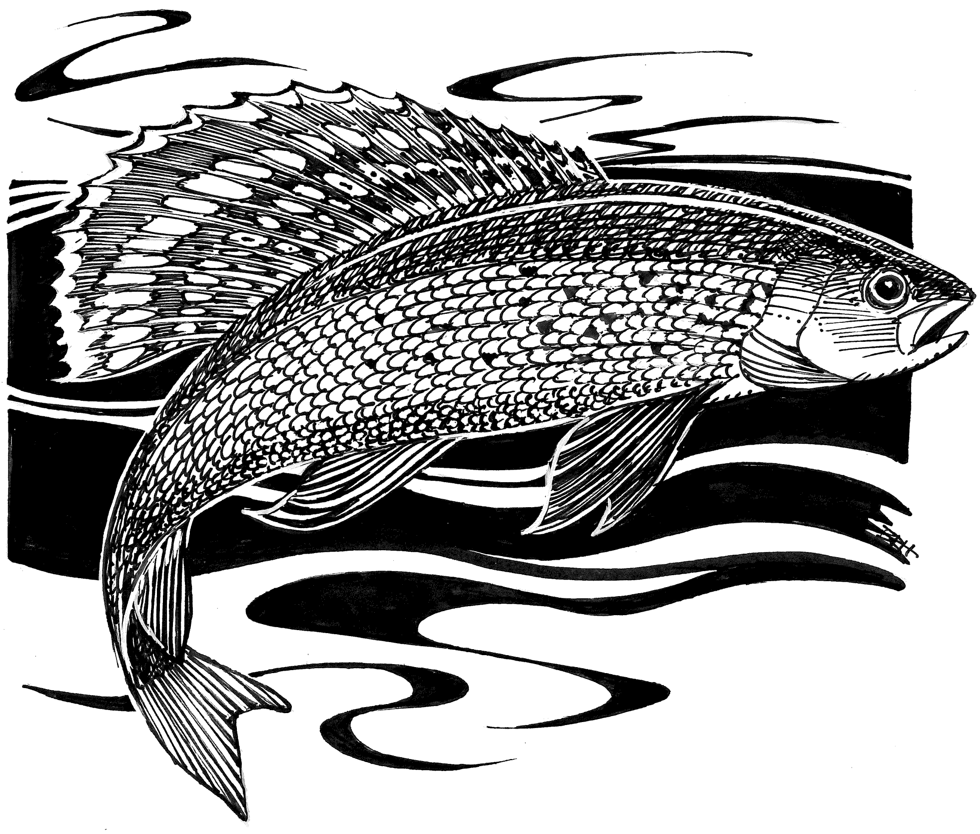
alberta's species at risk program

Status of the Arctic Grayling (*Thymallus arcticus*) in Alberta:

Update 2015



Alberta Wildlife Status Report No. 57 (Update 2015)

Alberta Conservation Association

Alberta Government

Status of the Arctic Grayling (*Thymallus arcticus*) in Alberta:

Update 2015

Prepared for:
Alberta Environment and Parks (AEP)
Alberta Conservation Association (ACA)

Update prepared by:
Christopher L. Cahill

Much of the original work contained in the report was prepared by Jordan Walker in 2005.

This report has been reviewed, revised, and edited prior to publication.
It is an AEP/ACA working document that will be revised and updated periodically.

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PREFACE

Every five years, Alberta Environment and Parks reviews the general status of wildlife species in Alberta. General status assessments have been conducted in 1991 (*The Status of Alberta Wildlife*), 1996 (*The Status of Alberta Wildlife*), 2000, 2005, 2010, and 2015 (available in a searchable database at http://aep.alberta.ca/fish-wildlife/species-at-risk/ since 2000). The general status process assigns individual species "ranks" that reflect the perceived level of risk to populations that occur in the province. Such designations are determined from extensive consultations with professional and amateur biologists, and from a variety of readily available sources of population data. The 2015 general status assessments for vertebrates used the same methodology as assessments from 2000 to 2010, and adopted methodology from NatureServe (http://www.natureserve.org/) for invertebrates and plants. A key objective of general status assessment is to identify species that may be considered for more detailed status determinations.

The Alberta Wildlife Status Report Series is an extension of the general status exercise, and provides comprehensive current summaries of the biological status of selected wildlife species in Alberta. Priority is given to species that are considered at some level to be at risk or potentially at risk (e.g., general status of *At Risk* or *May Be At Risk*, NatureServe rank of S1, Committee on the Status of Endangered Wildlife in Canada [COSEWIC] rank of *Endangered/Threatened* at a national level), and species that are of uncertain status (e.g., general status of *Undetermined*).

Reports in this series are published and distributed by Alberta Conservation Association and Alberta Environment and Parks. They are intended to provide up-to-date information that will be useful to resource professionals for managing populations of species and their habitats in the province. The reports are also designed to provide detailed information that will assist Alberta's Endangered Species Conservation Committee in identifying species that may be formally designated as *Endangered* or *Threatened* under Alberta's *Wildlife Act*. To achieve these goals, the reports have been authored and/or reviewed by individuals with unique local expertise in the biology and management of each species.

EXECUTIVE SUMMARY

The Arctic grayling (*Thymallus arcticus*) in Alberta is currently considered a S*pecies of Special Concern*, and is considered a high-priority candidate for assessment by the Committee on the Status of Endangered Wildlife in Canada. This report compiles recent and historical information on Arctic grayling in Alberta, assessing its current population status and identifying information gaps for future research.

The Arctic grayling is a cold-water species. In Alberta, grayling are primarily found in boreal and foothills streams in the Athabasca, Peace and Hay river drainages. These systems represent the southern extent of the species' North American range, with the exception of a few disjunct remnant populations in the upper Missouri River watershed in Montana.

Arctic grayling monitoring in Alberta has only recently been standardized. The Alberta Arctic grayling Fish Sustainability Index (FSI) summarizes the species' abundance and status in all watersheds containing grayling. This summary provided a significant part of the information used to evaluate grayling in this report. The FSI uses data from fisheries sampling projects, primarily electrofishing and angling, as well as qualitative information (e.g., interviews with anglers, retired biologists, and retired Fish and Wildlife officers, archived data sets, historical reports). The FSI assessed grayling status in two time periods: historical (pre-1960) and recent (2004–2014). Using this information, biologists speculate that grayling abundance has declined by roughly 70% since 1960; however, numbers of grayling in Alberta are reasonably described as remaining in the hundreds of thousands of adult fish. With a grayling generation time of seven years, this decline occurred over eight generations. Overharvest by anglers probably played an important role in this speculated historical decline, as grayling were a popular sport fish and are easily captured by anglers.

Human activities that degrade stream habitats, such as habitat fragmentation caused by improperly installed culverts, pose another important threat to Arctic grayling persistence in Alberta. Additionally, climate modelling suggests anthropogenic climate change will greatly reduce the amount of thermally suitable habitat available to grayling in Alberta during this century. The standardized sampling program will help inform grayling management in Alberta, and a climate adaptation strategy that focuses on maintaining or enhancing ecological resilience may mitigate threats related to climate change.

ACKNOWLEDGEMENTS

For preparation of the original 2005 manuscript by Jordan Walker*:
I would like to acknowledge the many people who have contributed to the preparation of this report. Special thanks must go to David Park (Alberta Conservation Association), Travis Ripley (Alberta Sustainable Resource Development), Dr. Michael Sullivan (Alberta Sustainable Resource Development) and Michael Bryski (Alberta Environment) for their generous contributions of data and time for discussions.

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* Note that some of the affiliations for people acknowledged in this section may be outdated.

For preparation of the updated manuscript in 2015 by Christopher L. Cahill:
I thank my M.Sc. supervisor Dr. William Tonn (University of Alberta; U of A) and Ph.D. supervisor Dr. John Post (University of Calgary; U of C) for providing me the opportunity to update this manuscript while also attending graduate school. Dr. Michael Sullivan (Alberta Environment and Parks; AEP) provided guidance regarding climate modeling, the Alberta Fish Sustainability Index, and provided many helpful comments on several drafts of this report. W. Hughson (Parks Canada), T. Clayton (AEP), J. Janes (Alberta Biodiversity Monitoring Institute), and J. Stelfox (Alberta Environment and Sustainable Resource Development – retired) contributed personal communications to C. Cahill and M. Sullivan. Important conversations and contributions from Laura MacPherson (AEP), Jessica Reilly (U of A/AEP), Fred Noddin (U of A), Craig Johnson (AEP), Bryan Maitland (U of A), Kyle Wilson (U of C), and Steph Mogensen (U of C) are also gratefully acknowledged. I extend thanks to Diana Stralberg (U of A), Dr. Erin Bayne (U of A), and Dr. Fangliang He (U of A) for important discussions regarding statistical modeling. Laura MacPherson and Chad Sherburne (AEP) provided much needed assistance with GIS and mapping. Dana Seidel (U of A) assisted with HawthsTools. Sue Peters (Alberta Conservation Association), Robin Gutsell (AEP), Matthew Faust (Great Lakes Fishery Commission), Mark Poesch (U of A), Marcel Macullo (AEP), and Stephen Spencer (Alberta Environmental Monitoring, Evaluation and Reporting Agency) greatly improved earlier versions of this manuscript.

All modelling in this report was performed using R Statistical Programming Software (R Core Team 2014, version 3.1.1), Hawth's Tools, and ClimateWNA version 4.85.

Preparation of this updated report was funded by Alberta Conservation Association and Alberta Environment and Parks.

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INTRODUCTION

The Arctic grayling (*Thymallus arcticus*; Pallus 1776) is a member of the Salmonidae family (trout, charr, whitefishes, salmon), featuring a prominent dorsal fin and brilliant colouration (Scott and Crossman 1985). Grayling require cold water, undisturbed habitats, and are vulnerable to angling (Nelson and Paetz 1992, Northcote 1995, Stewart et al. 2007). As a Holarctic species, *T. arcticus* is widespread in northern freshwater drainages, but has undergone range contractions or declines along southern distribution limits (Federal Register 2014). For example, the Arctic grayling was extirpated from Michigan in the 1930s (Vincent 1962), the species was petitioned for federal listing in the upper Missouri River watershed (although it was later determined that listing was not warranted; Federal Register 2014), and is currently designated as "critically imperilled" in the Peace-Williston River watershed in British Columbia (British Columbia Conservation Data Centre 2013). In Alberta, Arctic grayling occur naturally throughout northern portions of the province in the Hay, Peace, and Athabasca river drainages (Scott and Crossman 1985, Nelson and Paetz 1992), and have also been stocked in central and southern Alberta (Figure 1).

The Arctic grayling is considered a *Species of Special Concern* (Government of Alberta 2014), is ranked as *Sensitive*[*] in *The General Status of Alberta Wild Species 2010* (Alberta Environment and Parks [AEP] 2015a), and was identified as "vulnerable" by Alberta's Fisheries Management Division (Berry 1998); furthermore, it has a Provincial Heritage Status Rank of S3S4 (NatureServe 2014). Currently, no designation has been given by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), but the species is categorized by COSEWIC's Species Specialist Subcommittee for freshwater fishes as a "high-priority candidate" for status assessment in Canada (COSEWIC 2015).

This report summarizes current information on Arctic grayling and will be used to update its status in Alberta. Concerns regarding sustainability of this species in Alberta are quantified and then discussed, and recommendations for mitigating potential threats are provided.

DISTRIBUTION

1. – Alberta - In Alberta, the Arctic grayling is native to the Hay, Peace, and Athabasca river basins (Scott and Crossman 1985), and occurs mostly in rivers and streams. Approximately 1% of the global range of Arctic grayling occurs in Alberta, based on the maps of Kaya (1990, pp. 47–51), Vincent (1962, p. 12), Behnke (2002, p. 330), Scott and Crossman (1985, pp. 301–302), and Nelson and Paetz (1992).

The extent of occurrence of Arctic grayling in Alberta (414,682 km^2) was calculated as the shortest imaginary boundary (minimum convex polygon) drawn to encompass all known or inferred sites of present occurrence of grayling; the boundary excluded introduced (stocked) grayling in southwestern Alberta. The boundaries used for this area were the grayling location records in Alberta's Fisheries and Wildlife Management Information System (FWMIS; AEP 2015b; Figure 1). The area of occupancy (152,516 km^2) was calculated by summing the occupied 2-km by 2-km grid squares, which were overlaid on all the grayling waterways in northern Alberta (IUCN 2014). A more precise estimate of the area of occupancy for grayling in Alberta was calculated based on the grayling-occupied watersheds from the provincial Fish Sustainability Index (FSI; see *Population Size and Trends [1. Alberta]* for details). First, lengths for streams of orders 3, 4, and 5 in all grayling-occupied watersheds, assumed to encompass the primary lotic habitat

[*] See Appendix 1 for definitions of selected status designations.

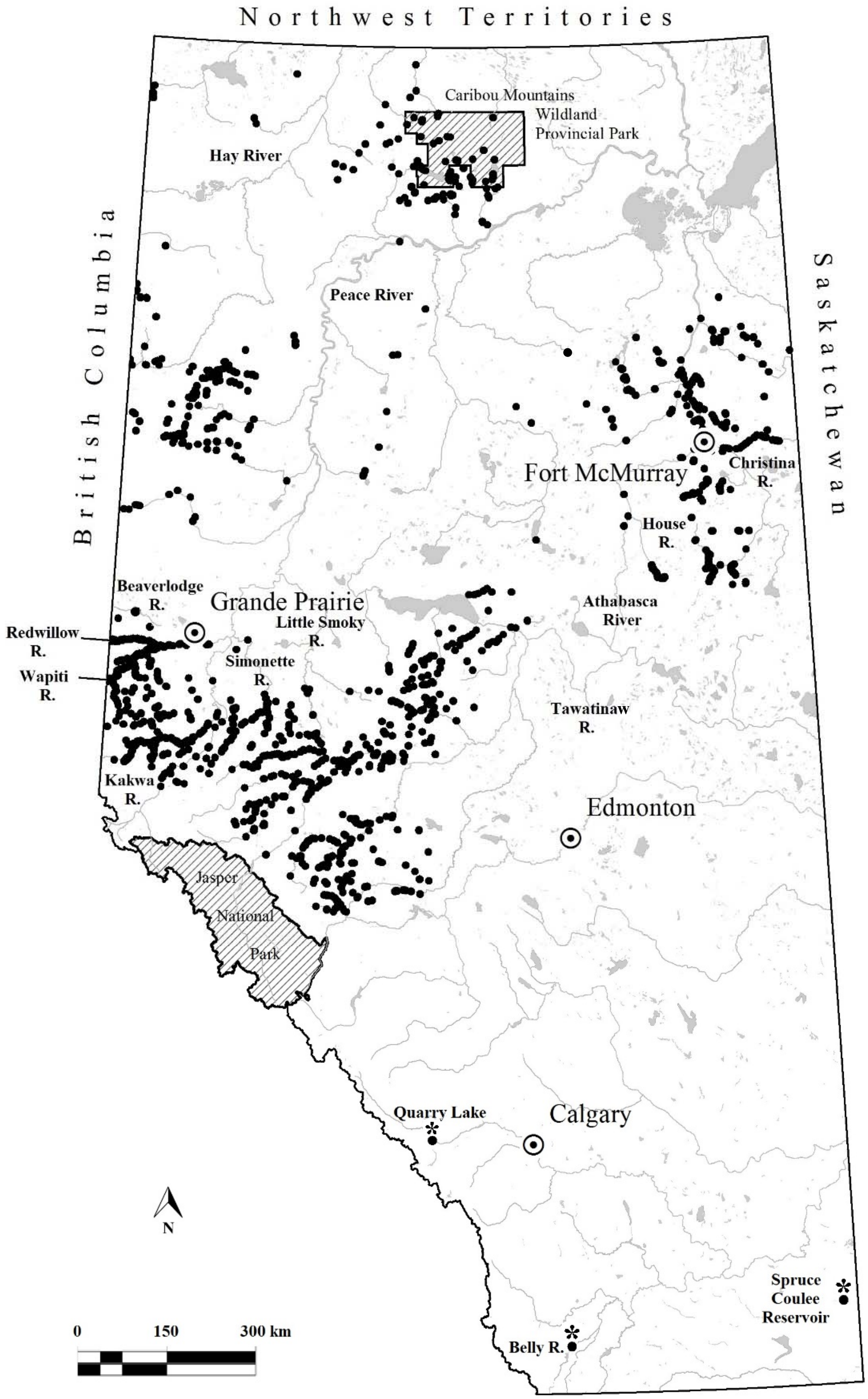

Figure 1. Geographic locations (n = 3337) where Arctic grayling have been captured in Alberta during 1956–2015. Circles represent locations where native grayling have been captured, whereas asterisks represent locations where grayling were introduced (stocked). Numerous other unsuccessful stockings have occurred throughout Alberta, and are not included on this map. Location records are taken from Alberta's Fisheries and Wildlife Management Information System (FWMIS) (January 2015).

for grayling in Alberta, were summed as 86,378 linear kilometres (43,085 km in stream order 3, 27,413 km in stream order 4, and 15,880 km in stream order 5). Second, the actual area of occupied habitat was approximated using estimated average width of a stream of grayling-occupied watercourses in northern Alberta. Average widths for streams of orders 3, 4, and 5 were approximated by randomly selecting 30 stream reaches in each stream order, and these averages were then used to approximate the total actual area of occupied habitat. Average stream widths of 3.5 m, 13.8 m, and 21.4 m, respectively, suggested the total actual area of occupied habitat is approximately 869 km^2 (i.e., 151 km^2 for stream order 3; 378 km^2 for stream order 4; and 340 km^2 for stream order 5; C. Sherburne pers. comm.).

The Arctic grayling is a well-studied game fish. FWMIS records suggest that native grayling occur in at least four geographically distinct regions (Figure 1). The largest grouping of grayling occurs in the Upper and Lower Foothills natural subregions, and extends east into the Central Mixedwood Natural Subregion (Figure 1; see Natural Regions and Subregions of Alberta map at Alberta Parks 2005). Another grouping occurs north of Grand Prairie primarily in the Upper Boreal Highlands Natural Subregion between the Peace and Hay rivers (Figure 1). Grayling also exist in the Boreal Subarctic Natural Subregion of the Caribou Mountains in north-central Alberta, and in the eastern Boreal Forest Natural Region (Central Mixedwood and Athabasca Plain natural subregions) around Fort McMurray (Figure 1). Reilly (2014) showed significant genetic differentiation in grayling from the Hay, Peace, and Athabasca river basins, and suggested this resulted from limited dispersal among basins.

In addition to native Arctic grayling in northern portions of the province, stocking has also occurred in Alberta (Figure 1). A disjunct grayling subpopulation occurs in the Belly River in southwestern Alberta, and was likely established by stocking nearby Elizabeth Lake in Glacier National Park in the United States in either 1924 or 1962; the species was undocumented prior to this time (T. Clayton pers. comm.). Grayling were stocked in lakes at least 12 times throughout Jasper National Park from 1954 to 1969 (Mayhood 1992), but no lakes or streams in the park are known to contain grayling currently (W. Hughson pers. comm.). Additionally, Quarry Lake in southern Alberta was first stocked with Arctic grayling in 1997, and then stocked annually during 2001–2013. Spruce Coulee Reservoir in southern Alberta was also stocked in 2013. Numerous other unsuccessful stockings have occurred throughout Alberta. However, stocked Arctic grayling do not contribute to the native population being assessed in this report because of the limited efficacy and small scale of Arctic grayling stocking programs in Alberta.

FWMIS data indicate that Arctic grayling have been documented at 3337 different geographic sites in Alberta (Figure 1). Many populations of wild species are separated into distinct "locations" (defined as distinct areas within which all individuals would be affected by a single threatening event). There is not sufficient information on the scale at which this species' threats operate (see *Limiting Factors*) to determine how many distinct locations exist in Alberta for Arctic grayling; however, there are likely more than ten locations.

1.1 Trends in Distribution - The distribution of grayling in Alberta has likely decreased in size, but most information regarding these decreases is qualitative. Human activities influence temporal changes in Arctic grayling distribution, as the species is easily captured by anglers and is negatively affected by habitat disturbances (Sullivan 1988, Nelson and Paetz 1992, Northcote 1995, Federal Register 2014). Qualitative evidence suggests that the distribution of Arctic grayling along the southern edge of the species' range has declined during the past 50 years. Berry (1998) suggested that changes in grayling distribution throughout the Foothills Natural Region of Alberta during the 1950s were due to angling exploitation. Interviews with anglers suggested that the quality of grayling fishing had deteriorated in many locations in the foothills region (Bryski 1997a, b, 1998, 1999a, b). Additionally, habitat alteration and degradation, and water quality issues have been cited as proximate causes for the extirpation of grayling in the Redwillow River watershed of the Foothills Natural Region near Grand Prairie (AECOM 2009). Widespread declines in distribution in the eastern boreal region have also been suggested, and were again attributed to overexploitation (Sullivan 1988).

The amount of annual variation in grayling distribution is currently unknown, but may be relatively high as grayling in Alberta exist along the southern periphery of the species' distribution (see review by Hardie and Hutchings 2010 on peripheral populations). Along distribution peripheries, species are generally subjected to suboptimal conditions, which may result in distribution fluctuations (Gaston 2003, Vecutich and Waite 2003). However, there are no data with which to determine the magnitude of any fluctuations in distribution that grayling might undergo in Alberta.

2. Other Areas - Arctic grayling have a continuous Holarctic distribution across northeastern Eurasia and northwestern North America (Scott and Crossman 1985, Behnke 2002). Within North America, grayling occupy drainages from Hudson Bay to Alaska, including the Northwest Territories, Yukon, and Nunavut, as well as northern areas of British Columbia, Alberta, Saskatchewan, and Manitoba (Figure 2). However, disjunct populations include an upper Missouri River population (Montana) and two populations that were extirpated from northern Michigan in the 1930s (Figure 2; Northcote 1995).

HABITAT

1. Requirements and Use - Arctic grayling are widespread throughout northern Alberta, but specific habitat requirements appear to limit their local occurrence. Arctic Grayling require cold, clear, and well-oxygenated waters (Nelson and Paetz 1992, Lohr et al. 1996, Federal Register 2014) with velocities less than 60 cm/sec, and gradients less than 4% (Vincent 1962). In Alberta, grayling are typically found in streams and rivers, but also occupy lakes (Scott and Crossman 1985, Nelson and Paetz 1992). Grayling generally live in areas of the province that are between 300 m and 1200 m above sea level, and are usually found north of the 53rd parallel (Scott and Crossman 1985). In tributaries of the Wapiti River, Alberta, phosphorus runoff was correlated to winter oxygen levels, and then qualitatively compared to grayling presence (Norris 2012). Streams with greater than 3-fold increases in phosphorus compared to pre-development levels did not support grayling (Norris 2012). Laboratory experiments suggest upper incipient lethal temperature (temperature survivable by 50% of subjects for one week) for Arctic grayling ranged from 23˚C to 25˚C (Lohr et al. 1996), and water temperatures along the southern edge of the species' distribution in Alberta occasionally surpass 25˚C (Blackburn and Johnson 2004). Wojcik (1955) found that adult grayling were stressed when water temperatures were above 17.2˚C.

Summer habitat use differs for juvenile and adult Arctic grayling (Northcote 1995), whereas wintering habitats appear similar for both life stages. In summer, young-of-year grayling are typically found in shallow areas with little flow, such as side channels (Stuart and Chislett 1979, Northcote 1995). In the Athabasca River basin, young-of-year grayling frequent mouths of tributaries from June to August

Figure 2. Distribution of Arctic grayling in North America, including two extirpated populations in the eastern United States (adapted from NatureServe 2014).

(Anonymous 1980a, b), and are typically found in streams with gravel or rubble bottoms and little silt (Lucko 1992). Experiments in Montana suggested young-of-year grayling preferentially select shallow (less than 21cm), low velocity (less than 4 cm/sec) habitats with cover throughout summer (McClure and Gould 1991). Adults use mainstem pools, riffles, and runs (Stuart and Chislett 1979), and prefer riffle-pool complexes throughout summer months (Anonymous 1978). Juvenile and adult grayling use winter refuge habitats such as large river side channels, backwaters, lakes, springs, and tributary streams (Wilson et al. 1977, Tack 1980, West et al. 1992, Stanislawski 1997).

Published information on grayling spawning habitat in Alberta is unavailable, although they likely spawn over gravel (Nelson and Paetz 1992). In British Columbia, Arctic grayling spawn over coarse gravel in shallow (0 cm–40 cm) glides, pools, and tails of runs, where velocities are between 0.5 m/sec–1.0 m/sec (Stewart et al. 1982). Bottom substrate consisted of 10%–50% cobble, 0%–80% gravel, and only 10%–20% fine substrate (Butcher et al. 1981). In interior Alaska, grayling spawned in riffles over pea-sized gravel (Warner 1955), and over gravel that ranged in size from 0.075 mm to 3.1 mm in diameter in the Chena River (Tack 1973).

2. Fragmentation - Energy and forestry development in Alberta's boreal forest has resulted in road densities in some areas of 5 km/km^2 – 6 km/km^2 (Park et al. 2008). Where these roads cross streams, culverts can obstruct grayling movement (Katopodis et al. 1978, Stewart et al. 2007); hanging or perched culverts (pipes with outfall elevation too high for fish to jump) are of particular concern as they block upstream fish passage (Furniss et al. 1991). Approximately 50% of culverts in northern Alberta are hanging culverts (Park 2006). Estimates of the number of hanging culverts in Alberta's boreal forest ranged from 7600 to 10,700, which fragmented an estimated 36,000 km to 50,000 km of stream (Park et al. 2008). Connectivity of grayling habitat has declined as a result of this fragmentation by culverts (See *Limiting Factors [2. Habitat Degradation, Fragmentation, and Loss]*), which poses a threat to Arctic grayling populations across the province.

Another study in the Foothills region of Alberta examined effects of culvert fragmentation on fish communities and populations, but low capture rates did not allow for specific conclusions regarding Arctic grayling (MacPherson et al. 2012). Maitland et al. (2015) demonstrated a reduction in fish species richness, including Arctic grayling, associated with culverts in a northern Alberta watershed. Whether such culvert fragmentation has resulted in genetic isolation of a previously contiguous population into subpopulations, based on International Union for Conservation of Nature (IUCN) criteria (i.e., exchange of less than one individual or gamete per year; IUCN 2012), is unknown but appears likely, particularly for subpopulations in upstream portions of watersheds. This suggestion is based on the high number of hanging culverts estimated by Park (2006), coupled with the rationale that upstream gamete exchange is virtually impossible if fish from lower portions of watersheds cannot ascend hanging culverts to reach fish in upstream portions of watersheds. Also unknown is the status of Alberta grayling with regard to the IUCN definition of "severely fragmented" (i.e., most [>50%] of the species' total area of occupancy is in habitat patches that are either smaller than would be required to support a viable population, or separated from other habitat patches by an impassable barrier or a large distance). A fundamental concept in population viability theory, however, is that small populations are more likely to become extinct than larger ones because of demographic stochasticity, genetic drift, and/or inbreeding depression (Boyce 1992); thus, culvert fragmentation reduces the viability and resilience of isolated subpopulations. Distances grayling would be expected to disperse between habitats are currently unknown, but migrations greater than 50 km have been observed in Alberta (Stanislawski 1997). The availability of suitable habitat that would support dispersal between habitats is also unknown, but likely limited as a result of culvert fragmentation in most areas (Park et al. 2008).

3. Trends - Anthropogenic activities have caused declines in quality and quantity of grayling habitat in Alberta, and these declines will likely continue in the future. In the Redwillow River watershed of the Foothills Natural Region, rivers have reduced flows and poor water quality because of phosphorus and nitrogen runoff from agriculture and livestock operations (AECOM 2009). Hanging culverts resulting from resource development and extraction have fragmented stream habitats, and Park et al. (2008) suggested that this has reduced the productive capacity of grayling habitat in Alberta. Current trends suggest much of the boreal forest in Alberta will reach practical maximum road densities within the next 50 years (i.e., the point at which human access needs are arguably fully met; 5 km/ km^2–6 km/km^2; Schneider 2002, Park 2006), resulting in increased habitat fragmentation from hanging culverts. Anthropogenic climate change will be a major stressor of grayling habitats during the next century, greatly reducing the availability of thermally suitable habitat in the province (see *Limiting Factors, 3. Anthropogenic Climate Change*), as well as having other multifaceted impacts on aquatic ecosystems (Schindler 2001).

4. Unoccupied Suitable Habitat - Interestingly, grayling do not currently occupy waters within Jasper National Park (JNP), even though they are present in the upper Athabasca River drainage adjacent to park boundaries and apparently suitable habitat (see *Habitat*) may exist in the Miette valley and in small Athabasca River tributaries from Athabasca Falls downstream to the eastern park boundary (Mayhood 1992). Accounts of grayling prior to their unsuccessful stockings during the 1950s and 1960s in JNP exist, but remain unsubstantiated (Bajkov 1927, Ross 1855 as cited in Mayhood 1992). No apparent physical barriers to grayling movement exist between JNP and adjacent populations (Mayhood 1992). The absence of grayling and the unsuccessful stocking attempts strongly suggest an unknown ecological factor preventing grayling from becoming established in JNP. This also suggests that JNP is an unlikely climate-change refuge for grayling in the Athabasca drainage.

BIOLOGY

This section focuses primarily on aspects of the species' biology that are relevant to its conservation, management and status.

1. Physical Description - Adult Arctic grayling are identified by their colourful and large dorsal fin, which is much larger than that of any other salmonid (Scott and Crossman 1985). Additionally, their sides are marked with distinct, diamond-shaped spots mostly in front of the pelvic fins (Scott and Crossman 1985). Adult Arctic grayling in Alberta are moderately sized, and are typically 27 cm–35 cm in length (fork length; measured from the tip of the snout to the fork in the tail), and weigh 200–600 grams.

Correct identification may be challenging when examining juvenile fishes, with young Arctic grayling occasionally being mistaken for young mountain whitefish (*Prosopium williamsoni*). Both species feature a silvery-grey color and parr marks (banding) along their sides (Nelson and Paetz 1992). The two juvenile species can be distinguished from one another as grayling have small dark spots on the sides of their body toward the head, and feature a large dorsal fin. Additionally, Arctic grayling have a terminal mouth and smoothly convex snout (viewed from above), whereas mountain whitefish have a subterminal mouth and more pointed snout (Nelson and Paetz 1992).

2. General Biology - For detailed accounts of grayling biology, see reviews by Armstrong (1986), Northcote (1995), Stewart et al. (2007), and the Federal Register (2014).

In Alberta, Arctic grayling live in streams, rivers and occasionally lakes (Nelson and Paetz 1992). Grayling require clear, cold-water habitats (Hubert et al. 1985), and are classified as a stenothermic (cold-water) species based on laboratory experiments (Lohr et al. 1996, Selong et al. 2001), similar to bull trout (*Salvelinus confluentus)* and Arctic char (*S. alpinus*).

In streams, grayling distribute themselves according to fish size. Larger fish tend to occupy better feeding sites in upstream locations with smaller fish occurring downstream (Tack 1980, Hughes and Reynolds 1994, Hughes 1999). Both juvenile and adult grayling are opportunistic, visual feeders, and typically feed on drifting aquatic invertebrates such as stoneflies, caddis flies, mayflies, and dragonflies, as well as small crustaceans, molluscs, and zooplankton (Wojcik 1955, Nelson and Paetz 1992). Grayling will also feed on terrestrial invertebrates such as beetles, midges, ants, and grasshoppers, which may make up to 50% of their diet (Joint and Sullivan 2003). Grayling occasionally eat small fishes and eggs, including those of their own species (Williams 1969 cited in Armstrong 1986, Stewart et al. 2007).

3. Reproductive Biology - Grayling are spring spawners, and move to spawning areas when water temperatures approach 4ºC (Northcote 1995). In Alberta, spawning occurs when water temperatures are between 5ºC and 10ºC (Hubert et al. 1985, Nelson and Paetz 1992, Joint and Sullivan 2003), which typically occurs mid-May to mid-June (Nelson and Paetz 1992). Spawning behaviour in Alberta appears similar to that in other parts of the species' range (Scott and Crossman 1985, Northcote 1995, Joint and Sullivan 2003, Stewart et al. 2007). Males arrive first to set up and defend territories that are 6 m^2–7 m^2 (Beauchamp 1981). Males use their large dorsal fins to attract females and display gaped mouths to deter competitors (Joint and Sullivan 2003). These life history attributes suggest grayling require visual isolation provided by diverse habitats to reduce intraspecific aggression during spawning (Beauchamp 1990). Female grayling typically remain in deeper water until entering shallows briefly to spawn (Tack 1971). Arctic grayling do not construct redds (excavations for fish eggs dug into gravel), and are considered broadcast spawners (Scott and Crossman 1985, Behnke 2002). After spawning, adults typically leave the smaller tributaries to return to larger rivers or lakes (Lawrence and Davies 1979).

Grayling eggs are smaller than the eggs of most other salmonids (i.e., 2.0 mm–3.0 mm prior to fertilization); consequently, grayling fecundity is relatively high (Northcote 1995). Estimates of grayling fecundity range approximately from 3000 to 8000 eggs per 0.5 kg body weight (e.g., compared to 800–1000 eggs per 0.5 kg body weight for most other salmonids; Falk et al. 1982, Behnke 2002). After spawning, grayling eggs sink and become lodged in substrate interstices where they incubate for 156 to 268 degree days (Stuart and Chislett 1979, Butcher et al. 1989, Northcote 1995, Behnke 2002). Newly emerged fry range in size from 7 mm to 15 mm (Watling and Brown 1955, Stuart and Chislett 1979, Beauchamp 1981), and are weak swimmers; Clark (1992) showed that stream discharge is a significant negative correlate to grayling recruitment. Arctic grayling occasionally exhibit natal homing in Alaska (Hop 1985, Hop et al. 1986, Northcote 1997).

4. Age, Growth, and Maturity - In Alberta, no formal (i.e., published) age and growth analysis has occurred for Arctic grayling. Additionally, grayling age estimation in the province has typically been performed using scales, which only yield reliable age estimates until maturity (Sikstrom 1983, Armstrong 1986, Skopets 1991, Stewart et al. 2007). Arctic grayling assessments in Saskatchewan suggest scales and otoliths (inner ear bones) yield similar age estimates to age five (Merkowsky 1989). Nonetheless, Berry (1998) concluded, using scale age estimates from 34 different locations during 1947–1996, that grayling growth rates across Alberta were similar, and that 50% of grayling were mature by age three and nearly all fish matured by age four. Subsequently, Ripley (1998), indicated that grayling in northwest Alberta took longer to mature, with 58% of these grayling reaching maturity by age four and 100% maturity by age eight. Scale estimates suggest Arctic grayling live to at least age 11 (Ripley 1998). However, scales typically underestimate grayling age by between five and nine years when compared to otoliths (Sikstrom 1983, Armstrong 1986, Skopets 1991, Stewart et al. 2007). Collections of grayling otoliths from fish in the relatively lightly exploited population in the Little Smoky River, however, show a maximum age of 11, at a fork length of 327 mm (Figure 3). This sample of fish also showed that full maturity for both males and females was at age four. Detailed length-age distributions and maturity data from unexploited populations do not exist in Alberta.

The assumption for this report is that grayling reach maturity at 4 years, and maximum age is 11 years. Generation length can be estimated from the average age of adult fish in an unexploited population, which in the Little Smoky River sample was approximately six years (n = 39 adult fish, mean age of adult fish = 5.6 years, SD = 1.9). As this population does have some fishing pressure, it is reasonable to assume the average age of adults in an unfished population may have been older. Generation length can also be estimated to be seven years, calculated as the average age between age-at-maturity and maximum age. This value (7 years) therefore serves as a reasonable generation length estimate for Alberta Arctic grayling.

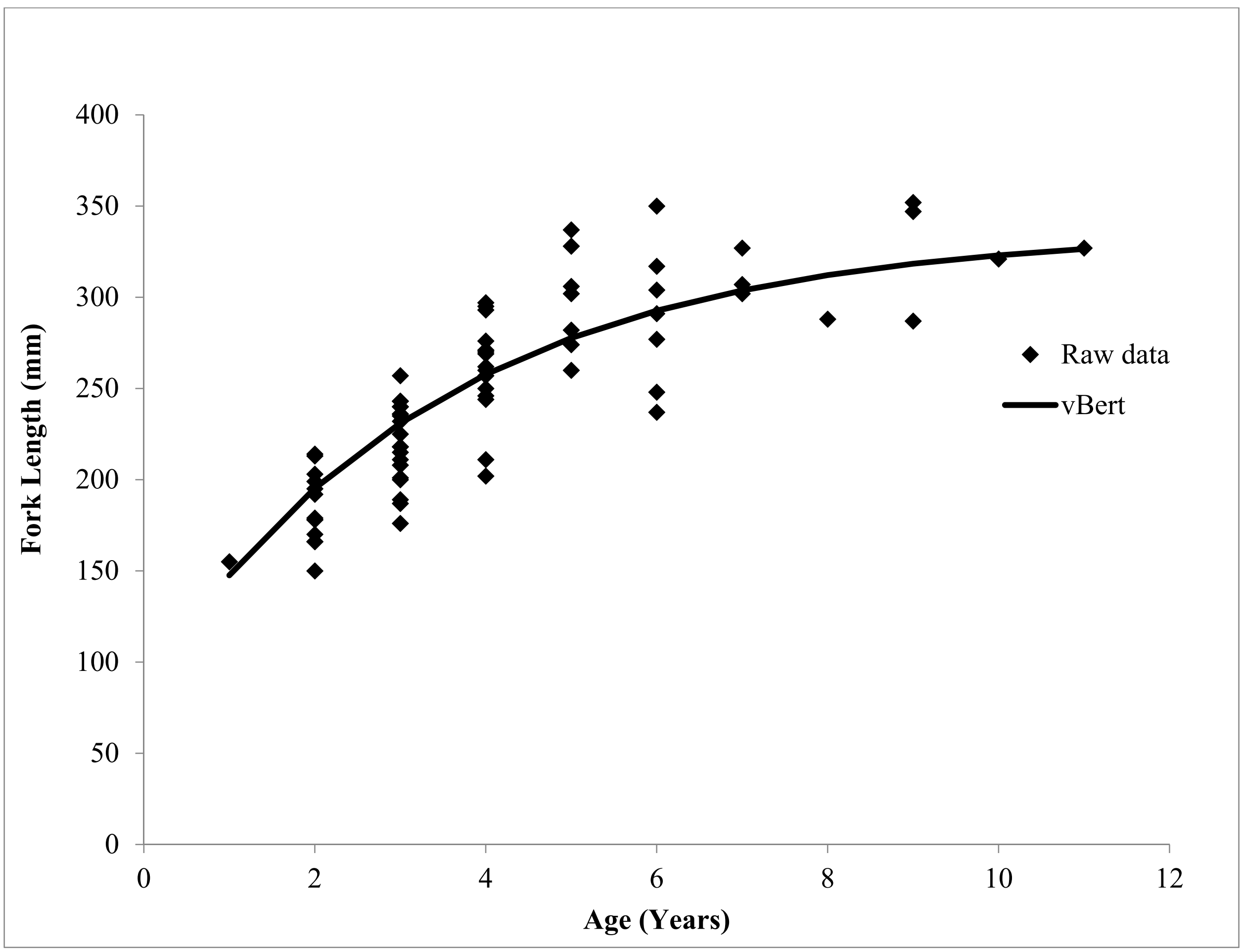

Figure 3. Von Bertalanffy growth model for Arctic grayling based on otolith-aged grayling from Little Smoky River (2007 data from Alberta Environment and Parks FWMIS database).

5. Movement - Arctic grayling undertake complex and incompletely understood migrations to feeding, overwintering, and spawning sites. Fluvial (stream- or river-dwelling) Arctic grayling use at least three major habitat types throughout their lifespan (Armstrong 1986, Northcote 1995). Migrations begin shortly after emergence when fry typically undergo short trophic migrations to summer feeding habitats in side channels, backwaters, and stream margins (Armstrong 1986). Many young-of-year undergo an overwintering migration to suitable refuges in autumn (Northcote 1995), but young have been observed under ice in small tributaries in Alberta (Bond and Machniak 1979). In Alberta, grayling appear to use natal streams for at least two summers (Anonymous 1980a, 1980b, Berry 1998). These migrations between feeding and refuge areas are repeated until sexual maturity is reached, and then fish migrate to spawning areas (Tack 1980). After maturity, adult grayling repeat these trophic, refuge, and spawning migrations annually (Northcote 1995). Lacustrine (lake-dwelling) grayling make similar migrations between lakes and streams to feed, overwinter, and spawn (Armstrong 1986).

In Alberta, grayling surveyed using radio-telemetry in the Little Smoky River made movements of 49 km (mean total movement of 30 radio-tagged grayling) during fall migrations to downstream overwintering habitats (Stanislawski 1997). Grayling were also detected leaving these overwintering pools and moving upstream to spawn in early May (Stanislawski 1997). Similarly, radio-tagged grayling in the Wapiti River system also moved downstream to overwintering locations in autumn, and migrated upstream to spawn during April and early May (Tchir et al. 2003). Seasonal habitat use by grayling has been observed in several rivers throughout Alberta (Berry 1998), suggesting the importance of movement to fulfill basic life history requirements. Reilly et al. (2014) showed that Alberta grayling exhibit moderate to high levels of genetic differentiation among rivers, with some rivers holding demographically independent units of Arctic grayling. These results suggest that immigration from adjacent rivers is unlikely to strengthen declining populations, or repopulate extirpated areas over short (i.e., several generations) timeframes.

POPULATION SIZE AND TRENDS

1. Alberta - Landscape-level analyses of fish population size and trends are logistically difficult and quantitatively challenging, and the use of non-standardized sampling procedures adds another level of complexity to assessing Arctic grayling status in Alberta. However, such assessments provide information on aquatic resource sustainability (Hilborn and Walters 1992, p. 3), and provincial fisheries managers have apportioned considerable effort into developing the Fish Sustainability Index (FSI) to assess existing data (Coombs and MacPherson 2014, ESRD 2014; see AEP 2015c for FSI background information). Following internationally accepted guidelines (NatureServe 2015, IUCN 2008, 2012), Alberta FSI evaluations rank subpopulations relative to a reference population occupying optimal habitat that is also relatively undisturbed by human activities (Coombs and MacPherson 2014). The FSI categories correspond to the broad status categories usually assigned to fisheries: recruitment overfishing, growth overfishing, and unexploited (Hilborn and Walters 1992, Haddon 2001, Walters and Martell 2004). For Alberta's grayling FSI, risk categories with quantitative thresholds for adult and immature grayling abundance are set using catch rate data from angling surveys (Table 1a) and from estimated density using mark-recapture and electrofishing studies (Table 1b). In addition to quantitative data, qualitative data from hundreds of interviews and studies from a variety of sources were used (e.g., reports from fisheries biologists, enforcement officers, anglers, First Nations fishers, environmental

Table 1a. Comparisons between angling catch rate and indices of adult (>28.3 cm fork length) grayling abundance as related to Alberta's FSI metrics. Abundance and density metrics correspond to the upper threshold of the angling CUE categories. From MacPherson (2014) and Sullivan (2011, 2013). CUE = catch per unit effort.

FSI Category	Angling CUE (fish / h)	Abundance (#fish / 300 m reach)	Linear Density (m / fish)	Density (fish / ha)[a]
1 (Very High Risk)	0 – 0.22	6.9	44	11.5
2 (High Risk)	0.22 - 0.44	13.8	22	22.9
3 (Moderate Risk)	0.44 – 0.66	20.6	15	34.4
4 (Low Risk)	0.66 – 0.88	27.5	11	45.8
5 (Very Low Risk)	0.88 – 1.1 (+)	34.4	9	57.3

[a] the derived equation is Density = 52.1*Angling CUE

Table 1b. Comparisons between electrofishing catch rates and indices of adult grayling abundance as used in Alberta's FSI metrics. Abundance and density metrics correspond to the upper threshold of the electrofishing CUE categories. From MacPherson (2014) and Sullivan (2011, 2013). CUE = catch per unit effort.

FSI Category	E-fishing CUE (fish / 10,000 s)	Abundance (# fish / reach)	Linear Density (m / fish)	Density (fish / ha)[a]
1 (Very High Risk)	4.5	6.9	44	11.5
2 (High Risk)	9.0	13.8	22	22.9
3 (Moderate Risk)	13.4	20.6	15	34.4
4 (Low Risk)	17.9	27.5	11	45.8
5 (Very Low Risk)	22.4	34.4	9	57.3

[a] the derived equation is Density = 2.56*Electrofishing CUE

consultants, collection permit returns, etc.) (see Appendices 2–4).

To assess potential changes in grayling status for the FSI, the historical status of grayling in each watershed was also estimated. The year 1960 was chosen as a threshold for "historical," based on the availability of angling survey data, electrofishing data, and qualitative fisheries records (e.g., Sullivan 1988, Bryski 1997a, 1997b, Valastin and Sullivan 1997, Berry 1998, Bryski 1998, Bryski 1999a, 1999b, Sullivan 2005). This also approximately corresponds to the period of time prior to the extensive oil development and increased access in Alberta's boreal regions (Schneider 2002).

The basic spatial unit in the Alberta FSI is the Hierarchical Unit Code (HUC) watershed. This watershed mapping protocol follows the USGS protocols for nested watersheds (Seaber et al. 1987). For Arctic grayling, the HUC watersheds represent reasonably spaced geographic units separated from other subpopulations to the extent that re-establishment following extirpation was deemed unlikely to occur within a decade (Reilly 2014, ESRD 2014). Arctic grayling HUCs include habitats temporally or seasonally occupied, exclude cases of vagrancy, and represent the pre-disturbance distribution of Arctic grayling in cases of local extirpation or range contraction (IUCN 2008, ESRD 2014).

In total, 59 HUCs in Alberta were assessed as currently or historically containing native grayling, although three additional HUCs contained introduced grayling (Figure 4). Of the 59 HUCs containing native grayling, declines in density ranks were estimated to have occurred in 49 watersheds (83%), while grayling density ranks in 10 watersheds (17%) remained static. No watersheds with increases were noted. Grayling were estimated to have been extirpated in 11 watersheds.

1.1 Adult Population Size - Mark-recapture estimates of the entire current population size are impractical because native grayling are extensively distributed in each of the 59 HUCs and any provincial abundance estimate must be considered a rough approximation. A simple method follows Rahel and Jackson (2007), and multiplies average adult abundance per km (determined using small-scale abundance estimates) by the linear extent of streams (km) to approximate stream fish abundance.

Sullivan (2015; attached as Appendix 5) used this method to provide two abundance estimates for native adult Arctic grayling in Alberta: historical period (pre-1960) and recent period (2004–2014). In brief, local biologists were able to assess the historical and recent status of grayling in 103 streams and rivers. The linear extent (km) of primary grayling habitat in these lotic systems was assumed to include all streams of order 3, 4, and 5, similar to calculations presented in the *Distribution* section of this report. These habitat areas were then assigned two density estimates (historical and recent) based on the assigned FSI rank. This approach suggests there are approximately 600,000 native adult Arctic grayling presently in Alberta (Figure 5). This approximation has many limitations; however, the point of this analysis was to suggest there are probably hundreds of thousands of Arctic grayling in Alberta.

1.2 Population Trend - Calculating a population trend for adult grayling using the FSI density ranks was done by comparing the recent (2004–2014) abundance approximation to a pre-1960 abundance approximation. This approach suggested the historical (pre-1960) abundance of grayling in Alberta was approximately 1.8 million adult grayling; by 2014, the abundance of grayling may have declined by approximately 70% relative to the pre-1960 abundance (Figure 5).

Based on a grayling generation time of 7 years, this 54-year decline may have occurred over a period of about 8 generations. Reports from biologists and interviews with anglers suggest that grayling had seriously declined by the early 1980s in many watersheds in northeastern Alberta (Bryski 1997a, 1997b, Valastin and Sullivan 1997, Berry 1998, Bryski 1998, Bryski 1999a, 1999b). An example of this decline is shown in data from the Muskeg River in northeastern Alberta. Counts of grayling at fish-fences show a decline in catches of 84% from 1976 to 1995 (20 years), followed by near-extirpation by 2003 (Figure 6 from Bond and Machniak 1979, and Schwalb et al. 2015). In other watersheds (e.g., Freeman, Pembina, and Christina rivers; MacPherson 2014), however, this initial rapid decline has not

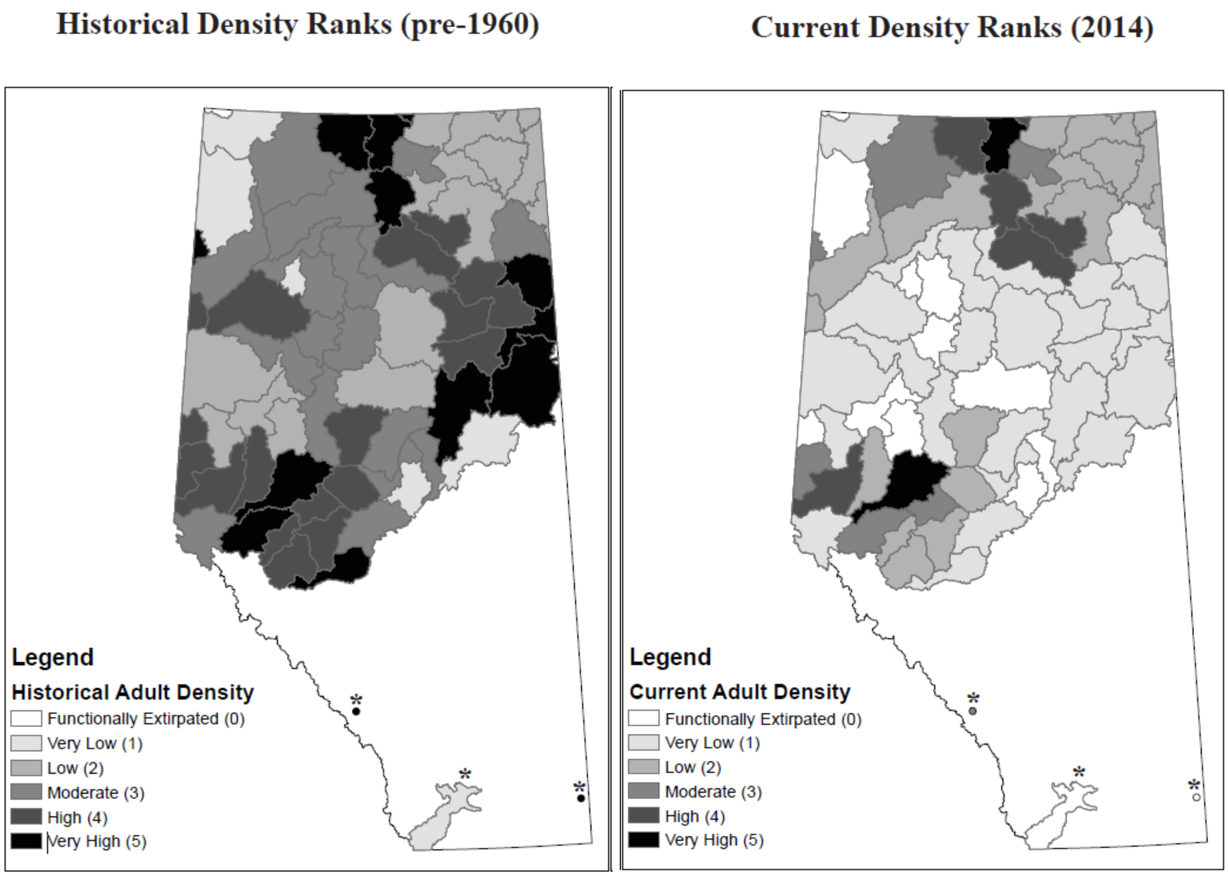

Figure 4. Maps of historical (pre-1960) and current (2014) adult grayling density ranks for each Hierarchical Unit Code (HUC) watershed, as determined by the Arctic grayling Fish Sustainability Index methodology (ESRD 2014). HUCs are delineated with light grey lines. Asterisks represent locations where grayling were introduced.

continued to near-extirpation. It is probable that as local grayling fisheries collapsed, few anglers continued to fish in these species-poor streams and grayling have been constrained and maintained at these low densities by fishing pressure and habitat issues.

No repeated measures or ranks exist anywhere in this analysis, and thus we are presently unable to comment on the fluctuation in numbers of the Alberta grayling population; however, the only available catch-per-unit-effort data from the Little Smoky River (a relatively undisturbed population; see *Limiting Factors*) has a coefficient of variation of 0.48 (Figure 7). This suggests fish in the Little Smoky River undergo population size fluctuations of approximately two- to three-fold, assuming population size is linearly related to catch-per-unit-effort. However, it is unknown whether this degree of fluctuation is typical of other watersheds.

If climate change greatly reduces the availability of thermally suitable habitat in the province during the next century (see *Limiting Factors, 3. Anthropogenic Climate Change*), and we make the reasonable assumption that the amount of thermally suitable habitat is a proxy for area of habitat, then population reductions of a similar scale could be predicted in the future.

1.3 Rescue Potential **-** The rescue potential of Alberta's Arctic grayling is an intriguing topic, given the species' migratory capability, geographic constraints, and climate change modelling. Arctic grayling in Alberta are capable of making mean annual migrations of at least 50 km (see *Biology*), suggesting

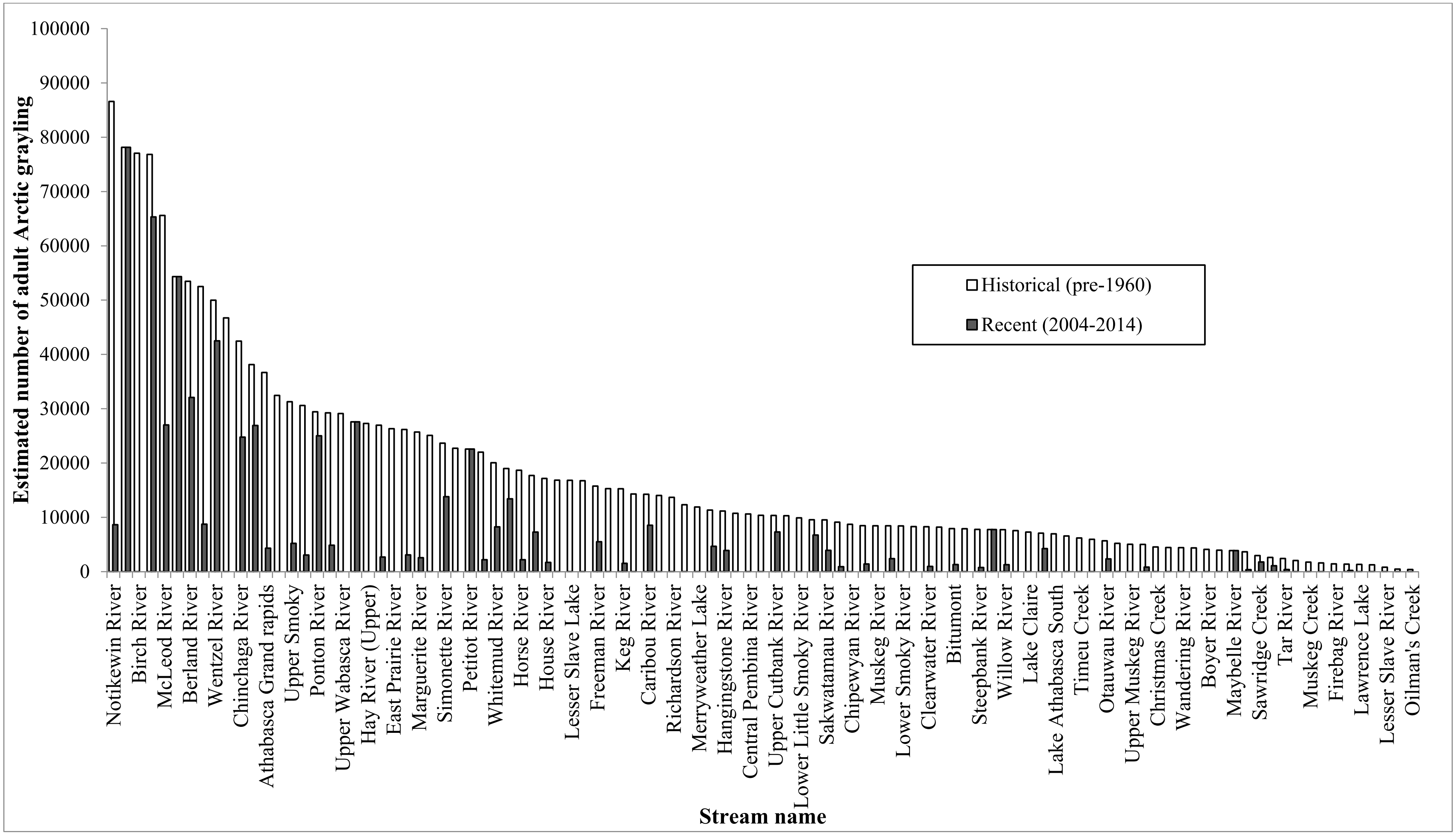

Figure 5. Estimates of abundance of adult Arctic grayling in 103 streams and rivers in Alberta. Grayling are estimated to have been lost in 51 of the 103 assessed streams and rivers. Estimates are based simply on GIS-based estimates of stream length (orders 3, 4, 5) and categorical estimates of density in specific habitats.

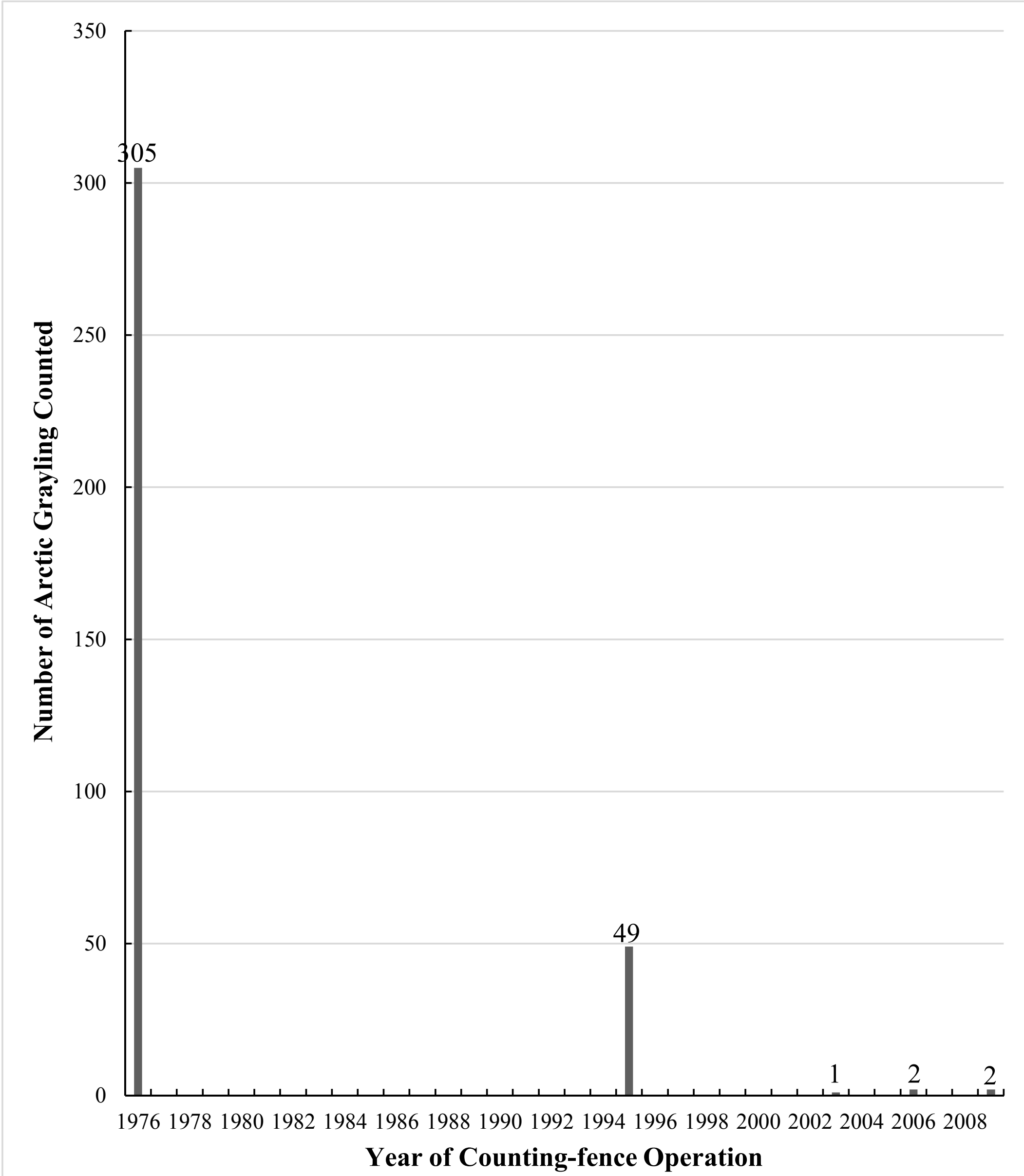

Figure 6. Decline in counts of Arctic grayling at a counting fence in Muskeg River, Alberta from 1976 to 2009. Data are from Schwalb et al. 2015 and Bond and Machniak 1979. The fence was operational in 1976, 1995, 2003, 2006, and 2009.

the species is capable of dispersing between habitats. Potential source populations in British Columbia, the Northwest Territories, and Saskatchewan are relatively healthy from a conservation status perspective (see *Status Designations [2. Other Areas]*). Moreover, high quality habitats are available in Alberta (see *Habitat [1. Requirements and Use]*), and as such it appears likely that potential immigrants would survive in Alberta. However, grayling in adjacent jurisdictions are largely isolated from native fish in Alberta. Grayling in the upper Missouri River watershed, Montana, are approximately 800 km to the south of native Alberta grayling, and genetic evidence suggests these fish have been isolated from fish in Canada for at least 10,000 years (Redenbach and Taylor 1999, Petersen and Ardren 2009). This suggests rescue from the south is unlikely. Alberta grayling also appear isolated from grayling to the west in the Peace River, as construction of the W.A.C. Bennett Dam west of Hudson's Hope, B.C. has resulted in widespread declines in grayling abundance

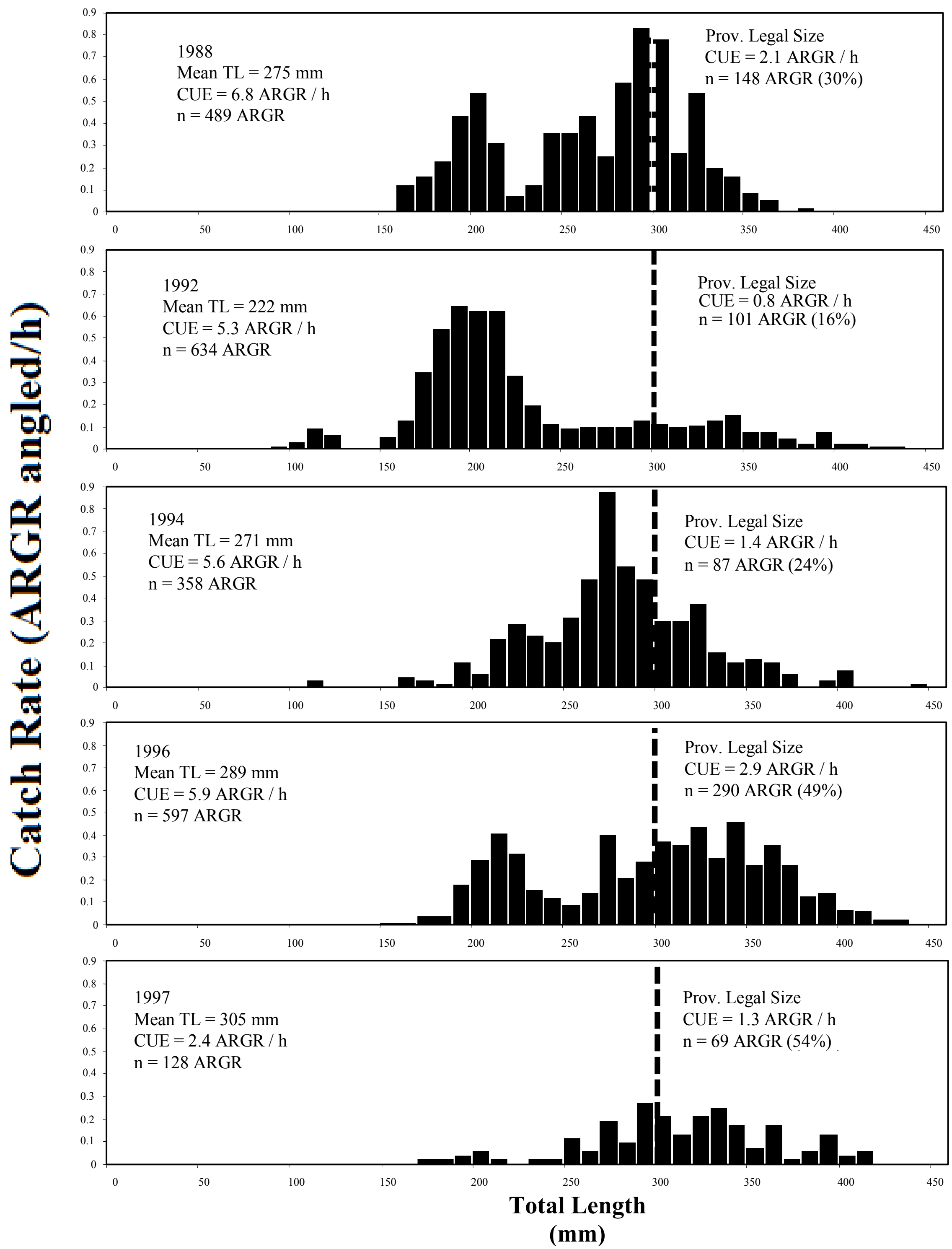

Figure 7. Total length frequency distributions (mm) for Arctic grayling angled from the Little Smoky River from 1988 to 1997 (AEP unpubl. data; TL = total length, CUE = catch per unit effort, ARGR = Arctic grayling). Dashed vertical lines correspond to what used to be the provincial minimum length harvest limit (300 mm).

and subsequent red-listing of the species in this region (Northcote 1993, 1995, B.C. Ministry of Water, Land and Air Protection 2002). This, coupled with the construction of the Site C Dam on the Peace River near Fort St. John, B.C. (Kiani et al. 2013, BC Hydro 2015), suggests that rescue from the west is similarly hindered. The Rapids of the Drowned, on the Slave River at the Alberta-Northwest Territories border, is a barrier to upstream fish movement (Boag and Westworth 1993), and thus rescue from the Northwest Territories through this major corridor also appears unlikely. Presently, grayling in Alberta do not appear isolated from grayling in Saskatchewan, as river drainages in Alberta cross into Saskatchewan; however, climate modeling (see Appendix 6) shows low-elevation portions of the province (north-eastern portions of Alberta and hence north-western Saskatchewan) will become thermally unsuitable for Arctic grayling. This modeling suggests that the rescue potential from Saskatchewan will become increasingly unlikely as temperature increases during this century. Together, this information suggests that the rescue potential of Alberta grayling by fish from outside jurisdictions is likely compromised relative to historical levels.

2. Other Areas - Arctic grayling have undergone notable declines attributed to overexploitation and habitat degradation (Armstrong 1986, Northcote 1995). Grayling disappeared from Michigan as a result of warming of streams, siltation from clear-cut logging in the 1860s, and replacement by non-native trout species (Behnke 2002). Disjunct Montana populations have been widely supplemented through extensive hatchery propagation and stockings into previously uninhabited waters (Behnke 2002). Stocks in the Williston watershed above the W.A.C. Bennett Dam in British Columbia have collapsed (Cannings and Ptolemy 1998). Angling has resulted in declines in grayling quality and abundance in Alaska (Riddler 1992). However, Arctic grayling populations are thought to be generally healthy throughout British Columbia, Manitoba, the Northwest Territories, Saskatchewan, and the Yukon Territory (see *Status Designations*).

LIMITING FACTORS

This section will focus on threats that have an anthropogenic origin, as well as on other factors that occur naturally if they are amplified by human activities and result in increased pressures on the population. Threats are generally listed in order of importance (i.e., beginning with recent/current/imminent threats that are well documented and have caused/are causing/will cause population-scale harm).

1. Angling - Historically, angling posed the most serious threat to Arctic grayling in Alberta, and likely caused the anecdotal declines in abundance and distribution noted earlier (see *Population Size and Trends*), particularly in streams easily accessible to anglers (i.e., streams near roads or other access points throughout northern Alberta). Recreational angling has been cited as a factor limiting inland fisheries in Canada (review by Post et al. 2002). Arctic grayling are a popular sport fish throughout their North American range (McPhail and Lindsey 1970, Armstrong 1986, Nelson and Paetz 1992), and angler harvest has negatively affected grayling populations outside Alberta (Wojcik 1955, Falk and Gillman 1974, Tack 1974). Arctic grayling are extremely vulnerable to overexploitation because they are easily captured by anglers (McPhail and Lindsey 1970, Scott and Crossman 1985, Northcote 1995), similar to that of other native salmonids in the Canadian Rocky Mountains of southern Alberta (Figure 8; Paul et al. 2003). In Alaska, Arctic grayling populations near major access points were exploited at rates between two and three times higher than populations in more remote areas (Riddler 1992). Exploitation rates have never been directly estimated for Alberta grayling populations, and thus the current effects of harvest on grayling are difficult to quantify; however, as of 2015 Alberta

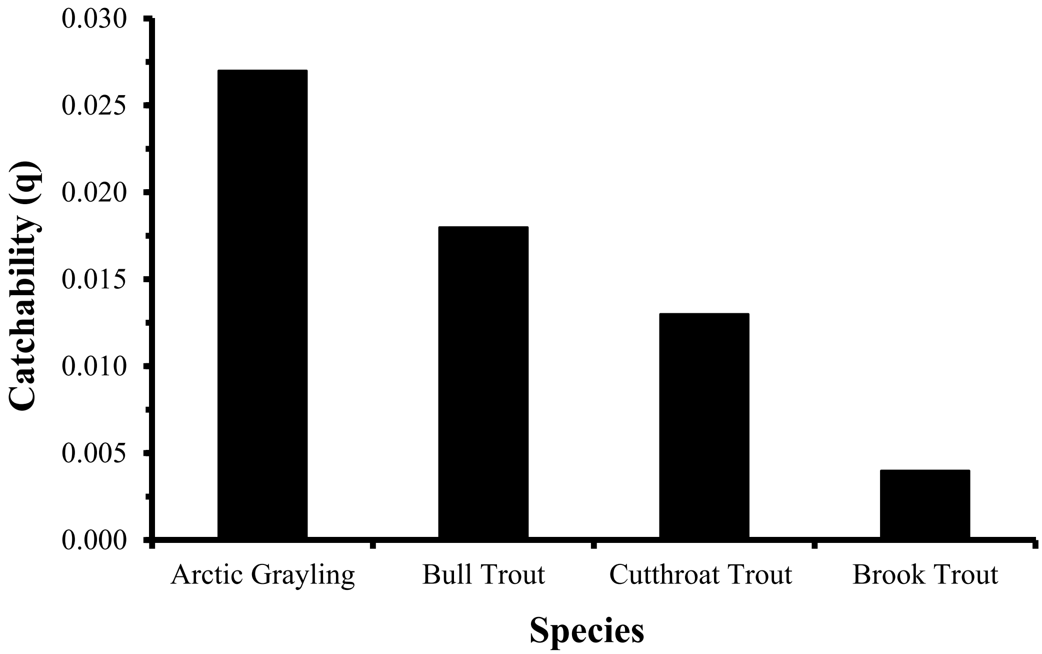

Figure 8. A comparison of Arctic grayling catchability (data from Ripley 1998) to the catchability of other stream fishes from Alberta (Paul et al. 2003).

anglers are no longer allowed to harvest Arctic grayling in Alberta, so this threat is probably minimized relative to its historical impact (see *Recent Management and Research*). Currently, the Little Smoky River is considered a reference stream for Arctic grayling because it is believed to be only lightly exploited (ESRD 2014). This fishery was surveyed using angling in 1988, 1992, 1994, 1996 and 1997 (Figure 7). Whether the differences in length-frequency distributions resulted from changes in recruitment, growth, or mortality is difficult to discern.

Anecdotal evidence suggests Arctic grayling in accessible regions of Alberta were historically overexploited under low to moderate angling pressure (Nelson and Paetz 1992). Studies by Carl et al. (1992) on the Beaverlodge River, Alberta, indirectly supported these conclusions, and recommended restrictive harvest regulations for this river. On the Little Smoky River, Alberta, catch rates declined from eight to four fish per hour as grayling fishing pressure increased during 1987–1990, suggesting exploitation was an issue (Hildebrandt and Hunt 1992). Detailed work on Arctic grayling in the Ft. McMurray area show counts of grayling at fish fences declined by two orders of magnitude in the Muskeg River between 1976 and 2009 (Schwalb et al. 2015). In the nearby Steepbank River, over 1700 grayling were counted at a fish fence in 1977 (Bond 1980), yet a total of only 63 grayling were counted in 118 separate fisheries studies on this river in the entire decade between 2001 and 2011 (data up to 2012 from FWMIS [AEP 2015b], summarized by M. Sullivan). These declines appeared to occur quickly and prior to widespread habitat alterations in this area from active oil sands mining, and are reasonably attributed to increased access and overfishing (Machniak and Bond 1979, Valastin and Sullivan 1997, Schwalb et al. 2015).

This appears concordant with qualitative evidence suggesting negative impacts of angling on grayling populations throughout the foothills region of Alberta from the 1950s to 1970s (Bryski 1997 a, 1997b, Bryski 1998, Bryski 1999a, 1999b). Sullivan (1988) suggested grayling in accessible rivers of the eastern boreal region were extremely vulnerable to overexploitation. Berry (1998) suggested declines occurred in grayling populations in the eastern boreal forest region of Alberta following increases in angler accessibility, particularly in the House and Christina rivers. As such, it appears likely that angler harvest negatively influences grayling in Alberta, and resulted in historical declines in areas accessible to anglers prior to the 1990s. In conclusion, the available evidence suggests that Arctic grayling are easily overharvested, and that populations are unsustainable when fish are accessible to anglers and not protected by fisheries management regulations.

2. Habitat Degradation, Fragmentation, and Loss - Currently, human activities that degrade, destroy, or fragment stream habitat pose the greatest threat to Arctic grayling persistence in the province. Arctic grayling require a diversity of clean, cold habitats, and the loss and degradation of quality habitat has been cited as one of the major causes in the decline or extirpation of Arctic grayling populations outside of Alberta (Hubbs and Lagler 1958, Armstrong 1986, Northcote 1995). Although not focused on Arctic grayling specifically, many studies show that economically important activities such as agriculture, resource extraction (e.g., forestry, mining), and road construction typically decrease the quality and stability of cold-water fish habitat (McIntosh et al. 1994, Cross and Everest 1997, MBTSG 1998, Park et al. 2008, AECOM 2009, Gresswell and Vondracek 2010). Therefore, it seems prudent to briefly highlight the impacts these activities frequently have on fish habitat.

A number of economically important activities known to degrade cold-water fish habitat occur throughout the Alberta grayling range (e.g., Schneider 2002, Gresswell and Vondracek 2010). For example, agriculture, grazing, road construction, resource extraction, and recreational development can all alter surface and groundwater flows (MBTSG 1998). Logging in high-gradient areas has resulted in extreme runoff events and flooding, and has changed groundwater recharge or seasonal flow levels to cold-water fish streams (Berry 1994, Cross and Everest 1997, McCart 1997, MBTSG 1998, Kuras et al. 2012). Mineral extraction has resulted in numerous local extirpations of native cutthroat trout (*Onchorynchous clarkii)* and bull trout throughout western North America (Woodward et al. 1997, Farag et al. 2003). Additionally, all of the activities listed above typically increase sediment accumulation in streams and can decrease canopy cover, which both cause increased thermal loading of streams (Berry 1994, Cross and Everest 1997, McCart 1997, MBTSG 1998, Sear and DeVries 2008, SRD and ACA 2009).

Although the specific effects of fragmentation on Arctic grayling are not well understood, extensive fragmentation of grayling habitat (*sensu* Park et al. 2008, Maitland et al. 2015) is of particular concern to aquatic resource managers in Alberta. Metapopulation theory suggests habitat patch size and isolation greatly influence the dynamics and persistence of species (Levins 1969, Hanski 1982, Hanski and Gilpin 1991), and that fragmentation often reduces the long-term sustainability of species in lotic systems (Zwick 1992). This is particularly true for species that require access to multiple habitats to fulfill basic life history requirements (Lucas and Baras 2001), such as Arctic grayling (Armstrong 1986). Landscape-level fragmentation caused by hanging culverts throughout Alberta's boreal forests compromises the resilience of Arctic grayling habitats, and increases the likelihood of population decline and loss resulting from unfavourable stochastic events such as droughts, floods, or excessively warm weather. Moreover, fragmentation decreases the likelihood of repopulation following local extirpation (Guy et al. 2008), as well as degrading existing habitat (Maitland et al. 2015).

A notable study by Scrimgeour et al. (2008) showed that grayling occurrence was positively related to percent disturbance and road density in the Kakwa and Simonette river watersheds in west-central Alberta. The authors suggested this resulted from nutrient enrichment of the watersheds mediated by forest harvesting, or because of the negative relationship between the highly piscivorous bull trout and percent disturbance and road density, which may have afforded grayling a predation refuge. However, two important points should be discussed regarding this paper. First, the importance of temperature increases resulting from increased nutrient loading and sediment transport were not included in Scrimgeour et al. (2008); this is problematic, considering temperature-stressed fish are less resilient to external stressors (Beechie et al. 2013), and given that climate modeling projections in this report suggest thermal stress will be a critical threat for Arctic grayling habitat across Alberta (see *Limiting Factors [3. Anthropogenic Climate Change]*). Second, Arctic grayling in Alberta rarely occur in streams where bull trout also currently occur (SRD and ACA 2009), and thus the watersheds used in Scrimgeour et al. (2008) are likely an exception in terms of their competitive regimes. We suggest these issues may limit the possibility of Arctic grayling responding in a manner suggested by Scrimgeour et al. (2008), and thus question the generalizability of this study across Alberta for Arctic grayling.

3. Anthropogenic Climate Change - The amount of suitable habitat ultimately limits fish populations (Minns 1997, Jones and Tonn 2004), and thus anthropogenic climate change poses the most serious, tenable threat to Arctic grayling persistence in Alberta. Temperature is an important ecological resource for ectothermic organisms such as fish (Magnuson et al. 1979), and fish survival, egg development, competitive ability, and growth are all temperature-dependent (Pauly 1980, Taniguchi et al. 1998, King et al. 1999, Teletchea et al. 2009). Many authors have expressed concern about the potential effects of climate warming on aquatic ecosystems (Magnuson et al. 1990, Tonn 1990, Kernan et al. 2010). Cold-water species near the southern limits of their distribution appear most vulnerable to climate-induced range contractions (Keleher and Rahel 1996, McCullough et al. 2009, Williams et al. 2009). For example, European grayling (*Thymallus thymallus*) have been extirpated from lower portions of the Rhone River (Daufresne et al. 2003) because of reproductive disruption caused by elevated temperatures (McCullough et al. 2009). As air temperatures increase, distributions of cold-water fishes are expected to shift upwards in latitude and elevation to offset the effects of regional warming (Riemann et al. 2007). As a result, climate change will likely impact grayling throughout the province, particularly in low elevation areas throughout northern Alberta.

Many approaches have been used to relate fish distributions to thermally suitable habitats (Magnuson et al. 1990). Biogeographic distribution limits of salmonids across North America are usually associated with excessively warm summer temperatures that cause physiological stress (Meisner 1990, Keleher and Rahel 1996, Rahel et al. 1996, Harig and Fausch 2002). Researchers examining air-temperature limits for cold-water fish often use mean warmest month temperature (MWMT; Rahel 2002), and assume that air and water temperatures are correlated. This assumption appears realistic for time scales greater than one week when mean air temperatures are less than 25˚C (Mohseni et al. 1998), and thus MWMT has been used to predict changes in stream-dwelling salmonid distributions to climate change across the western United States (Keleher and Rahel 1996). Similar increases in MWMT resulting from climate change will likely reduce the amount of thermally suitable habitat for Arctic grayling in Alberta.

In Appendix 6, we model temperature increases across the range of grayling in Alberta, and estimate the amount of thermally suitable habitat currently available to Alberta grayling. We also present landscape-level losses of thermally suitable habitat approximated for ca. 2025, 2055, and 2085 using an ensemble of 16 numerical General Circulation Models (GCMs). Based on this analysis, it appears that the amount of thermally suitable habitat for grayling in Alberta could decrease by approximately 50% by 2025, and continue to decrease by a cumulative loss of more than 90% by 2055 and later (Figure 9; see Appendix 6 for details).

These findings are comparable to other studies in the western United States suggesting thermal habitat losses for stream-dwelling salmonids of up to 71.8% by 2100 (Keleher and Rahel 1996), and suggest Arctic grayling in Alberta will be at higher risk of local and regional extirpation later in this century. Eastern and northern portions of the grayling range in Alberta appear most at risk in terms of modelled temperature increases; this is because these regions feature relatively low elevation, which also coincides with general predicted impacts of climate change on cold-water fishes (Riemann et al. 2007). Accordingly, these results also highlight the importance of protecting grayling habitat in the relatively high-elevation Upper and Lower Foothills subregions.

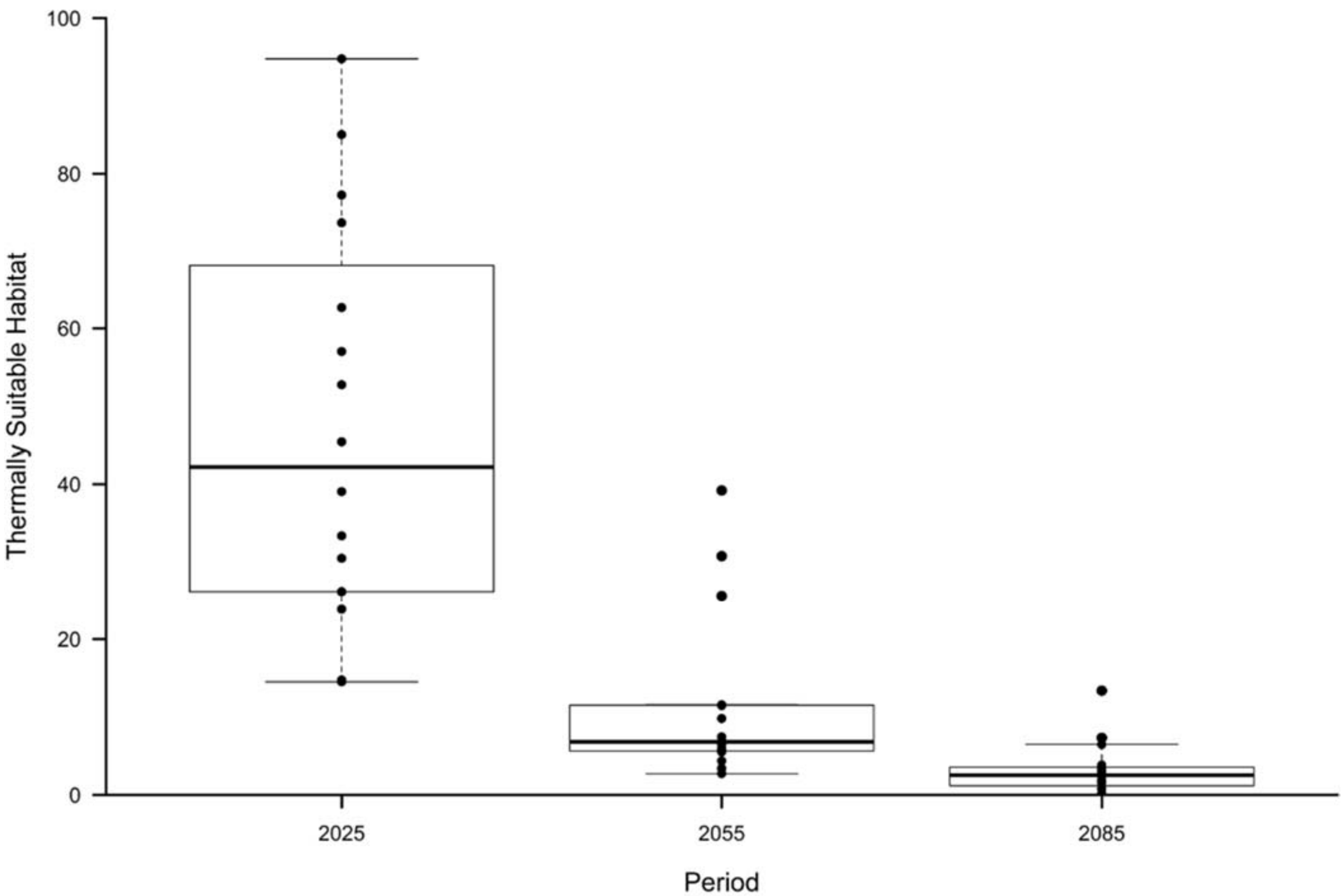

Figure 9. Projected losses of thermally suitable habitat across the Arctic grayling range in Alberta for ca. 2025 (2011–2040), 2055 (2041–2070), and 2085 (2071–2100). Projections were determined by comparing randomly generated points (n = 5579) that fell within the thermally suitable temperature range during a normal period (1961–1990) to projected points falling within that range during future periods. Black dots represent estimates downscaled from individual global circulation model (GCM), and are used to bracket structural uncertainty across an ensemble of 16 GCMs.

STATUS DESIGNATIONS*

1. Alberta - Arctic grayling in Alberta was assigned the general status of *Sensitive* in 2000 (ESRD 2014), and was formally identified as a *Species of Special Concern* in response to a recommendation made by Alberta's Endangered Species Conservation Committee in 2006 (Fish and Wildlife Division 2008). The Alberta Conservation Information Management System (using NatureServe methodology) ranks Arctic grayling as S3S4 throughout its native range, and the introduced Belly River population in southern Alberta as SNA (ACIMS 2014, NatureServe 2015).

2. Other Areas – Conservation rankings for Arctic grayling vary widely across North America, but globally the species is considered stable and is ranked G5 (NatureServe 2014). Arctic grayling are ranked S3 in the Northwest Territories, S5 in the Yukon Territory, S4 in British Columbia, S5 in Saskatchewan, and S4 in Manitoba (NatureServe 2014). In the United States, the species is ranked SX in Michigan, S1 in Montana and S2 in Wyoming (NatureServe 2014).

Currently, no designation has been given to Arctic grayling by COSEWIC, but the species is categorized by COSEWIC's Species Specialist Subcommittee for freshwater fishes as a "high-priority candidate" for status assessment in Canada (COSEWIC 2015). In British Columbia, grayling in the Williston-Peace watershed were red-listed following construction of the W.A.C. Bennet Dam on the Peace River (B.C. Ministry of Water, Land and Air Protection 2002, B.C. Conservation Data Centre 2013), indicating they are threatened or endangered. In Montana, the Arctic grayling was considered for several years as a candidate for federal listing as an *Endangered* or *Threatened* species; however, it was determined in 2014 that listing was not warranted (Federal Register 2014).

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* See Appendix 1 for definitions of selected status designations.

RECENT MANAGEMENT AND RESEARCH IN ALBERTA

In 1998, the Fisheries Management Division implemented a provincial management strategy and recovery plan in response to perceived declines in grayling abundance (Berry 1998). Minimum size limits for recreational anglers were increased from 30 cm to 35 cm, and bag limits were reduced from five grayling to two in an attempt to reduce harvest. Additional management actions established catch-and-release fisheries at some locations, and the harvest season was reduced to June, July and August. These regulations were not evaluated, and as a result their utility in reducing mortality caused by angling is difficult to determine. Currently, the 2015 Alberta Sport Fishing Guidelines prohibit anglers from keeping any Arctic grayling (i.e., province-wide bag limit of zero fish).

In 2014, the Arctic grayling FSI was completed, and provincial fisheries biologists plan to simplify provincial regulations and align them with FSI status ranks (M. Sullivan pers. comm.). The changes to the 2015 Sport Fishing Regulations (i.e., catch-and-release for all grayling) reflect this process. A new provincial management plan for grayling will be written during 2015–2016 (C. Johnson pers. comm.). Currently, Arctic grayling is being considered for use as a boreal indicator species by AEP, given its perceived sensitivity to environmental disturbances and angling (M. Sullivan and C. Johnson, pers. comm.).

Considerable research concerning Arctic grayling in Alberta has occurred since 2005. Park et al. (2008) established the levels of fragmentation resulting from hanging culverts across much of Alberta's boreal forest. MacPherson et al. (2012) determined the efficacy of different types of sampling gear in low-density grayling streams, and recommended angling as a useful standardized sampling gear. A technical report by Christie et al. (2010) suggested snorkel surveys may be a feasible sampling technique in mid-sized foothills streams. Scrimgeour et al. (2008) discussed how levels of land use altered stream fish assemblages and species, including Arctic grayling, in the Simonette and Kakwa rivers. In 2011, an international Arctic grayling research symposium took place in Grand Prairie, Alberta, and featured presentations on sampling, biology, and conservation (presentations available at http://www.tucanada.org/index.asp? p=2124). A thesis by Norris (2012) suggested increased phosphorus runoff impaired grayling habitat in the Wapiti River watershed. Reilly et al. (2014) investigated the population genetics of Arctic grayling throughout the Hay, Peace, and Athabasca river basins, and found moderate to high levels of genetic differentiation among rivers in their study. These studies have contributed important information regarding Arctic grayling ecology, and have improved our understanding of a number of threats to the species in Alberta.

Advancing the state of Arctic grayling habitat science and management could benefit Alberta conservation efforts. In general, few projects to restore stream habitat for Arctic grayling have been implemented (Northcote 1995), and no published examples documenting grayling stream habitat restoration exist for Alberta; this is alarming, considering many of the threats facing the species within the province are habitat-related. However, habitat compensation projects in the Northwest Territories show grayling respond to habitat manipulations in pristine environments, where both a diversion channel and a nature-like fishpass increased connectivity and provided nursery and spawning habitat (Jones et al. 2003, Courtice et al. 2014). Moreover, although examples of grayling habitat restoration do not exist from Alberta, a powerful framework for triaging salmonid habitat science and management does exist. Roni et al. (2002) showed that habitat modifications for salmonids should be strategically prioritized at the watershed level as habitat management funding is limited, and they identified protection of existing high-quality habitats as top priority. Roni et al. (2002) also suggest reconnecting isolated but otherwise high-quality fish habitats such as stream regions made inaccessible by culverts (*sensu* recommendations in Park et al. 2008), and projects designed to restore stream processes (e.g., road decommissioning, maintenance and restoration of riparian areas) as a second priority. Instream habitat management (e.g., addition of instream structures or nutrients) was suggested only after the higher priorities were met (Roni et al. 2002). In this framework, the resilience of salmonid ecosystems and populations is strategically increased at the landscape scale. Research activities designed to evaluate the efficacy of any such habitat management activities, in a scientifically defensible manner with appropriate controls, could greatly assist resource managers (Bradshaw 1996). Similarly, research exploring the feasibility of monitoring stream temperature using remote sensing (see Torgersen et al. 2001) could make it possible to document thermal refugia and guide habitat management at the landscape level.

SYNTHESIS

Arctic grayling are adapted to cold water and their presence in Alberta represents the southern edge of their North American range. Grayling appear to have undergone declines in abundance when comparing qualitative historical information to surveys conducted during the 1990s, particularly in accessible regions near the southern limit of their range (Berry 1998). Evidence suggests the inferred declines probably resulted from overharvest by anglers, but land-use changes and natural variation in both distribution and abundance may have played important roles. Minimal standardized quantitative information exists regarding population dynamics and abundance, but a structured assessment of quantitative and qualitative information compiled by regional fisheries biologists in the Alberta

Fish Sustainability Index suggests grayling have declined compared to historical levels. Historically, overharvest was likely an important threat as grayling are easily captured by anglers, but almost no data regarding exploitation levels exist. The most imminent threat facing Arctic grayling in Alberta is the ongoing loss, degradation, and fragmentation of their habitats, and modeling in this report suggests anthropogenic climate change will become a critical stressor of grayling habitat within the next 30 years. Furthermore, the rescue potential of the Arctic grayling population in Alberta appears compromised. Studies designed to further quantify how land use in Alberta affects grayling habitat would be useful; in particular, determining the levels of watershed development associated with grayling population decline or local extirpation (i.e., the thresholds or limits to within-watershed development) could have important conservation implications, especially when considering the management of cumulative effects in a landscape undergoing rapid development (e.g., Schneider 2002). Additional studies designed to quantify differences in Arctic grayling biology above and below suspected movement barriers may provide better insights into specific impacts of fragmentation on the species; however, it is important to note that a detailed, mechanistic understanding of the effects of fragmentation on Arctic grayling is not necessary for developing timely management strategies to cope with this limiting factor (see also Walters and Martell 2004, Park 2006, Roni and Beechie 2012).

The conservation of grayling in Alberta during this century will require robust management strategies that emphasize ecological resilience, a commitment to standardized monitoring, and prioritization of limited resources. These actions should be implemented despite the apparent data deficiencies, and then be updated as appropriate data are collected. Management approaches based on resilience view events at the landscape rather than local level, emphasize diversity among habitats, and focus on keeping options open to spread risk (Holling 1973). Increasing ecosystem resilience by protecting pristine habitats, increasing connectivity between diverse habitats, and minimizing external stressors may help hedge bets against an uncertain climatic future (Beechie et al. 2013). Similarly, focusing protection on the largest subpopulations or habitats appears to be a particularly robust climate adaptation strategy (Hodgson et al. 2009). Establishing long-term, standardized monitoring programs designed to survey grayling and the quality of their habitat (i.e., stream temperature, discharge, groundwater inputs) would greatly inform future management decisions. Issak et al. (2012) suggest short-term, robust prioritization actions are required to mitigate long-term climate risk for salmonids, and caution that fisheries management action or inaction within the next decade will have disproportionate impacts on the fish remaining a century from now.

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Appendix 1. Definitions of status ranks and legal designations.

A. General Status of Alberta Wild Species Categories (used in 2000, 2005, 2010, and 2015 General Status exercises) (Government of Alberta 2011)

Rank	**Definitions**
At Risk	Any species known to be *At Risk* after formal detailed status assessment and legal designation as *Endangered* or *Threatened* in Alberta.
May Be At Risk	Any species that may be at risk of extinction or extirpation, and is therefore a candidate for detailed risk assessment.
Sensitive	Any species that is not at risk of extinction or extirpation but may require special attention or protection to prevent it from becoming at risk.
Secure	Any species that is not *At Risk, May Be At Risk* or *Sensitive*.
Undetermined	Any species for which insufficient information, knowledge or data is available to reliably evaluate its general status.
Not Assessed	Any species that has not been examined during this exercise.
Exotic/Alien	Any species that has been introduced as a result of human activities.
Extirpated/Extinct	Any species no longer thought to be present in Alberta (Extirpated) or no longer believed to be present anywhere in the world (Extinct).
Accidental/Vagrant	Any species occurring infrequently and unpredictably in Alberta, i.e., outside its usual range.

B. Alberta Species at Risk Formal Status Designations

Species designated as *Endangered* under Alberta's *Wildlife Act* include those listed as *Endangered* or *Threatened* in the Wildlife Regulation (in bold).

Endangered	**A species facing imminent extirpation or extinction.**
Threatened	**A species likely to become endangered if limiting factors are not reversed.**
Species of Special Concern	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Data Deficient	A species for which there is insufficient scientific information to support status designation.

C. Committee on the Status of Endangered Wildlife in Canada (after COSEWIC 2013)

Extinct	A species that no longer exists.
Extirpated	A species that no longer exists in the wild in Canada, but occurs elsewhere.
Endangered	A species facing imminent extirpation or extinction.
Threatened	A species that is likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction.
Special Concern	A species that may become threatened or endangered because of a combination of biological characteristics and identified threats.
Not at Risk	A species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient	A category that applies when the available information is insufficient to (a) resolve a wildlife species' eligibility for assessment, or (b) permit an assessment of the wildlife species' risk of extinction.

D. United States Endangered Species Act (U.S. Fish & Wildlife Service 2005)

Endangered	Any species that is in danger of extinction throughout all or a significant portion of its range.
Threatened	Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Appendix 1 continued:

E. Heritage Status Ranks:

Subnational (S) ranks in Alberta (after Alberta Conservation Information Management System 2015)

S1	Known from five or fewer occurrences or especially vulnerable to extirpation because of other factors.
S2	Known from 20 or fewer occurrences or vulnerable to extirpation because of other factors.
S3	Known from 100 or fewer occurrences, or somewhat vulnerable due to other factors, such as restricted range, relatively small population sizes, or other factors.
S4	Apparently secure. Taxon is uncommon but not rare. Potentially some cause for long-term concern because of declines or other factors.
S5	Secure. Taxon is common, widespread, and abundant.
SX	Taxon is believed to be extirpated from the province. Not located despite intensive searches of historical sites and other appropriate habitat. Virtually no likelihood that it will be rediscovered.
SH	Known from only historical records but still some hope of rediscovery. Evidence that the taxon may no longer be present but not enough to state this with certainty.
S?	Not yet ranked, or rank tentatively assigned.
S#S#	A numeric range rank is used to indicate any range of uncertainty about the status of the taxon. Example: S2S3 or S1S3. Ranges cannot skip more than two ranks.
SU	Taxon is currently unrankable because of a lack of information or substantially conflicting information. Example: native versus non-native status not resolved.
SNR	Not ranked. Conservation status not yet assessed.
SNA	Not applicable. A conservation status rank is not applicable because the species or ecosystem is not a suitable target for conservation activities. Example: introduced species.
S#?	Inexact numeric rank. Applied when a specific rank is most likely appropriate but for which some conflicting information or unresolved questions remain.

Global (G), National (N) and other Subnational (S) ranks (after NatureServe 2015)

G1/N1/S1	Critically Imperiled. At very high risk of extinction or elimination due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors.
G2/N2/S2	Imperiled. At high risk of extinction or elimination due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
G3/N3/S3	Vulnerable. At moderate risk of extinction or elimination due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
G4/N4/S4	Apparently Secure. At fairly low risk of extinction or elimination due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
G5/N5/S5	Secure. At very low risk or extinction or elimination due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats.
GX/NX/SX	Presumed Extinct/Extirpated. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood of rediscovery.
GH/NH/SH	Possibly Extinct/Extirpated. Known from only historical occurrences but some hope of rediscovery.
G?/N?/S?	Inexact Numeric Rank. Denotes inexact numeric rank.
G#G#/ N#N#/S#S#	A numeric range rank (e.g., G2G3, G1G3) is used to indicate the range of uncertainty about the exact status of a taxon or ecosystem type. Ranges cannot skip more than two ranks.
GU/NU/SU	Unrankable. Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
GNR/NNR/ SNR	Unranked. Conservation status not yet assessed.
GNA/NNA/ SNA	Not Applicable. A conservation status rank is not applicable because the species is not a suitable target for conservation activities

Appendix 2. Historical (pre-1960) Fish Sustainability Index adult grayling density ranks for each Hierarchical Unit Code (HUC) watershed, as ranked by provincial biologists. Ranks ranged from 0 (no grayling) to 5 (highest possible density, likely at carrying capacity). Reliability of the adult density ranks was also evaluated in terms of the quantity and quality of information (qualitative and/or quantitative) used to make these ranks. Quantity ranks were as follows 1: No Data; 2: Insufficient Data; 3. Moderately Sufficient Data; 4. Nearly Sufficient Data; 5. Sufficient Data. Quality ranks were as follows: 1. Imprecise and Inaccurate; 2. Precise but Inaccurate; 3. Accurate but Imprecise; 4. Likely OK; 5. Precise and Accurate. Adapted from ESRD 2014. Asterisks represent locations where grayling were introduced. Personal communications are listed at the end of the Appendix. FWMIS = Fisheries and Wildlife Management Information System.

Hierarchical Unit Code (HUC) Watershed	**Historical Adult Density Rank**	**Monitoring Quality**	**Monitoring Quantity**	**Historical Adult Density Comments (CUE = catch per unit effort; HUC=Hierarchical Unit Code; FL = fork length)**
ATHABASCA BELOW FORT ASSINIBOINE	3	3	3	Weighted stream score 2.7. Timeu Creek HUC - Cunningham (1961) reported that Arctic grayling were present, but not abundant in the area he sampled. He went on to say "The stream is reported to support a large grayling population in its headwaters". Doris Creek was reported by a farmer to contain grayling, but Arctic grayling have not been seen for several years (Cunningham 1961). Electrofishing CUE of 0.8 grayling/min in Timeu Creek (R,L&L 1994). Chisholm HUC - Professional opinion (V. Buchwald). Timeu Creek is identified as holding Arctic grayling (M.Paetz and J.O'Neil map, 1994; see Appendix 4)
ATHABASCA RIVER ABOVE BERLAND RIVER	4	2	2	The Oldman Creek in the upper Athabasca tributaries was noted as containing abundant historical Arctic grayling populations (see Appendix 4).
ATHABASCA RIVER ABOVE WHITECOURT	4	2	2	Chickadee Creek "supports a thriving Arctic grayling population" (Cunningham 1961). These comments may not be reflective of historical abundance in the entire HUC (i.e., mainstem - Athabasca River). However, Pine Creek, Windfall Creek, Oldman Creek, Chickadee Creek are identified as holding Arctic grayling (see Appendix 4)

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
BEAVERLODGE RIVER	4	5	5	Weighted stream score 4.99. **Redwillow-** Ward (1951) reported "in the years 1936 to 1939 there was a very spirited spawning run in to the Beaverlodge River". In one afternoon at the railway dam in Hythe, a farmer with a dip net took home a wagon-box full of grayling. Lucko (1993) stated that the Beaverlodge was used as a source of eggs for the provincial grayling program between 1983 and 1987 and was one of the largest Arctic grayling runs known in the province. However, even in 1993 things were changing—all the Arctic grayling (n=89) captured ran up the Redwillow instead of the Beaverlodge, like they had done formerly. **Above Redwillow-Beaverlodge-** Professional opinion (V. Buchwald)
BERLAND - WILDHAY RIVERS	5	4	3	Found in ASRD (2005) were electrofishing results of 0.4–0.7 grayling/100m in the Wildhay River (R.L.&L 1993), 0.7 grayling/100m in Wroe Creek (Thornton 1983) and 1.3 grayling/100m in Fred Creek (Hominiuk 1985) and angling catch rate of 4.7 grayling/hour (Hawryluk 1981). Hightower Creek, Pinto Creek, Wildhay, and Berland River are identified as holding Arctic grayling (see Appendix 4)
Bow River-Ghost reservoir (Quarry Lake)*	0	5	5	Previous to 1997 stocking, no Arctic grayling were found in Quarry Lake.
BOYER RIVER - PONTON RIVER	3	4	4	Weighted stream score 3.3. **CARIBOU** (5); High electrofishing catch rate 1.3 grayling/min (summarized in Ripley 2009) **LAWRENCE** (5); High electrofishing catch rate 3.0 grayling/min (Ripley 2009 summarized historical data) **PONTON** (5); High electrofishing catch rate 1.2 grayling/min (Ripley 2009 summarized historical data). Ponton River noted to contain Arctic grayling (see Appendix 4). Rhude (1976a) reported catching Arctic grayling in the mainstem and two tributaries. **LOWER PEACE RIVER** (2); Professional opinion. **BOYER** (1); Professional opinion. Flemming Lake noted to contain abundant and some large grayling, spawning in outlet (Lawrence River) (J.O'Neil pers. comm.). Baldwin and Goater (2003) also noted capturing Arctic grayling in **Flemming Lake.**
BUFFALO - WOLVERINE RIVERS	3	1	2	Of all creeks in HUC, only Buffalo River identified as holding Arctic grayling (see Appendix 4).
BUFFALO RIVER	5	2	2	Rhude (1976a) reported catching 8 young of year Arctic grayling using B line at one location. Buffalo River upstream of Snake Lake held Arctic grayling (see Appendix 4)

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
CADOTTE RIVER AND LAKE	3	1	2	Otter and Upper Cadotte Rivers identified as containing Arctic grayling (see Appendix 4).
CALLING LAKE - HOUSE RIVER	5	3	3	Weighted stream score 4.66. **CALLING RIVER HUC** (5); Valastin and Sullivan (1997) historical survey reported Calling River was the best spot for grayling, catch 2-3 out of every pool and fill up a fishing basket in no time. Grayling in the creek south of the reserve averaged 1 lb. in the 1940s and 1950s. Caught 1.0-1.5 lb. grayling in the nets on Calling Lake. **DEEP CREEK HUC** (2); Professional opinion. **HOUSE RIVER HUC** (5); M. Mescalyk in Valastin and Sullivan (1997) historical survey reported that around 1968, grayling up to 18" were caught and hundreds of small grayling would go for the hook at the rapids. The House River is Arctic grayling waters (see Appendix 4).
CHINCHAGA RIVER	3	3	3	Electrofishing catch rate 0.3 grayling/min (Ripley 2009 summarized historical data).
CHIP LAKE - PADDLE RIVER	3	3	3	Weighted stream score 3.1**. Lobstick HUC**- Ward (1951) reported catching a 100 Arctic grayling per day in traps in Cold and Brule creeks during the spawning run. Miller and Macdonald 1949 reported Arctic grayling in Coldwater and Brule creeks. **Central HUC**-Bryski (1999b) in ASRD (2005) summarizes that angler historically reported good catches of grayling in Bigoray River, Paddy Creek, and Rat Creek. No references made to mainstem Pembina. **Paddle HUC**- Professional opinion (V. Vuchwald)

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
CHRISTINA RIVER	5	3	3	Weighted stream score is 4.74. **UPPER CHRISTINA HUC** (5); M. Paetz in Valastin and Sullivan (1997) historical survey reported in 1967 catching 33 grayling, all over 12", in less than an hour. In 1987 at the same spot it took two of them 2 days to catch 7 grayling with only one of them over 12". Jackfish River was a main spawning river. Another angler reported that in 1970 there was a fair number of grayling where the Wappau Creek flows into the May River. Stanislawski (1998) in ASRD (2005) reported an angling catch of >4 grayling/hr. in the May river and >3.5 grayling/hour in the Christina River. **WINEFRED RIVER HUC** (4); The Winefred River is known for grayling populations (Wallace and McCart 1984). **LOWER CHRISTINA HUC** (5); Stanislawski (1998) in ASRD (2005) reported an angling catch of 2.9 grayling/hr. Griffiths (1973) did not catch grayling in lower Christina, caught them in the lower Gregoire River and Surmont Creek. Winefred River, Sunday Creek, Jackfish River, Christina River, May River and the Goose River are noted to hold Arctic grayling (see Appendix 4).
CLEARWATER RIVER	5	2	3	Weighted stream score of the HUCs is 4.7. **Clearwater River HUC**: Stanislawski (1998) in ASRD (2005) reported an angling catch of 2.9 grayling/hr. **Hangingstone River HUC:** Stanislawski (1998) in ASRD (2005) reported an angling catch of 3 grayling/hr. Griffiths (1973) reported at one site "were found such large numbers that only a subsample was preserved…". **High Hill River HUC:** Stanislawski (1998) in ASRD (2005) reported an angling catch of >6 grayling/hr. Griffiths (1973) reported catching a "large number of mature Arctic grayling … along with countless fry". Clearwater River, High Hill River and the Hangingstone River are noted to hold Arctic grayling (see Appendix 4).
DOIG RIVER	4	1	2	Professional opinion (V. Buchwald).
ELLS - STEEPBANK RIVERS	4	4	4	Weighted stream score of the 6 HUCs is 4.25. **ELLS RIVER;** Stanislawski (1998) in ASRD (2005) reported an angling catch of >8 grayling/hr. In RAMP report (Golder 2004), Griffiths (1973) and Sekerak and Walder (1980) considered the Ells River to provide some of the highest quality tributary habitat in the Oil Sands region. Very limited fish capture data, but grayling were the most abundant sportfish in 1978 (Sekerak and Walder 1980). **MILDRED LAKE**; In RAMP report (Golder 2004), Golder (1998) had electrofishing catch rates in McLean Creek of 0.33 adults/100 s and 1.35 juveniles/100s, in Wood Creek of 0.70 grayling/100 s and Poplar Creek of 0.1-1.6 grayling/100s.

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
				Continued: **MUSKEG RIVER**; In RAMP report (Golder 2004), Machniak and Bond (1979) caught 305 grayling moving upstream near the mouth. O'Neil (1982) caught 904 grayling in Jackpine Creek 5.5 km above the confluence. Extensive series of AOSERP reports (n=28, cited in Golder 2004) indicate abundant large grayling in 1970s, e.g., with angling CUE in 1976 of 2.8, and hundreds of Arctic grayling in counting fences. **STEEPBANK RIVER**; In RAMP report (Golder 2004), Machniak and Bond (1979) caught 1,473 and 1,794 grayling in spring and fall trapping sessions in 1977. Golder 1996 boat electrofishing CUE of 0.31-1.16 grayling/100 sec. Stanislawski (1998) in ASRD (2005) reported a angling catch of >4 grayling/hr. **TAR RIVER**; Very little fish survey data. In RAMP report (Golder 2004), Golder (2002) reported the presence of juvenile arctic grayling; however, reported all sites were completely frozen in late winter. **BITUMONT**; Most streams on west side poor habitat (Griffiths 1973, Herbert 1979), except for Pierre Creek (all life stages). Mainstem should be adequate habitat. Major runs of Arctic Grayling (1000s of Arctic Grayling) into mainstem from Firebag and Steepbank rivers during late 1970s. The Sand River, Ells River, Jackpine Creek, Muskeg River North Steepbank River and the Steepbank River are noted to hold Arctic Grayling (see Appendix 4).
FIREBAG RIVER	5	3	3	Weighted score is 5. A great mix of muskeg (good flow) and unusually high hills (good oxygen) country. Once known as excellent grayling fishing, with "excellent supply of nutrients", "quality sports fishery" (Griffiths 1973, for Firebag R. and tributaries (which includes Marguerite). Trout Creek and the Firebag River are noted to hold Arctic Grayling (see Appendix 4).
FONTAS RIVER	5	5	4	High electrofishing catch rate 2.6 grayling/min (Ripley 2009). Data summarized from 1994 FWMIS data.

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
FREEMAN RIVER	4	3	4	Weighted stream score is 3.9 of all 4 HUC's. **Chisholm HUC-** Professional opinion (V. Buchwald), **Christmas HUC**- 'Christmas Creek supports an extremely fine grayling population (Cunningham 1961). Electrofishing CUE of 0.1 - 1.5 grayling/min in Weasome Creek (R,L&L 1994), **Freeman HUC**- Cunningham (1961) reported that Arctic grayling were plentiful in the Freeman in the Virginia Hill area. Cunningham (1961) reported that Arctic grayling especially smaller ones were numerous in Carson Creek Cunningham (1961) reported that Arctic grayling were numerous in the Morse River, but the scarcity of large Arctic grayling was due to heavy fishing pressure. **Sakwatamau HUC**- "Many large deep pools make the Sakwatamau one of the loveliest looking streams in the Province" (Cunningham 1961). In 1961, it could not be sampled at the time due to high water, but grayling were said to be "fairly numerous". Electrofishing CUE of 0.2-0.7 grayling/min in Carson Creek and 0.1-0.8 in Hope Creek (R,L&L 1994). Sakwatamau River, Carson Creek and Christmas Creek are identified as holding Arctic grayling (see Appendix 4)
HORSE RIVER	4	2	2	Weighted stream score is 3.97. **HORSE RIVER HUC** (4); Stanislawski (1998) in ASRD (2005) reported an angling catch of >2 grayling/hr. **ATHABASCA GRANDE RAPIDS HUC** (4); based on adult density comments. Horse River is noted to hold Arctic grayling (see Appendix 4).
JACKFISH RIVER	3	1	2	Professional opinion (V. Buchwald). Berry Creek, a tributary to the Jackfish, noted as containing Arctic Grayling (see Appendix 4)
KAKWA RIVER - CUTBANK RIVER	4	1	2	Professional opinion (V. Buchwald). The Cutbank River, Kakwa River, Daniel Creek, Chicken Creek, Kakwa River, Smoky River and Boulton Creek noted to hold Arctic grayling (see Appendix 4).
KEG RIVER	3	4	4	Weighted stream score 3.84. **KEG RIVER** (3); High electrofishing catch rate 4.0 grayling/min in the Kemp River (Ripley 2009). Kemp River is noted to hold Arctic grayling (see Appendix 4). Although there are high catch rates in the Kemp River, overall the Keg R. would be considered moderately abundant (3) **LOWER PEACE RIVER** (2); Professional opinion (V. Buchwald)
LOON RIVER - LUBICON RIVER	3	1	2	Professional opinion (V. Buchwald). Arctic Grayling once presence in Red Earth Creek (M.Sullivan pers.com) (see Appendix 4). Angler reports of Arctic grayling on an unnamed creek (tributary to the Loon River) at the crossing of HWY 686 (Isley, Q., (2013) pers comm.)

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
LOWER ATHABASCA RIVER	3	2	2	Weighted stream score of 3.16. **MAYBELLE RIVER** (4); Rhude (1976b) caught Arctic grayling at 3 of 5 sites using b-line. Fish were small 35-279 mm FL. **RICHARDSON RIVER** (3); Professional opinion (V. Buchwald). The Grayling River is noted to hold Arctic grayling (see Appendix 4).
LOWER BIRCH RIVER	4	1	2	Professional opinion (V. Buchwald). Birch drainage (Fillon, Edra, Bolton Creeks) and Mikwa drainage (Legend Lake) held Arctic grayling (see Appendix 4). 1967 test netting in Legend Lake did not detect Arctic grayling.
LOWER HAY RIVER IN ALBERTA	3	2	2	Did not include Hutch Lake/Meander River as it was scored as a 12 presence not suspected. **HAY RIVER** (3); Griffiths and Ferster (1974) caught a 'number' of Arctic grayling sampling Little Rapids Creek using primacord. Griffiths and Ferster (1974) caught eight yearling and 50 young-of-the-year Arctic grayling in a tributary of Jackpot Creek using primacord.
LOWER LITTLE SMOKY RIVER	2	1	2	Arctic grayling once present in Snipe Creek, New Fish Creek, Clouston Creek, and Puskwaskau Creek (J. O'Neil pers.com.). Landscape changed in 1950s and 60s due to agriculture (drained and cleared) (C.Johnson and J.O'Neil pers.com.). Spring Creek (near Crooked Lake) held Arctic grayling (J. O'Neil pers.com).
LOWER MACLEOD RIVER	4	1	2	Miller and Macdonald (1949) reported that the Edson River and tributaries are Arctic grayling waters and have a large population of mostly young fish. Trout Creek, Edson River, McLeod River, Moose Creek, Carrot Creek and Wolf Creek are historical Arctic grayling waters (see Appendix 4).
LOWER PEMBINA RIVER	1	2	2	**French HUC**- Professional opinion (V. Buchwald), **Lower Pembina HUC**- Renewable Resources Consulting Services Ltd (1971) reported not catching Arctic grayling , but did catch MNWH and didn't think the habitat was suitable for Arctic grayling. Arctic grayling may have used the mainstem Pembina River as a movement corridor (J. O'Neil and M. Sullivan pers. comm.).
LOWER WABASCA RIVER	3	1	2	Professional opinion (V. Buchwald). Rat Creek traditional fishery for Arctic Grayling for First Nations from Fort Vermillion (J. O'Neil pers. comm., heard comment in 1969). Rat and Senix Creeks indicated as containing Arctic grayling (see Appendix 4).

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
LOWER WAPITI RIVER - BEAR CREEK AND LAKE	2	1	2	Professional opinion (V. Buchwald)
MACKAY RIVER	4	3	4	In RAMP report (Golder 2004), Van Meer (1993) had a boat electrofishing CUE of 0.53 grayling/100 s. Small upstream migrations of grayling were reported by McCart et. al (1978) and Machniak et. al (1980). The Dunken River and MacKay river are noted to hold Arctic grayling (see Appendix 4).
McIVOR RIVER - LAKE CLAIRE	2	1	2	Weighted stream score 2.5 based on V. Buchwald professional opinion. However, Lake Claire and tributaries not identified as containing Arctic grayling (see Appendix 4) so downgraded the score to a 2.
MIKKWA RIVER	3	1	2	Birch drainage (Fillon, Edra, Bolton Creeks) and Mikkwa drainage (Legend Lake) held Arctic Grayling (see Appendix 4). 1967 test netting in Legend Lake did not detect Arctic grayling.
NORTH LESSER SLAVE LAKE	4	4	4	Weighted stream score is 3.71. **ASSINEAU HUC** (3); Miller and Paetz (1953) reported that it was "populated by small Arctic grayling up to 7 inches in length". D. Smith (pers. comm.) fished in the 1970s and captured large Arctic grayling in the headwaters. **DRIFTPILE RIVER HUC** (5); Valastin and Sullivan (1997) historical survey reported the Driftpile was a great place to catch grayling in 1965. **MARTEN RIVER HUC** (4); Electrofishing catch rate 0.2 grayling/min (Ripley 2009). Anecdotal reports of large numbers of small-medium grayling, no large fish in the 1970s. Rhude (1976) caught yearlings using b-line. **OILMANS CREEK HUC** (3); Professional opinion. **SWAN RIVER HUC** (4); Electrofishing catch rate 0.2 grayling/min (Ripley 2009). **LESSER SLAVE LAKE** (3); Professional opinion. Shaw, Narrows, Marten, Adams and Boulder Creek as well as the Assineau, Swan, Driftpile and Irveness River are historical Arctic Grayling waters (see Appendix 4).
NOTIKEWIN RIVER	4	4	4	Electrofishing catch rates of 0.56 grayling/min in the Meikle River, 0.65 grayling/min in the Hotchkiss River and 0.59 grayling/min in the Notikewin River (summarized in Ripley 2009). However, B. Lucko (senior fisheries technician) described the Notikewin as a "step below" Caribou Mountains, and Little Smoky populations, comparatively.

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
PEACE RIVER ABOVE PEACE RIVER	2	1	2	Professional opinion (V. Buchwald). Arctic grayling were historically present in Sweeney Creek, McLean Creek and Little Clear River (see Appendix 4). However, these tributaries make up very little part of Clear River system. Anecdotal info to suggest Arctic grayling may have been present in Clear River. May have been very low numbers of Arctic grayling that found their way down the Peace prior to Bennett Dam (K. Wilcox pers. comm).
PETITOT RIVER - BISTCHO LAKE	1	2	2	Griffiths and Ferster (1974) caught 10 Arctic grayling in the Petitot River using prima-cord. They caught the Arctic grayling at two of the four sites sampled. They caught the Arctic grayling at the two downstream of Bistcho sites but none upstream of Bistcho Lake two of the four sites sampled. Professional opinion is that Arctic grayling have limited distribution in Alberta portion of Petitot R. (K. Wilcox pers. comm.)
PUSKWASKAU RIVER - LOWER SMOKY RIVER	2	1	2	Professional opinion (V. Buchwald). Puskwaskau River is noted to hold Arctic grayling (see Appendix 4).
Ross-Bullhead-Secen Person Creeks (Spruce Coulee Reservoir)*	0	5	5	Previous to 2013 stocking, no Arctic grayling were found in Spruce Coulee Reservoir.
SAULTEAUX - DRIFTWOOD - LESSER SLAVE RIVERS	3	4	4	Weighted stream score is 3.4. **Driftwood HUC**- Rhude (1976b) caught Arctic grayling 135-221 mm FL using b-line, **Fawcett HUC**- Valastin and Sullivan (1997) historical survey reported grayling were easy to catch just before it ran into the Lesser Slave River. **Lesser Slave River HUC**- Professional opinion (V. Buchwald), **Muskeg River HUC**- Professional opinion (V. Buchwald), **Otauwau** HUC- Miller and Paetz (1953) stated "the present grayling population provides excellent fishing". **Saulteaux HUC**- Miller and Paetz (1953) stated that "the upper reaches of the stream are reported to contain a good population of arctic grayling. … the lower stretches have a few northern pike and pickerel". **Sawridge HUC**- Electrofishing catch rate 0.4 grayling/min (Ripley 2009). Coutts River, Saulteaux River, Ottauwau River, Sawridge Creek, Driftwod River and Fawcett River are historical Arctic grayling waters (see Appendix 4).
SCULLY CREEK - PEACE RIVER ABOVE KEG RIVER	1	1	2	Professional opinion (B. Lucko). However, given that Arctic grayling were believed to be moderately abundant in adjacent watersheds and their tributaries, it is assumed that Arctic grayling were present in low abundances at least seasonally (M.Sullivan pers. comm)

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
SIMONETTE RIVER	4	1	2	Professional opinion (V. Buchwald). Deep Valley Creek, Latornell River and Simonetter River are noted to hold Arctic grayling (see Appendix 4). Angler reports and photos of Arctic grayling in Spring Creek in the 1970s (J.O'Neil pers comm.)
SOUTH HEART - EAST & WEST PRAIRIE RIVERS	3	4	4	Weighted stream score of 3. **EAST PRAIRIE RIVER HUC** (3); Electrofishing catch rate 0.3 grayling/min (Ripley 2009). **LESSER SLAVE LAKE HUC** (3); Professional opinion (V. Buchwald). Golden and McGowan Creek as well as Upper East Prairie River (upstream from Bruce Creek) and Upper South Heart from Seal Lake downstream into Metis Settlement held Arctic grayling (see Appendix 4)
TAWATINAW RIVER	3	3	3	Weighted stream score of all 3 HUCs is 2.74. **Baptiste HUC**- P. Marchuk in Valastin and Sullivan (1997) historical survey reported catching the odd grayling in the spring or fall in Baptiste Lake. **Lawrence HUC**- Professional opinion (V. Buchwald), **Tawatinaw HUC**- Valastin and Sullivan (1997) historical survey reported grayling were easy to catch and average size of 1 lb. M. Paetz reported grayling in the late 1950s, but they were small.
UPPER BIRCH RIVER	4	1	2	Professional opinion (V. Buchwald). Birch drainage (Fillon, Edra, Bolton Creeks) and Mikwa drainage (Legend Lake) held Arctic grayling (see Appendix 4). 1967 test netting in Legend Lake did not detect Arctic grayling.
UPPER HAY RIVER IN ALBERTA	1	1	2	1969 study returned one Arctic grayling (caught in a tributary of the Shekilie River, not in FWMIS).
UPPER LITTLE SMOKY RIVER	5	5	5	Little Smoky River is a highly productive Arctic grayling streams in Alberta (Edson data files, angler reports, and FWMIS to support). **It is being used as the reference population for Alberta.**

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
UPPER MACLEOD RIVER	4	3	4	**McLeod HUC**-Sundance Creek was once considered to be one of the best grayling fisheries west of Edmonton (ASRD 2005). Electrofishing results found in ASRD (2005) were 1.6 grayling/min in Trout Creek (Hildebrandt (1994), 2.3-4.6 grayling/100m (Allan 1981) and 3.5 grayling/100m (Hominiuk 1986a). Although some of the creeks were historically very good, the rest of the HUC was probably not. Miller and Macdonald (1949) reported that the Edson River and tributaries are Arctic grayling waters and had a large population of mostly young fish. They also reported that Arctic grayling were very abundant in Sundance Creek and were also present in Sundance Lake and Hornbeck Creek. They were scarce in the Embarras and the Mcleod tributaries upstream of the confluence. Miller and Macdonald (1949) reported "'the Arctic grayling are confined to the lower reaches and are not common here, being much more plentiful in the tributaries". **Above McLeod HUC**- The McLeod watershed upstream from the series of barrier falls were fishless naturally. Naturalized populations of brook trout exist in the mainstem and tributaries. The McLeod River, White Creek, McPherson Creek, Embarras River, Lambert Creek, Prest Creek, Erith River, Raven Creek, Hanlan Creek, Lendrum Creek are identified as holding Arctic grayling (see Appendix 4)
UPPER PEMBINA RIVER	5	3	3	Weighted stream score is 4.8 did not include Above Upper Pembina River HUC as it was scored as presence not suspected (12). **UPPER PEMBINA RIVER HUC** (5); M. Paetz in Valastin and Sullivan (1997) historical survey reported lots of grayling in the Pembina River in the Coalbranch area. Electrofishing results found in ASRD (2005) were 0.5-12.7 grayling/100 in the Lovett River (O'Neil et al. (1988) and 5.5 to 14.3 in Hanson Creek (Seidel 1983). **CENTRAL PEMBINA RIVER HUC** (3); Bryski (1999b) in ASRD (2005) summarizes that anglers historically reported good catches of grayling in Bigoray River, Paddy Creek, and Rat Creek. No references made to mainstem Pembina. Paddy, Rat, Zeta, Dismal, Hanson and Crooked Creek as well as the Lovette and Pembina River are historical Arctic grayling waters (see Appendix 4).
UPPER SMOKY RIVER	3	1	2	Professional opinion (V. Buchwald). Sheep Creek noted to hold Arctic grayling (see Appendix 4).

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
UPPER WABASCA RIVER - PEERLESS LAKE	2	1	2	Historical rankings based almost entirely on professional opinion and in consultation with J. O'Neil and the Appendix 4 map. **Wabasca River: 2007-** ABMI seining and test netting, several small-scale consultant studies. **Trout River**: several smaller-scale environmental consultant studies. **Panny River:** no data in FWMIS. **Liege River: 2013** ESRD fire staff test angled the upper reaches of the mainstem. **1973-** historical F&W presence/absence survey. **Chipewyan River:** several smaller scale consultant studies.
UPPER WAPITI RIVER - NARRAWAY RIVER	4	1	2	Professional opinion (V. Buchwald). The Wapiti River, Narraway River and Nose Creek are noted to hold Arctic grayling (see Appendix 4).
UTIKUMA RIVER - WABASCA LAKES	2	2	2	Weighted stream score of 1.7 did not include Muskwa as presence not suspected. **UPPER WABASCA RIVER** (0). In 1970, sampled mainstem Wabasca River from Wabasca Lake to Panny River bridge and detected no Arctic grayling (J.O'Neil pers.comm.). Wabasca River was not noted as containing Arctic grayling (see Appendix 4). **WILLOW RIVER** (4); Rhude (1976) caught Arctic grayling 111-279 mm FL using b-line. Willow River held Arctic grayling (see Appendix 4). **MUSKWA** (12); See AdultDensityComments.
WANDERING RIVER - LAC LA BICHE	1	1	2	Weighted stream score of Owl and Wandering River HUCs are 1.4. Did not include Pine Creek as presence was not suspected in the HUC. Based on Professional opinion (V. Buchwald). Upper Wandering River (above Lyle Lake) noted to hold Arctic Grayling (see Appendix 4).
WATERTON RIVER*	1	3	3	Arctic grayling are not native to the Belly River; grayling were introduced in the upper drainage in Montana (ASRD 2005). According to Glacier Park records, grayling did not appear in the Belly river prior to the 1924 and 1964 stocking of Elizabeth Lake in Glacier National Park in Montana (T. Clayton, pers comm. in ASRD 2005). However, until genetic analyses have been completed for this HUC, we will presume that these grayling are native (L. MacPherson and C. Johnson pers. comm.) and are isolated naturally.
WENTZEL RIVER	5	4	4	High electrofishing catch rate 0.6 grayling/min (Ripley 2009 summarized historical data). Rennie Creek was noted to hold Arctic Grayling (see Appendix 4). Baldwin and Goater (2003) also noted capturing Arctic grayling in **Eva Lake.**

Appendix 2 continued:

HUC Watershed	Historical Adult Density Rank	Monitoring Quality	Monitoring Quantity	Historical Adult Density Comments
WHITEMUD RIVER - NORTH HEART RIVER	3	3	3	**NORTH HEART RIVER** (3); Miller and Paetz (1953) state "Arctic grayling are present in the stream. They rarely exceed 12 inches in length". **WHITEMUD RIVER** (3); Electrofishing catch rate 0.3 grayling/min (summarized in Ripley 2009). B. Lucko (senior fisheries technician) suggested North Heart system likely less productive than Whitemud, but historically they may have been more similar.
WHITESAND - YATES RIVERS	5	4	4	Scored as 5 as 99% of the HUC is the Whitesands and Yates and Buffalo River HUC. **BUFFALO RIVER** (5); Rhude (1976a) reported catching 8 young of year Arctic grayling using B-line at one location. **Whitesands & Yates River** (5); High electrofishing catch rate 0.5 grayling/min in the Yates River and 0.8 in the Whitesand River (Ripley 2009). Rhude (1976a) reported catching grayling in the Whitesand River using B-line including "numerous" fry at one location. He also caught 9 Arctic grayling about 35 cm in a tributary of the Whitesand. Rhude (1976a) reported catching grayling in the Yates River and tributary. Yates River, Honney Creek and Whitesands River are noted as containing Arctic grayling (see Appendix 4).

Personal communications:
Vance Buchwald (Alberta Environment and Parks [AEP])
Terry Clayton (retired; AEP)
Quentin Isley (Alberta Justice and Solicitor General)
Craig Johnson (AEP)
Brian Lucko (AEP)
Laura MacPherson (AEP)
Jim O'Neil (retired; Golder Associates)
Darryl Smith (Alberta Fish and Game Association)
Michael Sullivan (AEP)
KayeDon Wilcox (AEP)

Appendix 3. Current (2014) Fish Sustainability Index adult grayling density ranks for each Hierarchical Unit Code (HUC) watershed, as ranked by provincial biologists. Ranks ranged from 0 (no grayling) to 5 (highest possible density, likely at carrying capacity). Reliability of the adult density ranks were also ranked in terms of the quantity and quality of information (qualitative and/or quantitative) used to make these ranks. Quantity ranks were as follows 1: No Data; 2: Insufficient Data; 3. Moderately Sufficient Data; 4. Nearly Sufficient Data; 5. Sufficient Data. Quality ranks were as follows: 1. Imprecise and Inaccurate; 2. Precise but Inaccurate; 3. Accurate but Imprecise; 4. Likely OK; 5. Precise and Accurate. Adapted from ESRD 2014. Asterisks represent locations where grayling were introduced. Personal communications are listed at the end of the Appendix. FWMIS = Fisheries and Wildlife Management Information System.

Hierarchical Unit Code (HUC) Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments (CUE = catch per unit effort; HUC = Hierarchical Unit Code; FL = fork length)
ATHABASCA BELOW FORT ASSINIBOINE	1	4	3	Timeu Creek - 25 Arctic grayling > 110 mm FL captured in 1994 electrofishing, 1 Arctic grayling > 110 mm FL captured in 2000 test net; 9 Arctic grayling > 110 mm FL captured in 2010 electrofishing, none of which exceeded adult minimum size of 283 mm fork length. Chisholm - No surveys have been found that have captured Arctic grayling. As there are Arctic grayling found in the Athabasca River and in these types of streams in adjacent tributaries, it is assumed that Arctic grayling are present in these streams as well.
ATHABASCA RIVER ABOVE BERLAND RIVER	2	2	3	Density score based on data from the 2008/2009 boat electrofishing (mainstem) and sample angling, not totally representative of entire watershed.
ATHABASCA RIVER ABOVE WHITECOURT	3	4	4	Density score based on data from the 2008/2009 boat electrofishing (mainstem) and sample angling, not totally representative of watershed.
BEAVERLODGE RIVER	0	4	4	**Redwillow- Beaverlodge-** Extensive watershed-scale backpack electrofishing (27 sites) 2008 to 2010 didn't capture Arctic grayling and none present in 2006 fish kill. The last documented capture of Arctic grayling in the Beaverlodge River was in 1992. Arctic grayling were captured more recently in the Redwillow River, but not since 2002. **Above Redwillow-Beaverlodge-** Most of the watershed upstream from the falls is in BC; anecdotes and one piece of data from BC suggest that Arctic grayling may be present in the upper watershed. In 1969, 1 Arctic grayling (maturity unknown) was reported in the Redwillow River in B.C. (B.C. Fish Inventory Data Query; MC116, 01-JAN-1969; queried Jan 29 2013). ESRD sampled 1 site above the falls (no Arctic grayling observed) during the 2008-2010 Redwillow Beaverlodge watershed assessment.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
BERLAND - WILDHAY RIVERS	3	4	4	Based on 2008/2009 mainstem electrofishing and sample angling of the Berland (scored as 4) and sampling in Wildhay River watershed 2012 (scored as 2, however sampling occured during a high water year); overall watershed was scored as a 3, but may be 4.
Bow River-Ghost reservoir (Quarry Lake)*	3	2	2	Quarry Lake was first stocked with Arctic grayling in 1997. From 2001 to 2013 strain code QLQL was used with 500 Arctic grayling stocked in 2013, 2271 fry in 2012, 1900 fry in 2009 and 100 fry in 2001. In 1997, 1,904 Arctic grayling strain code FLFL were stocked. Fisheries management conducted an egg take at Quarry Lake in 2012, 2009, 2006, 2001 and 2008. Anecdotal reports of angling catch rates of ~2-3 Arctic grayling/hr.
BOYER RIVER - PONTON RIVER	2	4	4	Weighted stream score 2.4. **CARIBOU** (3); Only 2 adults over 283mm FL found in 1997 surveys. Low density of larger adults. However, may be a function of survey technique used to sample large adults. **LAWRENCE** (5); Large mature adults >283mm FL found in Unnamed and Flemming Lakes (lentic habitats/test netting). No adults over this size electrofished or angled. Only test-netting in lakes. Assuming migration into lotic (M. Sullivan personal comm. 2011). **PONTON** (4); Lack of information on mainstem and other tributaries down stream of Margaret Lake down to the Peace River. Angling CUE of 1.2 fish/hr. May be hyperstable CUEs. **LOWER PEACE RIVER** (6); Presence suspected based on observations of habitat suitability. Arctic grayling in adjacent watersheds. Peace River mainstem considered a hydrological barrier. No other tributaries to Peace River have documented Arctic grayling presence (suspected in tributaries from Caribou Mountains) **BOYER** (0); Surveys in the 1960s, '70s and 1992 near the confluence with the Peace River have failed to capture grayling. Survey comments suggest that habitats are low suitability for grayling. However, there is no evidence to suggest that grayling have never existed in this HUC. Scored as Extirpation Suspected. Baldwin and Goater (2003) also noted capturing Arctic grayling in **Flemming Lake.**

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
BUFFALO - WOLVERINE RIVERS	0	3	2	Scored as a 0 as Buffalo and Wolverine River had no adults detected and Lower Peace is presence suspected. **BUFFALO & WOLVERINE RIVER** (0); No adults found. However, juveniles found so adults must inherently be present. No angling was conducted during surveys, thus unknown adult presence. Low-moderate land use, limited pressure on fishery, adult presence potential is high. No CUE calculation. **LOWER PEACE RIVER** (6); Presence suspected based on observations of habitat suitability. Arctic grayling in adjacent watersheds. Peace River mainstem considered a hydrological barrier. No other tributaries to Peace River have documented grayling presence (suspected in tributaries from Caribou Mountains). Adjacent to La Crete, may be high pressure on fishery.
BUFFALO RIVER	5	3	2	No data to support. There is ideal habitat and little access/land use so suspect that abundance may be similar to historic levels.
CADOTTE RIVER AND LAKE	0	4	3	Found adult Arctic grayling in 1977 and again in 1978 at 6 locations (Walty 1980). Found 115 assumed adults, 25 measured over 283mm FL. 2012 traps/float trips/gill nets detected no adults.
CALLING LAKE - HOUSE RIVER	1	3	3	Weighted stream score 0.79. Did not include Deep Creek as it was scored as a 6 (presence suspected). **CALLING RIVER** (0); No recent surveys in FWMIS report capturing Arctic grayling. The adjacent HUC are ranked as no grayling detected. As no current evidence of grayling presence and surrounding HUCs are none detected adjusted rank of Calling River to align with the surrounding HUCs and to reflect available sampling data. No grayling have been reported/captured in this area since 1974. **DEEP CREEK** (6); No surveys have been found that have captured Arctic grayling. As there are Arctic grayling found in the Athabasca River and in similar streams in adjacent HUCs, professional opinion is that Arctic grayling are present in these streams as well. **HOUSE RIVER** (1); Limited recent electrofishing data and test angling by FMB. Sampling sites limited, not representative of HUC. Only sites that were easily accessible were sampled. Stanislawski 1996, 1998, Stanislawski & Brown 1996. **ATHABASCA GRAND RAPIDS** (1); Several angler reports no Arctic grayling caught in mainstem (1994, 1997), but Tripp and Tsui (1980) show high catch rates in late 1970s. 1993-2011, 86 electrofishing events in mainstem captured 1 adult.
CHINCHAGA RIVER	2	4	3	Few adults found in past survey years. Most work done is 1997. Lack of maturity and age data. FL and fishing effort available. Only 2 Arctic grayling >283mm FL.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
CHIP LAKE - PADDLE RIVER	1	4	3	**Lobstick-** 19,279 seconds of electrofishing effort from multiple sites between 2001– 2010 failed to capture any adult Arctic grayling. Arctic grayling reintroduced in 2009 from Bear pond or Big Iron pond originally Freeman stock. While young of year have been captured from these stocked fish, at this time it's believed that the population remains non-sustainable. **Central-** No Arctic grayling detected in the watershed since 1971, when 1 Arctic grayling was reported at Lac La Nonne, despite numerous mainstem and tributary sampling from 1990 - 2010. **Paddle-** The last report of Arctic grayling in the watershed was in 1979. Electrofishing at multiple sites in the watershed from 1999 - 2009 with 33,335 seconds effort failed to capture any Arctic grayling.
CHRISTINA RIVER	1	4	3	Weighted stream score is 1. Winefred River was not included as it was scored as presence suspected. **UPPER CHRISTINA** (1); Angling data was collected by Provincial Fisheries staff, electrofishing was done by consultants. Angling data doesn't encompass many sites, mostly sites that are easily accessible. May not be representative of the entire HUC. Suspect Arctic grayling may mature earlier here (i.e., younger). **WINEFRED RIVER** (6); The methods used to collect this data was prima cord and rotenone making it impossible to calculate density. Presence suspected but no surveys done since 1973. **LOWER CHRISTINA** (1); Sampling recorded in FWMIS for the lower Christina and tributaries (except Surmont), 21 angling (lotic) events in 1984 to 2001. No Arctic grayling caught. Total of 241 electrofishing events in HUC up to 2012 caught 2 Arctic grayling (both Surmont). Surmont Creek, once a "major spawning stream".
CLEARWATER RIVER	1	4	3	Weighted stream score of all 3 HUCs is 1.4. **Clearwater:** Considerable anglings events 1994 to 2008 (FWMIS). No Arctic grayling caught. In Saprae Creek, 2 adults in 9.5 h (CUE = 0.21). Between 2005 and 2012 in Clearwater, 43 electrofishing events caught a total of 65 Arctic grayling, 7 of which were adults. **Hangingstone River**: Only 2 out of 26 test angle sample events captured adults (> 283), both low CUE (1994 to 2002). From 2005-2008, 8 electrofishing events, with 7 capturing no fish, and 1 capturing 3 fish (in 2005). In 2011, Fis and Wildlife staff sampling captured 12 adults in 1 hour. **High Hill River**: Based on one angling event in 1997, CUE = 0.38 (4 fish caught), big grayling were present, but uncommon. 12 electrofishing events in 2007 to 2011 caught 1 adult (2010).
DOIG RIVER	2	2	1	16 fisheries inventory sites completed up to 1997. Found no adults over 283mm fork length. Fish could be mature at smaller size. Lack of survey data into BC side of HUC.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
ELLS - STEEPBANK RIVERS	1	4	4	Weighted stream score of all 6 HUCs is 0.5. **Bitumont**; Fort Creek (1996) angling did not capture Arctic grayling, only 2 semi-recent (1999) records in mainstem. Between 2005 and 2009, >100 electrofishing events recorded a total of 3 Arctic grayling. What happened to 1000s of mainstem fish that ran up the Firebag, Steepbank and Muskeg in the 1970s? **Ells River**; 1996 and 2000, high CUE sample angling. No adults caught in 2008 event (but low effort; 0.5 h). Between 2005 and 2009, 20 electrofishing events caught 3 Arctic grayling in total (all small). Did population really decline that much from 2000 to 2009? **Mildred Lake**; Beaver River/Cache/Donald/Clarke/Poplar Creek: 104 electrofishing events from 2000–2012 = 4 adult Arctic grayling. Mclean Creek (2000–2009) 29 electrofishing events = 5 Arctic grayling caught (4 in 2000, only 1 in 2004, none since). Watershed must be close to being extirpated. **Muskeg River**; Extensive angling from 1997 to 2008 caught no large Arctic grayling, electrofishing in 1997 caught several adults, but 56 mainstem electrofishing events since 2000 to 2009 only captured 1 immature Arctic grayling near mouth of the Muskeg River. Adults must be present somewhere to produce 1 immature, possibly from the Athabasca River. 36 electrofishing events between 2000 and 2009 captured zero Arctic grayling in Khahago, Green Stockings, Iyinimin, Pemmican, Wapasu Creeks. No sustainable population. Population appears extirpated. Steepbank River: Prior to 2000, numerous angling, counting fence and electrofishing samples. From 2001–2011, 118 electrofishing events caught 63 adult Arctic grayling. High likelihood that Steepbank population has seriously declined. Arctic grayling now might simply be vagrants from Athabasca River. **Tar River**; From 2002 to 2009, 36 electrofishing events caught 2 Arctic grayling, both immature near mouth, 2011 Golder Assoc. captured at least 1 Arctic grayling upstream of Comp Lake. No functional population present, no nursery function (Griffiths described as a nursery stream in 1973).
FIREBAG RIVER	1	2	2	Weighted stream score 0.5. **FIREBAG RIVER** (0): 1996–1998 test angling in FWMIS record 14 Arctic grayling >283 mm in 95 hours = CUE = 0.15, corroborated by low (3 Arctic grayling catch, all immature, no adults) in 6 electrofishing events from 2005 to 2008. **MARGUERITE RIVER** (1); Test-angling in 1997 CUE=0.22, 1998 CUE = 0.13 (OK effort); 2006 electrofishing = 0. Better data on Firebag (downstream), extremely low numbers. Electrofishing captured 2 Arctic grayling in 2006 and 1 grayling in 2009.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
FONTAS RIVER	3	1	1	Limited surveys. No Arctic grayling found >283mm FL. Assuming adults present, based on immature density. Electrofishing was the only sampling method used. Angling may have increased success or capturing adults (Diversified Environmental 1994). Scores reflect anecdotal comments/observations.
FREEMAN RIVER	2	4	4	Weighted stream score 1.71 did not include Chisholm as it was scored as a presence suspected. **CHRISTMAS CREEK** (0); 12 Arctic grayling > 110 mm FL captured in 1994 electrofishing survey, none of which exceeded adult minimum size of 283 mm FL. **FREEMAN RIVER** (2); Out of 262 "Arctic grayling" >110 mm FL captured in surveys, only 3 exceeded adult minimum size of 283 mm FL. Data suggest 1 but scored as 2 because of concerns that adults were not captured in the survey. **SAKWATAMAU RIVER** (2); Out of 249 "Arctic grayling" >110 mm FL captured in surveys, only 4 exceeded adult minimum size of 283 mm FL. **CHISHOLM** (6); No surveys have been found that have captured Arctic grayling. As there are Arctic grayling found in the Athabasca River and in similar streams in adjacent tributaries, it is assumed that Arctic grayling are present in these streams as well.
HORSE RIVER	1	4	4	Weighted stream score is 1. **Athabasca Grande Rapids**: Several angler reports no Arctic grayling caught in mainstem (1994, 1997), but Tripp and Tsui (1980) show high catch rates in the late 1970s. Between 1993and 2011, 86 electrofishing events in mainstem = 1 adult. **Horse River**: FRM Environmental 1998 test angling, CUE = 0.04 for > 282. 2001, 7 km of boat shocking caught 4 adults. From 2000–2009, 33 other electrofishing events caught 0 Arctic grayling. **Mildred Lake**: Professional opinion, but good samples from FWMIS.
JACKFISH RIVER	3	1	1	No records of Arctic grayling in area. M. Sullivan spoke to WBNP staff (Nov 2011, Nov 2012). Presence in upper portion of HUC suspected based simply on presence in Peace River and watersheds to west (Caribou Mountains). Arctic grayling believed to be resident in Jackfish River and tributaries (M. Sullivan and J.O'Neil pers.comm.). Given the limited land use and access in the area, and the absence of current data, it's believed that densities are the same as they were historically

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
KAKWA RIVER - CUTBANK RIVER	4	4	4	Weighted stream score 3.5. **KAKWA RIVER** (4); Although a lot of data has been collected, all ACA data were not used because sampling was biased towards bull trout. Metric was primarily based on T. Ripley's work 1997 and 2003 and professional judgement. Arctic grayling densities higher in upstream portions. **MIDDLE SMOKY RIVER & LOWER CUTBANK RIVER** (3); Decision based on FWMIS data. More recent backpack electrofishing and angling CUE categorizes this as low (i.e., 3 sites in rank 1), if older (1997–1992) angling data are used then it falls into rank 4 or 5. Categorized as 3, but data are sparse and old. **UPPER CUTBANK** (3); Data reported by Ripley (2009), backpack electrofishing CUE for adults (>350 mm TL) 1.02 fish/10000sec; immature (<350mm TL) 72.3 fish/10000sec. Recognize our maturity break is at 283 mm FL. 2012 CUEs lower; Provincial Fisheries staff didn't sample key mainstem habitats in 2012.
KEG RIVER	1	4	4	Scored as 1 as the Lower Peace is presence suspected. **KEG RIVER** (1); Lack of information of the mainstem of the Keg River and other tributaries. CUE (all fish), 66 fish/10000 sec. Score of 2 represents angling and anecdotal info. **LOWER PEACE RIVER** (6); Presence suspected based on observations of habitat suitability. Arctic grayling in adjacent watersheds. Peace River mainstem considered a hydrological barrier. No other tributaries to Peace River have documented Arctic grayling presence (suspected in tributaries from Caribou Mountains).
LOON RIVER - LUBICON RIVER	1	1	1	Presence suspected based on limited anecdotal data including angler reports from late 1980s, '90s several tributaries including Red Earth Creek and a few unnamed tributaries. Trap netting at the confluence of the Loon River and Wabasca River in 2011 did not detect any Arctic grayling. Locals from Red Earth Creek suggested that Arctic grayling are present on an unnamed (Crooked) creek (tributary to the Loon River) at the crossing of HWY 686. J. O'Neil (2013, pers. comm) confirms the presence of Arctic grayling with "Crooked Creek" from below the road crossing to the headwaters. Given that Arctic grayling have declined across their native range, and the increase in anthropogenic disturbance and angling pressure in this area, suspect that Arctic grayling densities are quite low (M. Brown, pers. comm.)

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
LOWER ATHABASCA RIVER	1	1	1	Weighted stream score 0.65. **MAYBELLE RIVER** (4); No electrofishing or angling data recorded in FWMIS. Interviews with government personnel, fishing guides and trappers out of Ft Chip (Feb 2011) provided no definite records of Arctic grayling; however, two trappers said they "had heard" of grayling in the area. M. Voyageur (local hunter/trapper with Chip Band) stated to M. Sullivan in Nov 2012 that grayling were numerous and abundant in the upper reaches of Keane Creek and was concerned with overfishing near mouth. Trevor Sellin (district officer) confirmed Arctic grayling in Keane Creek. **RICHARDSON RIVER** (0); In 1996, 3 immature, 0 adult Arctic grayling angled in Grayling Creek. 12 angling events 1996–2008 caught no other Arctic grayling. Five electrofishing events (in 2007) in Athabasca mainstem caught 0 Arctic grayling. Must be Arctic grayling in area as immature were caught, but in very low density. Interview with Morgan Voyageur (Nov 2012) did not mention any Arctic grayling in area.
LOWER BIRCH RIVER	4	1	1	Maybe good grayling population in upper sections; reports that habitats look suitable, but no meaningful data. Abundant in the Birch Mountains. In higher gradient tributaries. R. Campbell (WBNP, Nov 2012) said no Arctic grayling in lower Birch near Claire. Two new electrofishing events produced no new data. Given the limited land use and access in the area, and the absence of current data, it's believed that densities are the same as they were historically.
LOWER HAY RIVER IN ALBERTA	3	4	3	Did not include Hutch Lake/Meander River as it was scored as presence not suspected. **HAY RIVER** (3); 3 sites completed prior to 2010. James Creek, Steen River, Little Rapids Creek, Jackpot Creek, Dizzy Creeks surveyed in 2010 all found Arctic grayling. CUE of 2.02 fish/hr from 2012 Melvin and Slavey survey. **HUTCH LAKE/MEANDER RIVER** (presence not suspected); No Arctic grayling found historically.
LOWER LITTLE SMOKY RIVER	0	1	1	No Arctic grayling caught in lower Little Smoky, but upper Little Smoky has good CUE for mature Arctic grayling. K. Fitzsimmons and M. Blackburn (pers. comm) indicate that the lower Little Smoky has predominantly NRPK and WALL. Arctic grayling are in systems up and downstream from this watershed.
LOWER MACLEOD RIVER	2	4	4	**McLeod River**: Used mainstem sample angling data from 2010 and 2011.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
LOWER PEMBINA RIVER	0	3	3	**French;** No recent surveys in FWMIS report capturing Arctic grayling. The adjacent HUC are ranked as no grayling detected. As no current evidence of grayling presence and surrounding HUCs are none detected adjusted rank of French Creek to align with the surrounding HUCs and to reflect available sampling data. **Lower Pembina-** Electrofishing and test netting surveys conducted in the mainstem Pembina and most of the major tributaries within this HUC from 1990 to 2009 have not captured any Arctic grayling. No Arctic grayling ever captured, but presumed to be used for migration.
LOWER WABASCA RIVER	1	2	2	One electrofishing survey location in 2010 (Rat Creek), no adults found. However adult grayling are suspected. Anecdotal information of adult Arctic grayling presence at the confluence with the Wabasca and Rat Creek (score upgraded to 1 from zero).
LOWER WAPITI RIVER - BEAR CREEK AND LAKE	1	4	4	Summer electrofishing and angling data did not capture any Arctic grayling (suggesting a score of 0); however, ACA overwintering (telemetry) data indicates that Arctic grayling are overwintering in the Lower Wapiti mainstem. We therefore upgraded the score to a 1.
MACKAY RIVER	1	4	4	Angling in Mackay, 1998, adult CUE = 0.3; Dunkirk (2008) CUE = 0.25. Between 1997 and 2011, 35 electrofishing events captured 1 adult grayling. No Arctic grayling were captured in 28 electrofishing events from 2005–2011. Very poor angling CUE that doesn't correlate to Mitchell Consulting and Golder Consulting descriptions of good or excellent fishing.
McIVOR RIVER - LAKE CLAIRE	2	1	2	**LAKE CLAIRE** (6); One record in HUC to south (McIvor River HUC), but no confirmed Arctic grayling in this portion of the watershed. R. Campbell (WBNP) said no Arctic grayling were caught in years of net and angling sampling. Not a sustainable population, if even present. **MCIVOR RIVER** (6); No FWMIS data, other than one angling record near Lake Claire. Certainly not abundant or common. Presence of populations suspected in upper reaches, but no records. R. Campbell (WBNP) stated in Nov 2012 that no grayling were in McIvor R. near mouth, but he had heard of grayling in upper reaches. Given the limited land use and access in the area, and the absence of current data, it's believed that densities are the same as they were historically.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
MIKKWA RIVER	1	3	2	Suspect adults could be present. No substantial inventory information available. Assumed to be excellent habitat. Sub-alpine headwaters, low land use. Arctic grayling captured and considered abundant in Legend Lake in 2001. ACA completed a "scoping'" study at the headwaters of the Mikkwa River in 2013 (ACA 2014). Intent was to characterize the Arctic grayling population in the mainstem and tributaries to the Mikkwa River in the upper sections beginning downstream of Legend Lake. Due to low Arctic grayling catches not all sites were completed. Methodology used was angling and backpack e-fishing.
NORTH LESSER SLAVE LAKE	2	4	3	Weighted stream score is 1.7; did not include Lesser Slave Lake as it was scored as presence suspected. **ASSINEAU** (1); Lucko (1987) was the last known study that captured Arctic grayling in this drainage, no large fish and very few small fish. No captures in FWMIS. **DRIFTPILE RIVER** (1); 2001 ACA work detected 2 >283mm Arctic grayling in 2012, average adult CUE 1.0 fish/h. M.Sc. thesis work found 31 Arctic grayling: 3>283mm over 6.75hrs test angling, require greater sampling effort. **LESSER SLAVE LAKE** (6); If Arctic grayling are found then incidental presence if any in Lesser Slave Lake. Potential for Arctic grayling to live in several of the tributaries included in the HUC, but no records or data collected confirm presence. More work is required. **MARTEN RIVER** (2); Only 1 Arctic grayling > 283 FL caught in gill nets during ACA CFIP program (2003). 2012 M.Sc thesis work detected 1 Arctic grayling > 283mm FL. Number of juveniles found in 2003 (n=90) and 2012 (n=31) infers adult presence**. OILMAN'S CREEK** (1); Large decline in population suspected based on historical angler reports of good Arctic grayling catches pre 1990s. Test angling in 2012 and 2013 of 2km section west of hwy 88 detected grayling. **SWAN RIVER** (2); ESRD angling catch rates summer 2010 (using stratifued random sampling), 39.6 hours of angling over ~11.6 km of the mainstem reaches of the Swan River. 2012 test angling done for M.Sc. (looking at Arctic grayling genetics): 10.85 hrs, caught 30 Arctic grayling, 2 >283mm FL.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
NOTIKEWIN RIVER	1	4	4	Historical surveys have found low numbers of adults (FWMIS), total of 7 >283mm FL. Many survey locations throughout entire watershed. electrofishing primarily used to assess, no angling (0.33 electrofishing).
PEACE RIVER ABOVE PEACE RIVER	1	4	4	Scores represent Arctic grayling captured only in Peace River mainstem (no historical captures in tributaries). No winter sampling has taken place.
PETITOT RIVER - BISTCHO LAKE	1	2	1	Score represents AB side only. Lack of suitable habitat in headwaters (north of Bistcho Lake). Though Arctic grayling found in mainstem Petitot River, likely to occur predominantly in tributaries downstream of Bistcho Lake. Adults have been found in the Petitot R. in Alberta (Griffiths and Ferster 1974), however appears to be low numbers. They are confirmed on the BC side in low numbers but appear these were found in tributaries to the Petitot R.. Expect that adults mature smaller than 283mm.
PUSKWASKAU RIVER - LOWER SMOKY RIVER	0	1	1	Angling data CUE=0, Boat electrofishing data CUE=0, backpack electrofishing data CUE=0, No Arctic grayling caught; perhaps lower Smoky River may be over wintering area for Arctic grayling. Arctic grayling are in systems up and downstream from this HUC.
Ross-Bullhead-Secen Person Creeks (Spruce Coulee Reservoir)*	0	5	5	Arctic grayling were stocked for the first time in 2013 previous to stocking Arctic grayling did not live in this area. 4263 Arctic grayling strain QLQL with an average weight of 73.7 grams (length was not recorded) were stocked. In the fall of 2014, fisheries survey will be used to determine stocking success.
SAULTEAUX - DRIFTWOOD - LESSER SLAVE RIVERS	1	3	4	Weighted stream score is 0.63 did not include Lesser Slave Lake and Muskeg Creek as they were scored as 6 presence suspected. **DRIFTWOOD** (1); Grayling have not been detected since 1987 angling, no grayling detected by electrofishing from 2003–2006. Limited test angling in 2012 did not detect Arctic grayling. 2013 summer FMB test angling, sampled 6 Arctic grayling, observed several more. **FAWCETT RIVER** (0); 1 Arctic grayling >283mm detected in 1981–1983 but CUE info not available, no Arctic grayling detected since 1983, no river work recorded in FWMIS since 2002 CFIP. Population likely extirpated. **LESSER SLAVE LAKE** (6); If Arctic grayling are found than incidental presence if any in Lesser Slave Lake, potential for Arctic grayling to live in several of the tributaries included in the HUC, no records or data collected confirm presence. More sampling is required. **LESSER SLAVE RIVER** (10): Lesser Slave River appears to have only incidental “Arctic Grayling”, additional information required.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
				Continued: **MUSKEG CREEK** (6); Unknown, fish reported as random observation. No surveys for grayling conducted. **OTAUWAU RIVER** (2); Test angling to collect Arctic grayling for genetic analysis for M.Sc. thesis caught 33 Arctic grayling in 6.4 hrs fishing, 19 larger than 283 FL were found. Minimal sampling effort, likely hyperstable, further work required to determine distribution and relative abundance throughout water course. **SAULTEAUX RIVER** (1); Sampling in Saulteaux is very limited; Allan River seined in 1987 found 54 young of year. No adult Arctic grayling ever sampled in Saulteaux mainstem or other tributaries, anecdotal angle reports of presence. **SAWRIDGE CREEK** (3); Test angling to collect Arctic grayling samples for genetic analysis for M.Sc. Thesis caught 33 Arctic grayling in 4.75 hrs fishing, 26 > 283 FL were found. Minimal sampling effort, likely hyperstable. 2013 Provincial Fisheries staff angled several reaches and put in PIT tags/marks as part of scoping study for population estimate.
SCULLY CREEK - PEACE RIVER ABOVE KEG RIVER	0	4	4	No Arctic grayling are recorded in FWMIS for this HUC. ESRD, Northern River Basins Sudy, and historical surveys did not find Arctic grayling in that section of the Peace River near Scully Creek. However, given that Arctic grayling and found in neighbouring watershed tributaries it is assuming that Arctic grayling use the mainstem Athabasca for migrations and are present in low abundances seasonally.
SIMONETTE RIVER	2	4	4	Mathematically, the density score should be rank 1 (very high risk), however based on A. Meinke's field observations his professional opinion is that the score would be more appropriate at a 2 or 3. More field work required to categorize as 3; went with category 2.
SOUTH HEART - EAST & WEST PRAIRIE RIVERS	1	1	1	**EAST PRAIRIE** (1); Previous to 2013 only record of Arctic grayling presence was from 12 years ago when juveniles (<283mm fork length) of various size ranges were recorded. However, in 2013 ESRD fire staff indicated they had angled the river and caught Arctic grayling, estimated total length of 250– 275mm. **LESSER SLAVE LAKE** (6); If Arctic grayling are found than incidental presence if any in Lesser Slave Lake; potential for Arctic grayling to live in several of the tributaries included in the HUC, but no records or data collected confirm presence. More sampling is needed.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
TAWATINAW RIVER	0	2	2	Arctic grayling presence was suspected in Lawrence Lake but Arctic grayling are suspected to be extirpated from the Tawatinaw River and Baptiste River. **Baptiste** (7); No recent surveys in FWMIS report capturing Arctic grayling. The adjacent HUC are ranked as no grayling detected. As no current evidence of grayling presence and surrounding HUCs are none detected adjusted rank of Baptiste to align with the surrounding HUCs and to reflect available sampling data. Campground owner on northeast side of the lake indicated in 2002 that they haven't seen an Arctic grayling in 20 years. Heavy agriculture and eutrophication are likely limiting factors. Although Arctic grayling may be present in the Athabasca, this represents a very small portion of the HUC. This HUC is not sustainable for Arctic grayling. **Lawrence** (6); No surveys have been found that have captured Arctic grayling. As there are Arctic grayling found in the Athabasca River and in these types of streams in adjacent HUCs, it is assumed that Arctic grayling are present in this HUC. **Tawatinaw** (7); No recent surveys in FWMIS report capturing Arctic grayling. The adjacent HUC are ranked as no grayling detected. As no current evidence of grayling presence and surrounding HUCs are none detected adjusted rank of Tawatinaw to align with the surrounding HUCs and to reflect available sampling data.
UPPER BIRCH RIVER	4	1	1	**Birch River (6)** Maybe good grayling population in upper sections; reports that habitats look suitable, but no meaningful data. Abundant in the Birch Mountains. In higher gradient tributaries. R. Campbell (WBNP, Nov 2012) said no Arctic grayling in lower Birch near Claire. Two new electrofishing events produced no new data. Given the limited land use and access in the area, and the absence of current data, it's believed that densities are the same as they were historically.
UPPER HAY RIVER IN ALBERTA	0	2	1	1969 study returned one Arctic grayling (caught in a tributary of the Shekilie River, not in FWMIS). Survey in 2010 (2 sites) did not find adult Arctic grayling over 283mm FL.
UPPER LITTLE SMOKY RIVER	5	4	3	Based on 2007 sample angling data queried from FWMIS. Survey was designed to assess Arctic grayling.
UPPER MACLEOD RIVER	2	4	4	**McLeod River**-used mainstem angling data from 2010 and 2011, **Above McLeod River**- The McLeod watershed upstream from the series of barrier falls were fishless naturally. Naturalized populations of brook trout exist in the mainstem and tributaries.

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
UPPER PEMBINA RIVER	1	4	4	Weighted stream score is 0.9 did not include Above Upper Pembina River HUC as it was scored as a presence not suspected. **ABOVE UPPER PEMBINA RIVER** (presence not suspected); Used data from 2003 Pembina River report (Blackburn and Johnson 2004) and FWMIS query for Pembina. The watershed upstream from the falls are presumed to be fishless naturally. **CENTRAL PEMBINA RIVER** (0); No Arctic grayling detected in the watershed since 1971, when 1 Arctic grayling was reported from Lac La Nonne, in spite of numerous mainstem and tributary sampling from 1990– 2010. **UPPER PEMBINA RIVER** (1); Used data from 2003 Pembina River report (Blackburn and Johnson 2004). (FWMIS query for Pembina had numerous anomalies). Data was collected on mainstem Pembina using float electrofishing and sample angling.
UPPER SMOKY RIVER	1	3	3	Weighted stream score 0.13; however, upgraded to a 1 as adults were detected in the HUC. **UPPER MUSKEG** (0); Only one record from 2008 captured 5 Arctic grayling (all immature) above the Muskeg falls, assumption is that mature Arctic grayling are present as juveniles were observed. **UPPER SMOKY** (1); Based on FWMIS data. Angling CUE for 2002–1997 are rank 2 (high risk), 2002–1983 are rank 1 (very high risk). Backpack electrofishing CUE from 2007–2005 have a CUE= 0, 2007–1992 would be ranked as high risk (2), ACA only data would be ranked as very high risk (1).
UPPER WABASCA RIVER - PEERLESS LAKE	1	2	1	Scored as a 1, as the Liege R. was scored as a 1 accounting from 17% of the water in the HUC the remaining 83 % of the HUC was scored as a 6 presence suspected. **CHIPEWYAN RIVER** (6); Presence suspected based on geographic proximity to known Arctic grayling population in Chipewyan R. drainage. **LIEGE RIVER** (1); FMB report from 1973 indicates that test nets and B-line was used to inventory House Creek and Arctic grayling were found to be present, no data collected. Arctic grayling were caught in 2013 by AESRD fire staff test angling the upper reaches of the mainstem. **PANNY RIVER** (6); Presence suspected based on limited file data from 1973– FMB conducted presence/absence inventory, Arctic grayling occurred in lower reach near Wabasca River (numbers of fish not documented). Commercial fisherman indicated Arctic grayling in Burnt lake #1 & the mouth of the Penny R.. **UPPER WABASCA RIVER** (6); Presence suspected based on anecdotal data including angler reports from 1980s–1990s on a few unnamed tributaries. Potential for overwintering in Wabasca R. mainstem. Wabasca R. mainstem raft electrofishing inventory conducted by FMB during summer 2010 produced no grayling. **TROUT RIVER** (6); Presence suspected based on limited anecdotal data including angler reports from mid-1990s for one tributary; Hospital Creek, unknown sampling methods. Information to calculate CUE not available.

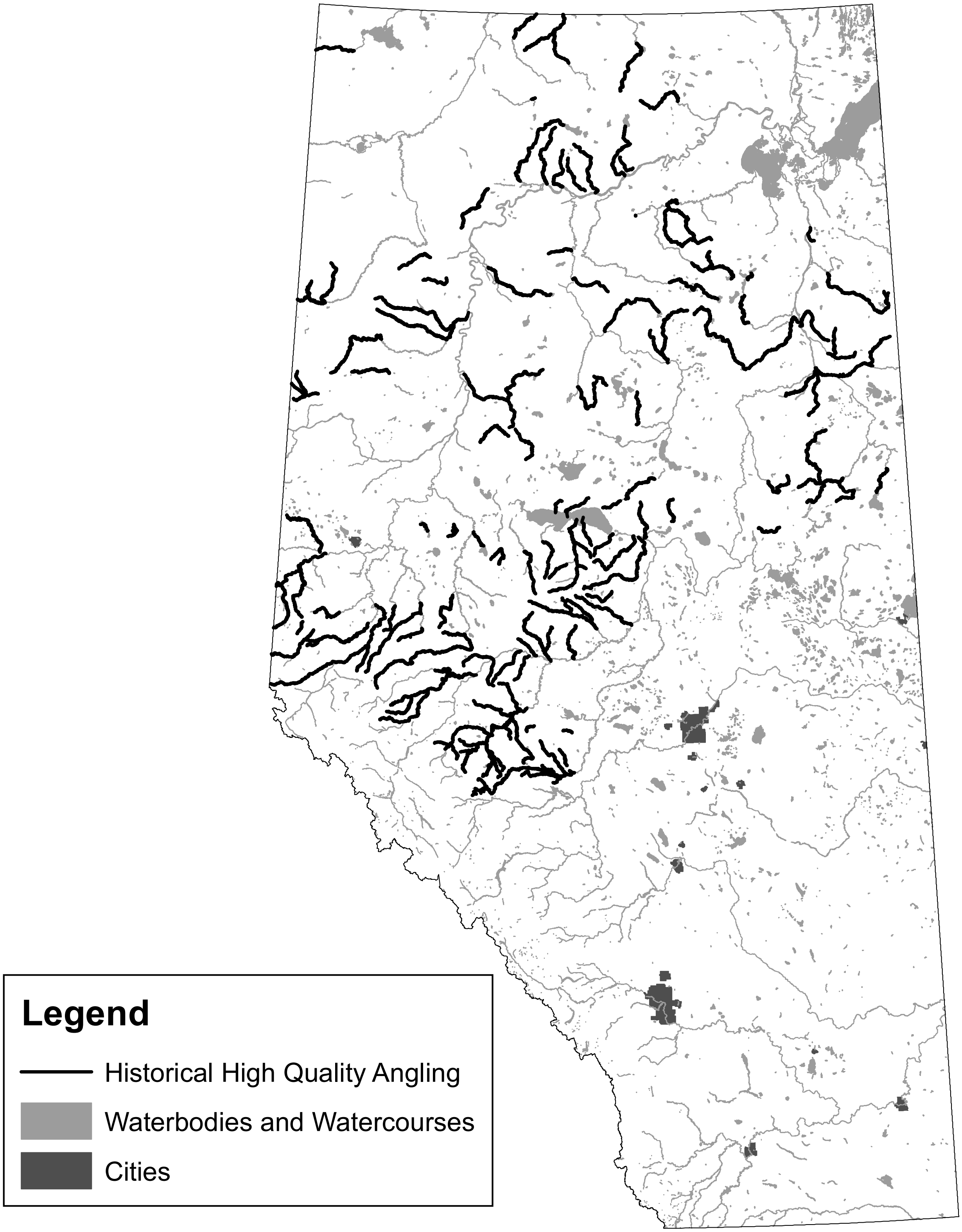
Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
UPPER WAPITI RIVER - NARRAWAY RIVER	3	4	4	**Upper Wapiti-Narraway-** Densities within Wapiti mainstem ranged from high to low, similar on Pinto and Nose Creeks with the highest densities in the headwaters in AB. Narraway River seemed to have moderate to high densities. An estimated area weighted mean would put this as a 3. **Above Upper Wapiti-Narraway**- Older studies reported no fish above Torrens Falls historically; non-native cutthroat trout were stocked in the 1960s and 1980s to create a population and recreational fishery.
UTIKUMA RIVER - WABASCA LAKES	0	2	2	**UPPER WABASCA** (6); Presence suspected based on anecdotal data including angler reports from 1980s–1990s on a few unnamed tributaries. Potential for overwintering in Wabasca mainstem. Wabasca mainstem raft electrofishing inventory conducted by FMB during summer 2010 recorded no Arctic grayling. **WILLOW RIVER** (1); Presence suspected based on anecdotal angler reports and FMB trap net in 1984 to assess Walleye *Sander vitreus* spawning run, 1 Arctic grayling was captured, presence considered incidental. **MUSKWA** (12); Created as a separate HUC by local biologists (i.e., M. Brown) because it was presumed to lack gradient, tannic water, muskeg area and is a Northern Pike *Esox lucius* and Yellow Perch *Perca flavescens* dominated system.
WANDERING RIVER - LAC LA BICHE	1	1	1	Presence suspected in the Owl River but extirpation in the Wandering River and presence not suspected in Pine Creek HUC. **Owl River:** This is based on capture of Arctic grayling in Gold creek downstream of Lac La Biche (Griffiths & Ferster 1974) & presuming Arctic grayling may be present upstream of the lake. No surveys have been found. **Wandering:** A 1974 study using prima cord and rotenone found Arctic grayling in the area. No recent surveys in FWMIS report capturing Arctic grayling. As no current evidence of grayling presence and surrounding HUCs are none detected, adjusted rank of Wandering River to align with the surrounding HUCs and to reflect available sampling data. **Pine Creek**: A 1974 study using prima cord and rotenone found Arctic grayling in the area.
WATERTON RIVER*	0	3	3	In 1999, Fish & Wildlife and Alberta Conservation Association used a gator boat to electrofish the mainstem Belly River from the US International Boundary downstream to the Payne Lake Diversion Weir. The purpose was to collect relative abundance info on Bull Trout. No "Arctic grayling" were caught or observed. Additional recent surveys in this watershed include: **2012-** Trout Unlimited Fish Rescue using electrofishing, **2011-**One immature Arctic grayling was captured at the Mountain View Leavitt Aetna Headwater Canal during the 2011 TU fish rescue (Peterson et al. 2012). **2009-** ACA Lower Belly River Fish Inventory using float and backpack electrofishing, **2008-2009**- Royal AB Museum specimen collection using seining, minnow traps, angling and backpack electrofishing. **1995-2000-** Waterton

Appendix 3 continued:

HUC Watershed	Current Adult Density Rank	Monitoring Quality	Monitoring Quantity	Current Adult Density Comments
				Continued: Lakes National Park Bull Trout investigations using fish traps, angling, telemetry, redd surveys.
WENTZEL RIVER	4	4	3	Found many large Arctic grayling (FL>283mm) using angling, electrofishing, and netting in Eva and Wentzel Lakes. High catch rates recorded. Angling 0.21 fish/hr. in Wentzel River only. Several sites surveyed in upper- and mid-reach locations using several techniques. Baldwin and Goater (2003) also noted capturing Arctic grayling in **Eva Lake.**
WHITEMUD RIVER - NORTH HEART RIVER	1	4	4	Weighted stream score 0.49. **HEART RIVER** (0); Limited habitat in mid-lower reaches. Schroeder (1973) report states Arctic grayling 234-333 mm present in the headwaters. Surveyed several sites 2009/10/11, no Arctic grayling found, possible extirpation. **WHITEMUD RIVER** (1); Current adult density remains low. Surveys have not found substantial adult presence >283mm FL. Limited angling information. FWMIS data extraction. 100% maturity believed to occur < 283mm.
WHITESAND - YATES RIVERS	4	4	4	Scored as 4 since 99% of the HUC is in the Whitesands and Yates HUC. **Whitesands and Yates**(4); isolation and low fishing pressure. Whitesand surveyed in 1976, no adults were captured (L. Rhude). Angled in 2010, 2 sites, 3 adults found but from only 2 survey locations. 0.26 fish/hr. Score upgraded based on limited survey areas but high productive capacity. **BUFFALO RIVER** (6); No data to support, ideal habitat suspect. Arctic grayling in nearby watersheds. **CONIBEAR LAKE** (12); Survey by Nelson and Paetz (1972) showed likely no Arctic grayling above Campbell Falls on Little Buffalo River (NWT). Likely no grayling in this watershed, but possible in lakes to far west end of watershed (in tributaries to Sass River).

Personal Communications:
Mike Blackburn (Alberta Environment and Parks [AEP])
Kevin Fitzsimmons (Alberta Conservation Association)
Adrien Meinke (AEP)
Jim O’Neil (retired; Golder Associates)
Travis Ripley (AEP)
Michael Sullivan (AEP)



Appendix 4. Sites where high-quality angling for Arctic grayling could be found historically; i.e., prior to more recent increases in human development activities—generally before circa 1960, depending on local patterns in population and industry. Sites were identified based on personal observations by Martin Paetz (Alberta's first government fisheries biologist during the 1950s; later the Director of Fisheries) and Jim O'Neil (retired; Golder Associates), and then combined with information from interviews and meetings with angler groups across Alberta. The information was originally compiled on a large wall map and subsequently digitized and stored by Alberta Environment and Parks, Fisheries Management.

Appendix 5. Estimation of historical and recent abundance of grayling in Alberta (Sullivan 2015).

Area x Density Estimate of Alberta's Arctic Grayling Population Size

Prepared by Michael Sullivan, Alberta Environment and Parks

Dec 2015

Introduction

"How many grayling live in Alberta?" To some degree, this question is unanswerable. No population estimate could ever be conducted on the provincial scale, annual variation would make most estimates outdated by the time they were calculated, and the migratory nature of grayling precludes precise estimates. However, a rough estimate of grayling numbers in each major watershed, as well as a provincial estimate, is still a useful parameter. For a species-at-risk assessment, the question is not strictly "How many animals live here?" but rather, "which category best describes the population: <250 animals, <2500 animals or <10,000 animals?" (IUCN 2012). Estimates of this useful but imprecise nature would also provide biologists with information on the scope of management and recovery planning; i.e., on a provincial scale, which watersheds have the highest priorities for restoring and maintaining provincially significant numbers of grayling?

The objective of this analysis is to derive an approximate estimate of the potential numbers of adult (sexually mature) Arctic grayling in each watershed in Alberta. This estimate will be for two time periods; the historical period (pre-1960) and the recent period (2004–2014). The estimated habitat area (stream km) for current GIS data is combined with a watershed-scale density assessment from the 2014 Alberta Arctic grayling Fish Sustainability Index (MacPherson 2014) to derive the potential numbers of grayling in each watershed. The estimates will not have associated levels of either accuracy or precision, as they are simply rough approximations based on two extrapolated concepts: potential densities in suitable habitat, and GIS-based approximate areas of habitat.

Methods

The habitat area in each watershed was derived using recent (2014) GIS stream layers in ArcView (ESRI, ArcGIS 10.1). The length in km of streams in Strahler orders 3, 4, and 5 was calculated for 103 streams and rivers in Alberta. These watersheds were assessed by area fisheries biologists to have historical or recent populations of Arctic grayling.

Each watershed was assessed to the historical (pre-1960) and recent (2004–2014) status of grayling following the Arctic grayling Fish Sustainability Index (FSI) protocols (Coombs and MacPherson 2014, MacPherson 2014). In brief, the status was determined using data from fisheries sampling (e.g., angling catch rates, electrofishing catches, seine and trap nets, etc.) and from interpretations of reports from anglers, enforcement officers, and First Nations fishers.

Appendix 5 continued:

The categorical status of adult grayling corresponds to density estimates using field studies and population estimates from Alberta (see Table 1a in *Population Size and Trends* for angling catch rates and 1b for electrofishing catch rates; from MacPherson [2014] and Sullivan [2011, 2013]). In these following analyses, density estimates refer to adult grayling. These are fish of age 4 and older, and larger than 28 cm fork length (Coombs and Sullivan 2011).

Results

A total of 103 separate streams and rivers were assessed as having grayling in either the historical (pre-1960) or recent (2004–2014) periods. In total, these streams were estimated (using GIS) as having approximately 86,000 km of grayling habitat (stream order 3 = 42,928 km, stream order 4 = 27,330 km, and stream order 5 = 15,806 km; see Table 1 within this appendix).

Combining the length of each stream order with the assessed corresponding density of adult grayling resulted in an estimate of nearly 0.6 million adult grayling in Alberta in the recent period (2004–2014) (see Table 1 within this appendix). This can be compared to the historical (pre-1960) estimate of approximately 1.8 million grayling. This represents a potential decline of grayling numbers by 70% compared to historical levels. Averaged across habitat types and watersheds, this suggests that the average grayling density has declined from approximately 20 adults/km to 7 adults/km.

The abundance estimates (historical and recent) for each assessed stream and river are shown in Figure 5 (see *Population Size and Trends, 1. Alberta* section of report). The cumulative abundance of grayling in the historical period (Figure 1 within this appendix) suggests that 50% of Alberta's grayling were once found in 19 (19/103, 18%) important streams and 80% of all grayling were found in only 45 streams (45/103, 44%). In the recent period, 50% of Alberta's grayling are now found in only 6 streams, and 80% are found in only 16 streams (Figure 2 within this appendix). Of the 103 assessed streams, grayling may have been lost in 51 streams.

Discussion

These approximate calculations are not intended to provide either accurate or precise estimates of grayling abundance. They do, however, provide information useful for grayling management in Alberta:

1) Grayling may have declined by roughly 70% from pre-1960 levels to the recent period (2004–2014).
2) Grayling numbers in Alberta, estimated at 600,000 adults, are certainly still in the hundreds of thousands.
3) Relatively few streams and rivers may hold the majority of grayling in Alberta, and recovery and maintenance efforts should consider the provincial-level importance of certain waters.

Appendix 5, Table 1. Estimates of habitat area and abundance of grayling in Alberta streams and rivers.

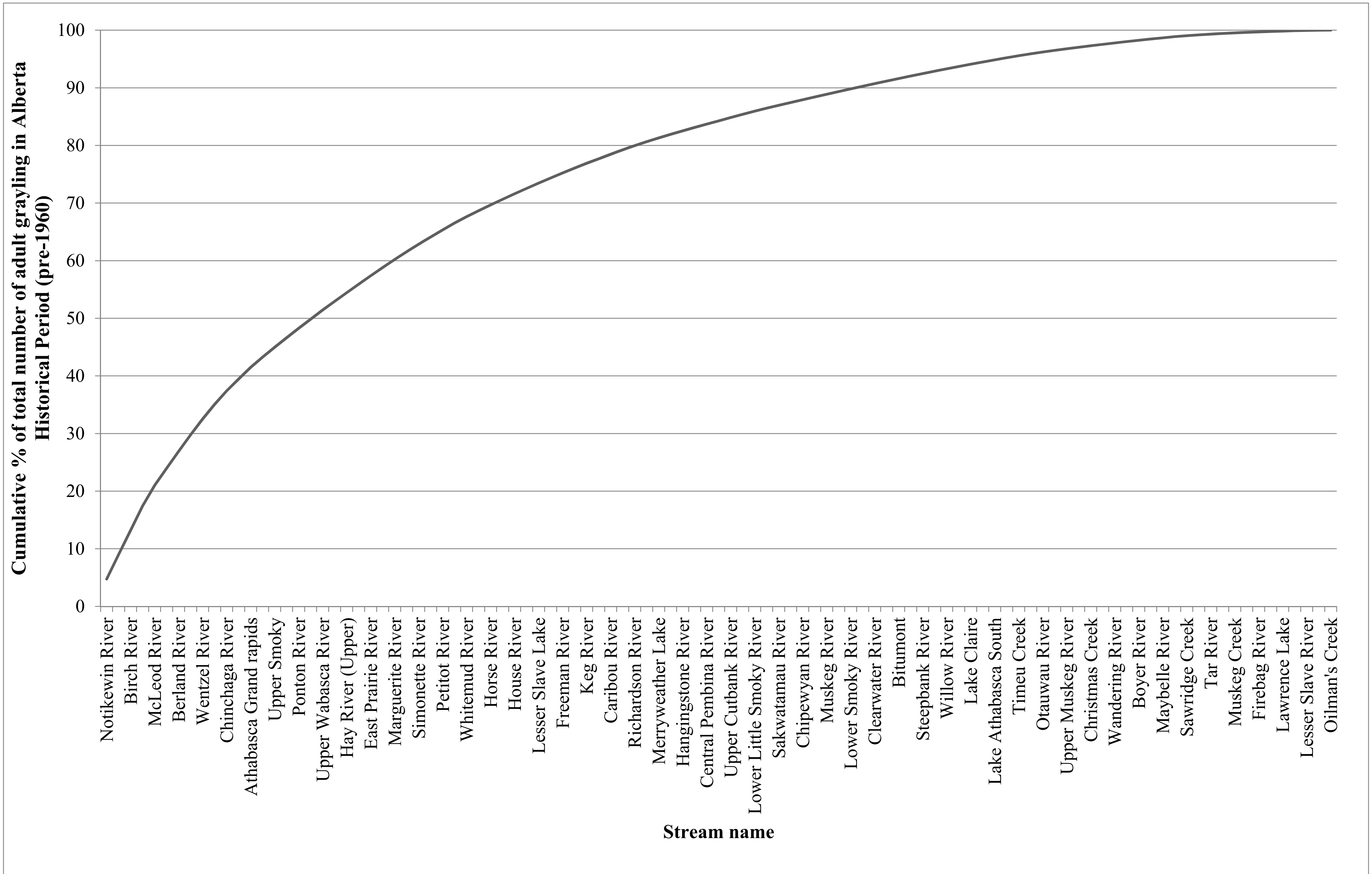
River/Stream Name	Length (km) Order 3,4,5	FSI Rank Historical (pre-1960)	Historical Density Est. ARGR/km	Historical #	FSI Rank Recent (2004-2014)	Recent Density Est. ARGR/km	Current #
Notikewin River	2886	*5*	*30*	*86587*	1	3	8659
Hay River (Lower)	4341	*3*	*18*	*78137*	3	18	78137
Birch River	3022	*4*	*25.5*	*77057*	6	0	0
Whitesand/Yates Rivers	2561	*5*	*30*	*76836*	4	25.5	65311
McLeod River	2572	*4*	*25.5*	*65593*	2	10.5	27009
Little Smoky River	1811	*5*	*30*	*54332*	5	30	54332
Berland River	1783	*5*	*30*	*53476*	3	18	32086
Upper Peace River	2918	*3*	*18*	*52516*	1	3	8753
Wentzel River	1666	*5*	*30*	*49990*	4	25.5	42492
Buffalo River	1558	*5*	*30*	*46727*	6	0	0
Chinchaga River	2359	*3*	*18*	*42466*	2	10.5	24772
Upper Athabasca	1496	*4*	*25.5*	*38142*	3	18	26924
Athabasca Grand Rapids	1438	*4*	*25.5*	*36667*	1	3	4314
Mikkwa River	1273	*4*	*25.5*	*32458*	6	0	0
Upper Smoky	1738	*3*	*18*	*31288*	1	3	5215
Upper Christina	1020	*5*	*30*	*30612*	1	3	3061
Ponton River	982	*5*	*30*	*29448*	4	25.5	25031
Lower Wabasca River	1625	*3*	*18*	*29251*	1	3	4875
Upper Wabasca River	1618	*3*	*18*	*29119*	6	0	0
Kakwa River	1082	*4*	*25.5*	*27586*	4	25.5	27586
Hay River (Upper)	2600	*2*	*10.5*	*27303*	0	0	0
Upper Pembina River	899	*5*	*30*	*26978*	1	3	2698
East Prairie River	1463	*3*	*18*	*26333*	0	0	0
MacKay River	1027	*4*	*25.5*	*26179*	1	3	3080
Marguerite River	857	*5*	*30*	*25716*	1	3	2572
Loon River	1395	*3*	*18*	*25101*	6	0	0
Simonette River	1315	*3*	*18*	*23663*	2	10.5	13803
Ells River	758	*5*	*30*	*22730*	0	0	0
Petitot River	2149	*2*	*10.5*	*22566*	2	10.5	22566
Lower Christina	734	*5*	*30*	*22010*	1	3	2201
Whitemud River	786	*4*	*25.5*	*20045*	2	10.5	8254
Upper Wapiti-Narraway	745	*4*	*25.5*	*19006*	3	18	13416
Horse River	733	*4*	*25.5*	*18679*	1	3	2198
Swan River	695	*4*	*25.5*	*17712*	2	10.5	7293
House River	572	*5*	*30*	*17157*	1	3	1716
North Heart River	660	*4*	*25.5*	*16837*	0	0	0

Appendix 5, Table 1 continued:

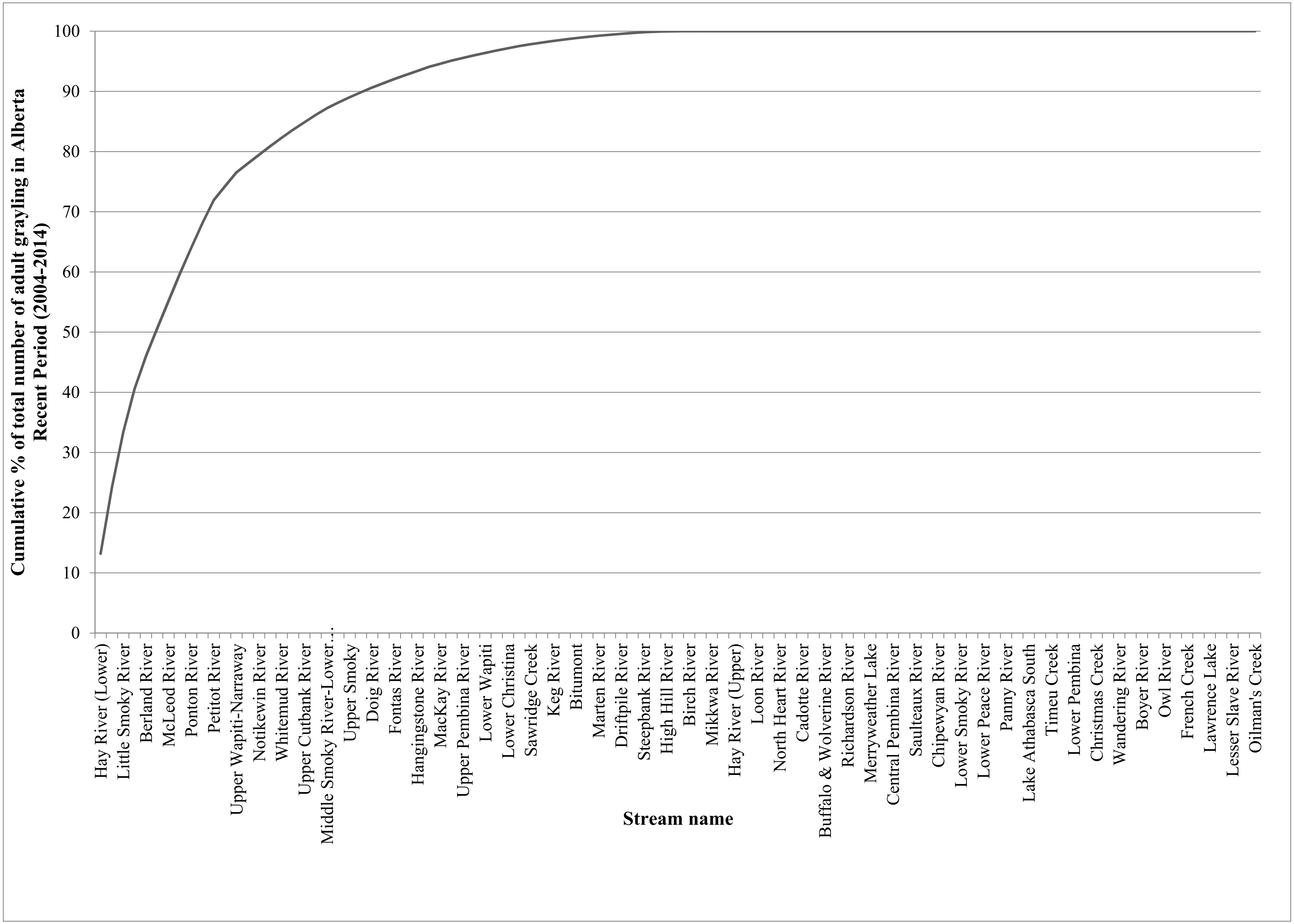
River/Stream Name	Length (km) Order 3,4,5	FSI Rank Historical (pre-1960)	Historical Density Est. ARGR/km	Historical #	FSI Rank Recent (2004-2014)	Recent Density Est. ARGR/km	Current #
Lesser Slave Lake	934	*3*	*18*	*16820*	6	0	0
Cadotte River	930	*3*	*18*	*16748*	0	0	0
Freeman River	526	*5*	*30*	*15765*	2	10.5	5518
Lobstick River	510	*5*	*30*	*15302*	7	0	0
Keg River	509	*5*	*30*	*15263*	1	3	1526
Buffalo/Wolverine River	1362	*2*	*10.5*	*14304*	0	0	0
Caribou River	475	*5*	*30*	*14250*	3	18	8550
Winefred River	779	*3*	*18*	*14025*	6	0	0
Richardson River	761	*3*	*18*	*13690*	0	0	0
Redwillow-Beaverlodge	411	*5*	*30*	*12323*	7	0	0
Merryweather Lake	1134	*2*	*10.5*	*11904*	6	0	0
Doig River	445	*4*	*25.5*	*11351*	2	10.5	4674
Hangingstone River	372	*5*	*30*	*11170*	2	10.5	3909
Calling River	358	*5*	*30*	*10752*	7	0	0
Central Pembina River	589	*3*	*18*	*10611*	7	0	0
McIvor River	577	*3*	*18*	*10386*	6	0	0
Upper Cutbank River	406	*4*	*25.5*	*10344*	3	18	7301
Saulteaux River	572	*3*	*18*	*10298*	0	0	0
Lower Little Smoky River	943	*2*	*10.5*	*9906*	6	0	0
M.Smoky L. Cutbank River	375	*4*	*25.5*	*9558*	3	18	6747
Sakwatamau River	374	*4*	*25.5*	*9536*	2	10.5	3927
Driftpile River	304	*5*	*30*	*9114*	1	3	911
Chipewyan River	484	*3*	*18*	*8718*	6	0	0
Liege River	471	*3*	*18*	*8476*	1	3	1413
Muskeg River	282	*5*	*30*	*8459*	0	0	0
Lower Wapiti	804	*2*	*10.5*	*8438*	1	3	2411
Lower Smoky River	803	*2*	*10.5*	*8428*	6	0	0
Fawcett River	326	*4*	*25.5*	*8302*	7	0	0
Clearwater River	325	*4*	*25.5*	*8276*	1	3	974
Lower Peace River	781	*2*	*10.5*	*8204*	6	0	0
Bitumont	441	*3*	*18*	*7935*	1	3	1322
Trout River	439	*3*	*18*	*7897*	6	0	0
Steepbank River	260	*5*	*30*	*7788*	1	3	779
Lawrence River	259	*5*	*30*	*7758*	5	30	7758
Willow River	430	*3*	*18*	*7732*	1	3	1289
Panny River	420	*3*	*18*	*7552*	6	0	0

Appendix 5, Table 1 continued:

River/Stream Name	Length (km) Order 3,4,5	FSI Rank Historical (pre-1960)	Historical Density Est. ARGR/km	Historical #	FSI Rank Recent (2004-2014)	Recent Density Est. ARGR/km	Current #
Lake Claire	695	*2*	*10.5*	*7298*	6	0	0
Fontas River	237	*5*	*30*	*7099*	3	18	4259
Lake Athabasca South	387	*3*	*18*	*6970*	6	0	0
Paddle River	626	*2*	*10.5*	*6573*	7	0	0
Timeu Creek	243	*4*	*25.5*	*6203*	0	0	0
Driftwood River	331	*3*	*18*	*5961*	7	0	0
Otauwau River	223	*4*	*25.5*	*5681*	2	10.5	2339
Lower Pembina	496	*2*	*10.5*	*5210*	7	0	0
Upper Muskeg River	280	*3*	*18*	*5043*	0	0	0
Mildred Lake	278	*3*	*18*	*5008*	1	3	835
Christmas Creek	152	*5*	*30*	*4557*	0	0	0
Tawatinaw River	247	*3*	*18*	*4454*	7	0	0
Wandering River	422	*2*	*10.5*	*4434*	7	0	0
Chisholm	416	*2*	*10.5*	*4367*	6	0	0
Boyer River	1368	*1*	*3*	*4105*	7	0	0
Peace Point	377	*2*	*10.5*	*3958*	6	0	0
Maybelle River	152	*4*	*25.5*	*3879*	4	25.5	3879
High Hill River	122	*5*	*30*	*3649*	1	3	365
Sawridge Creek	99	*5*	*30*	*2963*	3	18	1778
Marten River	103	*4*	*25.5*	*2625*	2	10.5	1081
Tar River	134	*3*	*18*	*2419*	1	3	403
Owl River	684	*1*	*3*	*2051*	6	0	0
Muskeg Creek	98	*3*	*18*	*1766*	6	0	0
French Creek	154	*2*	*10.5*	*1619*	7	0	0
Firebag River	48	*5*	*30*	*1429*	0	0	0
Assineau River	77	*3*	*18*	*1384*	1	3	231
Lawrence Lake	127	*2*	*10.5*	*1337*	6	0	0
Baptiste	71	*3*	*18*	*1272*	7	0	0
Lesser Slave River	46	*3*	*18*	*823*	10	0	0
Deep Creek	44	*2*	*10.5*	*465*	6	0	0
Oilman's Creek	22	*3*	*18*	*392*	7	0	0
Totals	**86,063**			**1,828,685**			**592,530**



Appendix 5, Figure 1. Cumulative historical (pre-1960) abundance of adult Arctic grayling in 103 streams and rivers in Alberta. Total historical abundance estimated at approximately 1.6 million adult grayling. Estimates are based simply on GIS-based estimate of stream length (orders 3, 4, 5) and categorical estimates of density in specific habitats.



Appendix 5, Figure 2. Cumulative recent (2004–2014) abundance of adult Arctic grayling in 103 streams and rivers in Alberta. Grayling are estimated to have been lost in 51 of the 103 assessed streams and rivers. Estimates are based simply on GIS-based estimate of stream length (orders 3, 4, 5) and categorical estimates of density in specific habitats.

Appendix 6. Modelling Anthropogenic Climate Change.

In this appendix, we model temperature increases across the range of grayling in Alberta, and estimate the amount of thermally suitable habitat currently available to Alberta grayling. We also present landscape-level losses of thermally suitable habitat approximated for ca. 2025 (2011–2040), 2055 (2041–2070), and 2085 (2071–2100) using an ensemble of 16 numerical General Circulation Models (GCMs).

6.1 Development of Models

Mean annual temperature (MAT; ˚C) was modeled across the range of Arctic grayling to determine if temperatures increased during 1961–2011. To do this, the southern boundary of the Arctic grayling range in Alberta was assumed to follow the southern boundary of the Athabasca River watershed, based on historical observations and FWMIS records (see Figure 1 in *Distribution*). All areas north of this watershed boundary were assumed to represent the historical grayling distribution, and ArcGIS® 10.1 (Environmental Systems Research Institute, Redlands, California, USA) and Geospatial Modelling Environment (formerly HawthsTools; Beyer 2004) were used to generate 5579 random points across this region. Upon visual inspection, this number of random points appeared sufficient to measure resource availability at the population level (Manly et al. 2002). A digital elevation map raster layer with a resolution of 30 m was used to obtain elevation data. Latitude, longitude, and elevation (m) were extracted for each random location. Because consistent long-term temperature records were not available for all locations, data from local meteorological stations were interpolated over the landscape using the Parameter-Elevation Regressions on Independent Slopes Model (PRISM; Wang et al. 2012). Bilinear interpolation and elevation adjustments were then used to downscale climate data to specific points of interest (Wang et al. 2006). MAT was derived from the interpolated climate data, and averaged across all random points for each year during 1961–2011 to provide a time series of climate data across northern Alberta. We modeled temperature changes in this time series with a generalized least squares model with an autoregressive lag -1 (i.e., AR-1) correlation structure, and fit this model using maximum likelihood (α=0.05). This correlation structure allowed us to explicitly account for autocorrelation in the temperature time-series and correct this bias. Model assumptions were assessed visually using residual plots (*sensu* Zuur et al. 2009).

FWMIS locations (latitude, longitude) where Arctic grayling were captured in the province were then used to provide information on grayling presence at the landscape level (see Figure 1 in *Distribution*). Care was taken to ensure no duplicate records existed within the dataset. All data (n=3337) were imported into ArcGIS® 10.1 (Environmental Systems Research Institute, Redlands, California, USA), and a digital elevation map raster layer with a resolution of 30 m was used to obtain elevation data for each location. Climate data were downscaled using PRISM, bilinear interpolation, and elevation adjustments (Wang et al. 2006). MWMT (˚C) was derived for each presence location during a normal period (1961–1990) using interpolated climate data. The 5^{th} and 95^{th} percentiles of these interpolated MWMT values were then assumed to represent the range of thermally suitable Arctic grayling habitat in Alberta.

The 5579 randomly generated points were used to quantify the amount of thermally suitable habitat available across the Arctic grayling range. For the normal period, this was done by deriving MWMT from interpolated climate data for each random location during 1961–1990, and then calculating the proportion of MWMT values falling within the thermally suitable range. This was assumed to represent all (100%) of the thermally suitable grayling habitat

Appendix 6 continued:

available during the normal period. For future periods, the proportion of thermally suitable habitat was calculated in a similar manner, and was standardized to the proportion available during the normal period to provide a relative measure of change. A suite of 16 numerical GCMs recommended for use by the Intergovernmental Panel on Climate Change (IPCC) was used to model climate change for ca. 2025 (2011–2040), 2055 (2041–2070), and 2085 (2071–2100; see Table 1 within this appendix; ABMI 2012, IPCC 2013).

The Representative Concentration Pathway 8.5 (i.e., RCP8.5) emissions scenario developed by the International Panel on Climate Change best approximated current worldwide emissions (i.e., 2005–2012; Peters et al. 2013), so this scenario was used to represent a status quo emissions scenario for all GCM predictions. GCM predictions were downscaled using PRISM, bilinear interpolation, and elevation adjustments, and MWMT was derived for each random location. Minimum, median, and maximum GCM predictions from the ensemble are presented for each timeframe to bracket structural uncertainty across the ensemble. All modeling was performed using Climate Western North America and R statistical computing (Wang et al. 2006; R Core Team 2014).

6.2 Modelling Results

During 1961–2011, MAT significantly increased across the range of Arctic grayling in Alberta and was described by the equation ($p < 0.01$, df = 49; Figure 1 within this appendix):

$$MAT = 0.0331(Year) - 65.83$$

During 1961–1990, FWMIS records and historical observations suggested Arctic grayling lived in locations where MWMT ranged from 12.2˚C to 17.7˚C, and 95% (3170/3337) of all locations were between 13.1˚C and 17.2˚C (Figure 2 within this appendix). Randomly generated points across the range of grayling suggested that 94.4% (5267/5579) of the landscape fell within the thermally suitable grayling range (13.1˚C–17.2˚C) during the normal period. GCM projections for ca. 2025 suggested thermally suitable habitat losses ranging from 6% to 86%, with a median loss estimate of 58% (see Figure 9 in *Limiting Factors*). Estimates of thermal habitat losses for ca. 2055 ranged from 61% to 97%, with a median estimate of 93% (Figure 10). By ca. 2085, thermal habitat losses ranged from 87% to 100%, with a median estimate of 97% (see Figure 9 in *Limiting Factors*). For all periods, this modeling also suggests there will be no appreciable gains in thermally suitable grayling habitat resulting from climate change.

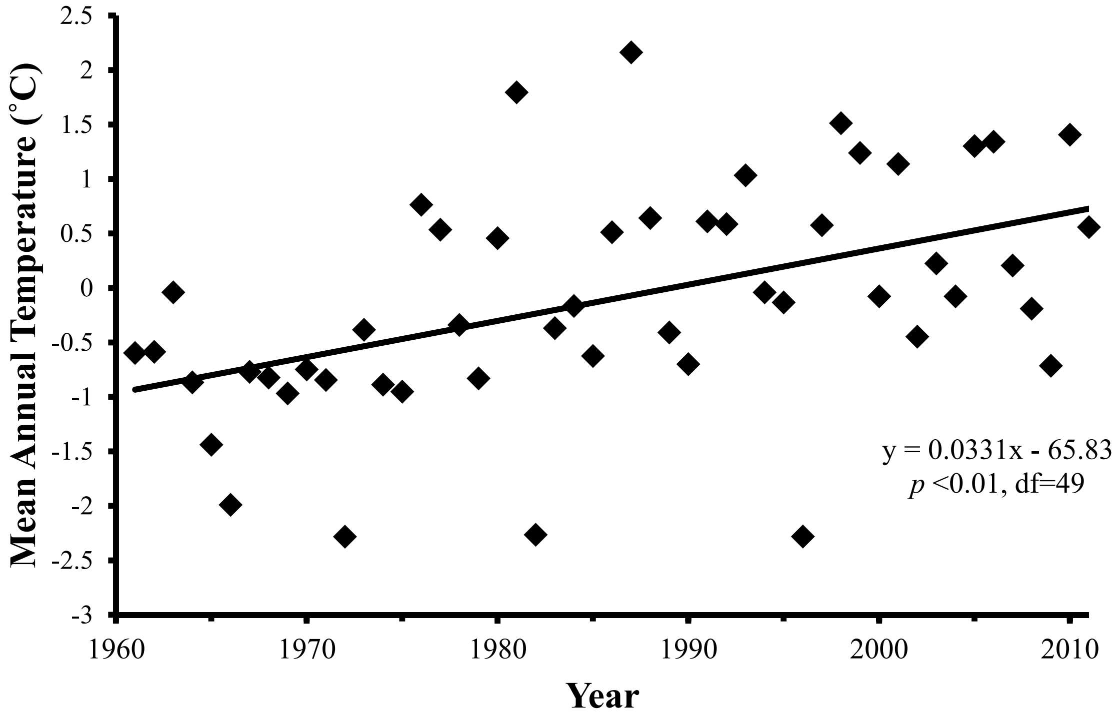
6.3 Climate Model Discussion

Results from MAT modeling suggest air temperatures across the range of Arctic grayling in Alberta have significantly increased during 1961–2011. This is consistent with more general climate predictions (Mbogga et al. 2009), and establishes climate change as a pervasive threat to Arctic grayling in Alberta. Not all of the random locations (94.4%, 5267/5579) within the Arctic grayling range fell within the thermally suitable range (13.1˚C–17.2˚C MWMT) during the normal period, indicating MWMT was somewhat heterogeneously distributed across the northern Alberta landscape, similar to other resource availability studies (Southwood 1977). As expected, different GCM projections provided a range of estimates for losses in thermally suitable grayling habitat, particularly for 2025 (losses from 6%–86%, median = 58%). However, large declines in thermally suitable habitat exist for all GCM projections for 2055 and 2085).

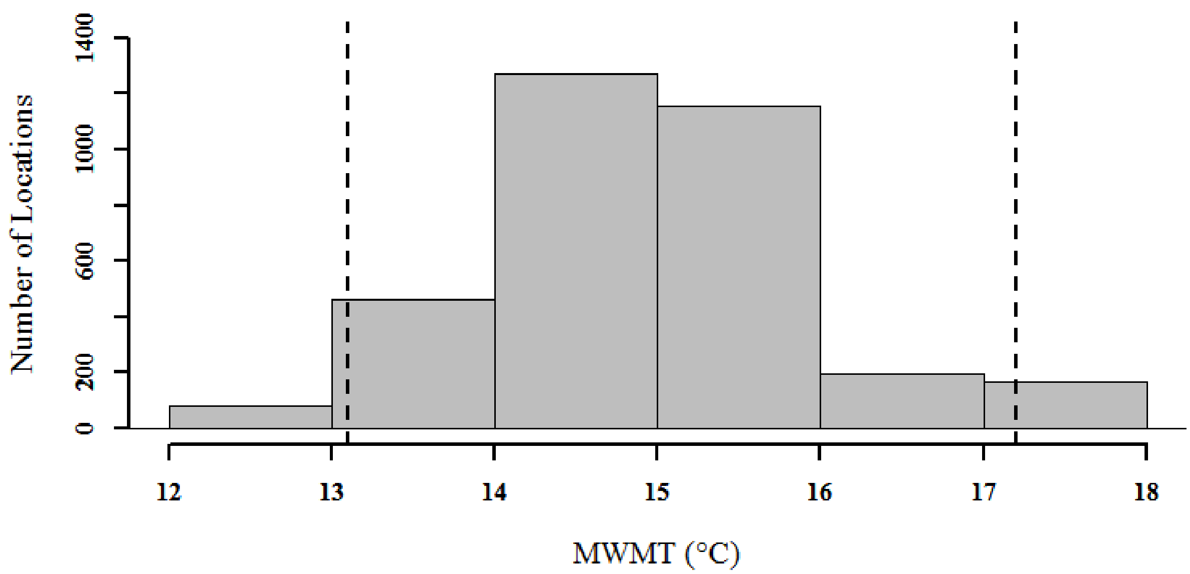
Several potential concerns regarding this analysis should be addressed. First, this analysis does not directly model biotic interactions (e.g., competition). Nevertheless, MWMT is

Appendix 6, Table 1. Numerical Global Circulation Models (GCMs) used by the Intergovernmental Panel on Climate Change in Assessment Report Five (IPCC 2013), and corresponding climate modelling groups responsible for their development.

Global Circulation Model	Climate Modelling Group
ACCESS1-3	Commonwealth Scientific and Industrial Research Organisation, Australia, and Bureau of Meteorology, Australia
BCC-CSM1	Beijing Climate Center, China Meteorological Administration
CanESM2	Canadian Centre for Climate Modeling
CCSM4	National Center for Atmospheric Research
CMCC-CM	Centre Euro-Mediterraneo per l Cambiamenti Climatici
CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
GFDL-CM3	Geophysical Fluid Dynamics Laboratory
GISS-E2-H	NASA Goddard Institute for Space Studies
HadGEM2-ES	Met Office Hadley Centre
IPSL-CM5B-LR	Institut Pierre-Simon Laplace
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MPI-ESM-MR	Max Planck Institute for Meteorology
MRI-CGM3	Meteorological Research Institute
NorESM1-M	Norwegian Climate Centre



Appendix 6, Figure 1. Increases in mean annual air temperature (˚C) across the range of Arctic grayling in Alberta, based on interpolated weather data during 1961–2011 (p<0.01, df=49). Each diamond represents the average air temperature per year calculated from 5579 randomly distributed locations across the Alberta grayling range.



Appendix 6, Figure 2. Distribution of mean warmest month air temperatures (MWMT; ˚C) for all geographic locations (n = 3337) in Alberta where grayling have been captured (taken from Alberta's Fisheries and Wildlife Management Information System, January 2015). MWMT values were interpolated from weather data during 1961–1990, and averaged for each location during this period. Dashed lines represent 5th and 95th MWMT percentiles.

Appendix 6 continued:

associated with upper limits to survival in salmonids, and is expected to correlate with factors influencing salmonid distributions and habitat suitability (Rahel 2002). Second, the adaptive capacity (defined here as the ability or potential to respond successfully to climate change) of Arctic grayling may offset warming temperatures at the population level. The adaptive capacity of grayling and other salmonids at the population level is currently unknown (McCullough et al. 2009), and such capacity in Arctic grayling is probably reduced in Alberta because of additional stressors (e.g., angling, habitat loss and fragmentation). Third, patterns of post-glacial dispersal may influence where Arctic grayling currently live in Alberta. Post-glacial dispersal routes of Arctic grayling in North America were complex (Stamford and Taylor 2004), but the North American Arctic grayling distribution transcends the Rocky Mountains, a zoogeographic barrier, which indirectly suggests factors other than dispersal barriers were important in limiting their distribution. Fourth, sample locations in the FWMIS database are spatially biased, with most Arctic grayling sampling occurring in four main regions in Alberta (see Figure 1 in *Distribution*). However, these locations coincide with coldest and warmest MWMT areas across the range of the species in the province, and likely still approximate high and low temperature tolerances for grayling. Fifth, this model did not consider local refugia that may influence persistence, so should only be used to provide general predictions regarding Arctic grayling. For example, Chu et al. (2008) suggest that cold-water streams with low groundwater inputs are more sensitive to the effects of climate change than are streams with high groundwater discharges, and we are unaware of studies that look for this pattern in northern Alberta streams; such information would be greatly beneficial to fisheries managers.

Finally, this assessment did not take into consideration the importance or interaction of multiple factors (e.g., stream flow, population dynamics, species interactions, etc.), which are expected to have myriad consequences for aquatic ecosystems (Schindler 2001). As a result, this analysis can only provide a tool for evaluating the extent to which Arctic grayling is at risk of significant climate-induced range contractions and population declines (Wilsey et al. 2013), particularly throughout the low-elevation portions of the species' range in Alberta. To triage limited resources at the landscape scale, additional modelling exploring the effects of climate change would be necessary, together with other statistical and decision-making analyses. The climate modelling presented in this report is not accurate enough to be the only basis for deciding to abandon management of Arctic grayling in certain areas.

Appendix 7. Technical Summary

A summary of information contained within this report, and used by the Scientific Subcommittee of Alberta's Endangered Species Conservation Committee for the purpose of status assessment based on International Union for the Conservation of Nature criteria. For a glossary of terms used in this technical summary, go to http://www.iucnredlist.org/technical-documents/categories-and-criteria, and http://www.cosepac.gc.ca/eng/sct2/sct2_6_e.cfm

Genus species: *Thymallus arcticus*
Common name: Arctic grayling
Range of occurrence in Alberta: Widespread throughout the Hay, Peace, and Athabasca river watersheds.

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time as indicated in the most recent IUCN guidelines is being used) Generation length is estimated to be 7 years, calculated as the average age between age-at-maturity (4 years) and maximum age (11 years). The average age of adult fish measured in a population with some fishing pressure was six years; this measured age is consistent with the estimate of seven years for generation length, since the average age in a pristine population would be expected to be somewhat longer. See Biology (4. Age, Growth, and Maturity), pp. 8–9.	7 years
Is there an inferred continuing decline in number of mature individuals? Biologists infer a past decline has occurred and, because threats (angling, habitat loss and degradation) have not been stopped, it is reasonable to assume continuing decline in population. Moreover, climate change will also become a critical stressor of grayling populations in the future. As a result, it is conservative to assume a continuing decline. See Population Size and Trends (1.2 Population Trend), pp. 12–13; Limiting Factors, pp. 17–21.	Likely

Appendix 7 continued:

Estimated percent of continuing decline in total number of mature individuals within 2 generations. Comparing historical and current abundances, based on Fish Sustainability Index (FSI) ranks, results in an estimated reduction of 70% in 54 years. There were no repeated measures taken during this period, however, and so it is not possible to determine either the shape of the past decline or what the precise decline rate would have been for the most recent two generations (14 years). Given the total decline over the longer period, it is possible, but not demonstrable, that the decline exceeded the threshold of 20% in the last two generations. Climate change ensemble modelling from this report suggests that the amount of thermally suitable habitat for grayling in Alberta will decrease by approximately 50% by 2025, and continue decreasing so that by 2055 and later it will have declined by more than 90% relative to historical levels. If one were to assume that the amount of thermally suitable habitat is a proxy for area of habitat, population reductions of a similar scale could be predicted. This suggests that a decline by 50% is possible in the next two generations (2014–2028). See Population Size and Trends (1. Alberta), pp. 10–17; Limiting Factors (3. Anthropogenic Climate Change), pp. 20–21.	Decline rate is undetermined but, based on past estimated and future predicted declines, a loss of mature individuals exceeding the threshold of 20% within two generations (during 2014–2028) is possible.
Inferred percent decline in total number of mature individuals over the last 3 generations. Based on comparison of grayling density (as estimated from FSI ranks) between 1960 and 2014, a decline of roughly 70% over 54 years has occurred. However, with no repeated measures taken during this period, it is not possible to determine either the shape of the past decline or what the precise decline rate would have been for the most recent three generations (21 years). Given the total decline over the longer period, it is possible, but not demonstrable, that the decline exceeded the threshold of 30% in three generations (1993–2014). See Population Size and Trends (1. Alberta), pp. 10–17.	Decline rate is undetermined but, based on past estimated decline, a loss of mature individuals exceeding the threshold of 30% over the past three generations (during 1993–2014) is possible.

Appendix 7 continued:

Suspected percent reduction in total number of mature individuals over the next 3 generations. Anthropogenic activities have caused declines in quality and quantity of grayling habitat in Alberta, which will likely continue in the future. Without knowing the shape of the past decline, however, the rate of future decline cannot be accurately predicted based on the rate of past decline. Climate change ensemble modelling from this report suggests that in the future, the amount of thermally suitable habitat for grayling in Alberta will decrease, as described above. If one were to assume that the amount of thermally suitable habitat is a proxy for area of habitat, population reductions of a similar scale could be predicted over the next three generations (2014–2035). See Population Size and Trends (1. Alberta), pp. 10–17; Limiting Factors (3. Anthropogenic Climate Change), pp. 20–21.	Decline rate is undetermined but, based on past estimated and future predicted declines, a loss of mature individuals exceeding the threshold of 30% within three generations (during 2014–2035) is possible.
Inferred percent reduction in total number of mature individuals over any 3-generation period, over a time period including both the past and the future. See Population Size and Trends (1. Alberta), pp. 10–17; Limiting Factors (3. Anthropogenic Climate Change), pp. 20–21.	Decline rate is undetermined but, based on past estimated and future predicted declines, reduction over any 3-generation period exceeding the threshold of 30% within three generations (21 years) is possible.

Appendix 7 continued:

Are the causes of the decline clearly reversible and understood and ceased? It is likely that angling, as well as habitat degradation and loss, played important roles in inferred past population declines in Alberta. Both factors have been attributed to notable grayling declines elsewhere. Although Alberta harvest regulations have been changed in response to speculated population declines, the efficacy of these regulations in reducing mortality is unknown. Additionally, habitat alteration and degradation resulting from economically important activities such as agriculture, resource extraction, industrial and residential development, and road construction are ongoing and typically reduce the quality of cold-water fish habitats. Further, although anthropogenic climate change is clearly understood, it is not reversible in a pragmatic resource management sense. See Population Size and Trends (2. Other Areas) p. 17; Limiting Factors (1. Angling, 2. Habitat Degradation, Fragmentation and Loss, 3. Anthropogenic Climate Change) pp. 17–21; Recent Management and Research, pp. 22–23.	No
Are there extreme fluctuations in number of mature individuals? There are no province-wide repeated direct measures of abundance or indices of abundance, so it is impossible to directly calculate fluctuations. The best available information indicates that grayling catch-per-unit-effort varies by approximately 3-fold in the Little Smoky River (a relatively undisturbed population). There is not enough information to determine whether this pattern is typical of other watersheds. See Population Size and Trends (1.2 Population Trends), pp. 12–13; Figure 7, p. 16.	Unknown

Extent and Occupancy Information

Estimated extent of occurrence See Distribution (1. Alberta), p. 1–3; Figure 1, p. 2.	414,682 km^2
Area of occupancy (AO) (Always report 2-km x 2-km grid value; other values may also be listed if they are clearly indicated). See Distribution (1. Alberta), p. 1–3; Figure 1, p. 2	152,516 km^2 (based on 2-km x 2-km grid) 869 km^2 (actual area of habitat occupied, determined by multiplying linear extent of streams by average stream width)

Appendix 7 continued:

Is the total population severely fragmented? Hanging culverts are prevalent throughout Arctic grayling range in Alberta, and reduce connectivity of grayling habitats. However, it is unknown whether Alberta grayling meet the IUCN definition of "severely fragmented" (i.e., most [>50%] of the species' total area of occupancy is in habitat patches that are either smaller than would be required to support a viable population, or separated from other habitat patches by a large distance). Whether culverts limit movement to less than 1 individual or gamete per generation is unknown, but we speculate that severe fragmentation has occurred in upstream portions of watersheds (e.g., as hanging culverts do not allow for upstream fish movement, upstream portions would be isolated in terms of individual and/or gamete exchange). See Distribution (1. Alberta) pp. 1–3; Habitat (2. Fragmentation), p. 6.	Likely
Number of locations Arctic grayling have been documented at 3337 different geographic sites in Alberta (Figure 1). These are not all separate locations; however, there are likely more than ten geographically or ecologically distinct areas in which a single threatening event (e.g., habitat loss or climate change) could rapidly affect all Arctic grayling present in those areas. See Distribution (1. Alberta), p. 3.	Likely more than 10 locations.
Is there an observed/inferred/projected continuing decline in extent of occurrence? Climate change modelling in this report suggests that large portions of Arctic grayling range within Alberta will become thermally unsuitable during this century (i.e., 87%–100% loss of suitable habitat by ca. 2085). No new habitat in Alberta will become available to grayling. In particular, declines in the extent of occurrence will likely occur in low-elevation regions throughout the southern and eastern portions of the grayling range; grayling distributions will be forced upwards in latitude and elevation to offset the effects of regional warming. See Limiting Factors (3. Anthropogenic Climate Change) pp. 20–21.	Projected decline

Appendix 7 continued:

Is there an observed/inferred/projected continuing decline in index of area of occupancy? Climate change modelling in this report suggests that large portions of Arctic grayling range within Alberta will become thermally unsuitable during this century (i.e., by ca. 2085). In particular, declines in the area of occupancy will likely occur in low-elevation regions throughout the southern and eastern portions of grayling range; grayling distribution will be forced upwards in latitude and elevation to offset the effects of regional warming. See Limiting Factors (3. Anthropogenic Climate Change) pp. 20–21.	Projected decline
Is there an observed/inferred/projected continuing decline in number of populations? Grayling in Alberta are estimated to have been extirpated from 11 (of 59) watersheds during the period 1960–2014. If current threats continue, extirpation is expected to continue in the future. In addition, climate modelling projects that grayling populations in Alberta will also be at high risk of local and regional extirpation in the future because of increasing temperatures. See Population Size and Trends (1. Alberta) pp.10–17; Limiting Factors (3. Anthropogenic Climate Change) pp. 20–21.	Projected decline
Is there an observed/inferred/projected continuing decline in number of locations? Current threats to this species may not be mitigated (from which a decline in locations is inferred), and climate modelling also projects large declines in suitable habitat available to the species, which is expected to result in decline in number of locations. See Limiting Factors (1. Angling; 2. Habitat Degradation, Fragmentation, and Loss; 3. Anthropogenic Climate Change), pp. 17–21.	Inferred/projected decline

Appendix 7 continued:

Is there an observed/inferred/projected continuing decline in area of habitat? Currently, the largest threat to this species is habitat degradation, fragmentation, and loss caused by agriculture, resource extraction (e.g., forestry, mining), and road construction throughout the Alberta grayling range. Moreover, if one were to assume that amount of thermally suitable habitat is a proxy for area of habitat, climate modelling indicates large declines in the area of habitat available to grayling will occur during the next century (i.e., 61%–97% loss by ca. 2055; 87%–100% loss by ca. 2085). See Limiting Factors (2. Habitat Degradation, Fragmentation, and Loss; 3. Anthropogenic Climate Change) pp. 19–21.	Inferred/projected decline
Are there extreme fluctuations in number of populations? As there are no repeated measures of the number of populations it is impossible to calculate fluctuations in the number of populations. We have no reason to expect extreme fluctuations in the number of populations. See Population Size and Trends (1.2 Population Trend), pp. 12–13.	Unknown
Are there extreme fluctuations in number of locations? Fluctuations are likely, considering grayling exist along the southern periphery of the species' distribution; however, whether fluctuations are "extreme" (greater than one order of magnitude) is unknown. See Distribution (1.1 Trends in Distribution), pp. 3–4.	Unknown
Are there extreme fluctuations in extent of occurrence? See Distribution (1.1 Trends in Distribution), pp. 3–4.	No
Are there extreme fluctuations in index of area of occupancy? See Distribution (1.1 Trends in Distribution), pp. 3–4.	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Qualitative ranks in the 2014 Arctic grayling FSI were converted to approximate densities and multiplied by the linear extent (km) of streams in each watershed for an approximation of current abundance of 600,000 adult grayling. See Population Size and Trends (1.1 Adult Population Size), pp. 12.	Hundreds of thousands

Appendix 7 continued:

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years]. A quantitative analysis was not done for this species.	Not applicable

Threats (actual or imminent, to populations or habitats)

Angling. Arctic grayling are easily captured by anglers, and qualitative evidence suggests grayling were overexploited even under moderate angling pressure in Alberta. Historically, this was likely the most important threat to grayling in Alberta.

Habitat loss, degradation, and fragmentation resulting from economically important activities such as agriculture, resource extraction, industrial and residential development, and road construction typically decrease the quality of cold water fish habitats and reduce ecological resilience. Currently, this is likely the most important threat to grayling in Alberta.

Anthropogenic climate change (e.g., loss of thermally suitable habitat). Modeling in this report demonstrates temperature has already significantly increased across the Arctic grayling range in Alberta, and predicts large reductions in the amount of thermally suitable grayling habitat. This suggests grayling are at higher risk of local and regional extirpation during this century. This will likely be the most important threat to grayling persistence in Alberta in the future.

See Limiting Factors, pp. 17–21 and Appendix 6.

Rescue Effect (immigration from outside Alberta)

Status of outside population(s)?

Conservation rankings for Arctic grayling vary widely across North America. In British Columbia, grayling in the Williston-Peace watershed were red-listed following construction of the W.A.C. Bennett Dam on the Peace River; this listing indicates that they are threatened or endangered (BC Conservation Data Centre 2013, BC Ministry of Water, Land and Air Protection 2002). In Montana, the Arctic grayling was considered for several years as a candidate for federal listing as an *Endangered* or *Threatened* species; however, it was determined in 2014 that listing was not warranted (Federal Register 2014).

See Population Size and Trends (1.3 Rescue Potential) pp. 13–17; Status Designations (2. Other Areas), p. 22.

Appendix 7 continued:

Is immigration known or possible? Radio telemetry studies have documented Arctic grayling in Alberta migrating mean distances of 49 km, indicating the species is highly mobile. However, grayling in adjacent jurisdictions are largely isolated from grayling in Alberta. Grayling in Montana are approximately 800 km from grayling in northern Alberta. Dam construction on the Peace River has resulted in large declines in grayling abundance in this region, reducing the potential of rescue from the west. The Slave River rapids at the Northwest Territories-Alberta border may limit upstream grayling movement into Alberta and reduce rescue potential from the north. The Alberta population does not appear isolated to the east as river drainages in Alberta cross into Saskatchewan; however, as climate change will have the most dramatic impacts in low elevation portions of eastern Alberta and western Saskatchewan, immigration from Saskatchewan will become unlikely during this century See Biology (5. Movement) p. 10; Population Size and Trends (1.3 Rescue Potential), p. 13–17.	Possible, but unlikely
Would immigrants be adapted to survive in Alberta? See Population Size and Trends (1.3 Rescue Potential), p. 13–17.	Yes
Is there sufficient habitat for immigrants in Alberta? There is ongoing loss, degradation, and fragmentation of grayling habitats in Alberta, and modeling in this report suggests anthropogenic climate change will become a critical stressor of grayling habitat within the next 30 years. So the availability of habitat (and hence, rescue potential) for Arctic grayling in Alberta will be compromised. See Population Size and Trends (1.3 Rescue Potential), p. 13–17.	Yes (but see caveat)

Appendix 7 continued:

Is rescue from outside populations likely? Arctic grayling are capable of dispersing between habitats. And potential source populations in British Columbia, the Northwest Territories, and Saskatchewan are relatively healthy from a conservation status perspective. Moreover, high-quality habitats are available in Alberta, and as such it appears likely that potential immigrants would survive in Alberta. However, grayling in adjacent jurisdictions are largely isolated from native fish in Alberta. And climate modeling shows low-elevation portions of the province (north-eastern portions of Alberta and hence north-western Saskatchewan) will become thermally unsuitable for Arctic grayling. This modeling suggests that the rescue potential from Saskatchewan will become increasingly unlikely as temperature increases during this century. Together, this information suggests that the rescue potential of Alberta grayling by fish from outside jurisdictions is likely compromised relative to historical levels. See Population Size and Trends (1.3 Rescue Potential), p. 13–17.	Unlikely

Current Status

Provincial: *Species of Special Concern*; S3S4
National: N5
Elsewhere: S1 (Montana), SX (Michigan), S3 (Northwest Territories), S4 (British Columbia), S5 (Saskatchewan), S4 (Manitoba), Yukon Territory (S5)

See Status Designations, pp. 22.

Author of Technical Summary: Christopher L. Cahill (University of Calgary)

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(as of December 2015)

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