grayling of the upper Peace Basin is presented in Figure 13.

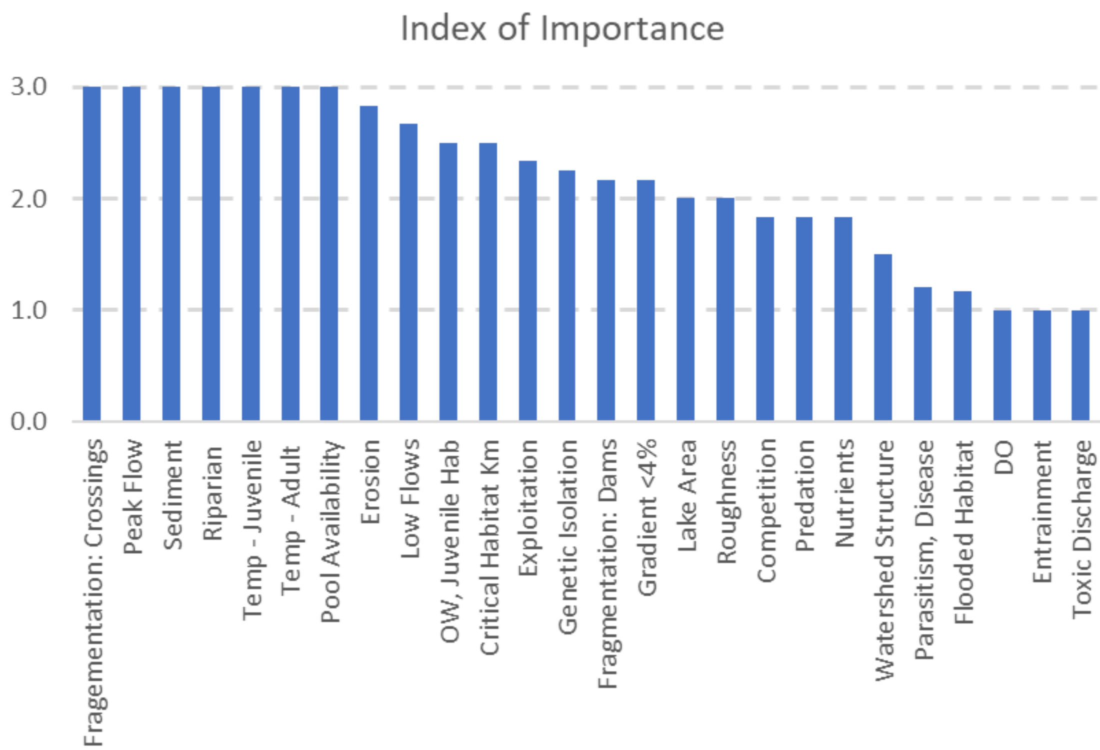

Figure 13. Arctic Grayling limiting factors and threats from a review of the range-wide status literature, ranked during an expert's workshop in terms of relative importance within the Williston Reservoir watershed. Priority level 3 is the highest importance; priority level 1 is low importance or not applicable.

6.3 Stressor-Response Curves and Stressor Magnitude Inputs

A total of 11 high-priority stressors were developed into stressor-response functions in advance of the CEMPRA modelling. Literature reviews and derivation of the stressor-response functions are presented in technical document which comprises Appendix B. Six of these stressors (Table 4) were selected for the CEMPRA modelling which fit the following criteria:

1. The stressor was deemed to be important potential factor affecting Arctic Grayling system capacity in the upper Peace Basin
2. A plausible stressor-response curve was available
3. Stressor magnitude data were available or could be estimated reliably
4. The stressor provided a tractable target for near-term recovery actions including conservation, restoration, and enhancement.

Table 4. Stressors utilized in the CEMPRA modelling for Arctic Grayling in the upper Peace Basin. Stressor-response curve development and background rationale are described in Appendix B.

Stressor	Indicator(s)	Rationale
Peak Flow	Equivalent Clearcut Area (%)	High and variable flows limit spring rearing space for young-of-year and can strongly affect recruitment success; also linked to changes in river morphology affecting productivity for salmonids
Sediment and Surface Erosion	WSEP[1] Tier 1 Indicator Score	Negative effects directly on the health and survival of individual fish, and also through degradation of habitat for feeding and reproduction (turbidity, stream morphology).
Fragmentation - Culverts	Small Stream Crossing Density (No./km^2)	Small streams are important for spawning and fry rearing but critical habitats have been poorly described. Restricted access to this habitat type can seriously harm or eliminate Arctic Grayling from a watershed
Stream Temperature - Juveniles	Maximum Weekly Average Temperature	Generally, young-of-year Arctic Grayling fry do well in warm summer rearing areas where survival is linked to rapid growth rate during the first year, but physiological stress occurs above 18°C
Stream Temperature - Adults	Maximum Weekly Average Temperature	Arctic Grayling subadults/adults prefer cooler summer rearing temperatures than juveniles; Williston Arctic Grayling are found in water temperatures below 15°C.
Angling Mortality	Remoteness, Stream Crossing Density	Arctic Grayling are highly catchable relative to other salmonids and angling harvest has resulted in declines across the species' range. The stressor-response curve assumes relatively high catch-and-release survival.

[1] BC Watershed Status Evaluation Program

We built the CEMPRA models using stressor-response functions (Figure 14) defined by a combination of quantitative data and semi-quantitative scoring gathered via an expert elicitation exercise (see Appendix B). These were merged with spatial layers of stressor magnitudes compiled using GIS indicators, model outputs, or available empirical data.[8] For the maximum weekly average temperature (MWAT) layers, a spatial stream network model (O'Connor et al. 2025) was matched to layers where it was available, and a simpler basin-level regression model (data on file from ESSA Technologies, 2025) was used for the remaining layers. The GIS layers were calculated individually for two spatial scales: 1) sub-basins suggested by the critical habitat spatial layer (Section 5), and 2) at a finer resolution, 1:20,000 BC Government Watershed Atlas Assessment Watersheds (Watershed Assessment Units: WAUs).

[8] A folder containing the data package and model code will be uploaded to the BC Ecological Reports Catalogue (EcoCat) along with this report.

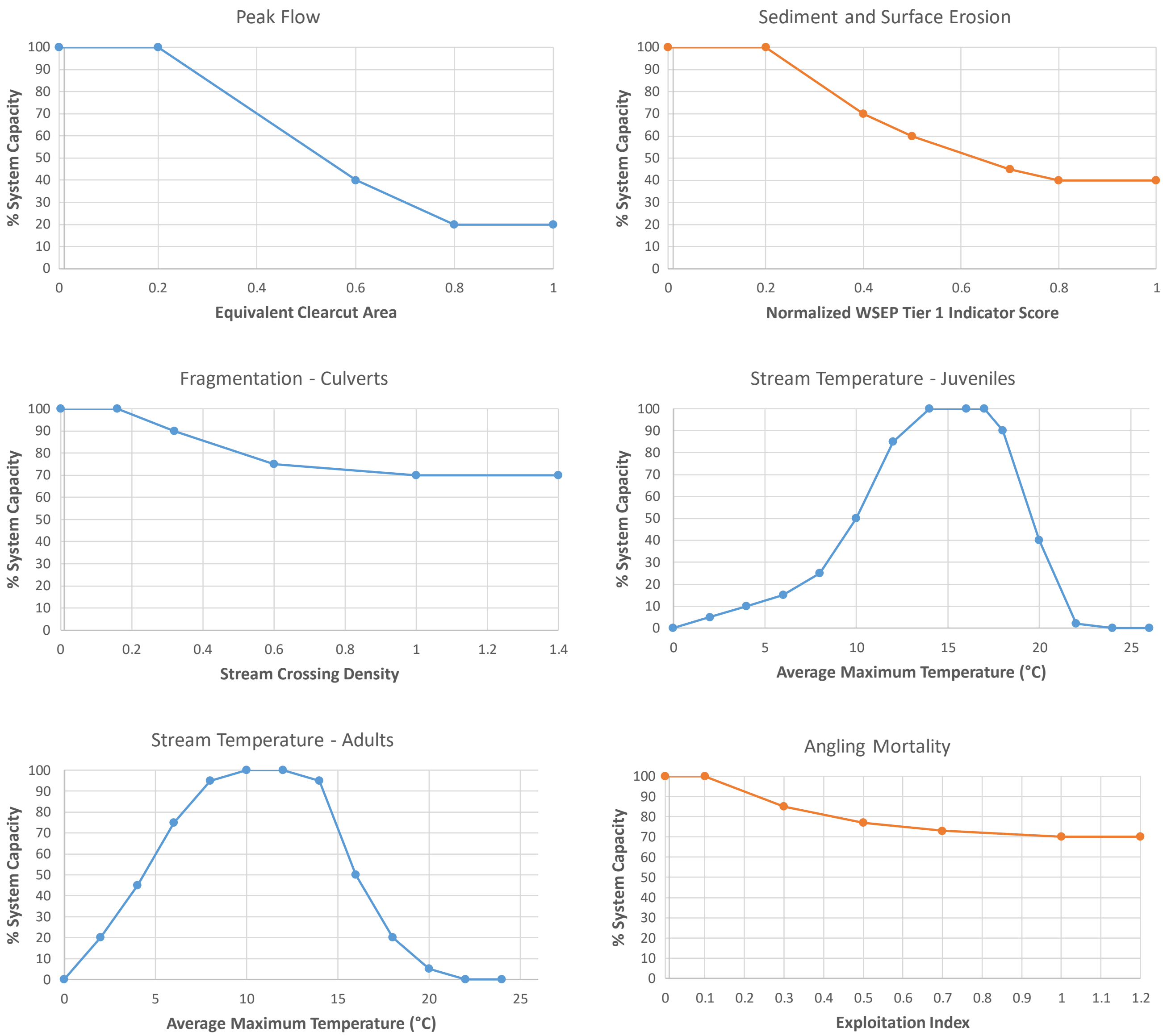

Figure 14. Hypothesized relationships (stressor-response curves) between Arctic Grayling system capacity and six priority stressors for the upper Peace Basin.

6.4 Priorities for Conservation and Restoration

Using the CEMPRA modelling framework, system capacity scores were computed for individual stressors and for their cumulative effects at both spatial scales (Figure 15, Figure 16). For areas with known, discrete life stage partitioning (i.e., the Parsnip River and Lower Omineca sub-basins), stressor magnitudes were omitted from the calculation where species were known not to be (e.g., the angling index was omitted from juvenile-only habitats to not unduly influence the habitat capacity score).

The interpretations of CEMPRA outputs must consider the scale of analysis. Sub-basin scale outputs (Figure 15) represent limitations to putative local populations and/or critical habitats, and the spatial scale to which abundance and trend monitoring data can be related (Section 4) but may be too large to delineate focused, prescriptive conservation actions. WAU-scale models depict much finer outputs that are especially valuable for identifying targets for recovery actions where the effects of limiting factors are most acute (Figure 16), but may not accurately represent system capacity at the population scale. Despite this limitation, WAU-scale models can help practitioners home in on specifically where to work and what priority stressors would benefit from action, though these insights must be considered carefully against upstream and downstream connectivity of these stressors.

The CEMPRA outputs are a particularly useful line of evidence for prioritizing Arctic Grayling conservation, restoration, and enhancement actions. To facilitate this prioritization and identify opportunities on the landscape, ranked lists of all locations included in the CEMPRA model were produced for each of the two spatial scales analyzed. Spatial units (sub-basins or WAUs) with low system capacity scores can be interpreted as priority areas for restoration (Table 5, Table 7) and areas with high system capacity scores as priority areas for conservation (Table 6, Table 8).

Across scales, the priority limiting factors were generally sedimentation issues, temperature, and peak flows. Waters of the Ingenika, Upper and Lower Finlay, and the Omineca core areas were top candidates for protection and conservation, while the Parsnip, Nation, and Williston core areas were top candidates for restoration. Discrete exceptions to both generalities apply when examined across scales and when referencing on-the-ground observations. The CEMPRA models are intended to aid conservation practitioners in planning by providing context, and we emphasize the importance of context in their interpretation as well. Within top contenders on each list, there are exceptions when looking at different scales that are critically important to consider when planning boots-on-the-ground intervention. As just one example, reaches of the lower Table River were among priority sites for restoration, while reaches of the upper Table River were among priority sites for conservation.

The CEMPRA outputs enable prioritization among limiting factors, but are not implicitly prescriptive. Next steps for practitioners will be to reference the priority stressors indicated by the model and to design an appropriate restoration plan(s). For example, if ‘sedimentation and surface erosion’ is indicated as a priority stressor for a given location, determining the appropriate restoration action will first require a site assessment of what is driving the GIS indicator (e.g., land use, post-fire erosion, unstable slopes, road crossings, etc.).

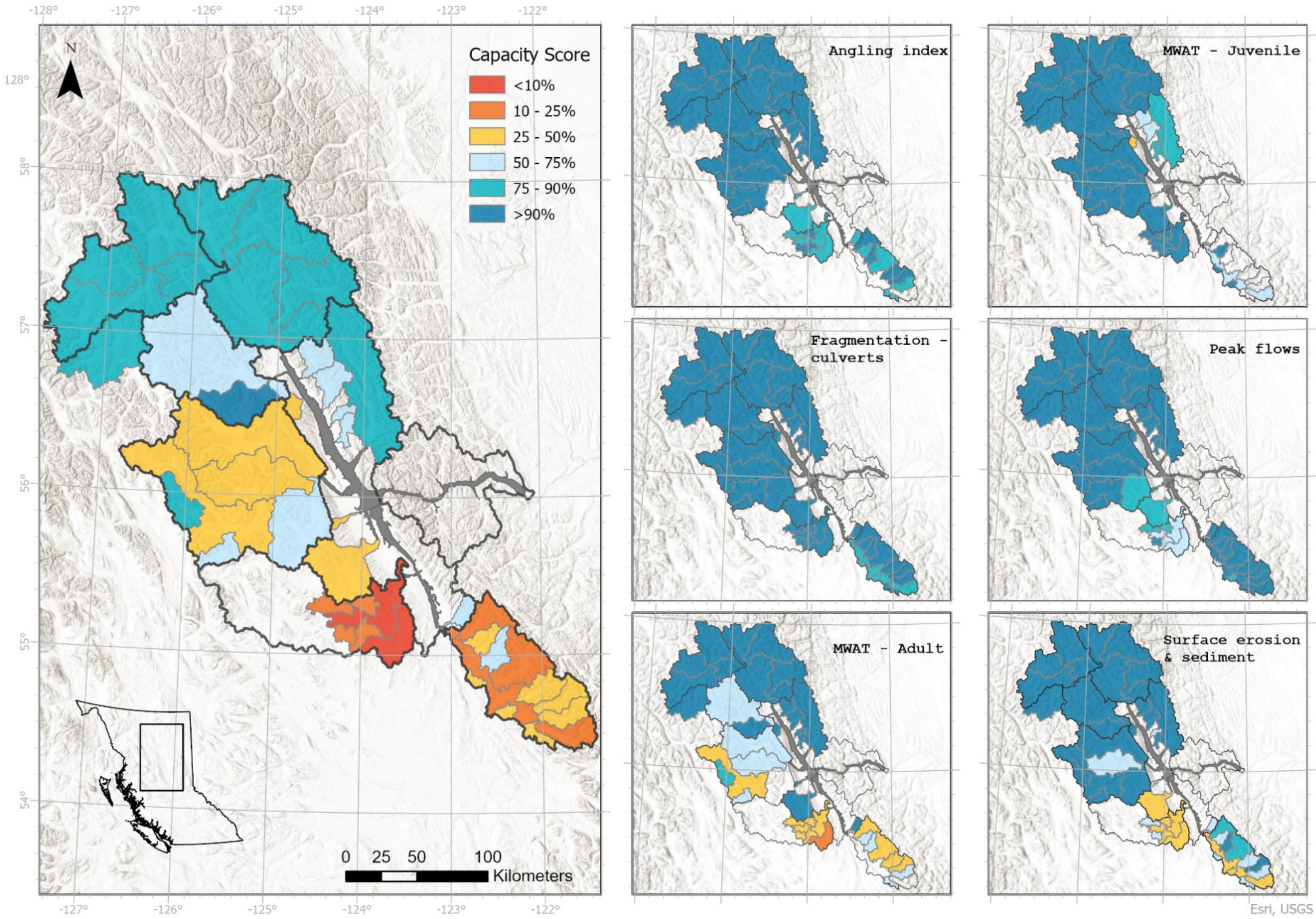

Figure 15. CEMPRA model outputs at the sub-basin scale. Cumulative effects on system capacity are shown in the left panel and the response scores of the individual stressor layers are shown on the right. Sub-basins with no system capacity scores are included within an Arctic Grayling core area but do not have any known critical habitats.

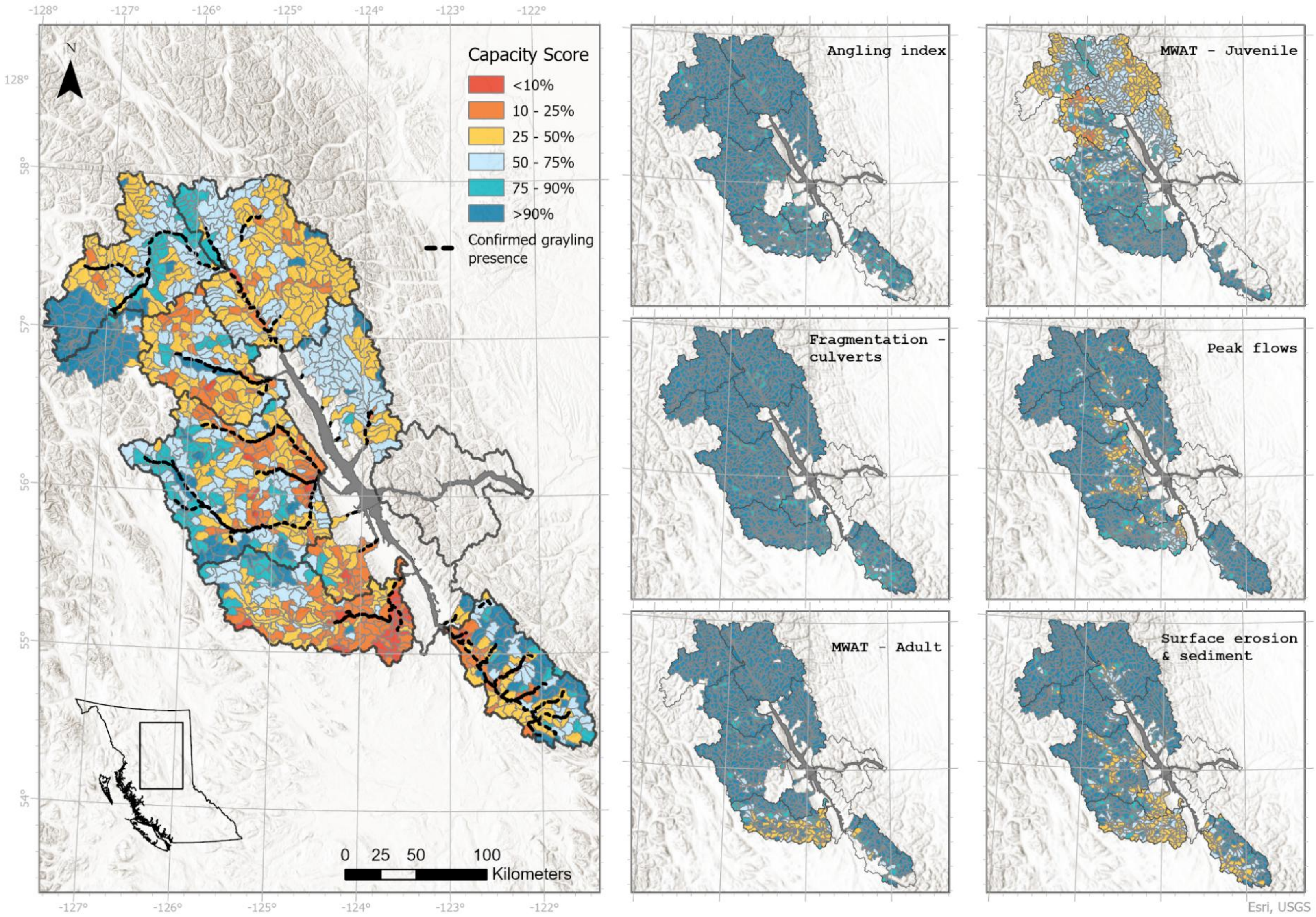

Figure 16. CEMPRA model outputs at the Watershed Assessment Unit (WAU) scale. Cumulative effects on system capacity are shown in the left panel and the response scores of the individual stressor layers are shown on the right. WAUs with no system capacity scores are included within an Arctic Grayling core area but are not within the watershed contributing area of any known critical habitat.

Table 5. Restoration priorities at the sub-basin scale (sub-basins with high cumulative effects), ranked according to estimated cumulative effects of stressors on system capacity. System capacity is the product of individual stressor scores, each computed using the stressor response functions against the stressor magnitude layers at this scale.

Core Area	Sub-basin	System Capacity	Angling Index	Fragmentation - culverts	MWAT - Adult	MWAT - Juvenile	Peak Flows	Sediment & Surface Erosion
Nation	Philip Creek	0.04	0.89	0.92	0.21	0.91	0.65	0.40
Nation	Nation River	0.07	0.87	0.99	0.30	0.97	0.68	0.43
Nation	Rainbow Creek	0.10	0.92	0.96	0.41	1.00	0.71	0.40
Nation	Munroe Creek	0.12	0.96	0.98	0.42	1.00	0.77	0.40
Nation	Sylvester Creek	0.13	0.84	1.00	0.33	0.99	0.89	0.54
Nation	Suschona Creek	0.19	0.91	1.00	0.35	1.00	1.00	0.59
Parsnip	Misinchinka River	0.19	0.91	1.00	0.25	NA	1.00	0.84
Parsnip	Anzac River	0.21	0.90	1.00	0.27	NA	1.00	0.88
Parsnip	Parsnip River	0.21	NA	0.88	NA	0.55	1.00	0.44
Parsnip	Table River	0.25	0.92	0.96	0.39	NA	1.00	0.72
Parsnip	Firth Creek	0.25	NA	0.87	NA	1.00	0.57	0.52
Williston	Manson River	0.28	0.86	0.96	0.95	0.99	0.86	0.43
Parsnip	Bills Creek	0.29	NA	0.83	NA	1.00	0.87	0.40
Williston	Fries Creek	0.34	0.76	1.00	1.00	0.67	1.00	0.66
Omineca	Osilinka River	0.35	0.97	1.00	0.56	1.00	0.92	0.70
Parsnip	Colbourne Creek	0.38	0.79	1.00	0.68	1.00	1.00	0.71
Parsnip	Hominka River	0.39	0.93	0.99	0.45	NA	1.00	0.95
Parsnip	Wichcika Creek	0.40	0.88	1.00	0.75	NA	1.00	0.61
Parsnip	Missinka River	0.43	0.83	0.97	0.73	NA	1.00	0.72
Omineca	Upper Omineca River	0.45	1.00	1.00	0.45	1.00	1.00	1.00
Omineca	Mesilinka River	0.47	1.00	1.00	0.54	1.00	0.94	0.92
Williston	Factor Ross Creek	0.49	1.00	1.00	1.00	0.49	1.00	0.99
Parsnip	Reynolds Creek	0.53	0.96	1.00	0.55	NA	1.00	1.00
Williston	Mischinsinlika Creek	0.53	0.78	1.00	0.97	NA	1.00	0.70
Williston	Collins Creek	0.54	0.96	1.00	1.00	0.78	1.00	0.73

Table 6. Conservation priorities at the sub-basin scale (sub-basins with low cumulative effects). Complete list of sub-basin rankings that fall above the 60th percentile of system capacity, implying relatively low impacts of limiting factors on conservation status and extirpation risk. System capacity is the product of individual stressor scores, each computed using the stressor response functions against the stressor magnitude layers at this scale.

Core Area	Sub-basin	System Capacity	Angling Index	Fragmentation - culverts	MWAT - Adult	MWAT - Juvenile	Peak Flows	Sediment & Surface Erosion
Ingenika	Swannell River	0.92	1.00	1.00	0.96	0.96	1.00	1.00
Upper Finlay	Upper Finlay	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Upper Finlay	Toodoggone River	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Upper Finlay	Lower Upper Finlay	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Lower Finlay	Pesika Creek	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Lower Finlay	Lower Finlay River	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Lower Finlay	Kwadacha River	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Lower Finlay	Fox River	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Lower Finlay	Akie River	0.89	1.00	1.00	0.98	0.91	1.00	1.00
Omineca	Ominicetla Creek	0.85	1.00	1.00	0.85	1.00	1.00	1.00
Williston	Ospika River	0.78	1.00	1.00	1.00	0.78	1.00	1.00
Omineca	Lower Omineca River	0.74	NA	1.00	NA	1.00	0.76	0.98
Williston	Davis River	0.72	1.00	1.00	1.00	0.72	1.00	1.00
Williston	Lafferty Creek	0.71	1.00	1.00	1.00	0.78	1.00	0.92
Williston	Chowika Creek	0.69	1.00	1.00	1.00	0.69	1.00	1.00
Ingenika	Ingenika River	0.67	1.00	1.00	0.67	1.00	1.00	1.00
Omineca	Silver Creek	0.66	1.00	1.00	0.66	1.00	1.00	1.00

Table 7. Restoration priorities at the WAU scale (WAUs with high cumulative effects), ranked according to estimated cumulative effects of stressors on system capacity. System capacity is the product of individual stressor scores, each computed using the stressor response functions against the stressor magnitude layers at this scale. For WAUs that do not have a gazetted name, the HUC_ID column has been preserved to aid practitioners in restoration planning when referencing the GIS files produced with this report. Note that WAUs represent a finer assessment scale than whole drainages, thus gazetted names inherited from the larger scale will appear at several different points on the list depending on where that reach is in the larger drainage.

HUC_ID	WAU	System Capacity	Angling Index	Fragmentation - culverts	MWAT - Adult	MWAT - Juvenile	Peak Flows	Sediment & Surface Erosion
11897	Philip Creek	0.03	1.00	0.84	0.30	0.96	0.27	0.40
12021	Nation River	0.03	1.00	1.00	0.40	1.00	0.20	0.40
12019	Nation River	0.04	1.00	0.81	0.43	1.00	0.28	0.40
11899	NA	0.07	0.72	0.73	0.80	1.00	0.39	0.40
11911	Philip Creek	0.07	0.98	0.97	0.28	0.96	0.65	0.40
3667	Finlay River	0.08	1.00	0.88	1.00	0.75	0.27	0.43
12952	Misinchinka River	0.08	0.79	0.92	0.31	NA	0.90	0.40
12025	Nation River	0.10	1.00	1.00	0.32	0.98	0.76	0.40
9369	Omineca River	0.10	1.00	0.97	0.41	1.00	0.34	0.72
9322	Osilinka River	0.10	1.00	0.98	1.00	0.74	0.29	0.49
10381	Mesilinka River	0.10	1.00	1.00	0.78	1.00	0.20	0.64
11931	Sylvester Creek	0.11	0.96	1.00	0.35	1.00	0.67	0.47
12020	Nation River	0.12	1.00	1.00	0.38	1.00	0.58	0.53
11926	Rainbow Creek	0.12	0.97	0.97	0.44	1.00	0.69	0.40
13056	Parsnip River	0.12	NA	0.70	NA	0.61	0.72	0.40
9323	Osilinka River	0.13	1.00	1.00	0.96	0.98	0.32	0.45
9286	Osilinka River	0.14	1.00	1.00	0.70	1.00	0.46	0.43
13014	Table River	0.14	0.86	0.75	0.55	NA	1.00	0.40
18929	Omineca River	0.14	1.00	0.95	0.46	1.00	0.39	0.85
12022	Nation River	0.15	1.00	1.00	0.37	1.00	0.71	0.58
11921	NA	0.15	1.00	1.00	0.51	1.00	0.62	0.48
12675	Ospika River	0.16	1.00	0.82	1.00	0.53	0.88	0.42
11940	Suschona Creek	0.16	0.88	0.96	0.40	1.00	1.00	0.48
11891	Nation River	0.16	1.00	1.00	0.47	1.00	0.68	0.51

10319	Mesilinka River	0.16	0.95	0.84	0.75	1.00	0.69	0.40
13021	Table River	0.17	0.74	0.75	0.75	NA	1.00	0.40
12023	Nation River	0.17	1.00	1.00	0.35	1.00	0.73	0.68
13059	Parsnip River	0.18	NA	0.83	NA	0.79	0.68	0.40
10363	Lay Creek	0.18	0.98	0.87	1.00	0.58	0.92	0.40
12983	Anzac River	0.18	0.97	0.96	0.35	NA	1.00	0.56
12951	Parsnip River	0.18	NA	0.92	NA	0.61	0.81	0.40
10378	Mesilinka River	0.18	1.00	0.93	0.68	1.00	0.73	0.40
13055	Parsnip River	0.19	NA	0.71	NA	0.93	0.70	0.40
5051	Ingenika River	0.19	0.86	1.00	0.68	1.00	0.36	0.90
10377	Mesilinka River	0.19	1.00	0.92	0.54	1.00	0.94	0.40
3665	Finlay River	0.19	1.00	0.89	1.00	0.70	0.44	0.70
10383	Mesilinka River	0.20	1.00	1.00	0.78	1.00	0.26	1.00
3664	Finlay River	0.21	1.00	0.97	1.00	0.67	0.61	0.52
3426	Manson River	0.21	0.98	0.90	1.00	0.85	0.70	0.40
13057	Parsnip River	0.22	NA	0.90	NA	0.57	1.00	0.43
12024	Nation River	0.22	1.00	1.00	0.33	0.98	1.00	0.69
12964	Colbourne Creek	0.22	0.83	1.00	0.77	1.00	0.87	0.40
10386	Mesilinka River	0.24	1.00	0.76	0.98	0.91	0.87	0.40
13003	Anzac River	0.24	0.84	0.87	0.84	NA	0.97	0.40
5148	Ingenika River	0.24	1.00	1.00	0.71	1.00	0.50	0.67
13054	Parsnip River	0.24	NA	0.92	NA	0.57	0.95	0.48
5068	Swannell River	0.24	1.00	1.00	1.00	0.87	0.53	0.53
10379	Mesilinka River	0.24	1.00	0.93	0.71	1.00	0.59	0.62
16777	Moosehorn Creek	0.25	0.75	0.91	0.98	0.41	1.00	0.88
10385	Mesilinka River	0.25	1.00	1.00	0.98	0.90	0.69	0.40
3663	Finlay River	0.25	1.00	0.97	1.00	0.68	0.87	0.44
12018	Nation River	0.25	1.00	0.93	0.41	1.00	0.99	0.66
12968	Colbourne Creek	0.25	0.70	0.87	0.96	0.97	1.00	0.44
12982	Firth Creek	0.25	NA	0.87	NA	1.00	0.57	0.52
10382	Mesilinka River	0.26	1.00	1.00	0.81	1.00	0.32	1.00
11902	NA	0.26	1.00	0.97	0.97	0.93	0.73	0.40
5053	Swannell River	0.26	1.00	0.98	0.98	0.91	0.56	0.54

3855	Warneford River	0.27	1.00	1.00	1.00	0.54	0.50	1.00
12632	Ospika River	0.27	0.84	0.88	1.00	0.53	1.00	0.71
3609	Akie River	0.27	1.00	1.00	1.00	0.56	0.48	1.00
5147	Ingenika River	0.28	1.00	0.99	0.86	1.00	0.50	0.65
18932	Omineca River	0.28	0.97	1.00	0.50	1.00	0.58	1.00
13002	Anzac River	0.29	0.76	0.90	0.73	NA	1.00	0.57
13027	Hominka River	0.29	0.90	0.86	0.60	NA	1.00	0.62
13004	Anzac River	0.29	0.81	0.88	1.00	NA	1.00	0.41
3666	Finlay River	0.29	1.00	1.00	1.00	0.73	0.83	0.48
13060	Parsnip River	0.30	NA	0.74	NA	1.00	1.00	0.40
9325	NA	0.30	1.00	0.99	0.97	0.95	0.74	0.44
13061	Parsnip River	0.31	NA	0.77	NA	1.00	1.00	0.40
13036	Missinka River	0.32	0.98	0.88	0.84	NA	1.00	0.44
13049	NA	0.32	NA	0.72	NA	0.98	1.00	0.45
3452	Manson River	0.32	1.00	0.97	1.00	0.83	0.85	0.47
3469	Fries Creek	0.34	0.76	1.00	1.00	0.67	1.00	0.66
3502	Davis River	0.34	1.00	1.00	1.00	0.71	0.48	1.00
12870	Mischinsinlika Creek	0.35	0.84	1.00	1.00	NA	0.95	0.44
3568	Finlay River	0.35	1.00	1.00	1.00	0.68	0.95	0.55
10388	Mesilinka River	0.37	1.00	0.83	0.94	1.00	1.00	0.47
13041	Missinka River	0.38	0.87	0.84	0.98	NA	1.00	0.52
3662	Finlay River	0.38	1.00	0.96	1.00	0.63	0.91	0.70
13044	Wichcika Creek	0.38	0.87	1.00	0.79	NA	1.00	0.56
9371	Omineca River	0.38	NA	1.00	NA	1.00	0.38	1.00
13063	Parsnip River	0.38	NA	0.89	NA	1.00	1.00	0.43
10384	Mesilinka River	0.41	1.00	0.84	0.98	0.91	0.71	0.75
9372	Omineca River	0.41	NA	1.00	NA	1.00	0.41	1.00
13033	Hominka River	0.42	0.76	0.96	0.97	NA	1.00	0.59
13032	Hominka River	0.42	1.00	0.84	0.88	NA	1.00	0.57
16784	Toodoggone River	0.43	1.00	1.00	0.99	0.43	1.00	1.00
16781	Lawyers Creek	0.43	1.00	1.00	0.99	0.44	1.00	1.00
10380	Mesilinka River	0.43	1.00	1.00	0.79	1.00	0.55	1.00
12973	Reynolds Creek	0.44	0.84	0.98	0.84	NA	1.00	0.63

16783	Toodoggone River	0.44	1.00	1.00	0.99	0.44	1.00	1.00
9370	Omineca River	0.44	NA	1.00	NA	1.00	0.44	1.00
13012	Bills Creek	0.45	NA	0.89	NA	1.00	0.91	0.56
16786	Finlay River	0.46	1.00	1.00	1.00	0.73	0.84	0.75
3495	Collins Creek	0.48	0.94	1.00	1.00	0.73	1.00	0.69
3875	Kwadacha River	0.48	1.00	1.00	1.00	0.48	1.00	1.00
18878	Silver Creek	0.48	1.00	1.00	0.71	1.00	1.00	0.68
3748	Finlay River	0.48	1.00	1.00	1.00	0.48	1.00	1.00
3917	Fox River	0.48	0.85	1.00	1.00	0.76	0.75	1.00
9373	Omineca River	0.49	NA	1.00	NA	1.00	0.49	1.00
16782	NA	0.49	1.00	1.00	1.00	0.49	1.00	1.00
12645	NA	0.51	1.00	1.00	1.00	0.51	1.00	1.00
13064	Parsnip River	0.52	NA	1.00	NA	0.95	1.00	0.54
18933	Omineca River	0.52	1.00	1.00	0.62	1.00	0.98	0.86
12676	Ospika River	0.53	1.00	1.00	1.00	0.53	1.00	1.00
3747	Finlay River	0.53	1.00	1.00	1.00	0.53	1.00	1.00
3837	Warneford River	0.54	1.00	1.00	1.00	0.54	1.00	1.00
3584	Akie River	0.55	1.00	1.00	1.00	0.57	0.96	1.00
12960	Misinchinka River	0.55	0.92	0.98	0.95	NA	1.00	0.64
16758	Toodoggone River	0.55	1.00	1.00	1.00	0.55	1.00	1.00
9324	Osilinka River	0.56	1.00	0.99	0.93	1.00	0.89	0.68
12677	Ospika River	0.57	1.00	1.00	1.00	0.57	1.00	1.00
9285	Omineca River	0.57	NA	1.00	NA	1.00	0.60	0.95
10387	Mesilinka River	0.58	1.00	0.90	0.98	0.91	1.00	0.72
13062	Parsnip River	0.58	NA	0.95	NA	1.00	1.00	0.61

Table 8. Conservation priorities at the Watershed Assessment Unit (WAU) scale. Complete list of WAU rankings that fall above the 60th percentile of system capacity, implying relatively low impacts of limiting factors on conservation status and extirpation risk. System capacity is the product of individual stressor scores, each computed using the stressor response functions against the stressor magnitude layers at this scale. For WAUs that do not have a gazetted name, the HUC_ID column has been preserved to aid practitioners in conservation planning when referencing the GIS files produced with this report. Note that WAUs represent a finer assessment scale than whole drainages, thus inherited gazetted names will appear at several different points on the list.

HUC_ID	WAU	System Capacity	Angling Index	Fragmentation - culverts	MWAT - Adult	MWAT - Juvenile	Peak Flows	Sediment & Surface Erosion
3677	Firesteel River	1.00	1.00	1.00	NA	NA	1.00	1.00
3675	NA	1.00	1.00	1.00	NA	NA	1.00	1.00
13010	Wooyadilinka Creek	0.99	NA	1.00	NA	0.99	1.00	1.00
13048	NA	0.99	NA	1.00	NA	0.99	1.00	1.00
13058	Parsnip River	0.98	NA	1.00	NA	1.00	1.00	0.98
12979	Reynolds Creek	0.98	1.00	1.00	0.98	NA	1.00	1.00
13022	Table River	0.97	1.00	1.00	0.97	NA	1.00	1.00
13046	Wichcika Creek	0.96	1.00	1.00	0.98	NA	1.00	0.97
18910	Ominicetla Creek	0.95	1.00	1.00	0.95	1.00	1.00	1.00
18937	Omineca River	0.93	1.00	1.00	0.96	0.98	1.00	1.00
5151	Ingenika River	0.93	1.00	1.00	0.96	0.96	1.00	1.00
5149	NA	0.92	1.00	1.00	0.97	0.95	1.00	1.00
18935	Omineca River	0.91	1.00	1.00	0.91	1.00	1.00	1.00
18901	NA	0.90	1.00	1.00	0.97	0.94	1.00	0.99
3749	Finlay River	0.89	0.99	1.00	NA	NA	0.96	0.94
18912	Ominicetla Creek	0.89	1.00	1.00	0.98	0.90	1.00	1.00
18939	Omineca River	0.89	1.00	1.00	0.98	0.90	1.00	1.00
18938	Omineca River	0.88	1.00	1.00	0.99	0.89	1.00	1.00
18911	Ominicetla Creek	0.87	1.00	1.00	0.99	0.88	1.00	1.00
3746	Finlay River	0.87	1.00	1.00	0.99	0.87	1.00	1.00
18900	Ominicetla Creek	0.86	1.00	1.00	0.86	1.00	1.00	1.00
18940	Omineca River	0.81	1.00	1.00	1.00	0.81	1.00	1.00
5152	Ingenika River	0.79	1.00	1.00	1.00	0.79	1.00	1.00

3883	Fox River	0.79	1.00	1.00	1.00	0.79	1.00	1.00
16791	Finlay River	0.79	1.00	1.00	1.00	0.79	1.00	1.00
18918	Carruthers Creek	0.79	1.00	1.00	1.00	0.79	1.00	1.00
3670	Delta Creek	0.78	1.00	1.00	1.00	0.78	1.00	1.00
16792	Finlay River	0.78	1.00	1.00	1.00	0.78	1.00	1.00
16787	NA	0.77	1.00	1.00	1.00	0.77	1.00	1.00
3916	Fox River	0.77	1.00	1.00	1.00	0.77	1.00	1.00
16789	Finlay River	0.75	1.00	1.00	1.00	0.75	1.00	1.00
10371	Kliyul Creek	0.75	1.00	1.00	0.99	0.88	1.00	0.86
16788	Finlay River	0.74	1.00	1.00	1.00	0.74	1.00	1.00
3745	Finlay River	0.74	1.00	1.00	1.00	0.74	1.00	1.00
3915	Fox River	0.73	1.00	0.99	1.00	0.74	1.00	1.00
16790	Finlay River	0.73	1.00	1.00	1.00	0.73	1.00	1.00
16785	Finlay River	0.73	1.00	1.00	1.00	0.73	1.00	1.00
12961	Misinchinka River	0.73	0.94	0.93	1.00	NA	1.00	0.83
18930	Omineca River	0.73	1.00	1.00	0.73	1.00	1.00	1.00
13023	Table River	0.73	0.92	0.95	0.99	NA	1.00	0.83
18926	NA	0.71	1.00	1.00	1.00	0.71	1.00	1.00
5150	Ingenika River	0.71	1.00	1.00	0.98	0.92	0.79	1.00
3889	McCook River	0.70	1.00	1.00	1.00	0.71	0.98	1.00
5118	Wrede Creek	0.69	1.00	1.00	1.00	0.69	1.00	1.00
3488	Lafferty Creek	0.67	1.00	1.00	1.00	0.78	1.00	0.86
18931	Omineca River	0.66	1.00	1.00	0.66	1.00	1.00	1.00
16793	Finlay River	0.65	1.00	1.00	1.00	0.65	1.00	1.00
18934	Omineca River	0.64	1.00	1.00	0.64	1.00	1.00	1.00
18936	Omineca River	0.64	1.00	1.00	1.00	0.64	1.00	1.00
3834	Kwadacha River	0.63	1.00	1.00	1.00	0.63	1.00	1.00
16695	Bower Creek	0.61	1.00	1.00	1.00	0.65	0.94	1.00
3570	Pesika Creek	0.61	1.00	1.00	1.00	0.61	1.00	1.00
3906	McCook River	0.61	1.00	1.00	1.00	0.61	1.00	1.00
13040	Missinka River	0.60	1.00	1.00	0.96	NA	1.00	0.63
3520	Chowika Creek	0.60	1.00	1.00	1.00	0.60	1.00	1.00

6.5 Limitations and Future Directions.

It is also important to note that CEMPRA outputs depict only the culmination of their inputs. Stressors for which we could not estimate stressor input data using a GIS-based approach did not make it into our model, but may be of importance on-the-ground (e.g., pool frequency; see Appendix B). As CEMPRA models are "living documents," future iterations of these models can be updated and improved as we learn more about Arctic Grayling in the region. This can include refinement of the present model as we learn more about the stressor-response patterns of these populations and/or refine more sophisticated stressor magnitude layers. Further, the present model designates habitat-based insights into spatial units. To be captured by this modelling approach, potentially useful candidate actions for restoration that are not habitat-based (e.g., adult translocation, remote-site incubation; Section 8) would require additional stressors (e.g., direct loss of mainstem river habitat) and, possibly, more nuanced interpretation. We recommend that future research and monitoring programs focus on priority data gaps that can provide sufficient information to determine the feasibility of these types of actions (e.g., continued genetic work and the estimation of life stage-specific vital rates).

The CEMPRA models used in this analysis represent the actionability of system stressors today (i.e., they represent what amounts to a "t_0" model). Following the impoundment of the Williston Reservoir, Arctic Grayling populations in the region have been in a state of flux, following post-disaster succession stages and pursuing a new equilibrium. The development of a "t_{-1}" model would provide contextual insights into the footprint impacts of the reservoir by quantifying the system capacity using a pre-impoundment distribution of stressors to be compared against today's t_0 model. This may be particularly relevant to the Williston and Upper Peace core areas where footprint impacts have already resulted in the extirpation of many populations (Section 4). Further, developing a "t_{+1}" model using downscaled climate change projections would both refine the priority conservation rankings and help practitioners "future-proof" their restoration project designs, to the extent possible. Finally, we encourage the continued collaboration among the Arctic Grayling restoration community of practice. These models provide a baseline reference for restoration planning. As projects are implemented, knowledge acquired and shared may help refine the models for potential future application and, importantly, provide collaborative insights into the evolving state of these systems.

7 CONSERVATION STATUS AND RISK

7.1 Arctic Grayling Core Area Conservation Status Method

The rule- and point-based method used to assess the status of Williston Arctic Grayling populations in the 2017 information synthesis (Stamford et al. 2017) was the *Core Area Conservation Status* method originally developed by the US Fish and Wildlife Service (Fredenberg et al. 2005) for Bull Trout, which has been applied throughout the range of that species (Rodtka 2009; Hagen and Decker 2011; USFWS 2015). The method has since applied in Canada to Bull Trout, Coastal Cutthroat Trout, Rainbow Trout, and Dolly Varden (Hagen and Decker 2011; Hagen et al. 2016; Rodtka 2009; Stamford et al. 2017). In the method, conservation status and risk rankings are based on categorical estimates for four indicator classes: 1) abundance of mature individuals, 2) trend, 3) distribution, and 4) threats (i.e., cumulative effects).

A significant amount of new information has been acquired since 2017, which is summarized in the preceding sections and which can be utilized to update the core area status assessments. To do this, it was necessary to adapt the Fredenberg et al. (2005) *Core Area Conservation Status* method to i) accommodate the form of the cumulative effects results, which are expressed in terms of % system capacity and ii) broaden category definitions to accommodate varying types of information about abundance. At the same time, the method was also simplified somewhat to provide a consistent 5 categories for each of the four indicators, essentially resulting in a departure from the original Fredenberg et al. (2005) rule- and point-based framework and a new *Arctic Grayling Core Area Conservation Status* method.

In our Williston Arctic Grayling conservation status and risk assessment framework, alphabetical scores corresponding to categorical estimates of abundance, trend, distribution, and threats (Table 9) were converted to numerical values with positive or negative signs. Numerical values range from -0.75 for category A (highest risk) to +0.25 for category E (lowest risk) across all indicators implying equal weighting for each indicator (Table 10). The numerical values were summed across categories and added to a baseline value of 3.0, meaning that resulting total across all four indicators can range from a minimum of 0 to a maximum of 4.0. The total was then compared to the range of values corresponding to each of four potential conservation status and risk rankings (C-Ranks) to assign a rank to the core area. The C-ranks are C1-High Risk, C2-At Risk, C3-Potential Risk, and C4-Low Risk (Table 10).[9] The numeric scoring procedure is compatible with unknown values for the conservation status indicators and assigns a numeric value of zero for each 'U' (unknown) alphabetic value, but we capped the allowable number of U values at 1 per core area. This framework ensures that a hypothetical 'Low Risk' TCU would have most indicator estimates at or near maximum system capacity (categorical estimates D and E; summed point total >3.0). A hypothetical 'High Risk' TCU would have indicator estimates comprised of categories A and/or B (summed total ≤1.0). Furthermore, for each ranked core area, knowledge of at least one of the two indicators abundance and trend would have been available for consideration.

[9] In the core area conservation status method, status and risk is described by 4 C-ranks, rather than NatureServe's 5 subnational S-ranks, with C1-High Risk=S1, C2-At Risk=S2, C3-Potential Risk=S3, and C4-Low Risk=S4 or S5 (Fredenberg et al. 2005).

Table 9. Codes for categorical estimates of abundance of mature individuals, trend (standardized for a 25-year period), distribution (linear km), and cumulative effects of threats and natural limiting factors (mode of % system capacity estimates among sub-basins), for Arctic Grayling Core Area Conservation Status method.

Indicator	**Code**	**Description (Examples)**
Abundance (adults)	A	1-50 adults; e.g., adult and juvenile GR are largely absent from suitable habitat or at extreme low densities
	B	50-250 adults; e.g., low numbers of mature GR indicating poor survival, lack of recruitment, possible overfishing
	C	250-1,000 adults; e.g., adult GR are found in many historic habitats but catch rates are low
	D	1,000-2,500 adults; e.g., adult GR are abundant with high catch rates in some areas, but below maximum abundance
	E	2,500-10,000 adults; e.g., population is an example of maximum system capacity; adults are extremely abundant
	U	Unknown
Trend (25-yr period)	A	Severely declining; decline of >60% in population, distribution, or number of occurrences
	B	Rapidly declining; decline of 30-60% in " " "
	C	Declining; decline of 10-30% in " " "
	D	Stable; population, distribution, or number of occurrences unchanged or remaining within +/- 10% fluctuation
	E	Increasing. increase of >10% in population, distribution, or number of occurrences
	U	Unknown
Distribution (km)*	A	<4 km
	B	4-40 km
	C	40-200 km
	D	200-1,000 km
	E	1,000-5,000 km
	U	Unknown
Threats (% system capacity)	A	≤10 %; e.g., destruction of species' habitat in area affected, with effects irreversible or requiring long-term recovery
	B	10-25%; e.g., long-term degradation or reduction of habitat in the core area
	C	25-60%; e.g., reduction of habitat or reversible habitat degradation in core area
	D	60-95%; e.g., low but significant reduction in core area habitat productivity
	E	>95%; cumulative effects of threats and natural limiting factors are relatively low
	U	Unknown

Table 10. Arctic Grayling core area rule- and point-based method for assessing conservation status and risk. Adapted from Fredenberg et al. (2005).

Arctic Grayling Core Area Numeric Scoring
(Starting value = 3.0)

Code	Population Size	Distribution*	Trend	Threats
U	0	0	0	0
A	-0.75	-0.75	-0.75	-0.75
B	-0.5	-0.5	-0.5	-0.5
C	-0.25	-0.25	-0.25	-0.25
D	0	0	0	0
E	+0.25	+0.25	+0.25	+0.25

* boost score by one rank (i.e. reduce risk) if anadromous or adfluvial

Points (P)	C-rank	Description
P≤1.0	C1	**HIGH RISK** - Core area at high risk because of extremely limited and/or rapidly declining numbers, range, and/or habitat, making the Arctic Grayling in this core area highly vulnerable to extirpation
1.0<P≤2.0	C2	**AT RISK** - High conservation concern: extirpation of local populations of Arctic Grayling may be occurring or a likely possibility, even if the species is likely to persist somewhere within the core
2.0<P≤3.0	C3	**POTENTIAL RISK** - Core area potentially at risk because of limited and/or declining numbers, range, and/or habitat even though Arctic Grayling may be locally abundant in some areas of the
P>3.0	C4	**LOW RISK** - Arctic Grayling common or uncommon, but not rare, and usually widespread throughout the core area. Cumulative effects of threats and natural limiting factors are relatively low
N/A	CU	**UNRANKED** - Core area currently unranked due to lack of information or due to substantially conflicting information about status and trends
N/A	CX	**EXTIRPATED** - Core population extirpated; not a viable core area

7.2 Parsnip

Categorical estimates for all four conservation status indicators abundance, trend, distribution, and cumulative effects (system capacity) were available for the Parsnip core area (Table 11). This core area was the only one to receive a C4-Low Risk ranking, albeit at the low end of the range of low-risk scores (>3.0 to ≤4.0). This was clearly on the strength of having both a large adult population size and significant increasing trend, which mitigated elevated cumulative effects. The modal cumulative effects score of B/C reflects the fact that cumulative effects scores were approximately equally split between category B (10-25% system capacity) and category C (25-60% system capacity) among Arctic Grayling sub-basins.

Table 11. Categorical estimates of conservation status indicators distribution, abundance (population size), trend, and % system capacity, rolled up as status rankings for Williston Arctic Grayling core areas. Cumulative effects categories are modal estimates among Arctic Grayling sub-basins in each core area (Section 6).

Geographic information		Status and risk indicators				Scores				Risk assessment	
ID	Core area	Distribution	Population size	Trend	Cumulative Effects	Distribution	Population size	Trend	Cumulative Effects	Numeric score	C-rank for occurrence
1	Parsnip	D	E	E	B/C	0	0.25	0.25	-0.38	3.13	C4-Low Risk
2	Nation	C	U	U	A/B	-0.25			-0.63	NA	CU-Unranked
3	Omineca	D	C/D	B	C/D	0	-0.13	-0.5	-0.13	2.25	C3-Potential Risk
4	Ingenika	C	D	D	D	-0.25	0	0	0	2.75	C3-Potential Risk
5	Lower Finlay	D	U	U	D	0			0	NA	CU-Unranked
6	Upper Finlay	D	U	U	D	0			0	NA	CU-Unranked
7	Williston	C	B	U	A/B	-0.25	-0.5	0	-0.63	1.63	C2-At Risk
8	Upper Peace	B	A	C	A	-0.5	-0.75	-0.25	-0.75	0.75	C1-High Risk

7.3 Nation

Conservation status in the Nation core area was not ranked (CU-Unranked) because of the lack of population data indicating abundance and trend (Table 11). Relatively serious cumulative effects among Arctic Grayling sub-basins of the Nation core area, however, nonetheless suggest conservation concern and that this core area should be included in recovery planning without delay.

7.4 Omineca

Categorical estimates for all four indicator classes were also available for the Omineca core area. The ranking of C3-Potential Risk (Table 11) implies populations in the core area are threatened by limited or declining numbers, range, and/or habitat even though Arctic Grayling may be locally abundant in some areas. Although Arctic Grayling are broadly distributed in the Omineca core area and the system capacity remains moderately high among Arctic Grayling sub-basins, a significant decline since the 1990s is of conservation concern.

7.5 Ingenika

Similar to the Parsnip and Omineca core areas, for the Ingenika core area categorical estimates were possible for all four indicator classes. The Ingenika core area is ranked C3-Potential Risk (Table 11) similar to the Omineca core area. However, the most important indicators driving these rankings are different. The relatively pristine Ingenika core has lower estimated cumulative effects, but is potentially at risk because of small population size and a limited distribution.

7.6 Lower Finlay

The Lower Finlay core area was not ranked (CU-Unranked) because of the lack of population data indicating abundance and trend (Table 11). This is a considerable information gap that limits our ability to identify conservation urgency for this core area. Low cumulative effects and a substantial distribution of Arctic Grayling in the core area suggest lower conservation urgency relative to more southerly core areas, however.

7.7 Upper Finlay

Similar to the Lower Finlay and Nation core areas, in the Upper Finlay core area population data were insufficient for a ranking (CU-Unranked) (Table 11). Arctic Grayling are known to have a relatively broad distribution and low estimated cumulative effects in this core area, and conservation urgency can be reasonably assumed to low relative to most other core areas. Without population data, however, it is difficult to assess the potential sensitivity of Upper Finlay Arctic Grayling to current and future resource developments in the form of mining.

7.8 Williston and Upper Peace

Although population data indicating abundance and trend are not available for the Williston and Upper Peace core areas, it is known that Arctic Grayling are currently rare enabling plausible estimates of low and extremely low abundance, respectively. Although direct habitat loss was not included in the current iteration of the cumulative effects modelling (Section 6), it is also known that loss of system capacity has been significant (Williston) or near complete (Upper Peace) because of flooded critical habitats following reservoir creation (Stamford et al. 2017). Our professional judgements about abundance, trend, and distribution therefore indicate Arctic Grayling are at risk in the Williston core area (C2-At Risk) and at high risk of extirpation (C1-High Risk) in the Upper Peace core area, if their extirpation in the latter has not already occurred (Table 11).

8 RECOVERY TECHNIQUES

8.1 Strategy

To help bridge potential gaps between recovery actions and the assessments presented in preceding sections, we also conducted a high-level review of recovery strategies and techniques potentially suitable for Arctic Grayling in the upper Peace Basin.

The fundamental impact to Arctic Grayling populations was the flooding of large mainstem habitats in the Finlay River, Parsnip River and their lower tributaries. This complex, high stream order habitat (Figure 17) was likely used by multiple populations seasonally and supported spawning, overwintering and juvenile rearing. Habitats like this remain in few unflooded core areas, and the current distribution and population structure of Arctic Grayling are significantly influenced by the availability of large mainstem habitats (Stamford et al. 2017; Appendix B). Therefore, the majority of study over the recent past has been focused on core areas which contain unflooded mainstem habitats (Hagen and Stamford 2021; Hagen and Stamford 2023; Hagen et al. 2025; O’Connor et al. 2026).

In the core areas where unflooded mainstem habitats sustain remnant populations of Arctic Grayling, the most cost-effective way to maintain populations is focusing conservation effort on remaining intact habitats (Roni et al. 2002). Conservation actions have already been initiated, for example the Fisheries Sensitive Watershed designations for the Anzac, Table, Hominka, and Missinka watersheds in the Parsnip core area (Hagen and Stamford 2023). Other conservation actions are currently under review by the BC Ministry of Water, Land, and Resource Stewardship (WLRS) and First Nations governments within the Upper Peace Basin. FWCP has taken a strong role in actively promoting conservation action by funding the development of current condition datasets, such as the Arctic Grayling critical habitats database used here (Appendix A). Cumulative effects modelling outputs of Section 6 comprise a further step to promote potential conservation targets.

Following conservation, the restoration and enhancement of unflooded habitats, which is discussed in Section 8.2, is the next strongest option to promote Arctic Grayling populations.

Methods to recover populations threatened or lost because of flooded mainstem habitats in the Williston and Upper Peace core areas (Section 8.3) will require further research and are the third priority.

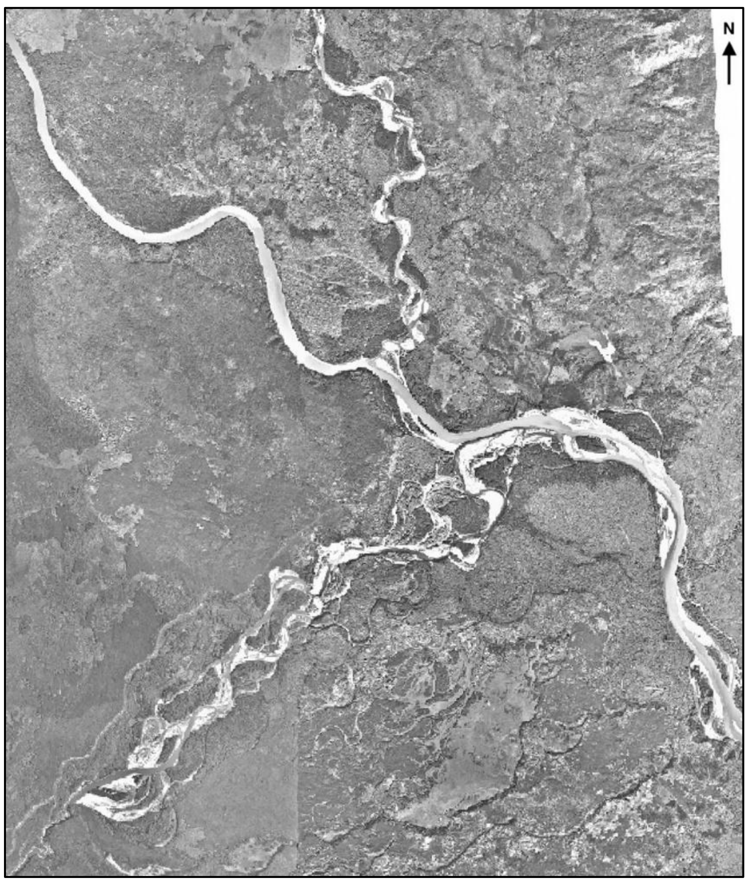

Figure 17. Confluence of the Ospika, Omineca and Finlay River pre-flooding. The Finlay is seen as a single channel flowing southeast, and the braided Ospika River, then Omineca River join it flowing south and northeast respectively.

8.2 Process-Based Restoration in Unflooded Watersheds

Stream restoration and enhancement have advanced significantly as a discipline since the last implementation of a large-scale enhancement projects in the Upper Peace Basin in the 1990s (Wilson et al. 2008). Monitoring and evaluation of existing restoration frameworks has led to the development of process-based restoration practices. Process-based restoration actions are those which improve degraded ecological processes in river and floodplain ecosystems (Beechie et al. 2022; Flitcroft et al. 2022). Examples include the restoration of ecohydraulic characteristics, hyporheic exchange, reconnection of floodplains, sediment management, drought and wildfire resilience and increases in habitat complexity (Beechie et al. 2010; Collins et al. 2012; Wohl et al. 2023, 2025; Mason et al. 2025; Noone et al. 2025). Methods vary widely and include low-tech approaches (e.g., beaver dam analogues, or post-assisted log structures), or intensive actions which require mechanical assistance such as log jam placements or physical channel alterations (e.g., pool or side-channel development), floodplain reconnection, road/crossing restoration or slope stabilization.

Process-based restoration has applicability in Arctic Grayling critical habitats within unflooded core areas of the Upper Peace Basin given the widespread impacts of industrial forestry and recent, stand-killing wildfires (e.g., Big Creek, Mesilinka River). Indeed, during multiple recent Arctic Grayling abundance surveys, habitat conditions in need of restoration have been anecdotally observed (Hagen et al. 2025; O'Connor et al. 2026). Process-based restoration is applicable across a range of stream sizes, and we recommend an initial focus on watersheds which currently support multiple Arctic Grayling life stages (Section 5; Appendix A) but with reduced system capacity (Section 6; Table 5, Table 7).

Specifically, we recommend assessment, restoration planning and prescription development within watershed assessment units which contain adult rearing and spawning/juvenile rearing habitats or are linked to them through downstream propagation of hydrological processes (e.g., peak flows, sediment transport, effects on water temperature). The known distributions of critical habitats mainly occur in mainstem rivers, and the lower sections of smaller tributaries. The extent to which smaller tributaries should receive restoration prescriptions depends on use by juvenile Arctic Grayling, which remains an information gap, and results of assessments which may identify restoration objectives for hydrologic processes or material transportation (i.e., sediment or large wood management). Simultaneously, certain small tributary streams are likely to receive enhancement efforts focused on Bull Trout (Rossi et al. 2026). Additionally, preliminary assessment, implementation and restoration monitoring provides opportunities to learn about habitat use and distribution, iteratively closing remaining data gaps on the species, and improving knowledge of effectiveness.

8.3 Enhancement/Augmentation of Lost and Threatened Populations

Evidence from multiple sources suggests Arctic Grayling still periodically utilize the Williston core area tributaries, as discussed in Section 5, suggesting that conservation and recovery actions in this core area are also justified. Arctic Grayling may also persist in the Upper Peace core area, although are extremely rare.

Although recovery actions in the Williston and Upper Peace core areas can be justified, significant challenges exist as do potential risks to remnant populations in other core areas. Given the uncertainty about life history and habitat use sustaining Arctic Grayling in the Williston core area, as discussed above, and the paucity of population data, delineating recovery actions and locations here will require further research. The value of successful recovery actions, however, would be extremely high given that extirpation of Arctic Grayling populations in the Williston, Upper Peace, and Dinosaur core areas is the most significant footprint impact of the W.A.C. Bennett and Peace Canyon dams on the species.

Two ongoing initiatives in other jurisdictions, Manistee River Arctic Grayling (Michigan USA; extirpated) and Upper Missouri River Arctic Grayling (Montana USA; threatened), are providing research and effectiveness monitoring for enhancement of extirpated or heavily impacted populations and are thus potential models for recovery of similar populations in the upper Peace Basin. The evaluation of these initiatives, albeit sourced from differing geographic locales, provides insight into the scope of monitoring, enhancement and aquaculture capacity which are needed to enhance lost or severely declined populations. The Michigan Arctic Grayling Initiative (MAGI 2017), and Candidate Conservation Agreements in the Upper Missouri River (FWP 2024a; FWP 2024b) both address invasive species interactions, climate change, fragmentation and land use (particularly private land and water use permitting) as limiting factors. It's important to note these challenges differ from the limiting factors identified for upper Peace Basin Arctic Grayling. Reintroductions of fluvial Arctic Grayling have been focused on stream reaches where introduced species removals are underway, barriers exist to maintain endemic species assemblages, and hydrologic conditions are suitable for Arctic Grayling (e.g., including overwintering habitats; MAGW 2022).

A particular focus of these initiatives has been the development of aquaculture expertise and infrastructure to support direct stocking and remote site incubation, which is aided by widespread investment in hatchery infrastructure in the conterminous United States. Importantly, these husbandry efforts include a particular focus on monitoring and maintaining natural (fluvial wild type) genetic diversity. Unfortunately, despite extensive efforts and some successful range expansion into small tributaries, the Upper Missouri River Distinct Population Segment viability has not improved, and it has recently been recommended again for listing under the Endangered Species Act (Rule et al. 2026). The Michigan Arctic Grayling Initiative is too early in its implementation to provide a reliable assessment of conservation status following enhancement action.

Among the efforts to enhance Arctic Grayling in the conterminous United States, one of the most effective strategies has been stocking of mountain lakes. Despite being the result of a propagation campaign to support sport fisheries, not a recovery effort, self-sustaining populations have been established in numerous states, including Wyoming, Utah, Montana, Washington, Colorado (Kreiner et al. 2025). These populations, sourced from adfluvial populations in the upper Missouri River, are now managed as genetic reserves and are of high conservation value, a concept which has been proposed in the Parsnip River watershed (Legault 2025).

In the upper Peace Basin, there have been at least two attempts at stocking lakes with Arctic Grayling. First, outfitters with the assistance of provincial biologists stocked multiple lakes in the Muskwa-Kechika Management Area with Arctic Grayling originating from around Finlay River in the mid 1950's (Woods 2001). Arctic Grayling successfully established in previously fishless, lake headed tributaries in Sikanni Chief River upstream of Sikanni Chief Falls and subsequent transplants by outfitters established populations in lake headed tributaries of Muskwa and Prophet rivers (e.g., Grizzly Lake, Redfern Lake, respectively). Second, in 1992 and 1993 Arctic Grayling adults captured in Nation River were transplanted upstream into Little Calais Lake and Calais Lake (upper Nation River watershed) by the Fish and Wildlife Compensation Program. Follow-up monitoring found no self-sustaining population of Arctic Grayling and cited presence of Rainbow Trout (concurrently stocked in connected lake systems) and life history strategy as contributing factors (Langston 1999).

Upper Peace Basin Arctic Grayling are primarily fluvial and in only two instances have adults been observed in lake inlet streams (Aiken Lake and Toodoggone Lake). Toodoggone River sustains the only lake inlet spawning population (Stamford et al. 2017). The successful transplants suggest, however, that the lake headed streams provided critical habitats for all life history stages (i.e., rearing, overwintering and spawning habitats) while critical habitats are missing in Calais and Little Calais lakes. Possibly, Nation River sustains a resident population adapted to the unique environmental conditions (warm) in the outlet of Chuchi Lake. Alternatively, the source population successfully transplanted into Sikanni Chief watershed might have had greater plasticity in life history traits better suited for survival in novel habitats and able to take advantage of new ecological opportunities. Such a life history (ecotype) is hypothesized to have been lost due to flooding (see Section 5). Further research is required to address difficult hypotheses about life history traits influencing movement strategy and life history tactics (Legault 2025). At the present time, the safest option for promoting range expansion and recovery in Williston and Dinosaur reservoirs is to focus on those limiting factors associated with critical habitats delineated in Williston core area.

8.4 Recovery Planning

Regardless of the specific method or set of methods employed, critical to the successful implementation of recovery actions is the development of watershed-level plans with measurable objectives which reflect watershed condition, appropriate scales of application and limiting factors for target species (Roni et al. 2026). The requirement to carefully plan and assess opportunities should not be underestimated in addition to the cost of implementing restoration or enhancement prescriptions. The CEMPRA results presented here provide a first step towards watershed or sub-basin restoration planning. Additionally, restoration planning should be completed in concert with potential enhancement/augmentation planning for Arctic Grayling and cross-ecosystem restoration planning focused on other priority species.

To design effective recovery plans, we recommend a methodological approach similar to what has been recommended for other priority species (e.g., Bull Trout; Rossi et al. 2026). Successful planning must be completed at the appropriate scales, address identified limiting factors for habitats and priority species and be designed in a manner which provides opportunities for effectiveness monitoring. Critical to successful implementation of recovery actions for Arctic Grayling is the clear articulation of goals and objectives, assessment to identify and address limiting factors and public review of initiatives. Under an adaptive management framework this allows for the iterative improvement of outcomes and simultaneously provides the ability to close remaining data gaps on species and limiting factors (Legault 2025; Roni and Beechie 2012).

Multiple sources of information are presented in this report which identify priority watersheds for recovery actions targeting Arctic Grayling. Abundance and trend data (Section 4) identify urgency for recovery actions. Critical habitat descriptions (Section 5; Appendix A) identify reaches important to Arctic Grayling life stages. The CEMPRA modelling quantifies hypotheses about limiting factors and outputs map locations where they are expected to limit system capacity (Section 6). Adaptive management and CEMPRA work together such that effectiveness monitoring by restoration and enhancement practitioners can improve future modelling and recommendations. Results of CEMPRA suggest that where reduced system capacities exist (e.g., Omineca, Parsnip, and Nation core areas), process-based restoration actions could benefit existing populations which have been experiencing decline.

The most important limiting factor threatening Arctic Grayling of the Williston and Upper Peace core areas is the loss of critical mainstem river habitat. Recovery actions in these core areas may be crucial, to avoid permanent loss of their Arctic Grayling populations. These core areas may require an extension to enhancement and augmentation actions in addition to watershed restoration, because of lost productivity of key spawning, overwintering, and juvenile rearing habitats that were flooded. Stocking or translocation may be the most effective compensation for extirpated populations. Any enhancement action must consider endemic genetic population structure, and address reasons for extirpation (e.g., critical juvenile rearing and overwintering habitat loss) before assessment and implementation. We recommend that the next step for FWCP is to develop recovery plans which can assess restoration and enhancement needs and address species limiting factors at the watershed scale. In this section, we have outlined an adaptive management framework, which includes on-the-ground actions for Arctic Grayling paired with monitoring which allow for iterative improvements in understanding of limiting factors and of the effectiveness of restoration and enhancement actions.

9 CONCLUSIONS AND RECOMMENDATIONS

At the outset of this report, we posed three questions, answers to which are needed to design and implement effective recovery actions for the species.

9.1 What is the Status of Remaining Populations (Conservation Urgency)?

The first of these concerned the status of remnant populations in the eight extant core areas of the upper Peace Basin. Status assessments estimate the viability of populations and thus identify the conservation urgency among them. The sections of this report contain summaries of four key indicators of conservation status: abundance (Section 4), trend (Section 4), distribution (Section 5), and cumulative effects (i.e., of threats and natural limiting factors; Section 6).

Rollup of these four indicators, using the rule- and point-based Arctic Grayling Core Area Conservation Status method (Section 7), identifies that conservation urgency is highest in the Williston (C2-At Risk) and Upper Peace (C1-High Risk) core areas, because of limited distribution, low population size, and low system capacity as a result of flooding of habitat necessary to complete the life cycle. Conservation urgency is lowest in the Parsnip core area (C4-Low Risk) because of high adult abundance and positive trends mitigating elevated threats, and intermediate (C3-Potential Risk) for the Ingenika core area and the Omineca core area. Given the importance of the knowledge for assessing conservation urgency, the fact that the three remaining core areas (Nation, Upper Finlay, Lower Finlay) are unranked constitutes a priority information gap that should be addressed in the near- to mid-term.

9.2 Where are Critical Habitats Located within Core Areas (Where to Work)?

The second key question posed in Section 1 concerned the locations and relative importance of critical habitats limiting key Arctic grayling life stages, i.e., locations where recovery actions should be focused. Significant investments by FWCP since the 1990s and in the recent period have significantly advanced the knowledge base with respect to Arctic Grayling habitats, and these stream segments are summarized in Appendix A. Detailed descriptions of these habitats and their Arctic Grayling populations has occurred and, in the case of the Parsnip core area particularly, could help to delineate locations where cost-effective conservation, restoration, and enhancement actions are most likely (Appendix A). Analyses conducted as part of this study have identified a significant information gap limiting our ability to properly assess threats or identify recovery actions, which is the lack of knowledge about the importance of small streams for Arctic Grayling spawning and early rearing. This is largely because 1) past studies have been mostly conducted in late summer, when juvenile Arctic Grayling may no longer be present in small streams that may be nonetheless critical for early growth and survival, and 2) snorkeling studies of abundance and trend, which target older life stages, have been prioritized because of the need to learn about conservation status within core areas (Stamford et al. 2017).

9.3 What are Key Factors Limiting System Capacity Currently (What to Do)?

Finally, we identified a third key question, concerning what factors were most likely to be limiting system capacity in Arctic Grayling watersheds, i.e., what kinds of recovery actions can be expected to maintain or improve the status of populations and the productivity of critical habitats. Addressing this question has been a significant focus of this information synthesis, through the first-ever application of the Cumulative Effects Modelling for Prioritizing Recovery Actions framework to Arctic Grayling populations in British Columbia (Section 6). Outcomes of the CEMPRA modelling include:

1. explicit hypotheses about how limiting factors (stressors) operate to limit Arctic Grayling system capacity (Appendix B),
2. detailed estimates of current conditions for many of these stressors at varying spatial scales,
3. estimates of which stressors are likely to be most limiting among Arctic Grayling sub-basins of the Williston Reservoir watershed, and, at an even higher resolution,
4. highly-localized hotspots (1:20,000 watershed assessment units) of elevated stressor magnitudes comprising targets for restoration actions.

The CEMPRA outcomes thus addresses the question of what to do and adds important new information for prioritizing where to work. This focus on limiting factors was necessary to make significant progress towards the study purpose of facilitating on-the-ground conservation, restoration, and enhancement actions that will maintain or recover populations of Arctic Grayling. Tables in Section 6 can now be used to delineate a large number of potential sites for conservation, restoration, and enhancement actions, and also to identify appropriate types of actions and their links to limiting factors. With respect to specific proposals for conservation, restoration, and enhancement actions, we have been deliberately non-prescriptive, instead identifying general approaches, methods and specific planning needs that provide a foundation for future learning and effective practice (Section 8).

The CEMPRA modelling (Section 6) has useful outcomes, but it is important to realize that these model outcomes are not validated against empirical data and may be inaccurate. For example, a significant deficiency is the lack of the 'Direct Habitat Loss' stressor, indicated by unflooded mainstem river length (Appendix B), in the CEMPRA model. Input data could not be organized for this iteration of the modelling, which had the consequence of estimating relatively high system capacity for the Upper Peace core area where Arctic Grayling may be on the verge of extirpation because of direct habitat loss. A second example is the model outputs of low system capacity for sub-basins of the Parsnip core area, where Arctic Grayling appear to reach their highest densities and are experiencing positive population growth. In this latter case, potential time lags between the recent, rapid expansion of industrial activity in Parsnip sub-basins and population responses may be an important contributing factor to this discrepancy. The solution is to recognize that the CEMPRA modelling is an iterative process. Stressor-response hypotheses, the quality of input data, and model outputs will all improve over time if additional investments in the framework are made. The outputs of the CEMPRA modelling presented in this report present a baseline that facilitates investments immediately in recovery actions. The timeline for revisiting the model likely depends upon the rate at which relevant new information is generated, such as 1) improved knowledge of the importance of small streams for Arctic Grayling recruitment, 2) improved knowledge of growth and survival at various life stages enabling more quantitative CEMRPA models, and 3) additional and/or improved stressor-response curves and stressor magnitude estimates, which may be produced in the near- to mid-term during status assessments in BC and Alberta or as outcomes of new study proposals.

In the meantime, existing information other than just the CEMPRA outputs can help to identify and prioritize recovery actions. Critical habitat descriptions and reference material cited in Appendix A, for example, contain valuable observations over the past 30 or more years. Observations made during snorkeling studies since 2018 provide further examples, e.g., documentation of ongoing fine sediment inputs from a major clay slump into the Table River at 18 km (Hagen and Stamford 2023) or, e.g., field observations of sediment and surface erosion originating in severe burns intersecting stream channels in critical habitat segments of the Mesilinka and Osilinka rivers (Hagen et al. 2025; O'Connor et al. 2026). Access to all of these areas is technically feasible, and fish values are high. We suggest CEMPRA outputs be complemented with reviews of other existing information to inform watershed level recovery planning which includes conservation, restoration and enhancement actions conducted at scales relevant to Arctic Grayling life history strategies.

9.4 Recommendations

Recommendations presented below are those that we consider essential for facilitating conservation, restoration, and enhancement actions that will maintain or recover populations, and which have been discussed in preceding report sections:

1. Utilize CEMPRA results to focus restoration actions on watersheds with reduced system capacity for Arctic Grayling (e.g., Omineca, Nation and Parsnip core areas).
2. Where possible, coordinate with ongoing restoration and enhancement actions (e.g., Irvine 2025; Legault 2025; Sofos and Pagliaro 2025) and other initiatives (e.g., BC Hydro Water Use Plan; Forest Landscape Planning) under watershed-based recovery plans.
3. Include effectiveness monitoring in planning for recovery actions, which will improve future actions and help to close remaining data gaps on species and limiting factors.
4. Conduct population monitoring in the Nation, Lower Finlay and Upper Finlay core areas to identify conservation status and refine knowledge of critical habitats and population limitation.
5. Improve understanding about the importance of small streams to Arctic Grayling spawning and early life history.
6. Determine the feasibility and genetic implications of non-habitat-based restoration levers (i.e., translocation or remote site incubation).

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APPENDIX A: *Critical Habitat Segments*

Notes:

*Sampling methods EF, SN, SW, AN, TY, GN, and eDNA refer to electrofishing, beach seine, swim counts, angling, telemetry, gill netting, and eDNA, respectively.

ID	Core Area	Gazetted Name	Reach	UTM Bottom UTM Top	Life Stage	Sampling Methods*	Key References
A1	Parsnip	Parsnip River	Mainstem	10 U 507156 6102960 10 U 573748 6038729	Adult	TY, SN, EF	Blackman 2002; Martins et al. 2020, 2022;
	Critical Habitat Comments: Parsnip River mainstem from Colbourne Creek to above Missinka, delineated based on radio telemetry records from Blackman (2002) and acoustic telemetry summary from UNBC-led FWCP spatial ecology study 2018-2021 (Martins et al. 2020,2022). Adult overwintering, migration, and spawning occurs in Parsnip mainstem and side channels, spawning habitat is encompassed by juvenile segments. Key habitat conservation action may be managing basin-wide cumulative hydrological effects.						
J2	Parsnip	Parsnip River	Mainstem	10 U 496205 6113471 10 U 573748 6038729	Juvenile	SN, EF	Anonymous 1978; Murphy and Blackman 2012; Mackay and Blackman 2012; PWFWCP 2005 unpublished; Hawkshaw and Shrimpton 2014; Martins et al. 2020, 2022;
	Critical Habitat Comments: Parsnip River mainstem from reservoir to above Missinka R, delineated based on extensive juvenile sampling especially below Table R and springtime telemetry ranges of adults from FWCP spatial ecology study 2018-2021. Juveniles widely distributed in Parsnip mainstem from above Missinka R to mouth, but clumped distribution. YOY fry and post-YOY juveniles co-occur in some sites, large, mainstem river with diverse habitat types including pools, riffles, side channels and cobble bars.						
A3	Parsnip	Misinchinka River	Mainstem	10 U 520763 6126366 10 U 528373 6130453	Adult	SW, eDNA	Langston and Blackman 1993; Stamford et al. 2017; Hagen and Stamford 2023
	Critical Habitat Comments: Moderate gradient section upstream of 38-km reach of low-gradient meanders. 2022 snorkeling found adult presence in Misinchinka mainstem at extreme low density, overall density estimate for Misinchinka mainstem below 70 km = 0.28 fish/km.						
J4	Parsnip	Misinchinka River	Mainstem	10 U 502675 6106277 10 U 511225 6109991	Juvenile	EF, SW, eDNA	PWFWCP 2005 unpublished (Parsnip GR fry survey); Langston and Blackman 1993; Hawkshaw and Shrimpton 2014; Stamford et al. 2017; Hagen and Stamford 2023
	Critical Habitat Comments: Juveniles present at top of lower reach below low gradient meanders but negative eDNA at this location in 2022. Juveniles not found higher in system despite significant effort in 2005.						
J5	Parsnip	Colbourne Creek	Mainstem	10 U 507156 6102960 10 U 517455 6099846	Juvenile	EF, SW, eDNA	PWFWCP 2005 unpublished (Parsnip GR fry survey); Hawkshaw and Shrimpton 2014; Hagen and Stamford 2022;

<table>
<tr><td></td><td colspan="7"><u>Critical Habitat Comments:</u> Reach is comprised of 17 km of Lower Colbourne Creek from where it crosses the railway to the mouth. Streamside logging, channel instability, and bedload movement common along reach, restoration opportunity. Although 8 km of snorkeling in 2021 did not detect any adult grayling, GR eDNA consistently detected at five locations distributed throughout the snorkel reach including a tributary at the top boundary. Juvenile-oriented sampling in 2005 and 2010 was negative. Life history patterns and population structure information needed for populations downstream of Anzac River.</td></tr>
<tr><td>A6</td><td>Parsnip</td><td>Reynolds Creek</td><td>Mainstem</td><td>10 U 519970 6085783
10 U 532086 6101786</td><td>Adult</td><td>SW, eDNA</td><td>PWFWCP 2005 unpublished (Parsnip GR fry survey); Hawkshaw and Shrimpton 2014; Hagen and Stamford 2021, 2022;</td></tr>
<tr><td></td><td colspan="7"><u>Critical Habitat Comments:</u> Most of the accessible length of Reynolds Creek, minus a 6-km section of small stream size and increased gradient below the migration barrier at 36 km. Threatened by intensive forestry beginning in 2021. Adult GR observed near top of critical habitat in both 2020 and 2021, but at very low density. Adults and fry present in lower end, and GR eDNA detected in between but not by snorkelling, suggests extreme low densities. Overall segment density estimate = 0.59 fish/km. Life history patterns and population structure information needed for populations downstream of Anzac River.</td></tr>
<tr><td>J7</td><td>Parsnip</td><td>Reynolds Creek</td><td>Mainstem</td><td>10 U 525931 6092203
10 U 532086 6101786</td><td>Juvenile</td><td>EF, SW, eDNA</td><td>PWFWCP 2005 unpublished (Parsnip GR fry survey); Hawkshaw and Shrimpton 2014; Hagen and Stamford 2021, 2022;</td></tr>
<tr><td></td><td colspan="7"><u>Critical Habitat Comments:</u> Top of critical habitat at 15 km is based on 2005 electrofishing results. Presence indicated from substantial electrofishing effort in 2005 (7 sites) and 2010 and visual observations of fry in 2021, and 2021 eDNA consistently positive in sites where snorkeling did not detect adults. Chuyazega Creek also positive eDNA. Life history patterns and population structure information needed for populations downstream of Anzac River, and possible divergent migratory behaviours (e.g., straying phenotype; Martins et al. 2022). Possible spawning areas in small streams (e.g. Reynolds, Colbourne, Firth, Bill's creeks), where do adults reside during rest of year?</td></tr>
<tr><td>J8</td><td>Parsnip</td><td>Firth Creek</td><td>Mainstem</td><td>10 U 525792 6076619
10 U 524399 6076112</td><td>Juvenile</td><td>EF</td><td>PWFWCP 2005 unpublished (Parsnip GR fry survey); Stamford et al. 2017;</td></tr>
<tr><td></td><td colspan="7"><u>Critical Habitat Comments:</u> Lake headed stream draining west side of Parsnip River watershed, most important role may be for spawning and juvenile rearing life stages given warm summer water temperatures (Bryce O'Connor M.Sc. Thesis research, UNBC 2023). Seven grayling records including fry and juveniles (68-90mm) collected far enough upstream (2.6 km) to indicate spawning occurred in stream. Life history patterns and population structure information needed for populations downstream of Anzac River. Where do spawners utilizing Reynolds, Colbourne, Firth, Bill's reside during rest of year? Possibly, homing to natal areas in small stream habitats support locally adapted life history traits (e.g., temperatures, rheotaxis).</td></tr>
<tr><td>A9</td><td>Parsnip</td><td>Anzac River</td><td>Headwater</td><td>10 U 552245 6092871
10 U 557591 6093397</td><td>Adult</td><td>SW</td><td>Hagen et al. 2019; Hagen and Stamford 2023</td></tr>
</table>

<u>Critical Habitat Comments:</u> Anzac River mainstem upstream of cascade (formerly considered a barrier), up to headwater fork where habitat limited by small stream size and increased gradient. Use by adult GR documented during reconnaissance swims in 2018, a year of low stream flow. Modeled GR density estimate of 21.4 fish/km during reconnaissance survey in 2018. Hagen and Stamford 2023 and Martins et al. 2022 provide basin-wide surveys of abundance and limiting factors, respectively. Anzac and Table Rivers are key candidates for more detailed studies at the sub-basin scale as recommended by Martins et al. 2022

A10	Parsnip	Anzac River	Upper	10 U 537238 6078204 10 U 552245 6092871	Adult	SW	Blackman and Hunter 2001; Blackman 2004; Cowie and Blackman 2012; Hagen et al. 2019; Hagen and Stamford 2023

<u>Critical Habitat Comments:</u> Highest estimated adult GR density anywhere in the Williston Reservoir watershed: 93.7 fish/km during reconnaissance swims in 2018. Hagen and Stamford 2023 and Martins et al. 2022 provide basin-wide surveys of abundance and limiting factors, respectively. Anzac and Table Rivers are key candidates for more detailed studies at the sub-basin scale as recommended by Martins et al. 2022.

A11	Parsnip	Anzac River	Lower	10 U 552245 6092871 10 U 526238 6075638	Adult	SW	Blackman and Hunter 2001; Blackman 2004; Cowie and Blackman 2012; Hagen et al. 2019; Hagen and Stamford 2023

<u>Critical Habitat Comments:</u> Lower 16 km of Anzac River mainstem, defined by reduced adult GR density relative to upper Anzac beginning at 16 km. Potentially associated with increased braiding and reduced gradient. 37.3 fish/km during reconnaissance swims in 2018. Hagen and Stamford 2023 and Martins et al. 2022 provide basin-wide surveys of abundance and limiting factors, respectively. Anzac and Table Rivers are key candidates for more detailed studies at the sub-basin scale as recommended by Martins et al. 2022.

J12	Parsnip	Anzac River	Mainstem	10 U 552245 6092871 10 U 550698 6090074	Juvenile	SN, EF, eDNA	Blackman and Hunter 2001; Blackman 2004; Cowie and Blackman 2012; Hawkshaw and Shrimpton 2014;

<u>Critical Habitat Comments:</u> Lower 43 km of Anzac River mainstem below North Anzac confluence and steep canyon reach. Lower ends of tributaries including North Anzac, Crocker Creek, Destilda Creek should also be included or refined into separate critical habitat segments. Post-YOY juveniles much more rare than YOY fry, also present in lower reaches of tributaries including North Anzac, Crocker Creek, possibly Destilda Creek (Hawkshaw and Shrimpton 2014), warrants follow-up surveys for tributary use.

J13	Parsnip	Bill's Creek	Mainstem	10 U 540561 6062762 10 U 540158 6061619	Juvenile	EF	Anonymous 1978; PWFWCP 2005 unpublished (Parsnip GR fry survey)

<u>Critical Habitat Comments:</u> Lower mainstem of lake-headed tributary on western side of Parsnip River watershed, key role may be for spawning and juvenile rearing life stages given warm summer water temperatures (Bryce O'Connor M.Sc. Thesis research, UNBC 2023). Only one fry collected in 2005 but far enough upstream (1.7 km) to indicate spawning may have occurred in stream. No adult sampling effort (e.g. AN) found, but numerous fry oberved (10 U 539146 6059930) rearing near crossing in 2021 (M. Stamford personal observation).

A14	Parsnip	Table River	Upper	10 U 558559 6067656 10 U 567666 6073730	Adult	SW	Cowie and Blackman 2012; Stamford et al. 2017; Hagen and Stamford 2023

<u>Critical Habitat Comments:</u> Upper Table River mainstem from GR migration barrier at 37.6 km to clay slump at 22 km. Reach defined based on reduced density downstream of 22 km in long-term index sites 22-18 km and 9-5 km. Second-highest estimated adult GR density in the Parsnip watershed: 69.9 fish/km based on observed densities in 2 long-term index sites. Hagen and Stamford 2023 and Martins et al. 2022 provide basin-wide surveys of abundance and limiting factors, respectively. Anzac and Table Rivers are key candidates for more detailed studies at the sub-basin scale as recommended by Martins et al. 2022.

A15	Parsnip	Table River	Lower	10 U 545547 6061836 10 U 558559 6067656	Adult	SW	Cowie and Blackman 2012; Stamford et al. 2017; Hagen and Stamford 2023

<u>Critical Habitat Comments:</u> Lower Table River mainstem from clay slump at 22 km to mouth; reach defined based on reduced density downstream of 22 km in long-term index sites 22-18 km and 9-5 km. Clay slump at 22 km has not allowed snorkeling observations in lower Table River since 2007: follow-up surveys highly advised. 13.6 fish/km based on pre-2007 densities in 2 long-term index sites.

J16	Parsnip	Table River	Mainstem	10 U 545547 6061836 10 U 560114 6070554	Juvenile	EF, SN	Mathias et al. 1998; Zemlak and Langston 1998; Blackman and Hunter 2001; Hawkshaw and Shrimpton 2014;

<u>Critical Habitat Comments:</u> Lower 26 km of Table River mainstem, delineated based on relatively extensive PWFWCP sampling. Post YOY juveniles relatively rare in watershed but encountered in lower portion of segment. Given the importance of the Table system for Parsnip GR, fine-scale survey of spawning and early-rearing habitat (e.g., YOY emergence surveys) are warranted to facilitate enhancement and conservation actions.

A17	Parsnip	Hominka River	Upper	10 U 573671 6061485 10 U 581191 6069185	Adult	AN, TY, SW, eDNA	Hagen and Stamford 2021;

<u>Critical Habitat Comments:</u> Hominka River mainstem between 48-32 km from mouth. Top of distribution confirmed by eDNA. Snorkeling observations suggest decent densities of fairly large adult grayling over 16 km of river channel. 14.6 adult GR/km estimated by Hagen and Stamford 2023 vs. 2.4 fish/km in lower Hominka. 2005 sampling captured two adults only by AN.

J18	Parsnip	Hominka River	Mainstem	10 U 558750 6054109 10 U 572137 6061263	Juvenile	EF	PWFWCP 2005 unpublished (Parsnip GR fry survey); Hawkshaw and Shrimpton 2014;

<u>Critical Habitat Comments:</u> Only one fry collected in 2005 but far enough upstream (>20 km) to indicate spawning occurred in stream. Significant sampling effort suggests low abundance and additional sampling effort required to evaluate spawning and fry rearing habitat.

A19	Parsnip	Missinka River	Mainstem	10 U 577380 6050157 10 U 583975 6053680	Adult	SW, AN, TY	Triton 1999; Martins et al. 2020, 2022; Hagen and Stamford 2023;

<u>Critical Habitat Comments:</u> Missinka River mainstem between a chute at 36.4 km to top of low-gradient meanders at 25 km based on decent numbers of adult GR in a single, 4-km section of the reach in 2019.

J20	Parsnip	Missinka River	Mainstem	10 U 561781 6048217 10 U 583229 6052577	Juvenile	EF	Triton 1999; Hawkshaw and Shrimpton 2014; Stamford et al. 2017;

<u>Critical Habitat Comments:</u> Many fry collected well upstream from mouth indicates spawning in stream.

A21	Parsnip	Wichcika Creek	Mainstem	10 U 561783 6048207 10 U 564032 6037426	Adult	SW, eDNA	Hagen and Stamford 2021, 2023;

<u>Critical Habitat Comments:</u> Very low adult GR densities, 0.50 fish/km during 2020 reconnaissance, but detected in most sites in lower 28 km of Wichcika Creek. Accessible reaches of lake-headed tributaries provide potential spawning habitat.

J22	Parsnip	Wichcika Creek	Mainstem	10 U 561783 6048207 10 U 555396 6044115	Juvenile	EF, eDNA	Anonymous 1978; PWFWCP 2005 unpublished; Hawkshaw and Shrimpton 2014;

<u>Critical Habitat Comments:</u> Lower 12 km of Wichcika Creek based on 2005 Parsnip GR fry study (PWFWCP unpublished 2005). 2020 eDNA sampling around 7 km corroborate fry study and suggest juvenile rearing areas in lower river. Numerous lake headed tributaries possibly provide spawning and juvenile rearing.

J23	Parsnip	Wooyadilinka Creek	Mainstem	10 U 536695 6064553 10 U 540595 6069125	Juvenile	EF, eDNA, SW	Hawkshaw and Shrimpton 2014; Hagen and Stamford 2023;

<u>Critical Habitat Comments:</u> Segment is based on presence of GR fry during 2010 EF survey. Snorkel survey of lower 1 km in 2022 eDNA failed to detect GR presence at 3 locations (including mouth). Does absence in 2022 indicate that some streams are not used every year?

A24	Nation	Nation	Nation Lower	10 U 467151 6149215 10 U 456630 6118247	Adult	AN, EF	LRDW 1992; Langston and Blackman 1993; Clark et al. 2005; Cowie and Blackman 2007

<u>Critical Habitat Comments:</u> Upstream coordinates at top cascade adults observed rearing downstream in canyon. Possible restricted movements upstream through cascades requires evaluation, possible demographic connections unresolved.

J25	Nation	Nation	Nation Lower	10 U 467151 6149215 10 U 456630 6118247	Juvenile	AN, EF	Langston and Blackman 1993; Cowie and Blackman 2007.
	<u>Critical Habitat Comments:</u> Upstream coordinates at top cascade in Nation River. Fry probably drift downstream from spawning sites in Philip Creek and Nation River, rearing locations appear consistent among years. Demographic influences of numerous cascades require investigation. For instance, putative dispersal phenotype downstream?						
A26	Nation	Nation	Nation Upper	10 U 456630 6118247 10 U 418472 6117173	Adult	AN, EF	LRDW 1992; Langston and Blackman 1993; Cowie and Blackman 2007
	<u>Critical Habitat Comments:</u> Tributary confluences appear to provide cool temperature refugia during summer. Demographic connections with downstream (below Philip Creek) completely unresolved.						
J27	Nation	Nation	Nation Upper	10 U 456630 6118247 10 U 422559 6117945	Juvenile	AN, EF	Langston and Blackman 1993; LRDW 1998 (Stamford 2000 unpublished); Cowie and Blackman 2007; Hawkshaw and Shrimpton 2014
	<u>Critical Habitat Comments:</u> Numerous widely distributed juvenile records in Nation Mainstem; Fry and possibly yearlings associated with tributary confluences. Minimal directed sampling for yearlings; use of other habitats types (e.g. tributaries, off channel) requires evaluation. Possible rapid growth rate (e.g., unique life history traits) among fry requires further evaluations.						
A28	Nation	Philip Creek	Philip Creek	10 U 458321 6128960 10 U 462729 6111811	Adult	AN, EF	Cowie and Blackman 2007; Clark et al. 2005
	<u>Critical Habitat Comments:</u> Upstream coordinate at fry record. Limited sampling directed at this life stage.						
J29	Nation	Philip Creek	Philip Creek	10 U 458321 6128960 10 U 462729 6111811	Juvenile	AN, EF	Cowie and Blackman 2007; Clark et al. 2005; Hawkshaw and Shrimpton 2014
	<u>Critical Habitat Comments:</u> Possible rearing locations upstream near lake outlets. Fry distribution appears patchy; upstream distribution require evaluation. Limited sampling directed at yearling life stage. Influence of lake chain and stable habitat for promoting fry rearing areas remains completely unresolved.						
J30	Nation	Munro Creek	Munro Creek	10 U 446592 6121939 10 U 446523 6122513	Fry	AN, EF	LRDW 1998 (Stamford 2000 unpublished); Cowie and Blackman 2007
	<u>Critical Habitat Comments:</u> Top coordinate upstream of fry records to include possible spawning habitats. Homing to spawning areas and diversity in life history traits, migratory behaviours unresolved.						

AJ31	Nation	Rainbow Creek	Rainbow Creek	10 U 440039 6123059 10 U 440112 6122794	Adult, Juveniles	AN, EF	LRDW 1998 (Stamford 2000 unpublished); Cowie and Blackman 2007
	<u>Critical Habitat Comments:</u> Adults and juveniles observed rearing in deep pool near the mouth. Movements upstream affected by ephemeral barriers, beaver dams, log jams. Fry rear close to Nation confluence, natal areas might include Rainbow Creek and Nation River. Important temperature refuge from Nation mainstem. Adult abundance requires evaluation, never rigorously estimated. Homing to spawning areas and diversity in life history traits, migratory behaviours, influence of cascades, unresolved.						
A32	Nation	Sylvester Creek	Sylvester Creek	10 U 429187 6122487 10 U 428814 6123974	Adults	AN, EF, SW	Hawkshaw and Shrimpton 2014; Cowie and Blackman 2007; LRDW 1998 (Stamford 2000 unpublished); LRDW 1952 (UBC Fish Museum)
	<u>Critical Habitat Comments:</u> GR once abundant in 1950's. Adults observed ~200 m upstream in 1998 but stream dominated by RB. Upstream coordinates from 1952 record. Important temperature refuge from warm lake headed mainstem; reason for decline in adult abundance requires evaluation						
J33	Nation	Sylvester Creek	Sylvester Creek	10 U 429187 6122487 10 U 426254 6124870	Fry	AN, EF, SW	Hawkshaw and Shrimpton 2014; Cowie and Blackman 2007; LRDW 1998 (Stamford 2000 unpublished); LRDW 1952 (UBC Fish Museum)
	<u>Critical Habitat Comments:</u> Upstream coordinates at 1998 fry record. Fry abundance appears to be variable among years at Nation confluence. Homing to spawning areas and diversity in life history traits, migratory behaviours unresolved.						
A34	Nation	Suschona Creek	Suschona Creek	10 U 422478 6117790 10 U 422491 6117664	Adult	EF, AN	LRDW 1998 (Stamford unpublished); Cowie and Blackman 2007; Hawkshaw and Shrimpton 2014
	<u>Critical Habitat Comments:</u> Grayling records at Nation confluence. Spawning never confirmed in this stream. Important warm summer temperature refuge. Further monitoring of natal habitat use and possible spawning needed to evaluate possible range contraction.						
J35	Nation	Suschona Creek	Suschona Creek	10 U 422478 6117790 10 U 422491 6117664	Juvenile	EF, AN	Hawkshaw and Shrimpton 2014; LRDW 1998 (Stamford 2000 unpublished).
	<u>Critical Habitat Comments:</u> Historically, fry captured in Suschona Creek and at Nation confluence. Further monitoring of natal habitat use needed to evaluate possible range contraction.						
F36	Omineca	Mesilinka River	Mesilinka River	10 U 383182 6252361 10 U 359900 6245113	Fry	AN, EF, SW	Koning et al. 1992; Larkin et al. 1999; LRDW 1997; Hagen et al. 2025; O'Connor et al. 2026
	<u>Critical Habitat Comments:</u> Fry records in low gradient sections, often associated with lake headed tributaries (e.g. Carina Creek, Tutezika River). Rearing locations consistent among years. Homing to spawning areas, reasons for recent decline in adult abundance, and metapopulation structure remain unresolved.						

J37	Omineca	Mesilinka River	Mesilinka River	10 U 405227 6227185 10 U 332446 6255652	Juvenile	AN, EF, SW	Langston and Blackman 1993; Larkin et al. 1999; LRDW 1997; EDI 2001; Clark et al. 2005; Hagen et al. 2025; O'Connor et al. 2026
	<u>Critical Habitat Comments:</u> Juvenile records widely distributed but patchy. Numerous juveniles observed in lower river in 2024 snorkel survey and other sampling.						
A38	Omineca	Mesilinka River	Mesilinka River	10 U 408900 6221600 10 U 324646 6256322	Adult	AN, EF, SW	Koning et al. 1992; Langston and Blackman 1993; Larkin et al. 1999; LRDW 1997; Clark et al 2005; Wilson et al. 2008; Hagen et al. 2025; O'Connor et al. 2026
	<u>Critical Habitat Comments:</u> Adult records widely distributed from mouth to headwaters (Aiken Lake inlet). Recent (2024) snorkel survey found significant decline in adult abundance and distribution within Mesilinka and fin ray microchemistry suggest remaining population complete life history within Mesilinka River. Metapopulation structure remains unresolved for core area.						
A39	Omineca	Lay Creek	Lay Creek	10 U 332107 6256081 10 U 332776 6256852	Adult	AN, EF, SW	LRDW 1997; Clark et al. 2005; Hagen et al. 2025
	<u>Critical Habitat Comments:</u> Important adult rearing habitat especially in lower reaches near Mesilinka confluence. Probably an important summer temperature refuge near Aiken Lake outlet.						
A40	Omineca	Kliul Creek	Aiken Lake Inlet	10 U 325044 6256491 10 U 324688 6256432	Adult	eDNA, SW	LRDW 1997; Beak Industrial 1998; O'Connor et al. 2026
	<u>Critical Habitat Comments:</u> Rearing adults observed upstream of Aiken Lake in snorkel observations but appear rare in recent eDNA sampling. Habitat use upstream of Aiken Lake remains unresolved, possibly periodic or density dependent.						
F41	Omineca	Osilinka River	Osilinka	10 U 404195 6216801 10 U 370308 6222153	Fry	EF	Stamford 1998 (unpublished); Cowie and Blackman 2003
	<u>Critical Habitat Comments:</u> Fry widely distributed in low gradient sections between Tenakihi Creek and Omineca confluence. Extent of homing to natal streams yet unresolved.						
A42	Omineca	Osilinka River	Osilinka	10 U 404195 6216801 10 U 363114 6222447	Adult	AN, EF, SW	LRDW 1998 (Stamford unpublished); Cowie and Blackman 2003; Clark et al 2005; O'Connor et al. 2026.
	<u>Critical Habitat Comments:</u> Adult records widely distributed throughout mainstem but mostly between Tenakihi and Wasi confluences. Fin ray and otolith microchemistry suggest adults rearing upstream complete their life history within Osilinka River. Snorkel surveys in 2025 estimated fewer than 100 rearing adults, and eDNA failed to deterct GR presence in tributaries.						
F43	Omineca	Omineca River	Omineca Main	10 U 407699 6221202 9 U 654761 6231867	Fry	EF, SN	Schell 2002; Cowie and Blackman 2003; Clarke et al. 2005

	<u>Critical Habitat Comments:</u> Wide distribution of fry clustered around four sections with possible association with headwaters and tributaries. Demographic connections and migratory behaviour remain unresolved, including the extent of homing to natal areas.						
J44	Omineca	Omineca River	Omineca Main	10 U 365712 6184399 10 U 335039 6192554	Juvenile	EF, SN, AN	Schell 2002; Cowie and Blackman 2003
	<u>Critical Habitat Comments:</u> Distribution of juveniles in middle reaches of Omineca River captured by beach sein in shallow riffles. More sampling effort recommended, especially toward alternative habitats (e.g., off channel areas).						
A45	Omineca	Omineca River	Omineca Main	9 U 685225 6217231 9 U 656559 6231361	Adult	AN, EF	Schell 2002; Cowie and Blackman 2003; Clark et al. 2005
	<u>Critical Habitat Comments:</u> Records of rearing adults close to headwaters and tributaries. More effort sampling in downstream habitats recommended to improve estimates of distribution and abundance.						
F46	Omineca	Silver Creek	Silver Creek	10 U 348090 6181795 10 U 345668 6171766	Fry	AN, EF, SW	Schell 2002; Cowie and Blackman 2003
	<u>Critical Habitat Comments:</u> Records suggest temporally consistent (2002, 2003) fry rearing in lower reaches. No records of adults and juveniles but limited upstream sampling. Demographic connections and migratory behaviour in core area remain unresolved.						
FA47	Omineca	Ominicetla Creek	Ominicetla Creek	10 U 326388 6199680 9 U 679405 6204039	Fry, Adults	AN, EF, SW	Schell 2002; Cowie and Blackman 2003
	<u>Critical Habitat Comments:</u> Adults rearing upstream toward headwaters, fry rearing downstream close to Omineca confluence. Demographic connections and extent of tributary use remain unresolved.						
A48	Omineca	Carruthers Creek	Carruthers Creek	9 U 677110 6226929 9 U 676252 6230765	Adult	EF, AN	Schell 2002; Cowie and Blackman 2003
	<u>Critical Habitat Comments:</u> Rearing adult records in 2003 but not found in 2002 possibly rare or periodic habitat use. Fry rearing in Omineca mainstem both upstream and downstream of confluence. Extent of habitat use in tributaries unresolved. Possibly too cold for fry and juveniles.						
F49	Ingenika	Ingenika River	Ingenika Main	10 U 373657 6289082 10 U 326287 6300504	Fry	EF	Cowie and Blackman 2004
	<u>Critical Habitat Comments:</u> Fry distributed in lower 76 km of mainstem but most abundant in low gradient middle river downstream of Pelly Creek. Extent of homing to spawning locations remain unresolved (e.g., genetic relatedness with Fox River).						

J50	Ingenika	Ingenika River	Ingenika Main	10 U 356773 6289814 9 U 682082 6303047	Juvenile	AN, EF, SW	LRDW 1998 (Stamford unpublished); Cowie and Blackman 2004, 2012; Strohm et al. 2020
	<u>Critical Habitat Comments:</u> Juveniles observed in shallow riffle habitat. Potentially also present in other habitat types and need focused sampling effort for this LH stage. Juveniles not observed in snorkel surveys						
A51	Ingenika	Ingenika River	Ingenika Main	10 U 371781 6289505 9 U 669111 6305246	Adult	AN, EF, SW	Clark et al. 2007; Cowie and Blackman 2004, 2012; Strohm et al. 2020
	<u>Critical Habitat Comments:</u> Snorkel surveys suggest rearing adults most abundant upstream during lower discharge levels but during higher discharge adults appear more dispersed among other habitats (e.g. tributaries, possibly other streams?). Demographic connections and migratory behaviours remain unresolved; preliminary analyses suggest genetic connections with Fox River						
AF52	Ingenika	Swannell River	Swannell River	10 U 371629 6289457 10 U 364597 6279830	Adult, Fry	AN, EF, SW	LRDW 1998 (Stamford unpublished); Cowie and Blackman 2004; Strohm et al. 2019.
	<u>Critical Habitat Comments:</u> Adults observed rearing in deep pools at the base of cascade barrier in 1996. EDNA sampling at pool outlet in 2018 suggest GR absent. Range contraction from tributaries might suggest loss of life history traits and diminished resilience.						
A53	Ingenika	Wrede Creek	Wrede Creek	10 U 335061 6297168 10 U 332889 6294219	Adult	EF	Bruce and Star 1986; Cowie and Blackman 2004; Stamford et al. 2020
	<u>Critical Habitat Comments:</u> Adults observed in mid 1970's and detected presence with eDNA in 2019. Demographic connections and migratory behaviour remain unresolved.						
.F54	Lower Finlay	Finlay River	Finlay Main	10 U 381622 6307329 10 U 330184 6368054	Fry	EF	FWCP 2006, 2007; LRDW 2006; Shrimpton and Clark 2012
	<u>Critical Habitat Comments:</u> Fry rearing locations with possible tributary associations. Demographic connections and migratory behaviour remain unresolved.						
J55	Lower Finlay	Finlay River	Finlay Main	10 U 381622 6307329 10 U 334671 6367543	Juvenile	EF, SN, AN	Fielden 1991;1992; FWCP 2006, 2007
	<u>Critical Habitat Comments:</u> Only two records of juveniles found. Possible interactions with native kokanee influence habitat use. Demographic connections and migratory behaviour remain unresolved.						
A56	Lower Finlay	Finlay River	Finlay Main	10 U 381622 6307329 10 U 322196 6371088	Adult	EF, SN, AN	Fielden 1991; 1992; FWCP 2006, 2007; Shrimpton and Clark 2012
	<u>Critical Habitat Comments:</u> Possible interactions between native kokanee and grayling might influence distribution. Demographic connections and migratory behaviour remain unresolved.						

AF57	Lower Finlay	Warneford River	Kwadacha Warneford	10 U 352552 6387313 10 U 365757 6407169	Adult/Fry	EF	LRDW 1963; Triton 2006
	<u>Critical Habitat Comments:</u> Single fry record in Quentin Lake outlet and 1963 record in Kwadacha River. Demographic connections and migratory behaviour remain unresolved.						
F58	Lower Finlay	Fox River	Fox River	10 U 339009 6368529 10 U 330225 6389240	Fry	EF	Triton 2005; FWCP 2006; Shrimpton and Clark 2012.
	<u>Critical Habitat Comments:</u> Fry abundance appears to increase further downstream, possible spawning locations in mainstem and tributaries. Demographic connections and migratory behaviour remain unresolved.						
J59	Lower Finlay	Fox River	Fox River	10 U 339009 6368529 10 U 333165 6380149	Juvenile	EF	RL&L 2000; Triton 2005; FWCP 2006
	<u>Critical Habitat Comments:</u> Possible that Weisner Lake improves habitat stability and might promote local movements. Demographic connections and migratory behaviour remain unresolved.						
A60	Lower Finlay	Fox River	Fox River	10 U 339009 6368529 10 U 330918 6386068	Adult	EF, AN	RL&L 2000; Triton 2005; FWCP 2006; Shrimpton and Clark 2012
	<u>Critical Habitat Comments:</u> Adult records at three locations but distribution and abundance probably higher. Preliminary genetic analyses among rearing adults suggest demographic connections between Ingenika and Fox rivers but migratory behaviours remain unresolved.						
F61	Lower Finlay	McCook River	McCook Creek	10 U 328839 6389876 10 U 327407 6395913	Fry	EF	Triton 2005; FWCP 2006
	<u>Critical Habitat Comments:</u> Single fry record, no GR found upstream. Demographic connections and migratory behaviour remain unresolved.						
U62	Lower Finlay	Pesika River	Pesika River	10 U 376583 6317409 10 U 377135 6317847	Unknown	EF, eDNA	Stamford et al. 2020.
	<u>Critical Habitat Comments:</u> Environmental DNA indicate present in 2018, possibly also further upstream. Demographic connections with surrounding streams (e.g., Fox, Ingenika) remain unresolved.						
A63	Lower Finlay	Akie River	Akie River	10 U 371168 6322310 10 U 379753 6333473	Adult	eDNA	LRDW 1962; Stamford et al. 2020.
	<u>Critical Habitat Comments:</u> Adult record upstream in 1962, eDNA detected presence downstream in 2019. Demographic connections with surrounding streams (e.g., Fox, Ingenika) remain unresolved.						

F64	Upper Finlay	Finlay River	Finlay Main	9 U 671241 6388012 9 U 664654 6390274	Fry	EF	FWCP 2006; Shrimpton and Clark 2012
	<u>Critical Habitat Comments:</u> Fry record in low gradient braided section between cascades. Demographic connections and tributary use unknown for this natal area.						
F65	Upper Finlay	Finlay River	Finlay Main	9 V 646221 6367655 9 U 626577 6331014	Fry	EF, SN	RL&L 2001; FWCP 2006; Shrimpton and Clark 2012; ChuCho Environmental 2018.
	<u>Critical Habitat Comments:</u> Records clustered in two low gradient sections upstream and downstream of bedrock rapids (same genotype). Demographic influences of homing and tributary use among natal areas needs evaluation.						
J66	Upper Finlay	Finlay River	Finlay Main	10 U 321340 6376776 9 U 626715 6329999	Juvenile	EF, SN, AN	RL&L 2001; FWCP 1997, 2006; ChuCho Environmental 2018.
	<u>Critical Habitat Comments:</u> Juvenile records widely distributed in mainstem and off channel habitats between Fishing Lakes and Cascadero falls. Scarce juveniles in Finlay Mainstem beach seines suggest off channel and tributary habitats are important.						
A67	Upper Finlay	Finlay River	Finlay Main	10 U 321340 6376776 9 U 626715 6329999	Adult	EF, SN, AN	Zemlak and Langston 1994; RL&L 2001; FWCP 2006
	<u>Critical Habitat Comments:</u> Adult records widely distributed from top of Long Canyon to base of Cascadero Falls; preliminary genetic analyses support demographic independence Lower Finlay. Extent of homing to spawning locations unresolved but a proportion of fry rearing in Finlay River originated from tributaries.						
FJ68	Upper Finlay	Finlay River	Delta Creek	9 U 646113 6352601 9 U 646107 6351772	Fry, Juvenile	EF	FWCP 2006
	<u>Critical Habitat Comments:</u> Limited juvenile sampling effort, critical habitat incompletely resolved for yearlings. Single sampling episode and one location in this tributary, more sampling needed.						
J69	Upper Finlay	Finlay River	239-761400	9 U 636514 6343814 9 U 636819 6343147	Juvenile	EF	RL&L 2001; FWCP 2006
	<u>Critical Habitat Comments:</u> Downstream reach used by smaller yearlings. Records include single sampling episode, two locations, more sampling needed. Limited juvenile sampling effort, critical habitat incompletely resolved for yearlings.						
F70	Upper Finlay	Toodoggone River	Toodoggone Lake Inlet	9 U 620085 6364027 9 U 602489 6362316	fry	AN, EF, GN	Norecol Environmental Consultants Ltd. 1986; Coombes 1987; FWCP 2006; Shrimpton and Clark 2012.

	<u>Critical Habitat Comments:</u> Records and habitat descriptions suggest fry abundant and rearing habitat optimal upstream of Toodogonne Lake. Additional fry and juvenile sampling needed.						
A71	Upper Finlay	Toodoggone River	Toodoggone River	9 U 647251 6364249 9 U 602489 6362316	Adult	AN, EF, GN	Norecol Environmental Consultants Ltd. 1986; Coombes 1987; FWCP 2006; Shrimpton and Clark 2012.
	<u>Critical Habitat Comments:</u> Adults rear throughout the stream both upstream and downstream from Toodoggone Lake. Divergent genotype among adults suggest local population and demographic independence from fry and adults captured in Finlay River. More rigorous evaluations needed to support possible separate core area (e.g., fry and juvenile genotype and migration behaviour).						
A72	Upper Finlay	Firesteel River	Firesteel River	9 U 625705 6334003 9 U 623850 6333113	Adult	EF, AN	FWCP 2006; Shrimpton and Clark 2012; ChuCho Environmental 2018.
	<u>Critical Habitat Comments:</u> Records show only rearing adults; fry records at Finlay confluence possibly originate from spawning in Firesteel. Same genotype throughout Finlay mainstem but demographic connections with Firesteel remain incompletely resolved.						
AF73	Williston	Manson River	Manson River	10 U 448339 6176775 10 U 434122 6166261	Adult/Fry	SW, eDNA	Bruce and Starr 1985; LRDW 1998, 2002; Hawkshaw and Shrimpton 2014; Strohm et al 2019; Stamford et al. 2020.
	<u>Critical Habitat Comments:</u> Rearing adults observed during 1998 and 2002 snorkel survey, fry observed in 2010 electrofishing, eDNA failed to detect GR presence in 2018 and 2019. GR rare or possibly extirpated. Alternatively, periodic habitat use by migratory adults (e.g., putative Large River adapted dispersing phenotype).						
J74	Williston	Fries Creek	Fries Creek	10 U 434783 6195788 10 U 427289 6192869	Juvenile	EF, eDNA	LRDW 1996; Strohm et al. 2019; Stamford et al. 2020
	<u>Critical Habitat Comments:</u> Single record of a juvenile rearing in 1996, eDNA failed to detect presence in 2018, further sampling required. Possible periodic habitat use by juveniles.						
A75	Williston	Chowika Creek	Chowika Creek	10 U 394088 6289974 10 U 395712 6292017	Adult	eDNA, EF, AN	LRDW 1996; Strohm et al. 2019; Stamford et al. 2020
	<u>Critical Habitat Comments:</u> Rearing adults observed in 1975 and 1996, eDNA detected presence in 2018 and 2019. Upstream fish sampling in 2021 failed to find GR. Putative dispersing phenotype (Large River adapted) linking subpopulations might rear periodically near embayment. Continue monitoring for consistent habitat use by putative dispersing phenotype.						
U76	Williston	Head of Finlay Arm	Williston Reservoir	10 U 495557 6114125 10 U 381349 6309026	Unknown	eDNA	Blackman 2002; Strohm et al 2019; Stamford et al. 2020.
	<u>Critical Habitat Comments:</u> Adult captured near Teare Creek in 1998, eDNA detected GR presence near Finlay mouth in both 2018 and 2019. Putative dispersing phenotype using Reservoir as migration corridor. Continue monitoring for consistent habitat use by putative dispersing phenotype.						

A77	Williston	Ospika River	Ospika River	10 U 440840 6243089 10 U 441378 6267709	Adult	eDNA, EF, AN	Bruce and Starr 1985; Strohm et al. 2019; Stamford et al. 2020; Stamford and O'Connor 2022.
	<u>Critical Habitat Comments:</u> Adult observed in 1975, eDNA detected presence in 2018, 2019, and 2021 among seven mainstem sites. Additional fish sampling effort needed to better describe critical habitats among life histories.						
F78	Williston	Ospika River	Ospika River	10 U 440840 6243089 10 U 440601 6248933	Fry	eDNA, SN, AN	Stamford et al. 2020; Stamford and O'Connor 2022.
	<u>Critical Habitat Comments:</u> Two fry captured in beach seine in 2021 indicate presence of natal habitat, top coordinates at fry capture location. Additional fish sampling effort needed to better describe critical habitats among life histories.						
U79	Williston	Ospika River	Aley Creek	10 U 442841 6258319 10 U 442841 6258319	Unknown	eDNA, EF, AN	Stamford et al. 2020; Stamford and O'Connor 2022.
	<u>Critical Habitat Comments:</u> Detected at one eDNA site near Ospika confluence in 2019, follow up electrofishing and angling failed to find GR in 2021. Additional fish sampling effort needed to better describe critical habitats among life histories.						
U80	Williston	Ospika River	Tributary, WSC: 230-935100-20600	10 U 442543 6264742 10 U 444679 6265197	Unknown	eDNA, EF, AN	Stamford et al. 2020; Stamford and O'Connor 2022
	<u>Critical Habitat Comments:</u> Detected with eDNA at Ospika confluence. Top boundary below impassable falls. Additional fish sampling effort needed to better describe critical habitats among life histories.						
U81	Williston	Collins Creek	Collins Creek	10 U 414843 6256032 10 U 415522 6258506	Unknown	eDNA, EF, AN	Bruce and Starr 1985; Strohm et al. 2019; Stamford and O'Connor 2022
	<u>Critical Habitat Comments:</u> Adult observed at mouth in 1975, eDNA detected presence at four sites in 2018. Electrofishing failed to find GR in 2021. Continue monitoring for consistent habitat use by putative dispersing phenotype. Additional fish sampling effort needed to better describe critical habitats among life histories.						
U82	Williston	Lafferty Creek	Lafferty Creek	10 U 418688 6245935 10 U 423174 6247362	Unknown	eDNA, EF, AN	Bruce and Starr 1985; Strohm et al. 2019; Stamford and O'Connor 2022
	<u>Critical Habitat Comments:</u> Adults observed in 1975, eDNA detected presence 6km upstream in 2018. Electrofishing failed to find GR in 2021. Continue monitoring for consistent habitat use by putative dispersing phenotype. Additional fish sampling effort needed to better describe critical habitats among life histories.						
U83	Williston	Davis River	Davis River	10 U 409430 6268135 10 U 409613 6269162	Unknown	eDNA, EF, AN	Bruce and Starr 1985; Strohm et al. 2019; Stamford and O'Connor 2022

Critical Habitat Comments: *Juvenile observed in 1975; eDNA detected presence in 2018 and 2019; Electrofishing failed to find GR in 2021; Continue monitoring for habitat use by putative dispersing phenotype.*

A84	Williston	Factor Ross Creek	Factor Ross Creek	10 U 395397 6275823 10 U 394363 6274196	Adult	SW, EF	Golder 2013.

Critical Habitat Comments: *Subadults observed and captured in 2012 during habitat assessment. Continued monitring for consistent habitat use by putative dispersing phenotype. Potentially fin ray microchemistry can inform retrospective movements (e.g., natal origin).*

J85	Williston	Mischinsinlika Creek	Mainstem	10 U 495525 6115371 10 U 504042 6122787	Juvenile	EF, eDNA	Hawkshaw and Shrimpton 2014; Hagen and Stamford 2023.

Critical Habitat Comments: *Segment is based on presence of GR fry during 2010 EF survey. Environmental DNA at 2 locations (including mouth) failed to detect GR presence in 2022. Mischinsinlika is of interest because it is isolated by flooding and contains significant habitat upstream. Putative dispersing phenotype.*

U86	Upper Peace	Peace Reach/Dinosaur Reservoir	Peace Reach	Extirpated?	Adult	eDNA, AN	Stamford et al. 2022.

Critical Habitat Comments: *eDNA detected in Pardonnet Creek in 2021, persistent angler observations in numerous other embayments continue to come into LRDW. No recent records or eDNA detections in Dinosaur Reservoir despite extensive sampling efforts. Putative dispersing phenotype linking subpopulations might periodically enter Peace Reach. No critical habitats delineated in streams due to rare eDNA detections, inferred ephemeral habitat use, absence of fry and juveniles, high gradient habitats upstream of flooded areas.*

APPENDIX B: *Arctic Grayling CEMPRA Model Stressor-Response Curves*

(Technical document)

Williston Watershed Arctic Grayling Cumulative Effects CEMPRA Model Stressor Response Curves

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Introduction

Construction of the 183-m high W.A.C. Bennett Dam was completed in 1967 and resulted in the formation of Williston Reservoir, which reached full pool in 1972 (Hirst 1991). Williston Reservoir flooded roughly 350 km of the Peace River, Finlay River, and Parsnip River valleys and caused profound changes to the ecologies of these watersheds. Prior to impoundment, Arctic Grayling were widespread and abundant in tributary streams of these valleys (Withler 1959; Bruce and Starr 1985). Impoundment resulted in the loss of Arctic Grayling populations in the lower reaches of the Parsnip and Finlay rivers and upper reaches of the Peace River, including tributary streams to these reaches in which they had formerly thrived (Northcote 1993; Stamford et al. 2016). Self-sustaining populations of Arctic Grayling now appear restricted to just eight of the larger watersheds (Parsnip, Nation, Omineca, Osilinka, Mesilinka, Ingenika, Finlay, Toodoggone).

The Peace Region Fish and Wildlife Compensation Program (FWCP) was initiated in 1988, and is a partnership between BC Hydro, the Province of British Columbia, Fisheries and Oceans Canada, First Nations, and local stakeholders. The FWCP objective is to conserve and enhance fish and wildlife (including their habitats) that have been impacted by BC Hydro hydroelectric dams. Since 2017, stated goals for Arctic Grayling research in the Williston Reservoir watershed have been 1) to maintain or improve the conservation status of Arctic Grayling populations, and 2) to maintain or improve the integrity and productivity of Arctic Grayling habitats (Stamford et al. 2017). A monitoring framework has been proposed that identifies information requirements for meeting these goals: 1) effective measures and methods for monitoring conservation status, and 2) sufficient knowledge to reliably maintain or increase the productivity of critical habitats (Hagen and Stamford 2017). Additionally, a recommended sequence of monitoring actions is included in the monitoring framework, which begins with acquiring population data to estimate conservation status (abundance, trend) and the distribution of critical habitats, and which then leads to assessment of limiting factors and implementation of on-the-ground conservation and enhancement actions.

The Cumulative Effects Modelling for Prioritizing Recovery Actions (CEMPRA) framework is a conservation tool designed to synthesize information about natural limiting factors and anthropogenic threats and to estimate their cumulative effects on the capacity of ecosystems for production of a particular species. The 'Joe Model' at the core of CEMPRA (named in honour of University of Alberta professor emeritus Joe Nelson) is a semi-quantitative static model composed of a series of stressor-response curves that describe the relationship between aquatic system capacity and the stressor variable (Bayly et al. 2024; MacPherson et al. 2020). To facilitate an increased focus on recovery actions in the Williston Reservoir watershed, in this report we develop stressor-response curves for Arctic Grayling for use within the CEMPRA framework.

Arctic Grayling Threats from Status Literature

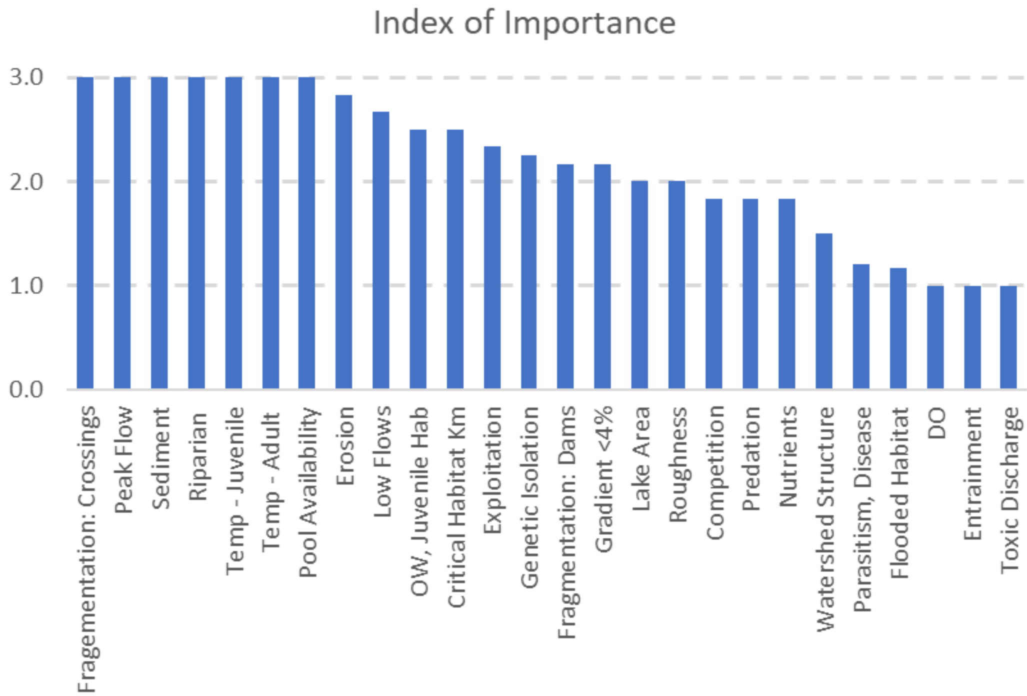

Figure B 1. Arctic Grayling threats from a review of the range-wide status literature, ranked during an expert's workshop (updated March 3, 2026) in terms of relative importance within the Williston Reservoir watershed. Priority #3 is the highest importance; Priority #1 is low importance or not applicable. Priority #2 and higher were the focus of this document

Arctic Grayling CEMPRA Joe Model Stressor-Response Curves

Peak Flow

A key requirement for newly-emerged Arctic Grayling fry is shallow, low-velocity margin habitat in close proximity to spawning areas (Stuart and Chislett 1979; Butcher et al. 1981; Stewart et al. 1982; Armstrong 1986; Blackman 2002a; Blackman 2004; Cowie and Blackman 2003; Cowie and Blackman 2004; Nykänen and Huusko 2004). Immediately following emergence, however, high and variable flows related to spring freshet limit the availability of low-velocity rearing space. When this is factored together with the low dispersal capabilities of the tiny grayling fry away from spawning areas, the potential for a significant bottleneck for grayling production is apparent. Tack (1974) noted absence of a whole year class in Chena River following a flood event and Clark (1992) found a significant correlation between recruitment levels and stream flows over a 14-year period. Large numbers of grayling fry have also been observed stranded in pools isolated from the main stream after water levels dropped (de Bruyn and McCart 1974; Cowie and Blackman 2003).

In addition to direct impacts on fish abundance, increased frequency of peak flow events linked to watershed disturbance (e.g., Johnson and Alila 2023) can also result in changes to river morphology affecting potential productivity for salmonids, such as reductions of habitat complexity and pool frequency, and the formation of an oversized channel (Government of Alberta [GOA] 2023 and references therein).

Equivalent Clearcut Area (ECA) is a modeled metric that indicates the potential influence of forest cover disturbance on stream flow and frequency of peak flow events (Grant et al. 2008; Winkler and Boon 2017; Porter et al. 2021). To model expected impacts of increased ECA from human and natural (e.g., fire) sources, we adapted (with some simplification) the stressor-response curve developed by the Government of Alberta for Bull Trout (GOA 2023), which assumes that trout populations are resilient to a low degree of change and could persist, albeit at very low density, in watersheds where hydrologic change is high (Figure B 2).

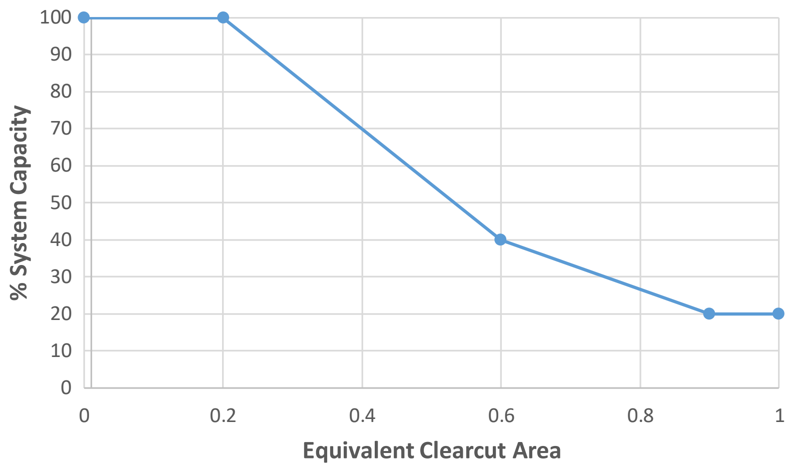

Figure B 2. Hypothesized relationship between Arctic Grayling system capacity and hydrologic change, as indicated by Equivalent Clearcut Area.

Sediment and Surface Erosion

Elevated sediment transport negatively affects Arctic Grayling populations, both through direct effects on the health and survival of individual fish, and also through degradation of habitat for feeding and reproduction. Arctic Grayling fry and juveniles are restricted in their ability to move and survival depends on rapid growth in natal streams. In habitats experiencing high inputs of fine sediment downstream of placer mines, young-of-year show reduced growth and signs of stress (Birtwell et al. 1984; McLeay et al. 1987). Adults continue to spawn in streams impacted by elevated sediment loads (possibly due to a strong heritable component to homing behaviour), but recruitment success is affected by sedimentation impacts, with offspring suffering increased mortality (alevins), starvation, and reduced growth rates during early rearing (Birtwell et al. 1984; Reynolds et al. 1989; Birtwell 1999; US Federal Register 2010). Clear stream reaches appear to be critical for summer rearing of subadult and adult Arctic Grayling, likely because they are highly dependent on sight for feeding (Birtwell et al. 1984; McLeay et al. 1987; Ott et al. 1998; Stewart et al. 2007).

In addition to elevated turbidity, sediment loads can alter the morphology of streams as well as the composition of the stream bed and associated habitats. Excessive fine sediment can cause increased stream embeddedness, which is detrimental to salmonids through losses of spawning habitat, juvenile overwintering habitat, and food sources such as aquatic invertebrates (Bjornn et al. 1977; Anderson 1998 and references therein). Excess inputs of coarse sediments reduce pool abundance by making the channel shallower, and by destabilizing channels and causing the stream to migrate laterally (Bjornn et al 1977; Anderson 1998 and references therein; Hogan and Bird 1998).

Roads are one of the most significant causes of increased erosion, as road construction exposes large areas of soil to potential erosion by rainwater and snowmelt while the roads themselves intercept and concentrate surface runoff, increasing its energy (WAP 1995a, as cited in Porter et al. 2021).

Construction, use and maintenance of resource roads located near watercourses are the most important source of suspended sediment generation in streams (Anderson 1998 and references therein). To model expected impacts of elevated sediment loads (beyond natural levels that Arctic Grayling are adapted to), on Arctic Grayling system capacity, we utilized GIS indicators defined by British Columbia's Watershed Status Evaluation Program (WSEP; Porter et al. 2021) (Table B 1).

The stressor-response curve is defined in terms of normalized WSEP 'Tier 1' indicator scores, which can be computed for each of the indicators using Table B 1. Inflection points on the stressor-response curve are delineated on the basis of an expert judgement study that suggested 'detectable' effects on watershed functions are first observed at normalized scores of 0.2, and the threshold of 'significant concern' is 0.4 (Essa Technologies 2017). The hypothesized stressor-response curve assumes that Arctic Grayling populations are resilient to a low degree of change, the threshold of 'significant concern' would equate to a reduction to about 70% of system capacity (Price et al. 2009), and populations could persist in buffered, refuge sub-basins even in watersheds where sediment threats have been elevated to very high levels (Figure B 3).

Table B 1. Conversion table relating observed levels of GIS indicators of anthropogenic sediment and erosion threats to normalized WSEP Indicator Scores.

Indicators	Score										
	0	**0.1**	***0.2***	**0.3**	***0.4***	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Roads < 100 m from a stream (km/km^2)	0.00	0.04	0.08	0.12	0.16	0.20	0.25	0.30	0.35	0.40	≥0.45
Roads on erodible soils < 100 m from a stream (no./km^2)	0.00	0.02	0.04	0.06	0.08	0.10	0.13	0.16	0.19	0.21	≥0.24
Stream crossing density (no./km^2)	0.00	0.08	0.16	0.24	0.32	0.40	0.50	0.60	0.70	0.80	≥0.90
Road density for entire sub-basin (km/km^2)	0.00	0.30	0.60	0.90	1.20	1.50	1.72	1.94	2.16	2.38	≥2.6

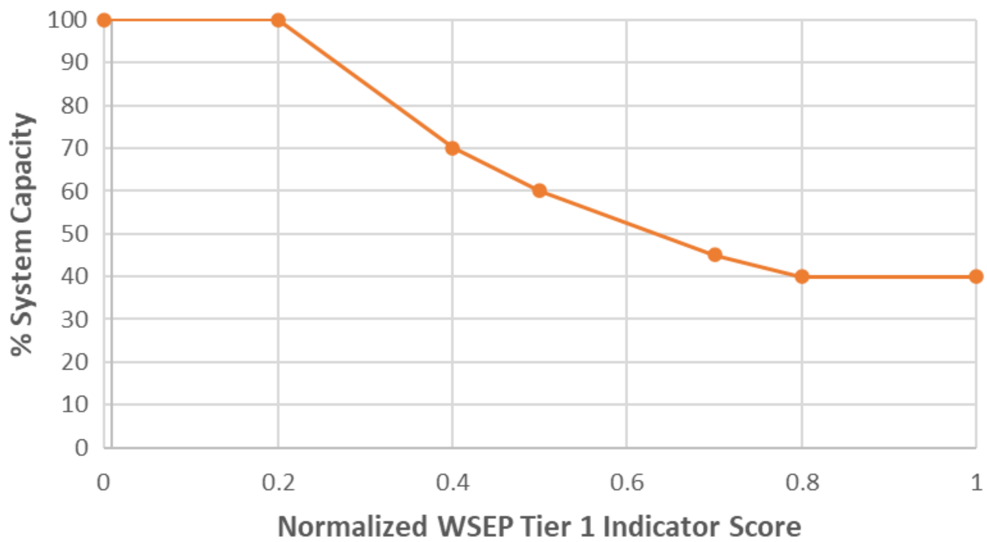

Figure B 3. Hypothesized relationship of Arctic Grayling system capacity to normalized indicator scores for GIS-based sediment and erosion indicators.

Fragmentation – Culverts

Arctic Grayling spawn in a wide variety of habitats, including mainstem rivers, large and small tributaries to streams and lakes, along lake shores at the mouths of inlets, and variable substrates including fines and large boulders (Tack 1980; Armstrong 1986; Blackman 2002a; Stewart et al. 2007; Larocque et al. 2014). Spawning habitats for Williston Arctic Grayling have been described only briefly for large river habitats in Parsnip, Anzac, and Table rivers (Blackman 2002) but natal habitats in small tributaries remain undescribed even though they provide important fry rearing areas (critical habitats) in all upper Peace Basin core areas (Stamford et al. 2017). Recent microchemistry analyses of retrospective movements also suggest that significant proportions (e.g., 13-27%) of fry rearing in large river habitats (e.g., Finlay, Osilinka, Mesilinka) originated from spawning areas in tributaries (Stamford 2023 data on file). The amount that Arctic Grayling spawn in tributaries is incompletely resolved and is probably different among core areas depending on different landscapes and physical habitat features among Williston watersheds. To address this data gap, Blackman (2004) recommended studies examining distribution and abundance of newly emerged fry, and identified dipnets, fine-mesh seines, and visual observations as potential sampling techniques.

Small tributaries, particularly lake headed, also provide important rearing and overwintering areas for yearling stage (~100mm fork length) Arctic Grayling throughout the species' range (e.g., Stuart and Chislett 1979; Anderson 2004; Stewart et al.2007, Stamford et al. 2016) and records indicate presence in tributaries despite minimal sampling effort focused on this elusive life history stage (Stamford et al. 2017). Beach seine efforts describe extensive overlap between juveniles and fry rearing in low gradient reaches in large rivers (e.g., Parsnip River: Mackay and Blackman 2005; Omineca River: Schell 2002), but similar sampling directed at older juveniles is lacking in tributaries (Stamford et al 2017). For instance, larger juveniles were almost absent in significant beach seine effort in the Finlay River mainstem where fry were abundant, which suggests preferred habitats are elsewhere in tributaries and off channel areas where records indicate presence (Stamford et al. 2017).

Disturbances to rare natal areas or restricted access (e.g. hanging culverts) to critical spawning and rearing habitat can seriously harm or eliminate Arctic Grayling from a watershed (Alberta Environment and Parks and Alberta Conservation Association 2015). Habitat alteration and linear developments affecting access should therefore be considered important threats mechanisms affecting the viability of Arctic Grayling populations, which may originate from any number of potential sources that are associated with road building and physical site disturbance (forest harvest, oil and gas extraction, dam construction, mining, linear developments). Oil and gas developments require vast networks of roads to access numerous drill sites. Poorly installed crossings can restrict access to critical spawning and rearing locations, so this source of threat is of particular concern with respect to access to critical habitats (Sullivan 2000; Anderson 2004). Risks also include diminished metapopulation resilience by depleting diversity in life history traits and future survival with environmental change (e.g., Anderson 2004; Alberta Environment and Parks and Alberta Conservation Association 2015; Golden et al. 2021; Brennan et al. 2024).

We found no inventory of culvert installations in Williston watershed but by some estimates between 70% and 90% of closed bottom culverts installed in Arctic Grayling streams are barriers to upstream dispersal (Grainger and Jedrzejczyk 2013; Hurkett and Redman 2016). Crossing densities included second and third order streams. Crossings on streams larger than third order are assumed to be open culverts or bridges. Using criteria from previous work (Government of Alberta 2023 and references therein), higher crossing densities were assumed to have higher reductions to system capacity. The stressor-response curve has an asymptotic maximum reduction to 70% of system capacity (Figure B 4) assuming small tributaries provide 30% of system capacity for spawning and juvenile rearing within core areas, based on microchemistry observations described above for the Finlay, Osilinka, and Mesilinka rivers (MS 2023 data on file). This asymptote is highly uncertain given key information gaps around fry and juvenile distribution, which should be prioritized.

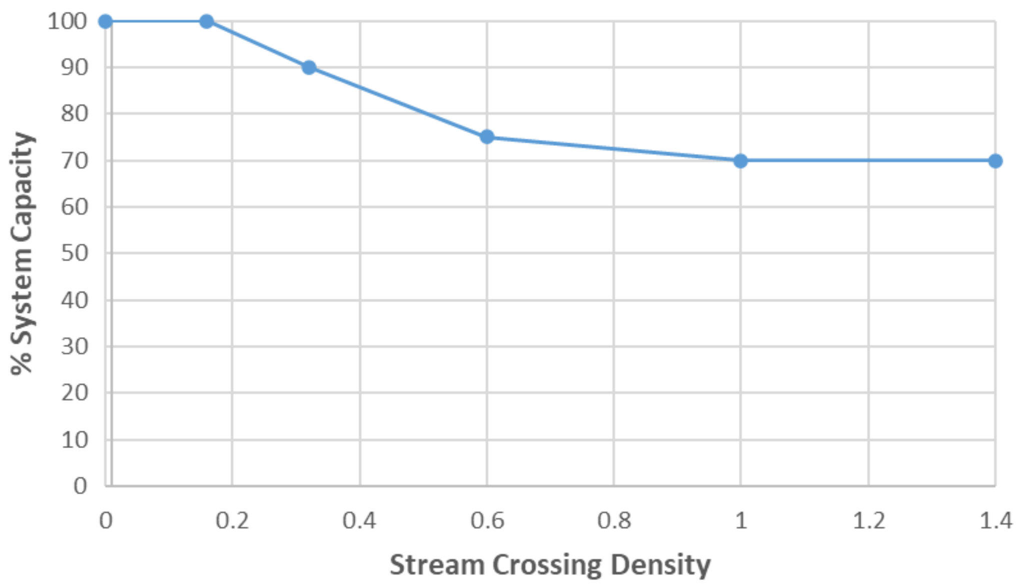

Figure B 4. Hypothesized relationship of Arctic Grayling system capacity to stream crossing density (No./km^2) restricting access to spawning, rearing, and possibly overwintering habitats for fry and juveniles.

Stream Temperature – Juveniles

Temperature is paramount among environmental parameters for regulating developmental processes and is an important selective factor maintaining variability within and among salmonid populations (Taylor 1991). Water temperature is a key factor limiting Arctic Grayling populations, both through direct effects on survival and growth, and likely also through temperature-mediated species interactions. Generally, young-of-year Arctic Grayling fry do well in warm summer rearing areas where survival is linked to rapid growth rate during the first year (Deegan et al. 1999; Stewart et al. 2007). In the upper Peace Basin, the lake-headed Nation River warms quickly in summer and remains about 3°C warmer than other Arctic Grayling streams, (e.g., compared with the Mesilinka River; Langston 1996). During late-summer sampling, Nation River Arctic Grayling averaged 68 mm, versus 38-45 mm in other systems sampled at the same time of year, and this larger size corresponded with a shift to deeper, swifter water and larger stream bed material (Cowie and Blackman 2007).

Temperature preference and the influence of stream temperature on juvenile Arctic Grayling distribution have been previously investigated in the Williston watershed (Hawkshaw et al. 2013; Hawkshaw and Shrimpton 2014). Temperature preferences among young-of-year Arctic Grayling fry did not vary between the Nation River and Table River populations and averaged 16.8 ± 0.7 °C. Laboratory trials of Arctic Grayling fry found a significant boost in growth beginning at 12ºC and reached an optimum at 16.96ºC, then physiological stress at 18ºC and reduced performance and increased mortality at 23.18ºC (Carrillo-Longoria et al. 2023). Comparing their temperature choice results to maximum ambient temperatures in the environment, Hawkshaw and Shrimpton (2014) insightfully hypothesized that

Williston Arctic Grayling fry would avoid maximum temperatures that exceeded the preferred temperatures. Overlap between fry and age-1+ Arctic Grayling in habitat preferences suggest that similar conditions may be preferred by older juvenile life stages also (Mackay and Blackman 2005). Additionally, there appears to be an ontogenetic shift in thermal preference across life stages which influences the distribution of Arctic Grayling age classes in a watershed (Hawkshaw et al. 2014; McPherson et al. 2023; O'Connor et al. 2025).

Temperature-mediated interspecific competition may also be a contributing factor limiting Arctic Grayling system capacity in warmer systems. In the relatively warm Nation River, Cowie and Blackman (2007) identified the potential for interactive segregation with high densities of juvenile Longnose Dace, Northern Pikeminnow, and suckers, which also utilize low-velocity margin habitat. Temperature preference for juvenile Rainbow Trout in the Williston watershed is higher than for Arctic Grayling (17.7 °C; Hawkshaw and Shrimpton 2014), which reflects the more southern distribution of Rainbow Trout and which may be a factor in the absence of Arctic Grayling from the extensive, low-gradient Pack River watershed, in which Rainbow Trout are abundant and widely distributed (Stamford et al. 2017).

To assess expected impacts of summer water temperature in fry rearing areas on Arctic Grayling system capacity, we utilized preliminary model estimates of water temperature generated as part of FWCP project PEA-F26-F-4235 (O'Connor et al. 2026 in prep). More accurate water temperature results, derived from a Spatial Stream Network Model (SSNM), will be incorporated into the CEMPRA model. The stressor-response curve (Figure B 5) adapted from Hubert et al. (1985), Hawkshaw and Shrimpton (2014) and Carillo-Longaria (2023) is consistent with the expectation that summer temperatures rising from 10ºC to 14°C equate to a boost in fry growth and attainment of maximum system capacity. The range in maximum system capacity between 14ºC and 17ºC allows for potential local adaptation among subpopulations shifting optimal growth rates to local natal temperatures (Haugen and Vollestad 2000). Physiological stress beginning at 18ºC and mortality at 23ºC are described by a decline in system capacity to zero. This also reflects the large fitness repercussions of exceeding optimal temperatures on the warm tail of performance curves and the typical vertebrate selection in natural settings of sub-optimal conditions to buffer against deleterious consequences (Ruel and Ayres 1999; Dillon et al. 2012; Dowd et al. 2015).

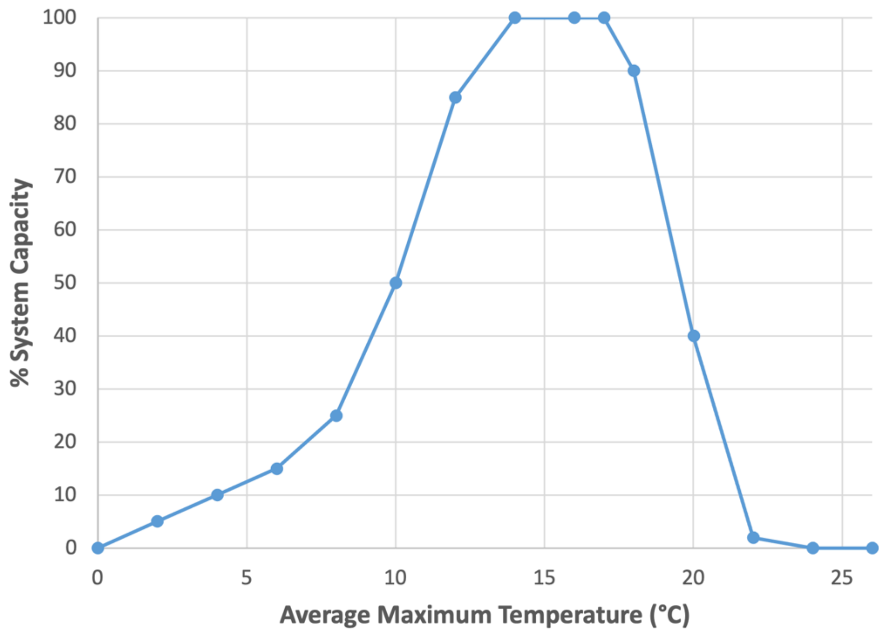

Figure B 5. Hypothesized relationship between Arctic Grayling system capacity and maximum weekly average summer water temperature in young-of-year rearing habitats.

Stream Temperature – Adults

Given the apparent ontogenetic shift in thermal preference across life stages, Arctic Grayling adults have a contrasting relationship to water temperature relative to young-of-year fry and older juveniles, preferring cooler summer rearing temperatures. Varying thermal preference results in life stage-specific habitat requirements which, in addition to growth-dependent movement is hypothesized to influence the distribution of age classes in a watershed (O'Connor et al. 2025). This necessitates a separate stressor-response curve for the adult life history stage (Figure B 6). Adult Arctic Grayling tend to move away from suboptimal temperatures > 16°C and can have higher growth rates during years when stream discharge is higher and summer water temperatures are lower (e.g., approaching 10°C; Lohr et al. 1996; Deegan et al. 1999). Similarly, this influences adult summer distributions within smaller streams and headwater tributaries with cooler temperatures.

In the Williston Reservoir watershed, recent research in the Parsnip River combined a SSNM with a dynamic site occupancy model to predict the distribution of Arctic Grayling based on summer water temperatures, stream magnitude (a surrogate for stream size), and gradient (O'Connor et al. 2025). When accounting for stream size and gradient, the model predicted a high probability of occupancy at sites where temperature ranged from 6.9°C-14.7°C, with a peak at 10.8°C. These findings were supported by a concurrent field-laboratory experiment which revealed median preference of 11.3°C (± 4.1°C; Bottoms 2023) and prior research by Hawkshaw et al. (2014) who captured Arctic Grayling in ambient temperatures up to 14.5°C in the Williston Reservoir.

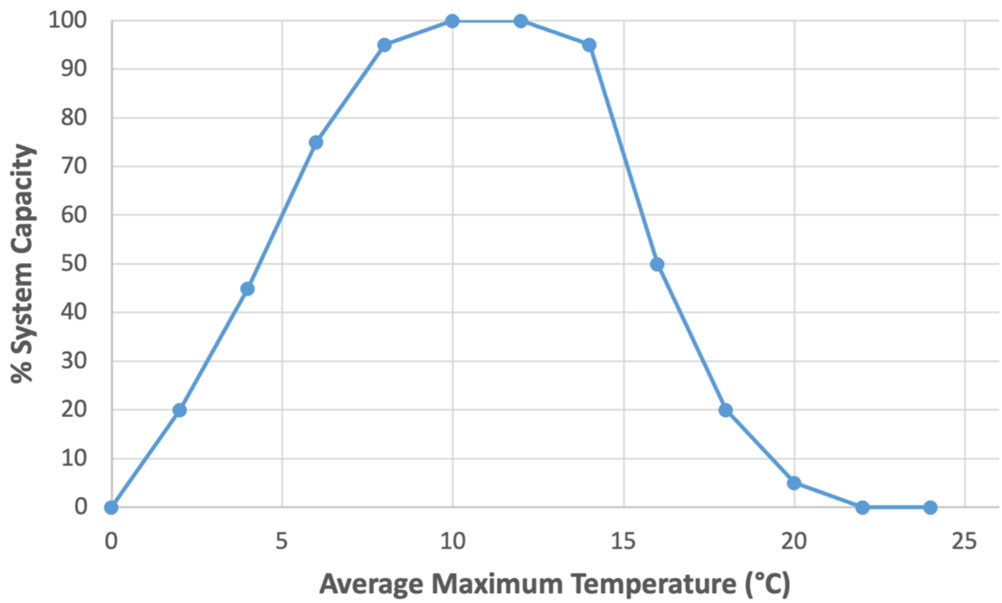

Figure B 6. Hypothesized relationship between Arctic Grayling system capacity and maximum weekly average summer water temperature in adult summer rearing habitats, adapted from O'Connor et al. 2025).

Angling Mortality

Adult and subadult Arctic Grayling are highly catchable relative to other salmonids (Paul et al. 2003) and can be rapidly depleted under even moderate angling pressure (Northcote 1993 and references therein). Angling harvest has resulted in declines in Alberta (Fitzsimmons and Blackburn 2009; Alberta Environment and Parks and Alberta Conservation Association 2015), British Columbia (Euchner 2010) and Alaska (Tack 1974; Armstrong 1986). Overexploitation of Arctic Grayling, concentrated at stream mouths following inundation, has been proposed as a contributing factor to the extirpation of the species from tributaries entering Williston Reservoir (Blackman 2001).

A model developed for evaluating the sustainability of recreational fisheries (Post et al. 2003) in Canada provided important background information for developing the stressor-response curve for Arctic Grayling of the Williston Reservoir watershed. Quantitative estimates for model parameters were not possible, so the model itself could not be utilized to predict effects on system capacity. Instead, general findings of the Post et al. (2003) simulation modeling, conducted using Bull Trout as an example, were utilized to identify three putative contributing factors to overexploitation risk for Arctic Grayling:

1. *Vulnerability*. We define vulnerability as the estimated proportion of the population or core area exposed to the exploitation threat. Angler access is a primary factor affecting vulnerability (Ridder 1992; Northcote 1993; Cahill 2015).
2. *Effort*. Proximity to major human population centers is a key predictor of angling effort at the landscape scale (Post et al. 2008).

3. *Fishing Mortality*. We assumed the mortality rate for captured fish would be affected by the existing regional fisheries regulations.

Since 1995, angling regulations across the Williston watershed do not permit harvest of Arctic Grayling, suggesting that the threat of overexploitation to Arctic Grayling population viability has been significantly reduced. However, incidental angling mortality and illegal harvest (intentional or unintentional) may still pose a significant threat to the viability of fish populations in Canada when angling effort and vulnerability are high (Post et al. 2003).

As the first step in relating Arctic Grayling system capacity to potential angling mortality, we used the index of potential exploitation of Rossi et al. (2026), which factors together categorical indicators for vulnerability and effort. Vulnerability was indicated by stream crossing density on 4th order or larger streams, while effort was indicated by the distance from Prince George, the region's major population center (Table B 2). We used this index as the input variable for the stressor-response curve for angling mortality for Arctic Grayling (Figure B 7). The stressor-response curve was also adapted from Rossi et al. (2026), and assumes 1) a catch-and-release regulation, 2) that vulnerability of fish declines in a curvilinear fashion as effort increases (due to having been caught previously and/or site disturbance; Post et al. 2008; Rossi et al. 2026), and therefore 3) that Arctic Grayling would be able to persist in watersheds even under a scenario of relatively high effort and vulnerability. The asymptotic estimate of 70% system capacity assumes that catch-and-release mortality for Arctic Grayling is relatively low (e.g., 10%; Falk and Gillman 1975). Furthermore, the stressor-response curve was not applied to watershed polygons used only by juvenile life stages.

Table B 2. Unitless index of angling threat to Arctic Grayling of the Williston Reservoir watershed (grey shaded area), estimated by factoring together indicator scores for 'Vulnerability' (road crossing density on 4th order and larger streams) and 'Effort' (distance from Prince George) (Adapted from Rossi et al. 2026).

		Vulnerability Score (Stream Crossings/km)			
Effort Score	Distance from Prince George	0	0.1	0.2	0.3+
1	>300 km	0	0.1	0.2	0.3
2	200-300 km	0	0.2	0.4	0.6
3	100-200 km	0	0.3	0.6	0.9
4	<100 km	0	0.4	0.8	1.2

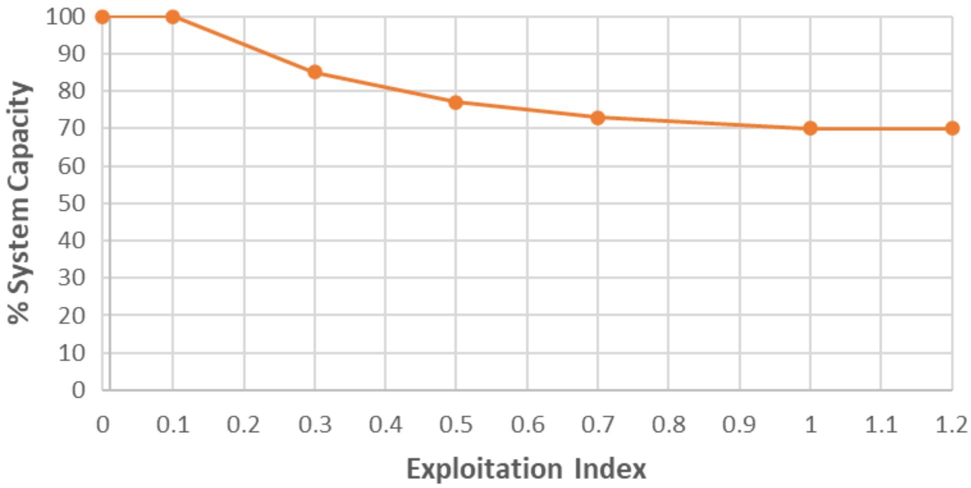

Figure B 7. Hypothesized relationship of Arctic Grayling system capacity to an exploitation index derived by factoring estimates of stream crossing density and distance from Prince George.

Stressor-Response Curves Not Included in the 2026 Analysis

Summer Flow

Flow is a master variable controlling the quantity and quality of stream habitat, but which is also affected by human activity (Poff et al. 1997; Rosenfeld and Enright 2025; Tenant 1976). Summer streamflow is thought to be an important factor affecting Arctic Grayling system capacity. In Arctic tundra streams, higher summer discharge has been associated with increased growth of subadult/adult Arctic Grayling (Deegan et al. 1999). Reduced stream flows in the Big Hole River, Montana, are coincidental with reduced grayling abundance and distribution (Federal Register, 2010). Potential linking mechanisms are dewatering of spawning sites, loss of connectivity among spawning, rearing, and refuge sites, and reduction of habitat volume intensifying competition and predation. In Alberta, altered surface and groundwater flows linked to agriculture, grazing, resource extraction, and recreational development are also considered threats to the species (Alberta Environment and Parks and Alberta Conservation Association 2015). Within the Williston watershed, low summer streamflow has also been suggested as a potential stressor. Large numbers of Arctic Grayling fry have consistently been captured and observed stranded in pools isolated from the main channel after water levels dropped in summer (e.g., Cowie and Blackman 2003, 2004, 2007).

The effects of flow on system capacity for stream-dwelling salmonids have been addressed in the recent meta-analysis of Rosenfeld and Enright (2025), in which context-dependent (e.g., snowmelt-driven versus glacial versus rainfall-driven flow regimes) stressor-response curves have been generated.

To model expected impacts of summer streamflow on Arctic Grayling system capacity, we utilized mean discharge estimates for the month of August, which were computed from recent discharge records at Water Survey of Canada streamflow gauging locations in study watersheds. August represents the core of the summer growth period in rearing habitats for both adult and juvenile Arctic Grayling following declines from freshet flows, but prior to emigration to overwinter locations. The stressor-response curve is defined in terms of streamflow levels standardized as percentages of mean annual discharge (MAD). Inflection points of the dome-shaped stressor-response curve are based on the Rosenfeld and Enright (2025) predictions for system capacity in relation to MAD, which estimate optimal flow at 57% of MAD with confidence intervals 36% to 96% MAD, with the steepest rate of decline between 13% and 0% MAD (Figure B 8).

The ‘Summer Flow’ stressor was not included in this iteration of the Joe modelling because of low data availability among sub-basins of the Williston Reservoir watershed.

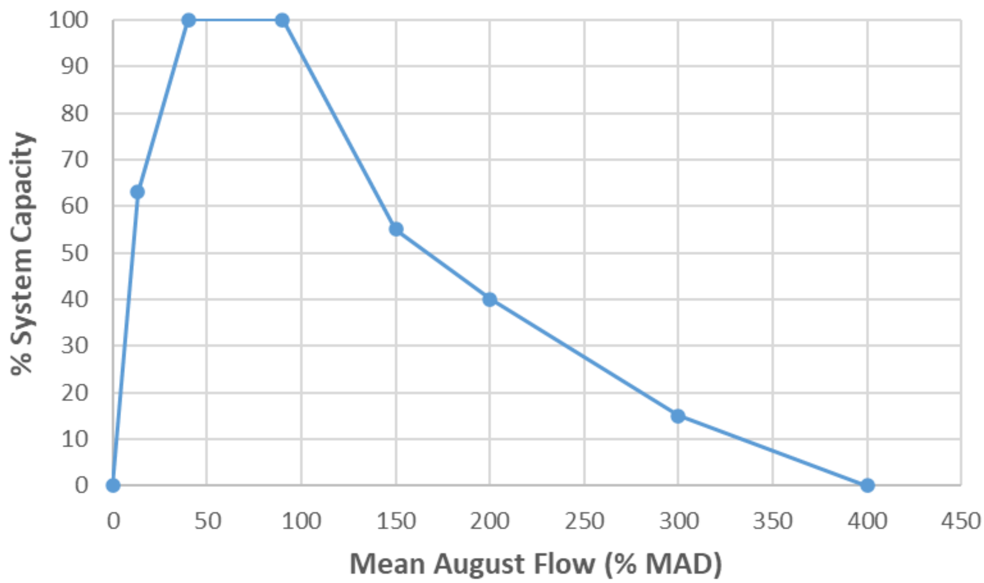

Figure B 8. Hypothesized relationship between Arctic Grayling system capacity and average August flow standardized as % Mean Annual Discharge (MAD), adapted from Rosenfeld and Enright (2025).

Riparian Disturbance

Disturbances to riparian zones can affect fish habitats by destabilizing stream banks, increasing surface erosion and sedimentation, reducing inputs of nutrients and woody debris, and increasing stream temperatures through reduced streamside shading (Porter et al. 2021 and references therein). In the Big Hole River, Montana, Arctic Grayling are positively associated with overhanging vegetation, with degradation of riparian habitat in Arctic Grayling reaches leading to increased erosion, reduced cover, increased water temperature, and decreased recruitment of large wood (Federal Register 2010, and references therein). Decreased canopy cover and consequent increased thermal loading has also been identified as a mechanism of Arctic Grayling habitat degradation in Alberta (Alberta Environment and Parks and Alberta Conservation Association 2015).

To indicate potential impacts of riparian disturbance (beyond natural levels that Arctic Grayling are adapted to) on Arctic Grayling system capacity, we computed two GIS indicators defined by British Columbia's Watershed Status Evaluation Program (WSEP; Porter et al. 2021) (Table B 3). However, we did not define a stressor-response curve in terms of normalized WSEP 'Tier 1' indicator scores or include the 'Riparian Disturbance' stressor in the Joe modeling. This was for two reasons. First, because of expected multicollinearity and overlapping impact mechanisms with the 'Sediment and Surface Erosion' and 'Stream Temperature' stressors, which were prioritized because of strong associations with Arctic Grayling (see Sections 2, 5, and 6). Second, logging of riparian areas along fish-bearing streams >1.5 m in width has been prohibited since 1995, as part of BC's *Forest Practices Code* Act (now *Forest and Range Practices Act*), suggesting that predicting riparian impacts to Arctic Grayling would not be as straightforward relative to a scenario of total riparian habitat loss.

Table B 3. Conversion table relating observed levels of GIS indicators of potential riparian disturbance to normalized WSEP Indicator Scores.

	Score										
Indicators	**0**	**0.1**	***0.2***	**0.3**	***0.4***	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Portion of stream logged (km/km^2)	0.00	0.03	0.06	0.09	0.12	0.15	0.18	0.21	0.24	0.27	≥0.30
Portion of fish-bearing stream logged (km/km^2)	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	≥0.50

Pool Availability

Access to pool habitat within clear stream reaches of moderate gradient appears to be a key habitat requirement for adult and subadult Arctic Grayling within the Williston watershed (Mathias et al. 1998; Blackman 2004; Bottoms et al. 2023) and elsewhere (e.g., Lower Nelson River watershed: Stewart et al. 1982; Big Hole River, Montana: Lamothe and Magee 2004; Kaya 1990). Adult and subadult Arctic Grayling (Figure 4) in the Parsnip River watershed utilize pool and glide habitats of >80 cm depth generally, with preferred locations being deeper water adjacent to the food-delivering thalweg flows (Blackman 2004). Using drone-based thermal mapping of the Anzac River, combined with reach- and landscape-scale snorkeling surveys, Bottoms et al. (2023) were able to demonstrate strong associations between Arctic Grayling and pool habitats. As described in Section 5, animations of hourly temperatures at the reach scale highlighted the spatial importance of pools as thermal refugia during temperature extreme events.

An index of pool habitat quality was developed by Bottoms et al. (2023) based on scoring criteria for pool size, internal thermal heterogeneity, effects of shade, and relative depth. Future CEMPRA applications would benefit from pool index scores estimated across adult/subadult Arctic Grayling summer rearing habitats, but these data are unavailable currently. The stressor-response curve (Figure B 9) is a placeholder, adapted from Hubert et al. (1985).

Although the ‘Pool Availability’ stressor is a limiting factor that could be targeted with recovery actions, it was not included in the Joe modeling because of missing data about pool frequency and/or quality. In this iteration of the Arctic Grayling CEMPRA analysis, pool restoration as a potential recovery action can be indicated, imperfectly, by the ‘Peak Flow’ and ‘Sediment and Surface Erosion’ stressor-response curves, as reduced pool depth and frequency are impact mechanisms associated with these stressors.

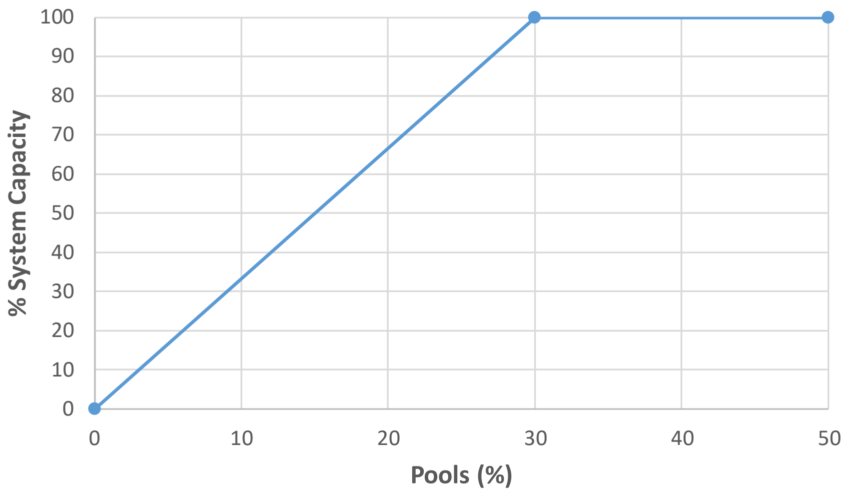

Figure B 9. Hypothesized relationship of Arctic Grayling system capacity to pool frequency in adult/subadult summer rearing habitats.

Fragmentation – Dams

Like other salmonid species, Arctic Grayling metapopulations are highly variable in their migratory behaviours and natal habitat characteristics, and landscape features have prominent influences on the population genetic structure. For instance, low gradient headwater areas appear to provide ecological opportunities for resident populations to differentiate from downstream migratory genotypes and evolve locally adapted resident life histories (Steed et al. 2010; Golden et al. 2021, O'Connor et al. 2026). Spawning site fidelity among resident adults appears to promote fine tuning of life history traits to local environmental conditions in natal streams (e.g., rheotaxis, Kaya 1989, Kaya and Jeannes 1995; growth rates adapted to natal water temperatures, Haugen and Vøllestad 2000). Low gradient headwater areas and tributaries often contain highly structured and locally moving metapopulations and appear to have limited capacity to exploit the complex fluvial habitats downstream (e.g. Buzby and Deegan 2000, 2004; Steed et al. 2010). Lake-adapted (adfluvial) metapopulations have been successfully transplanted to numerous lakes, however, and occur naturally throughout the species range, including above barriers (Northcote 1997; Stamford et al. 2016). In the north slope of Alaska, asymmetric gene flow from lake-adapted headwater resident metapopulations downstream into fluvial migratory metapopulation is thought to contribute unique alleles and improve resilience to climate change (Golden et al. 2021).

Large rivers provide important demographic connections between far reaching habitats for migratory Arctic Grayling, and large river adapted metapopulations (ecotypes) often tend to stray among natal habitats and phenotypic plasticity facilitates survival in novel environments (Wood et al. 2008). Such populations rapidly give rise to locally adapted resident populations within time spans of decades to hundreds of years (McPhail 1997; Wood et al. 2008; Golden et al. 2021; Brennan et al. 2025). [10]

Arctic Grayling metapopulations (core areas) that survived flooding of Williston Reservoir exhibit significant isolation by distance (Shrimpton and Clarke 2012), and each appear to migrate locally within their home watersheds (Clarke et al. 2005; O'Connor et al. 2026). The population structure evolved perhaps 2000 years ago (Stamford and Taylor 2005) and long before flooding of the large river habitats in Peace, Parsnip, and Finlay rivers. The loss of critical habitats now flooded by Williston Reservoir was therefore hypothesized to have caused the extirpation, or near extirpation, of once abundant and demographically distinct large river-adapted Arctic Grayling metapopulations (i.e., Williston and Upper Peace core areas; Stamford et al 2017). Recurrent eDNA detections, persistent observations of rearing subadults in Williston Core Area, and preliminary genetic analyses support the hypothesis, however, that large river-adapted tendencies to home to distant habitats might persist in Williston Core Area (Golder 2013; Stamford et al. 2022). Potentially, adults continue to migrate through the reservoir to complete their life history and sustain demographic connections among streams draining into Finlay Reach, as suggested by preliminary genetic analyses (Stamford et al. *in preparation*). Such a migratory behaviour that continues to move through the reservoir could inform future enhancement actions and potentially key to conserving the evolutionary potential in Williston Reservoir watershed Arctic Grayling.

The stressor-response curve for isolation by the reservoir (Figure B 10) reflects a great deal of uncertainty about the effects of flooding on the demographic connections among remnant metapopulations, and uncertainty about the importance of demographic exchange to system capacity. As a placeholder, we assume an asymptotic maximum 50% impact on surviving metapopulations, which assumes asymmetric gene flow downstream from locally adapted subpopulations continues to promote resilience within and among Arctic Grayling core areas. The loss of a minimum 24 local populations in the Williston and Upper Peace core areas due to flooding is hypothesized to have been due to direct habitat loss, which is delineated as a separate stressor ('Direct Habitat Loss').

The 'Fragmentation - Dams' stressor was not included in the Joe modeling because it is not considered a factor that should be targeted with current recovery actions, but may be included in future analyses (e.g., of dam footprint impacts), or as mitigation techniques are identified and approved.

[10] Among salmonids large river adapted metapopulations or ecotypes are thought to be ancestral and possess those life history traits that enhance resilience to environmental changes (e.g., McPhail 1997; Waples et al. 2008). In contrast, locally adapted resident populations are especially vulnerable to extirpation, but asymmetric gene flow potentially contributes unique alleles to downstream populations and improves overall resilience to environmental changes (Golden et al. 2021).

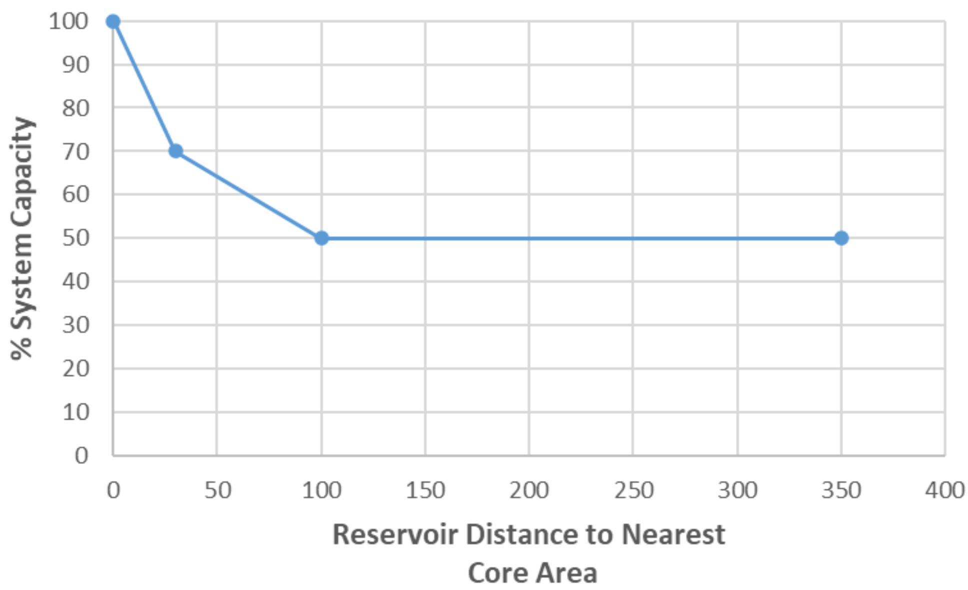

Figure B 10. Hypothesized system capacity resulting from fragmentation caused by dams and valley wide flooding between surviving Arctic Grayling metapopulations.

Direct Habitat Loss

By fall of their first summer of life, fluvial Arctic Grayling drift or move downstream into larger streams (e.g., large turbid rivers that often run clear during winter) to overwinter (Northcote 2003). These larger streams (e.g. Peace River, Mainstream 2012; Earthtone and Mainstream 2013) are often utilized by juvenile grayling 100-200 mm (age-1+ to age-2+) throughout the year, and the summer rearing habitats and overwintering locations may be in relatively close proximity (Tack 1980; Butcher et al. 1981; Northcote 1993; Stewart et al. 2007a). In the Parsnip River watershed, very few juvenile Arctic Grayling have been observed in areas other than the Parsnip mainstem, where they utilize low velocity areas of approximately 0.4-1.0 m depth (Blackman and Hunter 2001). At this size range (100-200mm), it is possible that the energetic cost of migration to clear habitats further upstream may outweigh benefits, or, alternatively, turbidity in lower reaches may provide a refuge from predation. Overwinter habitat utilized by subadult and adult Arctic Grayling may be in the same reaches utilized by juvenile Arctic Grayling year-round (e.g. Blackman and Hunter 2001; Blackman 2002a).

Flooding of roughly 350 km of the Peace River, Finlay River, and Parsnip River valleys eliminated much of the low gradient mainstem habitat that would have been used for rearing by juvenile grayling, and for overwintering for both juvenile and adult life stages. This habitat loss is the most plausible explanation for the relatively rapid extirpation of a minimum of 24 local populations of Arctic Grayling in direct tributaries to the reservoir (Stamford et al. 2017). In the upper Missouri River Basin, dams and reservoirs have also impeded migration and flooded critical habitats (Federal Register 2010). For example, a small remnant population of fluvial Arctic Grayling currently survives in Maddison River, Montana, possibly because overwintering areas escaped the full impacts from Ennis Reservoir formation (Kaya 2000; USFW 2010).

The stressor response curve is based on the positive associations found in the Williston Reservoir watershed between juvenile Arctic Grayling occurrence and 1) distance from the reservoir and 2) stream order (Hawkshaw et al. 2013; Hawkshaw and Shrimpton 2014). A substantial unflooded mainstem length appears to be necessary to complete the life cycle. Refinement of the curve was aided by the 1995-2022 quantitative study of Arctic Grayling distribution and abundance in the Parsnip River watershed (Hagen and Stamford 2023), which estimated marginal abundance in tributaries entering the lower Parsnip River watershed and increasing abundance in tributaries entering upstream up to a peak beginning at the Anzac River, the mouth of which is located roughly 60 km upstream of Williston Reservoir (Figure B 11). The 'Direct Habitat Loss' stressor was not included in the Joe modeling because it is not considered a factor that can be targeted with recovery actions currently, but may be included in a future study of dam footprint impacts.

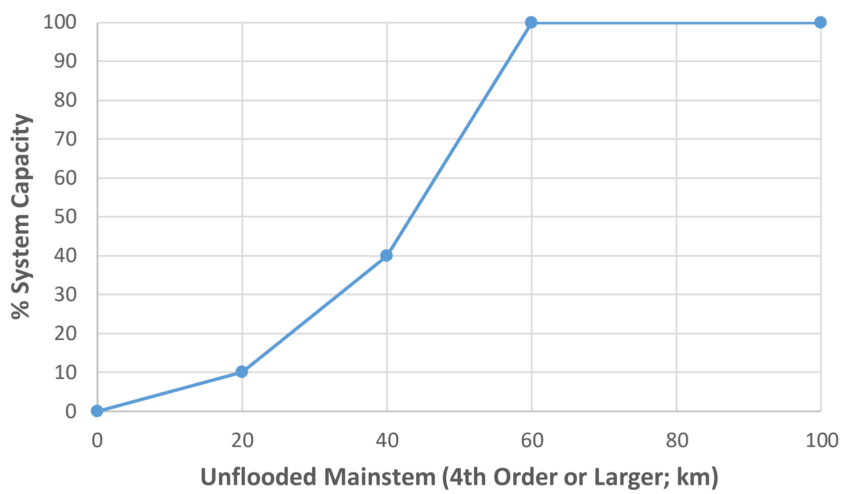

Figure B 11. Hypothesized relationship between Arctic Grayling system capacity and unflooded mainstem length downstream of occurrence.

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