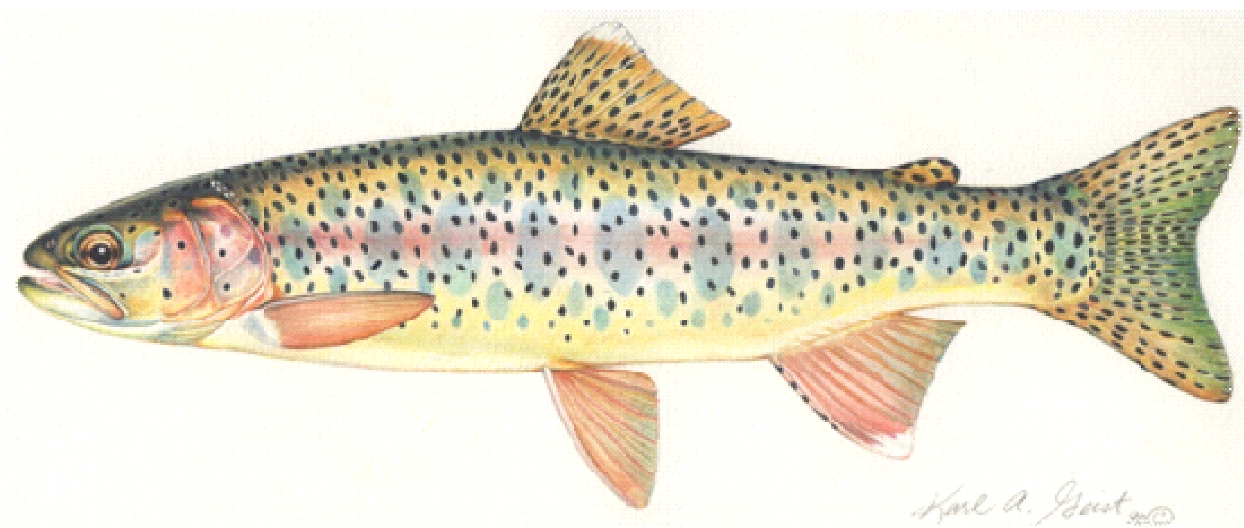
COSEWIC
Assessment and Status Report

on the

Rainbow Trout
Oncorhynchus mykiss

Athabasca River populations

in Canada



ENDANGERED
2014

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Rainbow Trout — Illustration by Karl Geist (with permission).

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COSEWIC
Assessment Summary

Assessment Summary – May 2014

Common name
Rainbow Trout - Athabasca River populations

Scientific name
Oncorhynchus mykiss

Status
Endangered

Reason for designation
This fish is an obligate resident of clear, cold flowing water in the upper Athabasca River drainage of Alberta. Quantitative sampling over the last two decades demonstrates that the majority of sites are declining in abundance with an estimate of >90% decline over three generations (15 years). Threats are assessed as severe due to habitat degradation associated with resource extraction and agricultural practices. Additionally, ongoing climatic change and associated altered thermal regimes and hydrology, habitat fragmentation, introgression from non-native Rainbow Trout, and fishing threaten the species. Potential impact of invasive Brook Trout is a concern.

Occurrence
Alberta

Status history
Designated Endangered in May 2014.

COSEWIC
Executive Summary

Rainbow Trout
Oncorhynchus mykiss

Athabasca River populations

Wildlife Species Description and Significance

Rainbow Trout (*Oncorhynchus mykiss*) is a species of salmonid that is characterized by a silver body covered in black spots with a pink horizontal band. In Canada, Rainbow Trout is native primarily to the western drainages of the continent. There are only three drainages east of the continental divide known to contain native populations of Rainbow Trout: Peace, Liard and Athabasca drainages, and Rainbow Trout (Athabasca River populations) (herein Athabasca Rainbow Trout) is the focus of this report. Athabasca Rainbow Trout are not considered a distinct subspecies, but qualify as a single designatable unit.

Distribution

Rainbow Trout populations are native to northeastern Siberia and western North America. Rainbow Trout is a popular sport and food fish, and as a result, this species is commonly raised in hatcheries and is now stocked in many waterbodies across the world. Athabasca Rainbow Trout are found throughout the headwaters of the Athabasca River system and its major tributaries in western Alberta. In general, the distribution of Athabasca Rainbow Trout is strongly influenced by water temperature, and these fish are commonly found in streams between 900 and 1500 metres above sea level.

Habitat

Native Rainbow Trout populations are found primarily in small cold headwater streams in the Athabasca drainage. Athabasca Rainbow Trout spawn in the spring in streams with fine gravel (free of silts and clays) and moderate flow rates. In the winter, the largest and deepest pools in any occupied stream reach are commonly used by Athabasca Rainbow Trout for wintering habitat. Therefore, habitat connectivity is important for Athabasca Rainbow Trout. The total estimated extent of occurrence is 24,450 km^2 and the index area of occupancy is 2,560 km^2 for Athabasca Rainbow Trout.

Biology

Athabasca Rainbow Trout differ from introduced Rainbow Trout populations in Alberta. For example, Athabasca Rainbow Trout spawn later in the spring, have slower growth rates and mature at smaller sizes. Athabasca Rainbow Trout are uniquely adapted to small, cold and unproductive headwater streams (that are characterized by a lack of competition and predation) and as a result, demonstrate slow growth rates. The diet varies across life-stages and consists primarily of aquatic and terrestrial insects. Where introduced Brook Trout (*Salvelinus fontinalis*) have established naturalized populations, they have become competitors for food and space with Athabasca Rainbow Trout.

Population Sizes and Trends

The total population size of Athabasca Rainbow Trout is unknown, but populations have been assessed in several streams within the Athabasca drainage. Across all sampled streams in the Athabasca drainage, 54% of streams had a reduction in population size recently. Meta-analysis of trends in abundance through time demonstrates that the Athabasca Rainbow Trout are declining at a rate of -96.5% over 15-year time period (3 generations).

Threats and Limiting Factors

Athabasca Rainbow Trout are threatened by several anthropogenic factors including impacts of invasive species, introgression with stocked fishes and industrial effluents. In addition industrial development, agricultural and forestry effluents and recreational activities also threaten the persistence of Athabasca Rainbow Trout. Climatic variability and change also threaten Athabasca Rainbow Trout through altered thermal regimes, altered water quantity and delivery schedules, and effects of glacial drawdown over sequential seasons on late summer flows.

Protection, Status, and Ranks

Internationally, Rainbow Trout have a global conservation status of *Secure* (G5), and a similar national status in Canada and the United States as *Secure* (N5). However, Athabasca Rainbow Trout are recognized by the Government of Alberta as a unique native strain that *May Be at Risk*. Athabasca Rainbow Trout are managed under the Eastern Slopes – Unit ES3 Sportfishing Regulations and all identified native Rainbow Trout populations are regulated as catch-and-release fisheries.

Habitat Protection or Ownership

The majority of occupied habitat for Athabasca Rainbow Trout is located within provincial jurisdiction and these areas are managed by the provincial Fisheries Management Branch. Additionally, the Willmore and Whitehorse Wilderness Parks contain occupied habitat and these wilderness parks have special provisions for securing habitat under provincial legislation, but angling is permitted. A small portion of the occupied habitat, approximately up to 10%, occurs within the boundaries of Jasper National Park and is managed under federal jurisdiction.

TECHNICAL SUMMARY

Oncorhynchus mykiss
Rainbow Trout — Truite arc-en-ciel
Athabasca River Populations — Populations de la rivière Athabasca
Range of occurrence in Canada (province/territory/ocean): Alberta

Demographic Information

Generation time	~ 5 yrs
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Yes
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
Projected percent reduction in total number of mature individuals over the next 3 generations.	44.4%
Estimated percent reduction in total number of mature individuals over any 3 generations, over a time period including both the past and the future.	96.5%
Are the causes of the decline clearly reversible and understood and ceased?	No
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	24,450 km²
Index of area of occupancy (IAO)	2,560 km²
Is the population severely fragmented?	No
Number of locations∗	>>10
Is there an observed continuing decline in extent of occurrence?	Yes
Is there an observed continuing decline in index of area of occupancy?	Yes
Is there an observed continuing decline in number of populations?	Yes
Is there an observed continuing decline in number of locations*?	Yes
Is there an observed continuing decline in [area, extent and/or quality] of habitat?	Yes
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations∗?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals**
Rainbow Trout (Athabasca River populations)	Unknown

∗ See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term.

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Unknown

Threats (actual or imminent, to populations or habitats)

Threats include several anthropogenic factors: impacts of invasive species, introgression with stocked fishes and industrial effluents. In addition, industrial development, agricultural and forestry effluents and recreational activities also threaten the persistence. Climatic variability and change are also threats through altered thermal regimes, altered water quantity and delivery schedules, and effects of glacial drawdown on late summer flows.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)?	Secure
Is immigration known or possible?	Unlikely
Would immigrants be adapted to survive in Canada?	No
Is there sufficient habitat for immigrants in Canada?	No
Is rescue from outside populations likely?	No

Data-Sensitive-Species

Is this a data-sensitive species?	No

History Status

COSEWIC: Designated Endangered in May 2014.

Status and Reasons for Designation:

Status: Endangered	**Alpha-numeric code:** A4bce
Reasons for designation: This fish is an obligate resident of clear, cold flowing water in the upper Athabasca River drainage of Alberta. Quantitative sampling over the last two decades demonstrates that the majority of sites are declining in abundance with an estimate of >90% decline over three generations (15 years). Threats are assessed as severe due to habitat degradation associated with resource extraction and agricultural practices. Additionally, ongoing climatic change and associated altered thermal regimes and hydrology, habitat fragmentation, introgression with non-native Rainbow Trout and fishing threaten the species. Potential impact of invasive Brook Trout is a concern.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A4bce with an estimated reduction in the number of mature individuals of greater than 90% over 3 generations, a decline in habitat quality, and introgression from non-native individuals of this species.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable Not applicable. The distribution is not small.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable Not applicable. The population size is not small.

Criterion D (Very Small or Restricted Population): Not applicable Not applicable. The population size is not small.
Criterion E (Quantitative Analysis): Not applicable. Probability of extinction cannot be calculated from the available data.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2014)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

COSEWIC Status Report

on the

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Oncorhynchus mykiss

Athabasca River populations

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2014

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Phylum: Chordata

Class: Actinopterygii

Order: Salmonifomes

Family: Salmonidae

Genus: Oncorhynchus

Species: *O. mykiss*

English common name: Rainbow Trout

French common name: Truite arc-en-ciel

Aboriginal names (Cree/Plains and Woodland): Kinasoo, namikos

Rainbow Trout (*Oncorhynchus mykiss*) belongs to the salmonid family (Salmonidae). Historically, Rainbow Trout was part of the genus *Salmo*, as it was considered morphologically similar to Brown Trout (*Salmo trutta*) and Atlantic Salmon (*Salmo salar*). However, DNA studies demonstrate that Rainbow Trout is genetically closer to Pacific Salmon in the genus *Oncorhynchus* (Stearley and Smith 1993) and as a result, Rainbow Trout is now part of this genus. Native Rainbow Trout of North America occur as both freshwater resident populations and anadromous (steelhead) populations.

Rainbow Trout populations are found in many west coast drainage systems of North America, in addition to three river drainages east of the continental divide (Peace, Liard and Athabasca rivers). There are up to four recognized subspecies of Rainbow Trout, of which the most widely distributed subspecies is the 'Columbia Redband Trout' (*O. m. gairdneri*) and the 'Coastal Rainbow Trout' (*O. m. irideus*), both of which are found in western North America, primarily west of the continental divide (Behnke 1992). Some authors have considered Rainbow Trout (Athabasca River populations), herein Athabasca Rainbow Trout, to be a distinct subspecies based on morphological and allozyme differences (Behnke 1992; Carl *et al.* 1994). Historically, the genetic distinctness of the Columbia Redband Trout and Athabasca Rainbow Trout was unknown and led to various hypotheses that describe the recolonization of waterbodies post-glaciation (McCusker *et al.* 2000a; McPhail 2007). However, recent genetic analysis has confirmed that Athabasca Rainbow Trout is not a distinct subspecies (McCusker *et al.* 2000a; Taylor *et al.* 2007).

Although Athabasca Rainbow Trout is not considered a distinct subspecies, these populations do represent a unique 'ecotype'. Athabasca Rainbow Trout are well-studied and are known to be uniquely adapted to cold, unproductive, headwater streams (that are characterized by a lack of competition and predation). These habitat characteristics have resulted in several differences in the morphology, biology and habitat use of Athabasca Rainbow Trout, in comparison with other (e.g. west slope) populations of Rainbow Trout.

Morphological Description

The general morphology of Rainbow Trout in the Athabasca drainage is atypical of other Rainbow Trout as detailed by Nelson and Paetz (1992). Athabasca Rainbow Trout exhibit several phenotypic differences from Rainbow Trout in other locations. The largest recorded native Athabasca Rainbow Trout is an age 5+ male (58.8 cm and 2.86 kg) that was stocked as a 30 mm young of year (Wampus Creek origin) into an isolated reclaimed end pit lake, but typically, the maximum size of Athabasca Rainbow Trout is less than 50 cm (or 1.25 kg) (Sterling, pers. comm. 2012). Similar to other Rainbow Trout, Athabasca Rainbow Trout have a silver-coloured dorsal surface, which is covered in black spots that extend towards the fins and lateral surface (Figure 1). There is also a horizontal pink band at the midpoint on the dorsal surface and this band increases in colour intensity with maturation. Radiating rows of black spots are found on the dorsal, caudal and adipose fins, with the remaining fins having few spots.

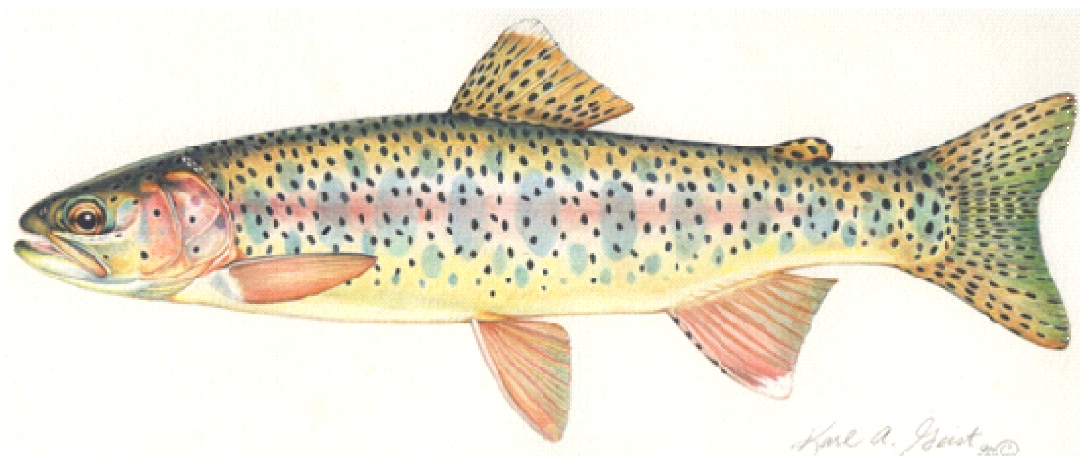


Figure 1. Adult Rainbow Trout. Illustration by Karl Geist (with permission).

Juvenile Rainbow Trout have between 8 and 12 oval-shaped 'parr' marks along the lateral surface. Unlike Rainbow Trout in other systems, Athabasca Rainbow Trout reside primarily in small, cold, headwater streams with gravel, boulder and cobble substrates and often possess parr marks throughout life. Parr marks (cryptic colouration) are likely retained as an adaptation against predation in this habitat (Sterling, pers. comm. 2012).

In general, Athabasca Rainbow Trout has similar physical features to the interior 'Columbia Redband Trout' (Behnke 1992). Athabasca Rainbow Trout also share many physical characteristics with Westslope Cutthroat Trout (*O. clarkii lewisi*) and are commonly mistaken for each other. Adult Rainbow Trout lack red slashes under the throat and basibranchial teeth and have larger scales than Westslope Cutthroat Trout. Westslope Cutthroat Trout are native to the Bow and South Saskatchewan rivers, but have been introduced into the native range of Athabasca Rainbow Trout (Nelson and Paetz 1992).

Population Spatial Structure and Variability

Athabasca Rainbow Trout are geographically separated from other native Rainbow Trout in North America as a result of the continental divide. This creates significant demographic isolation for Rainbow Trout. East of the Continental divide, native Rainbow Trout are present in three drainages (Athabasca, Peace and Liard), all of which are geographically separated, and this results in no movement of fish between drainages.

Rainbow Trout in the Athabasca River were first referenced as *Salmo irideus* by employees of the Grand Trunk Pacific railway in 1910, and were considered to be a separate population of Rainbow Trout based on morphological characteristics (Nelson and Paetz 1992). Carl *et al.* (1994) examined several allozyme loci from Rainbow Trout (n=174) in the Athabasca River (Wampus Creek) and adjacent Rainbow Trout and anadromous steelhead in the Fraser and Columbia drainages. Wampus Creek is a headwater tributary of the McLeod River, which flows into the Athabasca River. Their analysis indicated two main groupings: inland and coastal populations that were both genetically distinct from fish in the Athabasca River. Carl *et al.* (1994) hypothesized that Athabasca River populations of Rainbow Trout are a pre-glacial relict which separated from other Rainbow Trout populations west of the continental divide and have been reproductively isolated for over 64 000 years. Conversely, Behnke (1992) put forward the hypothesis that the Athabasca River populations of Rainbow Trout originated from the Columbia River 'Redband Trout' (*O. m. gairdneri*) based on morphological characteristics, allozyme evidence and chromosome counts. He hypothesized that these fish invaded the Fraser River after glaciation from a Pacific glacial refugium in the lower Columbia River area and then invaded the Athabasca River through Yellowhead Pass.

More recently, McCusker *et al.* (2000a) examined mitochondrial DNA (mtDNA) using a restriction fragment length polymorphism (RFLP) to determine the phylogenetic distinctiveness of Athabasca Rainbow Trout. Fish were collected from three creeks (n=15) in the Athabasca drainage (Wampus, Cabin and Halpenny), in addition to several other watersheds in British Columbia. Two clades were identified: clade A was found in every watershed (except the upper Liard), and clade B was mainly restricted to coastal watersheds (and was absent from the Columbia, Snake and Athabasca rivers). McCusker *et al.* (2000a) found that Athabasca Rainbow Trout had 0 haplotype diversity, indicating that these fish are genetically identical to haplotypes in the adjacent upper Fraser River (Figure 2). This suggests that Rainbow Trout recolonized the Athabasca

River at the end of the last ice age (approximately 10 000 years ago) via headwater transfer from the upper Fraser River, rather than from survival in a glacial refuge in the Athabasca region. Additionally, McCusker *et al.* (2000a) found that several of the alleles that distinguished Wampus Creek Rainbow Trout from other Rainbow Trout (as reported by Carl *et al.* 1994) were also present in Coastal Cutthroat Trout (*O. clarkii*) from Puget Sound. This suggests that the observed genetic distinctiveness reported by Carl *et al.* (1994) may have resulted from hybridization with introduced Cutthroat Trout.

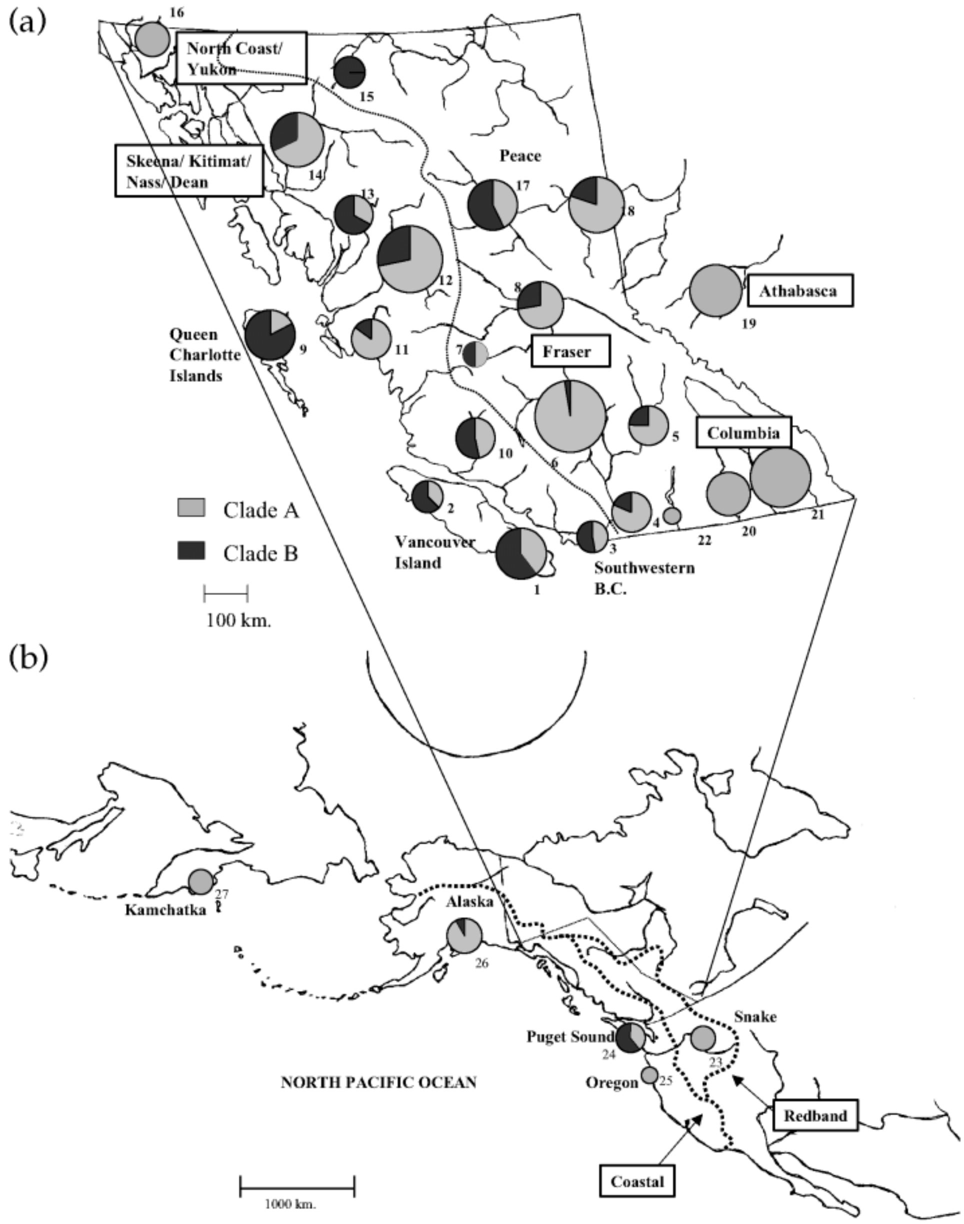


Figure 2. Distribution of clade A and B RFLP haplotypes in Rainbow Trout in (a) British Columbia and (b) adjacent areas of the North Pacific Ocean. The size of the pie is proportional to the number of samples taken. Source: McCusker *et al.* (2000).

Taylor *et al.* (2007) assayed Rainbow Trout from the Athabasca River drainage and other Rainbow Trout populations in British Columbia and examined variation at 10 microsatellite loci in order to assess the level of evolutionary distinctiveness of Rainbow Trout in the Athabasca River. Their results suggest that Athabasca Rainbow Trout are genetically similar to nearby populations in the Fraser River and these observations support the hypothesis that Rainbow Trout recolonized the Athabasca River from the Fraser River after the last ice age. The fixation index (F_{ST}) is a measure of genetic variation among populations and Taylor *et al.* (2007) found an overall high level of subdivision among wild populations in the Athabasca drainage (F_{ST}=0.30; 95% Confidence Interval 0.26-0.35). Taylor *et al.* (2007) notes that the F_{ST} value for Athabasca Rainbow Trout is higher than the F_{ST} value of 0.18 for wild Rainbow Trout populations in the Arrow Lakes' drainage in eastern British Columbia and somewhat lower than the reported F_{ST} value of 0.39 from a broader survey of Rainbow Trout populations across British Columbia. These fairly similar F_{ST} estimates for Rainbow Trout in a variety of locations suggest that Athabasca Rainbow Trout have approximately the same amount of genetic variation as other Rainbow Trout populations.

Variation in F_{ST} values among populations of Athabasca Rainbow Trout was best explained by grouping populations by contemporary watersheds. Taylor *et al.* (2007) found that their observed variation in allele frequency was strongly attributed to contemporary drainage systems (29.3%) rather than a distinction between Athabasca and non-Athabasca fish (12.6%) (Table 1). Because Athabasca Rainbow Trout have been isolated from other populations for the past 10 000 years and occupy a different biogeographic zone, Athabasca Rainbow Trout are thought to be uniquely adapted to their habitat. Athabasca Rainbow Trout are found in cold, unproductive, headwater streams (that are characterized by a lack of competition and predation) and are thermally isolated from more productive habitats (Sterling, pers. comm. 2012). These habitat characteristics have resulted in several differences in the morphology, biology and habitat use of Athabasca Rainbow Trout, in comparison with other populations of Rainbow Trout.

Table 1. Hierarchical dissection of variation when samples were arranged into different geographic groupings using analysis of molecular variance on allele frequencies across 10 microsatellite loci assayed in Rainbow Trout sampled from the Athabasca River area. Eastern groupings refer to the Columbia River watershed and eastward, and western groupings refer to the Fraser River and Queen Charlotte Islands. V_{bg} = percentage variation between groups, V_{ap} = variation among populations within groups, V_{wp} = variation within populations. P<0.05 (*), P<0.01 (**), P<0.001 (***). Source: Taylor *et al.* (2007).

Grouping	V_{bg}	V_{ap}	V_{wp}
1. Athabasca vs. non-Athabasca	12.6**	21.7***	65.8***
2. Eastern vs. western	10.2*	23.9***	65.9***
3. Athabasca vs. Columbia/Fraser vs. Queen Charlotte Islands	13.8**	20.4***	65.9***
4. Athabasca vs. Columbia vs. Fraser vs. Queen Charlotte Islands	23.4***	13.6***	63.0***
5. Athabasca River vs. McLeod River vs. Berland/Wildhay rivers	12.6***	11.5***	76.0***

The results of McCusker *et al.* (2000a) and Taylor *et al.* (2007) suggest that Athabasca Rainbow Trout are of post-glacial origin and do not warrant separate taxonomic designation. Although McCusker *et al.* (2000a) note the possibility that the Athabasca region may have been used as a refuge during the last ice age, more recent genetic research supports the hypothesis that Rainbow Trout populated the Athabasca River at the end of the last ice age (around 10 000 years ago) via headwater transfer from the upper Fraser River (McCusker *et al.* 2000a, Taylor *et al.* 2007).

Designatable Units

The Athabasca River is located within the Western Arctic National Freshwater Biogeographic Zone (NFBZ). East of the Continental divide, native Rainbow Trout are only present in three drainages within the Mackenzie River watershed (Athabasca, Peace and Liard). The Athabasca Rainbow Trout is considered a DU within *Oncorhynchus mykiss,* and separately from other Rainbow Trout in the Western Arctic NFBZ, as it satisfies both the “discrete” and “significance” criteria of the COSEWIC (2009) guidelines on DUs.

Although the Athabasca Rainbow Trout is found within the same NFBZ as fish in the Liard and Peace rivers, the Athabasca River is a distinct watershed that is never directly connected to the Peace or Liard rivers. The physical relationships of these rivers and the well-documented natal homing behaviour of salmonids such as *O. mykiss,* typically result in well-developed separation of breeding units at multiple spatial scales including those at the river and tributary scale. Indeed, such isolation is reflected in the countless studies of biochemical and molecular genetic discreteness of *O. mykiss* populations including those in the Athabasca River (e.g., reviewed by Hendry *et al.* 2004; see also Appendix 2 of Hendry and Stearns 2004; Taylor *et al.* 2007). Furthermore, McCusker *et al.* (2000a) surveyed mitochondrial DNA (mtDNA) variation in

O. mykiss from around the Pacific Rim and demonstrated that fish from the Athabasca River (three sites) were fixed for a single mtDNA lineage while those sampled from the Peace and Liard rivers (13 sites) contained a mixture of two lineages. Taylor *et al.*'s (2007) microsatellite DNA data also clearly demonstrated that fish from the Athabasca River were genetically distinct from those sampled in the adjacent portions of the upper Fraser River. Although fish from the Liard and Peace rivers were not studied by Taylor *et al.* (2007), given that these data strongly suggested that *O. mykiss* in the Athabasca River owed their ultimate origin to postglacial headwater exchanges with the upper Fraser River (see also Behnke 1992), it is reasonable to expect that the Athabasca Rainbow Trout would be even more divergent from fish in the Liard and Peace rivers, which likely had a separate origin from the Athabasca Rainbow Trout (see below). Finally, although Behnke (1992) suggested that Athabasca Rainbow Trout were part of the upper Columbia/Fraser "redband" rainbow trout complex, he also noted that the former were particularly divergent from the latter in lateral line scale counts, a character of taxonomic and phylogeographic significance in fishes (see examples in McPhail and Lindsey 1970). In summary, a combination of watershed structure and behavioural, molecular genetic, and morphological traits demonstrates that the Athabasca Rainbow Trout is discrete from other Rainbow Trout in the same or adjacent NFBZs.

The significance of this discreteness rests in several aspects of the distribution and biology of Rainbow Trout. First, although the Athabasca Rainbow Trout and other Rainbow Trout in the Western Arctic NFBZ are all eastward-flowing drainages, the Athabasca River is the only one with native Rainbow Trout that *originates* east of the Rocky Mountains (within the Columbia Icefields in Jasper National Park). The Liard River originates in the Cassiar Mountains while the Peace River originates in the Omineca Mountains, and both then flow through the Rocky Mountain Trench and then cut through the Rocky Mountains, west to east, before merging with the Mackenzie River east of the Continental Divide. Furthermore, McCusker *et al.* (2000b) used the mtDNA data discussed above and knowledge of postglacial watershed exchanges to conclude that Rainbow Trout in the Athabasca River probably had a distinct origin (exchange with the upper Fraser River) from those in the Liard and likely the Peace River (exchanges with Pacific Slope rivers such as the Stikine and Skeena rivers, see also Behnke 1992). Consequently, these observations suggest that the Rainbow Trout of the Athabasca River have a distinct biogeographical origin and history compared to those in other areas of the Western Arctic NFBZ. Second, as discussed above the Athabasca Rainbow Trout is found in a distinctive watershed which also has the southern-most location of the three Rainbow Trout bearing watersheds in the Western Arctic. This coupled with the origin of the Athabasca River east of the Continental Divide indicates that the distribution of Rainbow Trout in the Athabasca River is an unusual one for the species as a whole (where greater than 90% of the distribution originates or lies wholly west of the Continental Divide – see Fig. 13 in Behnke 1992).

While there is no direct evidence that this unusual distribution of the Athabasca Rainbow Trout has resulted in local adaptations *per se*, given that salmonid fishes, including rainbow trout, probably constitute the richest literature supporting local adaptation as a pervasive phenomenon in fishes (reviewed by Taylor 1991; Fraser *et al.*

2011, see also COSEWIC 2011 for Atlantic salmon (*Salmo salar*) examples) it is reasonable to infer that the unusual distribution of the Athabasca Rainbow Trout is associated with some degree of local adaptation to the environmental context of the Athabasca River drainage. The apparently common small size at maturity (Sterling, pers. comm. 2012) for many populations in the Athabasca River may, for instance, constitute an adaptation to the low growth potential of many of the streams in this area. Furthermore, Taylor *et al.* (2007) and Taylor and Yau (2013) used microsatellite DNA to assess the level of introgression between native Athabasca Rainbow Trout and stocked, non-native hatchery strains. The general lack of introgression at many localities despite repeated stocking events also suggests that native populations of Athabasca Rainbow Trout exhibit locally adaptive traits important for persistence in the Athabasca River environments which are not present in the non-native, stocked strains. In summary, the distinctive geographic distribution and origin of the Athabasca Rainbow Trout coupled with an inference of local adaptations associated with this unusual distribution satisfy the significance criterion of the COSEWIC DU guidelines.

Special Significance

Rainbow Trout in the Athabasca drainage are considered to be of special significance as they are one of the only native Rainbow Trout populations east of the continental divide. They occur in the Western Arctic biogeographic zone and have played an important role in many genetic, evolutionary and biogeographical studies (Carl *et al.* 1994; McCusker *et al.* 2000a; Taylor *et al.* 2007). Specifically, Athabasca Rainbow Trout have helped to shed new light on the recolonization of watersheds east of the continental divide post-glaciation (McCusker *et al.* 2000a; Taylor *et al.* 2007).

Although Athabasca Rainbow Trout do not represent a distinct subspecies, they are thought to be a unique ‘ecotype’ because of their inferred adaptations to their habitat. Athabasca River populations of Rainbow Trout are found in cold, unproductive, headwater streams (that are characterized by a lack of competition and predation). These habitat characteristics have resulted in several differences in the morphology, biology and habitat use of Athabasca Rainbow Trout, in comparison with other populations of Rainbow Trout in the Pacific drainage.

Athabasca Rainbow Trout were and continue to be an important resource for Aboriginal peoples of the area as summarized in an Aboriginal Traditional Knowledge source report for Athabasca Rainbow Trout (COSEWIC 2012). However, no Aboriginal Traditional Knowledge was found that extends the information required for a status designation.

DISTRIBUTION

Global Range

Rainbow Trout are endemic to northeastern Siberia and North America (McPhail 2007). Freshwater resident populations of North America range from the Kuskokwim River of Alaska to Baja California and include coastal and interior regions of British Columbia, Washington, Oregon and southern California, and east of the continental divide in three Arctic drainages (Behnke 1992; McPhail 2007). Rainbow Trout are found in both lakes and rivers, and are present as freshwater resident and anadromous populations. In North America, Rainbow Trout also occur as anadromous “steelhead” populations, and the anadromous form is restricted to the west coast of North America and has also been established in the Laurentian Great Lakes. In Asia, native Rainbow Trout exist in the Kamchatka region and extend from the Bering Sea in the north to rivers flowing into the Sea of Okhotsk in the south (McPhail 2007).

Due to the popularity of Rainbow Trout as a sport fish and food, fish hatchery-raised Rainbow Trout are stocked into many lakes and rivers and are now present on all continents except Antarctica. The first reported Rainbow Trout hatchery was established on San Leandro Creek (a tributary of San Francisco Bay) in 1870 (Halverson 2010). Since the 1950s, commercial production has grown exponentially, with a particular increase in production in Europe and Chile (FAO 2012).

Canadian Range

Native Rainbow Trout are found in many drainages that flow west of the continental divide to the Pacific Ocean in interior regions of British Columbia and the Yukon. In British Columbia, the original distribution of freshwater resident Rainbow Trout is largely unknown as a result of extensive and often unrecorded introductions (McPhail 2007). Native Rainbow Trout exist in three river systems east of the continental divide (Peace, Liard and Athabasca rivers) (Behnke 1992; Nelson and Paetz 1992). These three rivers flow north to the Arctic Ocean via the Mackenzie River. In Alberta, native Rainbow Trout are only found in the upper Athabasca River watershed. In British Columbia, native Rainbow Trout are found in the upper Peace drainage and the upper Liard drainage. According to McPhail (2007), there are persistent rumours that certain headwater populations in the upper Liard drainage (Turnagain and Eagle Rivers) are non-native and are the result of unauthorized introductions. No native Rainbow Trout exist in the Northwest Territories (Cott, pers. comm. 2013) and in the Yukon, there are no records of native populations of Rainbow Trout in the Liard watershed (Barker, pers. comm. 2013).

Rainbow Trout in Alberta are distributed through the headwaters of the Athabasca River system (including the major tributaries: McLeod, Berland / Wildhay, Sakwatamau and Freeman rivers) (Figure 3). Specifically, native Rainbow Trout are found in the main stem of Athabasca River (downstream of Sunwapta falls), the lower reaches of the Snaring, Maligne, Rocky and Snake Indian rivers below major waterfalls and the majority of the Miette River watershed (Miller and Macdonald 1949; Nelson and Paetz 1992; Rasmussen and Taylor 2009). The current distribution of Athabasca Rainbow Trout is highly correlated with elevation; Athabasca Rainbow Trout are absent in most streams with elevations less than 850 m and common in streams with elevations between 900 and 1500 m (FWMIS 2012; Table 2). In the upper watersheds within the Athabasca drainage, a large portion of the area is above 1500 m and this appears to influence the distribution of Rainbow Trout, especially in the Solomon Creek drainage. Conversely, in the lower watersheds, a large portion of the area is below 800 m and the distribution of Rainbow Trout is highly restricted and fragmented.

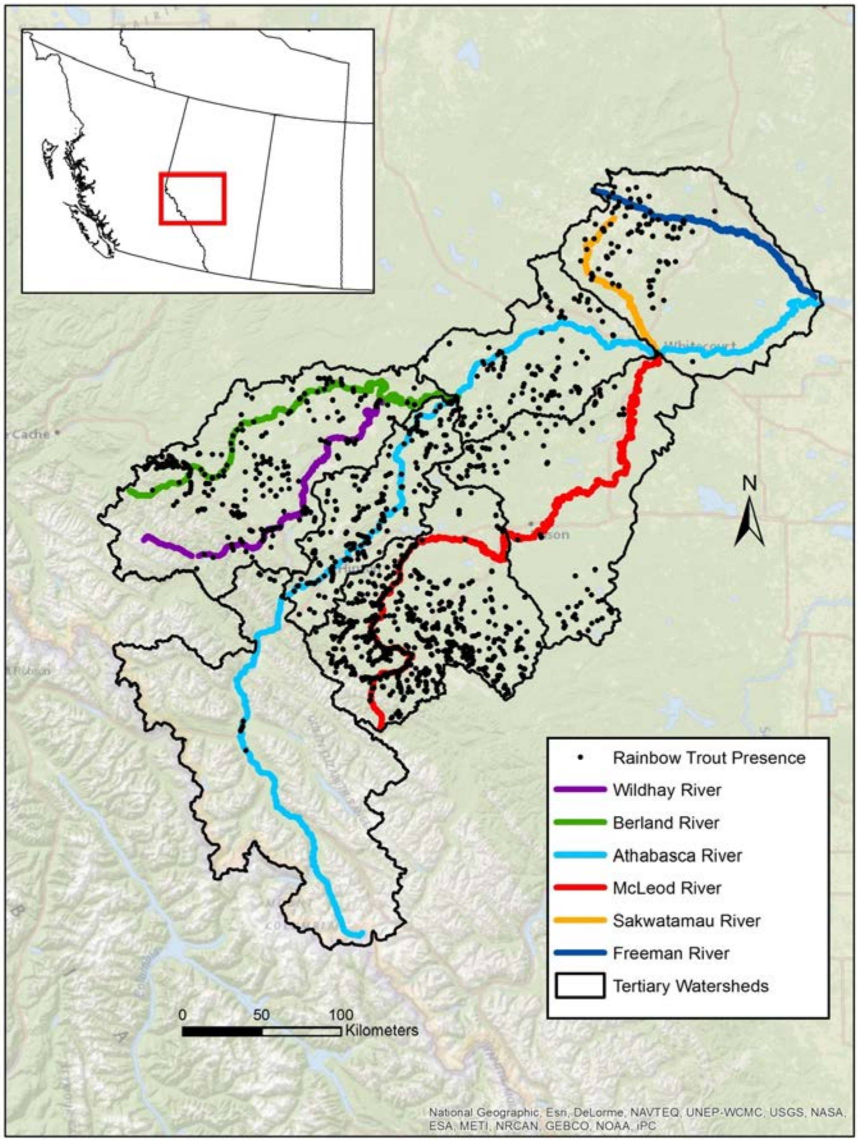


Figure 3. Distribution of Rainbow Trout (Athabasca River populations) and major rivers in the Athabasca watershed. Data points represent a sampling record where Rainbow Trout were present. Source: FWMIS (2012)

Table 2. General distribution of Athabasca Rainbow Trout based on elevation (masl). Source: FWMIS (2012)

Waterbody	Common	Rare	Absent
Athabasca River			
Main stem	> 850	< 800	
McLeod River			
Main stem	> 950	< 900	< 850
Wolf Creek		> 950	< 950
Edson River	> 1000	< 950	< 900
Trout Creek		> 950	< 900
Groat Creek		> 950	< 900
Shiningbank Creek		> 950	< 900
Unnamed Creek		> 850	< 850
Erith River	> 1000	> 950	< 950
Embarras River	> 1000	> 950	< 950
Berland River			
Main stem	> 950		
Freeman River		> 950	< 950
Sakwatamau River		> 950	< 950

In 1863, Dr. Walter Cheadle described catching small trout (2 oz) in the Athabasca drainage (likely near Edson) that appeared similar to the English Burn Trout with black spots and a narrow red line along its sides (Nelson and Paetz 1992). In 1910 and 1911, the explorers and employees of the Grand Trunk Pacific railway provided a description of Athabasca Rainbow Trout and they noted that these fish were particularly abundant in areas near Jasper National Park (Nelson and Paetz 1992). A review of historical accounts of fish in this area is given in detail in Mayhood (1992). The first accounts of stocking of Rainbow Trout in the Athabasca drainage are after the completion of the railway in 1917, and therefore, it is likely that both of these historical reports are describing the native Rainbow Trout.

Hatchery Populations of Rainbow Trout

Non-native Rainbow Trout have been historically stocked into the Athabasca drainage, and the first documented introduction occurred in 1926. These hatchery-raised fish came from a variety of sources outside Alberta, including California and the central interior of British Columbia (Taylor *et al.* 2007). Fish were widely introduced into the main stem of the Athabasca River within Jasper National Park and into numerous creeks within the McLeod drainage, in addition to several other locations in the lower reaches of the drainage (Figure 4). Taylor *et al.* (2007) and Taylor and Yau (2013) assayed 72 populations in the upper Athabasca watershed to determine levels of genetic introgression. They calculated an admixture coefficient (Q_i), which refers to the proportion of an individual's fish genome that was inferred to be of indigenous origin. Genetically "pure" indigenous samples (defined as a Q_i value greater than 0.95) were found in many areas that had historical documentation of stocking; however, several of the areas sampled contained non-native alleles, especially within Jasper National Park (Figure 4).

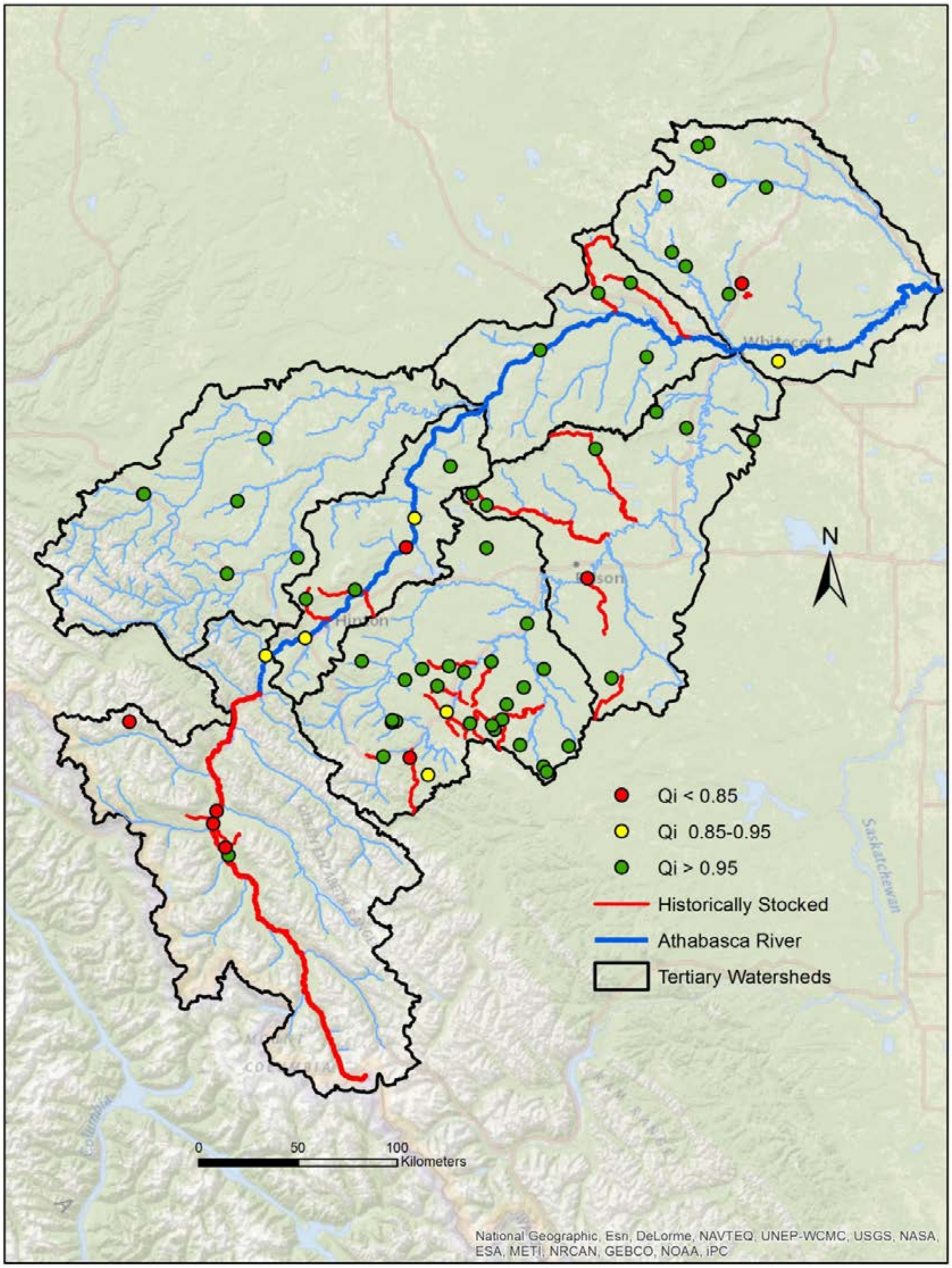


Figure 4. Sampling locations for genetic analysis to determine degree of introgression with hatchery fish. Data points represent a sample site where a genetic analysis was conducted to determine an admixture coefficient (Q_i). Genetically "pure" indigenous samples are defined as having a Q_i value greater than 0.95, and decreases in Q_i values correspond to an increase in non-native alleles. Source: Taylor and Yau (2013).

Within Jasper National Park, the results of Taylor and Yau (2013) suggest that a large portion of the native genotype has been lost in Jasper National Park and potentially in the main stem of the Athabasca as far down as the confluence of the Berland River. All sites sampled within Jasper National Park (with the exception of Buffalo Prairie Creek) show evidence of high levels of introgression between hatchery and wild Rainbow Trout. A sample site in the main stem of the Athabasca above the confluence with the Maligne River showed an almost pure sample of hatchery fish, with a mean Q_i value of 0.10. Therefore, it is likely that native Rainbow Trout within Jasper National Park are extirpated as a result of introgression with hatchery fish. Several of these naturalized populations within Jasper National Park likely contribute significant propagule pressure as non-native alleles were present in the main stem Athabasca River as far downstream as the confluence of the Berland River.

There is no evidence of introgression with hatchery populations in the Berland / Wildhay or the mid-Athabasca watershed. Four areas within the McLeod drainage showed evidence of introgression with hatchery fish. Rainbow Lake was historically stocked and fish sampled from the outlet stream had an average Q_i value of 0.88 and the upper reaches of the Embarras River had a Q_i value of 0.92 suggesting some degree of introgression. Fish sampled from MacKenzie Creek and Fish Creek showed slightly higher levels of introgression with hatchery fish and had average Q_i values of 0.83 and 0.84 respectively. Although stocking of hatchery fish into waterbodies within the McLeod drainage was widespread, the results of Taylor and Yau (2013) suggest that a large portion of the native genotype is preserved. In most cases, the number of introduced fish is unknown and relatively small numbers of introduced fish may have contributed to current observations of genetically pure fish.

As per COSEWIC (2010) manipulated population guidelines, where introgression in a population is considered extensive (as in Jasper National Park), these populations have been excluded from the Athabasca Rainbow Trout population status assessment. The upper part of the watershed within Jasper National Park shows substantial evidence of introgression so that the contemporary extent of occurrence and area of occupancy does not include these populations. In the remainder of the DU, the majority of sample sites show minimal evidence of introgression, and where there is strong evidence, these tend to be very localized situations (with the exception of the mainstem of the Athabasca River). This status assessment deals with the whole watershed with the exception of upper portion of the drainage within Jasper National Park. Further discussion of the effects of introgression is presented in the Threats and Limiting Factors section as per COSEWIC (2010) manipulated population guidelines.

Extent of Occurrence and Area of Occupancy

Information on the distribution of Rainbow Trout in Alberta was obtained using a simplified version of the Alberta Base Features Hydro Single Line Stream Network in the Fisheries and Wildlife Management Information System (FWMIS). The data were simplified (split channels and lakes removed) and capture information was recorded from either electrofishing or angling data for streams with Strahler Order greater than 1. Very few Order 1 channels have been sampled, as Order 1 streams typically do not contain any species of fish (Sterling, pers. comm. 2012). Order 1 streams are typically ephemeral, but when perennial flow is present and the mean channel width is greater than 0.75 m, Order 1 streams have sufficient power to create fish habitat (for example, pools and undercut banks). Order 1 channels that are known to contain Athabasca Rainbow Trout are usually direct tributaries of the main stem rivers in the area. Therefore, capture information and occupied habitat data for Order 1 streams were extrapolated based on the percentage of Order 1 streams sampled that contain Athabasca Rainbow Trout. Total lengths of streams containing Athabasca Rainbow Trout were summed by Strahler Order and tertiary watershed to assess occupied habitat (Table 3).

Table 3. Occupied habitat by Strahler stream order for all waterbodies in the Athabasca drainage. Source: FWMIS (2012)

Strahler Order	Total Stream Length (km)	Mean Wetted Width (m)	Total Area (ha)	Occupied Area (ha)	Cumulative Percent Occupied
1	20739	1.1	2281	11	0.07
2	7923	1.8	1426	684	4.44
3	4768	3.2	1526	1120	11.59
4	2596	6.9	1791	1280	19.76
5	1659	12.6	2090	1764	31.13
6	446	29.3	1306	1160	38.44
7	693	53	3675	2712	55.76
8	240	65	1561	968	61.94

Athabasca Rainbow Trout are commonly found at elevations between 900 m and 1500 m, and are present below 800 m only in the main stem of the Athabasca River, likely a reflection of colder water temperatures from summer glacial melt (Sterling, pers. comm. 2012). The distribution and abundance of Rainbow Trout in the Athabasca drainage is also related to Strahler Order and the cumulative proportion of occupied habitat increases with Strahler Order (FWMIS 2012; Table 3). Across tertiary watersheds, Athabasca Rainbow Trout occupy the most kilometres of stream habitat in the Upper McLeod basin and the total proportion of occupied kilometres varies between

0.12 and 0.30 (FWMIS 2012; Table 4). Sparse data exist for Athabasca Rainbow Trout within the boundaries of Jasper National Park. Therefore, the proportion of occupied stream length is estimated based on the total percent of occupied habitat by stream order for the entire habitat of Athabasca Rainbow Trout.

Table 4. Occupied habitat by tertiary watershed. Source: FWMIS (2012)

Tertiary Name	Major Basin	Total Stream Length (km)	Occupied Stream Length (km)	Percent Occupied
07AC	Berland / Wildhay	8938.1	11650.2	0.18
07AF	Upper McLeod	6436.9	1958.5	0.30
07AG	Lower McLeod	4488.7	778.2	0.17
07AD	Upper Athabasca	2637.9	659.5	0.25
07AE	Mid Athabasca	3920.2	706.6	0.18
07AH	Lower Athabasca	4229.5	757.9	0.18
07AA	Solomon Creek*	3293.8	379.2	0.12

* Solomon Creek data exclude area above major waterfalls and occupied length is estimated based on total percent occupied habitat and stream order.

Quantitative criteria and corresponding area calculations are applied to populations that are considered to be native Rainbow Trout (where native populations are assumed to have Q_i values greater than 0.95). It is estimated that the extent of occurrence (EO) for Athabasca Rainbow Trout is 24,450 km^2, based on the minimum convex polygon around extant populations. Historically, the EO was much greater and included areas within Jasper National Park. These areas are now occupied by non-native populations and therefore this suggests that the EO has declined over time. The index of area of occupancy (IAO) calculated over observations without substantial introgression is 2,560 km^2. The estimated IAO for Athabasca Rainbow Trout for all populations in the DU, including those that show evidence of hatchery introgression, is 4,050 $km^{2.}$ This suggests that the IAO for wild populations has declined approximately 36% (1-2560 km^2/4050 km^2) as a result of genetic introgression with hatchery fish.

Search Effort

Sampling locations for Athabasca Rainbow Trout stock assessments are selected based on random stratification by stream order. Based on sampling records, Athabasca Rainbow Trout are found in essentially all Strahler Order streams greater than 1, downstream of major waterfalls, in addition to the main stems of the major rivers in the area (see Extent of Occurrence and Area of Occupancy for distribution information). Detailed sampling has occurred on most of these streams and streams where hatchery-raised Rainbow Trout were historically introduced have been sampled to assess the degree of introgression between wild and introduced fish (see Canadian Range). For each sampling location, fish data were collected based on standard electrofishing or angling procedures.

HABITAT

Habitat Requirements

Athabasca Rainbow Trout are found in cold headwater streams and main stem rivers in the Athabasca drainage. As part of the Canadian Model Forest Program, 16 streams containing native Rainbow Trout populations within the Upper Athabasca River drainage were assessed for various habitat characteristics (R.L. & L Environmental Services Ltd. 1996; Table 5). In general, Rainbow Trout are cold-water species, and prefer water temperatures between 7 and 18 °C (Raleigh *et al.* 1984) and the reported upper lethal temperature for adults is approximately 27 °C (Lee and Rinne 1980). Essential habitat characteristics were measured for Athabasca Rainbow Trout in the Tri-Creeks watershed by Sterling (1986) and Sterling (1992) and are summarized in Table 6.

Table 5. Stream characteristics related to Rainbow Trout presence in Athabasca drainage foothills streams*. Source: R.L. & L Environmental Services Ltd. (1996)

Stream Characteristics	N	Mean	95% CI	Range
Average Gradient (m/km)	25	14	± 3.3	3-33
Elevation (masl)	25	1172	± 105	785-1550
Basin Area (km^2)	25	63	± 23	7-217
Distance from Mouth (km)	25	9	± 4.6	1-42
Distance from Source (km)	25	14	± 4.0	2-46
Wetted Channel Width (m)	25	5.4	± 0.92	2-10
Channel Depth (m)	25	0.28	± 0.05	0.1-0.5
Conductivity (μS/cm)	14	288	± 68	158-530

* Data were collected from 34 sample sites in 16 streams within the Upper Athabasca River drainage.

Table 6. Summary of essential habitat for each life-stage of the Athabasca Rainbow Trout. Source: Sterling unpub; Sterling 1986, 1992; Bjornn and Reiser 1991.

Life Stage	Function	Feature(s)	Attribute(s)
Egg / Embryo – (spawning through emergence); for resident (non-migratory) and fluvial (migratory) populations.	Spawning, incubation and early rearing (mid-May to mid-August)	Clean, small – medium gravel, gravel beds generally found upstream of riffle crests in small to medium perennial streams.	Gravel beds with rounded or angular gravels ranging in mean geometric particle size from 4-15 mm Water depth over gravel beds ranging from 5-40 cm, where flow is laminar (non-turbulent) with velocities ranging from 12-70 cm/s Fine sediment and silt (<2.0 mm) in spawning gravels not exceeding 15-20 % Optimum dissolved oxygen (DO) saturation >90% and minimum optimum DO concentration >8 mg/l Migration of fluvial populations on descending limb of the snowmelt hydrograph, at temperatures ranging from 4-6 °C. Mean water temperatures during spawning ranging from 6-10 °C Optimum water temperature during incubation ranging from 8-12 °C, with fatality at temperatures <3 °C or >18.5 °C
Fry (Young of year to age 1) Resident Fluvial	Nursery	A variety of habitats with reduced water velocity in small to medium perennial streams including: riffles, riffle crests, stream margins, boulder gardens and LWD	Optimum growth temperatures range 10-15 °C Temperature extremes as high as 22-24 °C and as low as 0 °C considered life threatening Shallow stream margins with a variety of abundant cover (overhead vegetation, aquatic vegetation, woody debris), non-embedded (free of fine sands, silts & clays <2 mm diameter) large gravel & cobble and reduced flow velocities
Fry, Juvenile & Adult	Over-wintering	Pools, beaver ponds and areas of hyporheic flow in perennial streams	Pools with a mean maximum depth of 0.65m and an average loss of volume of 80% by mid-winter Large cobble, free of fine sands, silts and clays in regions of hyporheic flow

In the Athabasca drainage, Rainbow Trout occur in two forms: stream resident and river migrant (Sterling, pers. comm. 2012). Stream resident populations live their entire life (both summer and winter) in small headwater streams. In the Tri-Creeks drainage, tagged fish were found to move less than 500 m during spawning and did not move between pools in the remainder of the year. In contrast, the river migrants live in the main stem rivers and migrate into small tributaries in the spring to spawn. These river migrant fish use the same spawning habitat as the stream resident form, but following spawning, they return to the larger river for summer and winter. In the Tri-Creeks watershed, the progeny of the river migrant fish were found to exit small streams in mid- to late September and rear and winter in the larger river.

In riverine systems, adult Rainbow Trout occupy riffles, runs, glides and pool structures, and tend to occupy deeper and faster-moving water than juveniles (McPhail 2007). In a study of Rainbow Trout in the Nazko River in central British Columbia, adult Rainbow Trout were found to occur most often in runs with cobble and boulder type substrate with depths between 0.5 and 1.0 m, and average water velocities between 0.40 and 0.8 m/s (Porter and Rosenfeld 1999). It is generally reported that overhead cover (in the form of large woody debris and riparian vegetation) is a critical component to habitat selection for Rainbow Trout in small streams (Flebbe and Dolloff 1995). Overwintering of Rainbow Trout usually occurs in primary pools (pools that span the width of the entire channel) in both the main stem rivers and small streams in the drainage. For non-migratory (resident) populations of Athabasca Rainbow Trout that overwinter in 3rd or 4th order streams, primary pools have an average maximum depth of 0.63 m and volume of 7.2 m^3 prior to freeze-up (Sterling and Cox 2013). By mid-winter (February), the mean volume of these pools is reduced by up to 80% (Figure 5).

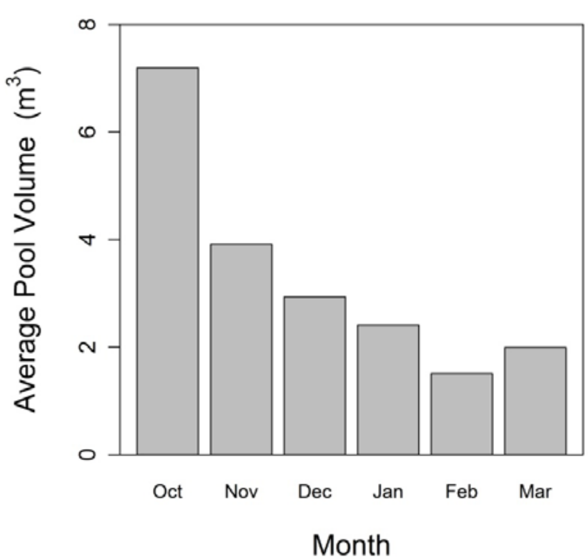


Figure 5. Mean volume of primary pools used for winter habitat. Source: Sterling and Cox (2013).

Rainbow Trout spawn in the spring, and Sterling (1992) reported that peak spawning occurred approximately 104 to 122 days after ice out (usually the first 10 days of June) for Athabasca Rainbow Trout in the Tri-Creeks watershed. Spawning occurs in small tributaries to rivers or in inlet or outlet streams of lakes. The reported water velocities and depths that are suitable for spawning for Rainbow Trout range from 0.30 to 0.90 m/s and 0.15 to 2.5 m respectively (Raleigh *et al.* 1984). Athabasca Rainbow Trout tend to have essential habitat characteristics for spawning at the lower ends of the reported ranges for Rainbow Trout. Sterling (1992) found spawning occurred in water temperatures between 6 and 10 °C, water depths between 0.05 and 0.4 m and velocities between 0.12 and 0.7 m/s (Table 6).

Female Rainbow Trout select spawning sites in habitats that increase aeration of eggs, often in areas with sub-gravel flow and low levels of fine sediment (McPhail 2007). Spawning habitat for Athabasca Rainbow Trout is characterized by clean, small to medium gravel beds, which are generally found upstream of riffle crests in small to medium perennial streams (Sterling 1992). Optimum water temperatures for egg incubation were measured in the Tri-Creeks watershed and were estimated to be between 8 and 12 °C (and fatal temperatures below 3 °C or greater than 18.5 °C). It is reported that Athabasca Rainbow Trout spawn later in the spring than the introduced Rainbow Trout in southern Alberta (late May - June rather than April - May) and spawning occurs in finer gravel substrates in comparison with the introduced Rainbow Trout (Sterling 1990; Nelson and Paetz 1992). Fry emerge in flowing water and establish territories in shallow water along stream margins. In one study of fry habitat selection in two Montana streams, Age 0+ fry were most often found in depths <20 cm, over small gravel substrates and water velocities of <0.01 m/s (Muhlfeld *et al.* 2001).

Habitat Trends

Selenium contamination from mountain coal mines poses a significant risk to habitat degradation for Athabasca Rainbow Trout (see Threats and Limiting Factors). Coal leases within the range of Athabasca Rainbow Trout are substantial. It has been noted that some tributaries of the McLeod River have experienced a significant decline in habitat quality as a result of open pit coal mining (Sterling, pers. comm. 2012). Sedimentation and concretions (up to 0.5 m thick in Luscar Creek) are also significant issues causing habitat degradation downstream from mountain coal mines.

It is estimated that coal mining has contributed to an irretrievable loss of approximately 15 km of ecologically important habitat (all of Cabin Creek and portions of Luscar, Jarvis, Sphinx, Mercoal, and Berries creeks and the Gregg and Embarras rivers) and it is estimated that proposed mining in the Erith River watershed will remove an additional 30 km of stream habitat (Sterling, pers. comm. 2012). Athabasca Rainbow Trout and Bull Trout (*Salvelinus confluentus*) have colonized an end pit lake (Sphinx Lake), but this lake has high levels of selenium and sedimentation and the future habitat suitability for fish in these lakes is unknown. It has been suggested that none of the created end pit lakes have yet been demonstrated to function as ‘compensation’ habitat (Sterling, pers. comm. 2012).

In the Tri-Creeks Watershed, experimental logging practices (removal of riparian buffer strips) have resulted in decreased levels of oxygen saturation and increased water temperature and have likely influenced habitat quality for Athabasca Rainbow Trout (Sterling 1992). Additionally, linear developments, primarily roads associated with land use activities (logging, mining, and oil and gas) and provincial infrastructure have resulted in many fragmented stream reaches.

BIOLOGY

The information in this section is from several different sources, which represent the most comprehensive assessment of Rainbow Trout biology in Canada (Nelson and Paetz 1992; McPhail 2007). The most comprehensive data for Rainbow Trout in the Athabasca drainage are from a study in the Tri-Creeks watershed (Sterling 1990, 1992). The Tri-Creeks watershed is the area encompassing Wampus Creek, Deerlick Creek and Eunice Creek within the McLeod River Watershed. A large diversity of life-history characteristics exist for Rainbow Trout; however, the following discussion is related to life-history characteristics of Athabasca Rainbow Trout.

Life Cycle and Reproduction

Rainbow Trout emerge from eggs buried under gravel by the female. Fecundity is highly correlated with body size, and in stream-dwelling populations, females produce approximately 300 eggs. Additionally, egg size varies with female size and fertilized eggs range from 2.8 to 4.0 mm in diameter. The range of water temperatures during egg incubation for several creeks in the Athabasca drainage was between 6.3 °C and 9.8 °C. Upon hatching, the alevins remain in the gravel until the yolk sac has been absorbed (approximately 32-42 days, depending on water temperature) and the reported mean length of fry at emergence is 20 mm in Wampus Creek (Sterling 1978). The emerging fry feed on larvae and nymphs of various aquatic insects along the edges of spawning streams, and in the Tri-Creeks watershed, the early instars of the mayfly (*Baettis spp.*) are an important food source in August.

Athabasca Rainbow Trout spawn every year and spawning occurs later than in most other Rainbow Trout found in southern Alberta. In the upper Deerlick Creek, spawning begins in late June and hatching occurs as late as September. In comparison, spawning of lower-elevation Rainbow Trout usually occurs between late April and May. In the Tri-Creeks area, the number of eggs was positively correlated with fork length ($r = 0.7856$) with an average of 293 eggs per female. In the Tri-Creeks watershed, Rainbow Trout were collected in August and assessed for maturity (Table 7). The percentage of the population (per age class) that is mature refers to the proportion of a specific age-class that would have spawned that spring. These data suggest that in the Athabasca system, a very small proportion of females mature as early as age 3 and approximately 50% of females are mature by age 5. In comparison, males reach maturity as early as age 1 and the majority are mature by age 4.

Table 7. Sexual maturity and sex ratios for Rainbow Trout in ten age-classes in the Tri-Creeks Experimental Watershed (1973-1985). Adapted from Sterling (1990).

Age (years)	Sample Size	% Mature Females in Sample	% Mature Males in Sample	Sex Ratio (Female / Male)
1	219	0.0	0.9	0.81
2	369	0.0	13.0	0.83
3	264	2.4	38.6	0.97
4	196	26.1	52.5	0.87
5	126	50.8	42.1	1.38
6	74	43.2	55.4	0.81
7	52	44.3	53.8	0.86
8	22	31.9	68.1	0.47
9	9	55.6	44.4	1.25
10	7	57.1	42.9	1.33
Total	1338			0.92

Rainbow Trout in the Tri-Creeks watershed (comprising Wampus, Deerlick and Eunice creeks in the McLeod River drainage) are reported to have the slowest growth rate of Rainbow Trout in North America and these growth rates are representative of all small stream populations throughout the range of Athabasca Rainbow Trout. It is suggested that fish in the Tri-Creeks watershed may be the slowest-growing in the world, which is likely a reflection of the environmental conditions. For a single very unproductive habitat reach in the extreme headwaters of Eunice Creek, the average length at age 2 was 52 mm and less than 10 g in weight (in comparison, the average length and weight at age 2 for Rainbow Trout in Okanagan Lake in British Columbia are 120 mm and 136 g respectively). In general, the stream-resident populations of Athabasca Rainbow Trout are smaller than the neighbouring river migrant populations in the larger rivers (FWMIS 2012; Figure 6).

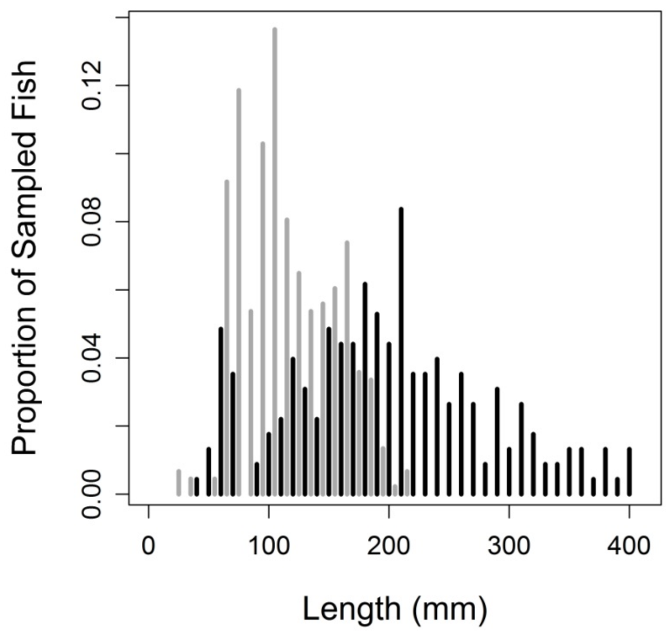


Figure 6. Difference in length distributions for stream resident and river migrant populations. Proportion of sampled fish by 10 mm length bin from creeks in the Tri-Creeks experimental watershed (grey bars) and the main-stem of the Berland and Athabasca Rivers (black bars). Main-stem river counts have been horizontally offset to the right for presentation. Source: FWMIS (2012)

Mortality rates (by age class) were measured for fish in the Tri-Creeks watershed. Annual mortality declined with age until age 3 and then increased with age until life expectancy was reached. Age 1 to 3 fish had similar survival rates (0.53 to 0.58) as did Age 5 to 9 fish (0.83 to 0.90). The oldest recorded Rainbow Trout in the Tri-Creeks watershed was age 10.

Similar to other salmonids, female Rainbow Trout select spawning sites in areas with sub-gravel flow. Before spawning commences, the female excavates a nest site by turning on her side and strongly moving her caudal fin. This motion causes gravel to be moved downstream by the current. During excavation, the female determines how turbulent the flow is in the bottom of the egg pit. Usually a few larger stones are captured to create a pocket to hold the eggs. During this process, the female is accompanied by a dominant male and various numbers of satellite males. The dominant male exhibits aggressive behaviour and attempts to drive away the satellite males. After gamete release, the female moves upstream and begins excavations upstream to cover the nest with gravel. A female will often create several nests, each nest upstream of the last.

The diet of Rainbow Trout varies with location, body size, season and time of day. Elliott (1973) examined feeding habits of Rainbow Trout in stream populations in the central Pyrenees Mountains. These high-elevation streams are likely similar to those in the Athabasca drainage. Elliott (1973) found that juveniles primarily feed during the night on the drifting stages of aquatic insects. Adults feed on both terrestrial and aquatic emerging insects. In cold streams (<8 °C), Rainbow Trout feed only on drifting benthic invertebrates at night and in warmer streams (>8 °C), they have a second feeding period during the daylight that targets terrestrial invertebrates and aquatic insects. Near sunrise and sunset, invertebrate drift increases substantially and this corresponds with an increase in feeding activity. Athabasca Rainbow Trout are thought to be opportunistic feeders; they binge during crepuscular periods and graze at other times. Diet composition was studied in the Tri-Creeks drainage and differences were noted to correspond to substrate characteristics (Sterling, pers. comm. 2012). In stream reaches with considerable boulder/cobble substrates (and a greater diversity of aquatic insects), the diet was primarily composed of aquatic invertebrates. In contrast, fish residing in stream reaches with finer gravel tended to have a larger proportion of terrestrial invertebrates in their diet.

Physiology and Adaptability

Rainbow trout are raised in hatcheries across the globe and are often termed 'an entirely synthetic fish' (Halverson 2010) and, therefore, the possibility exists to supplement populations incapable of recovering using fish from healthy local populations. However, because Athabasca Rainbow Trout are uniquely adapted to their specific environment and supplementing at-risk populations with a non-native genome is likely to decrease the population's local adaptability and result in an increased risk of extinction, stocking is not a viable option.

Dispersal and Migration

The distribution of Rainbow Trout in the Athabasca drainage is highly influenced by water temperature in addition to physical barriers such as waterfalls. In the Lower Foothills Natural Subregion, many of the drainages (Sakwatamau, Freeman, Groat, Edson, Trout, Wolf and Shiningbank) are isolated populations. These populations are likely non-migratory and are thermally isolated from the more continuously distributed stocks found in the Upper Foothills Natural Subregion (Sterling, pers. comm. 2012).

Additionally, road development associated with land use activities (logging, mining, and oil and gas) have resulted in many fragmented stream reaches (see Habitat Fragmentation and Resource Extraction). It is estimated that approximately 20% of stream culvert crossings on small 3rd and 4th order steams within the range of Athabasca Rainbow Trout are barriers to fish movements (Sterling, pers. comm. 2012).

Interspecific Interactions

Between 1924 and 1977, hatchery raised Brook Trout (*Salvelinus fontinalis*) were introduced into lakes (and a few creeks) within the upper Athabasca River within Jasper National Park (FWMIS 2012). Fish and Wildlife Division records show that Brook Trout were first introduced into several streams in the Athabasca River drainage (outside Jasper National Park) in 1940 and the last stream stocking occurred in 1964. Numerous lakes in Alberta are now stocked with sterile (3N) Brook Trout. Electrofishing data from the Tri-Creeks watershed demonstrated that Brook Trout have invaded streams where no stocking had occurred. Between 2000 and 2005, Brook Trout made up approximately 30.7% of the trout population, in comparison with 5.8% between 1970 and 1979. Other data from FWMIS (2012) suggest that Brook Trout have dispersed into the main river systems and subsequently colonized many tributaries where no stocking occurred. The steady increase in the proportion of Brook Trout in the non-stocked waterbodies over time suggests that non-stocked systems will likely end up with Brook Trout populations similar to the streams that were directly stocked (Rasmussen and Taylor 2009). Genetic introgression (through hybridization) with Brook Trout is impossible due to differences in spawning time (Sterling, pers. comm. 2012).

The presence of Brook Trout in the habitat of Athabasca Rainbow Trout is hypothesized to result in Rainbow Trout moving to other habitats as a result of interspecific competition (Rasmussen and Taylor 2009). At present, the biotic interaction between introduced Brook Trout and native Rainbow Trout is unclear. The increasing range and abundance of the introduced Brook Trout suggest that these fish are well adapted for conditions in the Athabasca River system. The biology of Brook Trout differs substantially from Rainbow Trout and allows them to thrive in the Athabasca system. Unlike Rainbow Trout, Brook Trout spawn in the fall and are pre-adapted to small streams (Fausch 2008). Brook Trout have been known to select spawning sites with upwelling groundwater (that causes the stream not to freeze over in the winter). In comparison, Rainbow Trout spawn in the spring and populations are strongly impacted by flood events that occur frequently during the spawning season. Brook Trout also exhibit rapid growth during their first two years of life, and often spawn at ages 1+. Differences in the biology of Brook Trout in comparison with Athabasca Rainbow Trout, coupled with the observation of increased abundances of Brook Trout in the Athabasca drainage suggests that the threat exists for Athabasca Rainbow Trout populations to be replaced by introduced Brook Trout.

There is also a small threat of hybridization with Cutthroat Trout (Sterling, pers. comm. 2012). Mowitch Creek (in Jasper National Park) supports a naturalized population, and this creek is a tributary to the Wildhay River above Rock Lake. Rainbow Trout - Cutthroat Trout hybrids were identified in Rock Creek (above Rock Lake) as early as 1983 (FWMIS 2012; Sterling, pers. comm. 2012). At this point, no Cutthroat Trout or hybrids have been found in Rock Lake. Additionally, the threat exists for Cutthroat Trout to escape from a self-sustaining population in Utopia Lake (Jasper National Park, Fiddle River watershed), but no hybrids have been confirmed from the Fiddle or Athabasca River.

A wide variety of fish species are present within the habitat of Athabasca Rainbow Trout. Juvenile Bull Trout are commonly found in the lower reaches of many small creeks, and mature adults spawn in the lower reaches of several streams in August and September. It is hypothesized that adult and sub-adult Bull Trout and Burbot (*Lota lota*) are likely the major predators of juvenile Rainbow Trout in the Athabasca drainage in 2nd to 4th order streams (Sterling, pers. comm. 2012). Mountain Whitefish (*Propsopium williamsoni*), Brook Trout, White Sucker (*Catostomus commersoni*), Longnose Sucker (*Catostomus catostomus*), Spoonhead Sculpin (*Cottus ricei*), and Longnose Dace (*Rhinichthys cataractae*) are all present within the Athabasca system and tributaries. In streams where Athabasca Rainbow Trout are common, the native fish community is fairly sparse (mainly Bull Trout, Mountain Whitefish, Burbot and Spoonhead Sculpin). However, in the larger rivers, the fish community is diverse and the community proportion of Rainbow Trout is small.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

The majority of abundance data for Rainbow Trout in the Athabasca drainage exist from electrofishing catch-per-unit area from the Fish and Wildlife Management Information System. Streams were surveyed to determine species, occurrence, abundance and community composition at the ‘reach’ scale. Detailed sampling and long-term monitoring has occurred in three reference creeks in the Tri-Creeks Experimental Watershed. Fish were captured between 1969 and 2010 at permanent sampling plots that ranged between 300 and 1000 m in length in the lower reaches of each stream. Sampling events occurred in areas that are known to contain native Athabasca Rainbow Trout and areas with evidence of introgression of hatchery fish (see Canadian Range). The 10 (of 131) streams known to contain non-native alleles are marked with an “*” in Appendix 1.

Where data were available, fish abundance was estimated for other streams within the Athabasca drainage (excluding the Tri-Creeks Experimental Watershed) using mark-recapture or depletion removal techniques. Suitable data existed in the FWMIS for a total of 122 tributaries of the major river systems. The dates of the population estimates ranged between 1970 and 2005, although the majority of the assessments occurred after 1990. Many of the assessed streams were subjected to recreational fishing before surveys occurred. For streams sampled in multiple years, population estimates are given as averages of annual estimates.

Sterling *et al.* (2012) compared fish density estimates (from mark-recapture and depletion removal) with 1st-pass catch-per-unit effort (CPUE) and catch-per-unit-area (CPUA) derived from 114 population estimates in 19 streams. The majority of sampled streams corresponded to 3rd and 4th Strahler Stream Order. Fish density was linearly related to 1st-pass CPUA, and depletion removal population estimates had a stronger correlation with CPUA (R^2=0.9596) than mark-recapture population estimates (R^2=0.8576). Using the depletion removal population estimates, CPUA was a better predictor of fish density, than CPUE (Figure 7).

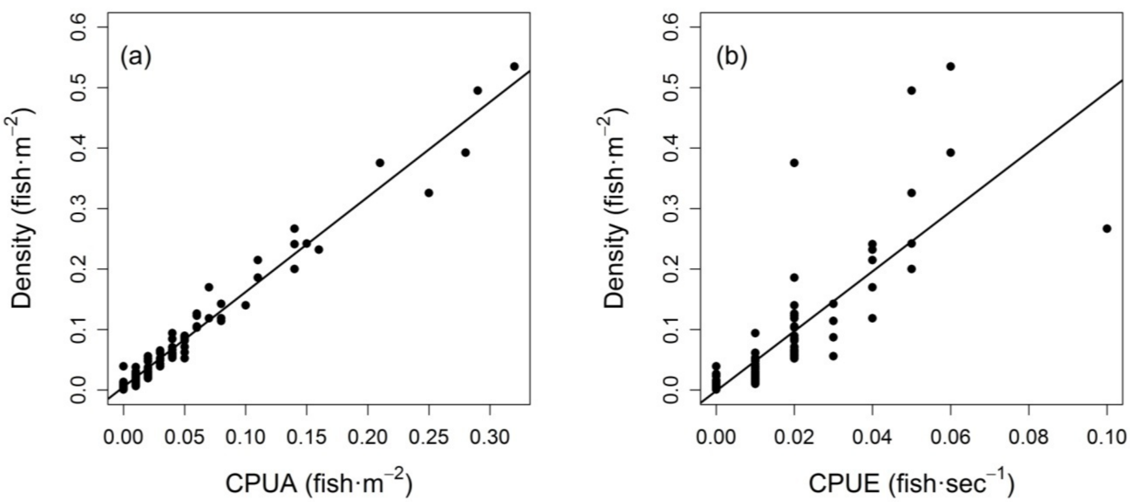


Figure 7. Relationship between Athabasca Rainbow Trout density and 1st-pass CPUA (R^2=0.9735) or 1st-pass CPUE (R^2=0.6803). Source: Sterling *et al.* (2012).

CPUA data were compiled for tributaries that were sampled at least twice in the past 15 years (and showed no evidence of introgression with hatchery fish) to determine trends in abundance over time. First-pass electrofishing CPUA was calculated for each year and stream based on sampling events in July and August. Between 1997 and 2012, 57 streams met the above criteria to determine trends in abundance over time using CPUA data. There has been no published meta-analysis of trends in abundance over time across populations within the Athabasca River drainage. Therefore, the following method was developed to assess the quantitative criteria for the assessment of wildlife species (Appendix E3; Table 2; COSEWIC 2013).

Trends in CPUA, $A_{i,t}$, for time *t* and stream *i* were assessed by fitting an exponential model to the data,

(1) $\ln\left(\hat{A}_{i,t}\right) = \beta_i + \alpha_i t.$

Because limited replication existed for CPUA estimates for each year (in each stream), uncertainty in the estimate of CPUA was incorporated based on the average coefficient of variation for streams that had more than one observation per year ($\overline{CV} = 0.6149$). Using this uncertainty, parameter estimates for the slope (α_i) and intercept (β_i) were estimated for each stream using Bayesian techniques in order to obtain probability distributions of the estimated parameters and corresponding quantitative criteria. In other words, using Bayesian techniques, the uncertainty in trends over time in each stream as a result of observation error, can be propagated through to estimate uncertainty in trends over time across streams. Equation (1) was fit to observed abundance estimates $A_{i,t}$ using a normal log-likelihood function, based on *n* observations per stream,

(2) $$lnL = -\frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln(\sigma^2) - \frac{1}{2\sigma^2}\sum_t^T\left(A_{i,t} - \mu\right)^2.$$

The analysis was run using openBUGS (Bayesian Inference Using Gibbs Sampling) software, version 3.2.1 (available at http://www.openbugs.info/w/). This software implements a Monte Carlo Markov Chain (MCMC) (based on the Gibbs sampler) to obtain a representation of the posterior probability density function (Thomas *et al.* 1992). To estimate model parameters, the MCMC was run for 100,000 iterations, and the first 10,000 iterations were removed to eliminate any "burn-in" effects. Chains were initialized from two different starting points. Convergence of the chains was visually assessed by monitoring trace plots of the Markov chains as well as examining the Gelman-Rubin convergence diagnostics (provided in the BRugs package for the R programming environment). The pseudocode for the model is given in Appendix 2.

The rate of change in CPUA per year t ($\%\Delta_1$) across all sampled streams (*i*) is equal to,

(3) $$\%\Delta_1 = \frac{\sum_i^I \hat{A}_{i,t=2} - \sum_i^I \hat{A}_{i,t=1}}{\sum_i^I \hat{A}_{i,t=1}}$$

and rate of change in CPUA in N_{Years} is equal to,

(4) $$\%\Delta_{N_{Years}} = (1 + \%\Delta_1)^{N_{Years}} - 1$$

Abundance

Miller and Macdonald (1949) were the first to conduct fisheries surveys in the upper Athabasca watershed. The majority of the information provided on population densities is expressed in relative terms: *'Rainbow trout are present in incredible numbers in every little creek and beaver dam, in the larger tributaries and in the main McLeod*'. More robust fisheries inventories in the upper Athabasca drainages began in the mid-1960s. In 1965, the Tri-Creeks Experimental Watershed program began to study the effects of timber harvesting on aquatic communities. There is no information available on population abundance from Aboriginal Traditional Knowledge sources for Athabasca Rainbow Trout (COSEWIC 2012).

The status of Athabasca Rainbow Trout populations is based on benchmark densities from reference streams in the Tri-Creeks Experimental Watershed. Although considerable natural variability exists for these streams, fish abundance in these un-fished streams has historically been above 100 fish·0.1 ha^{-1} (0.1 fish·m^{-2}) and rarely below 30 fish·0.1 ha^{-1} with the exception of Eunice Creek (Figure 8). In contrast, fish abundance in Mary Gregg and Antler creeks (which are exposed to recreational fishing in addition to land-use impacts of coal mining) have fluctuated within the range of 20 to 50 fish·0.1 ha^{-1}. Rasmussen and Taylor (2009) established population benchmarks based on these values. They hypothesized that populations above 50 fish·0.1 ha^{-1} would likely provide resilience to natural factors (such as flood events and competition from introduced species). This benchmark density estimate is comparable to other estimates of salmonid density in other non-impacted boreal streams in Canada (Tucker and Rasmussen 1999; Morinville and Rasmussen 2003). Although these benchmark density estimates are from salmonid streams in Quebec, this is the best available information to compare with population estimates from the Tri-Creeks Experimental Watershed prior to logging. Based on COSEWIC criteria, streams with a 50% reduction from the undisturbed benchmark (less than 50 fish·0.1 ha^{-1}) are considered moderate risk and streams with a 70% reduction (less than 30 fish·0.1 ha^{-1}) are considered high risk.

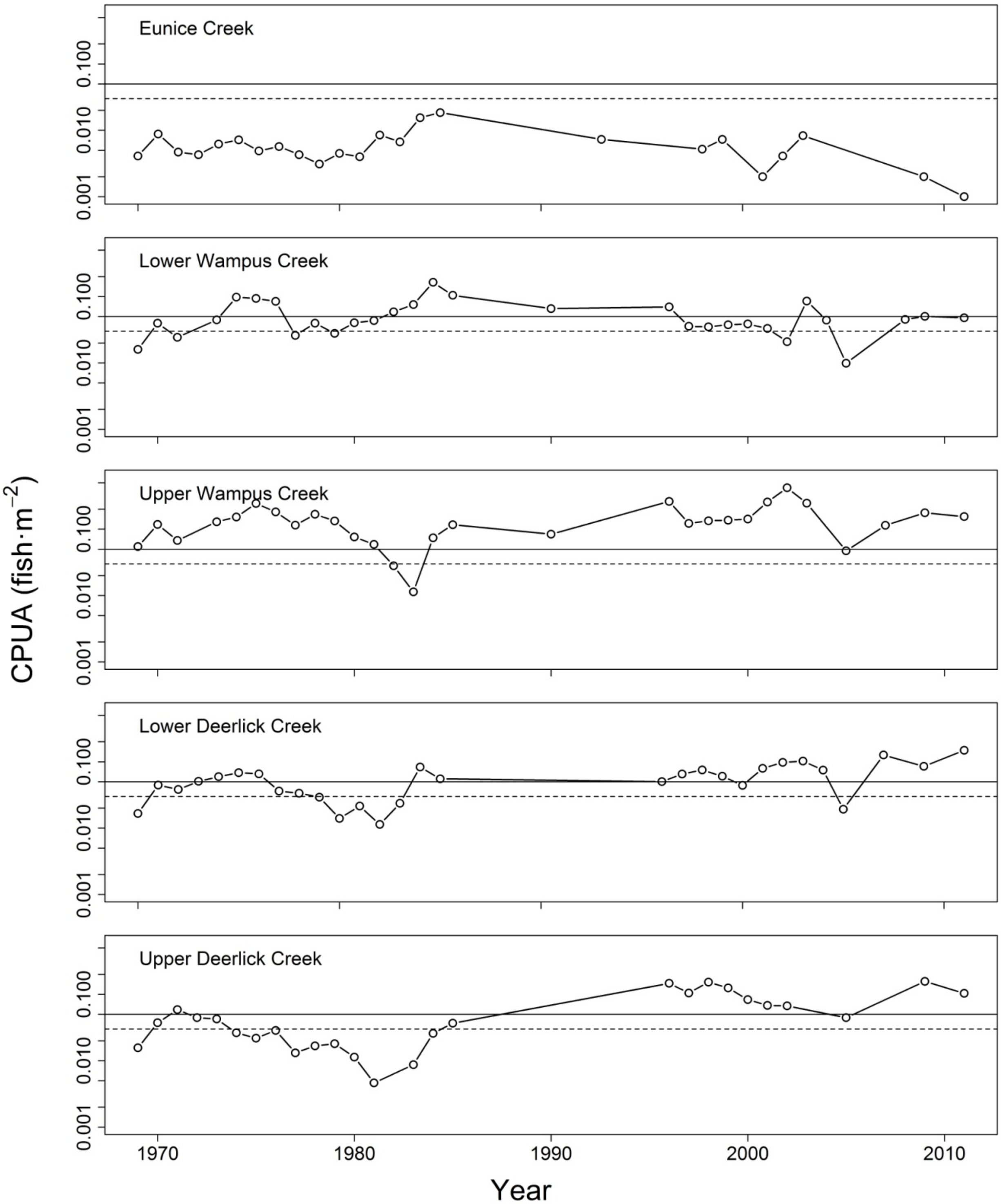


Figure 8. Time-series of 1st-pass electrofishing CPUA data for five reference creeks in the Tri-Creeks experimental watershed. The y-axis is plotted on a log-scale and the axis labels have been transformed for interpretation. The solid and dashed lines refer to the benchmark densities of 50 fish·0.1 ha^{-1} and 30 fish·0.1 ha^{-1} respectively. Source: FWMIS (2012).

Populations in the high risk category are highly vulnerable to both depensatory factors and stochastic events that can prevent the population from recovering from low densities. In the Athabasca system, Rasmussen and Taylor (2009) hypothesize that streams in the high risk category will remain dependent on immigration from the main river system to sustain populations. Populations in the moderate risk category (between 30 and 50 fish·0.1 ha^{-1}) are likely impacted by land-use changes or other factors that have resulted in population decline. Populations with densities in this range are considered to have a reduced resilience against both natural and human-induced disturbances (Rasmussen and Taylor 2009).

Across all river systems where density data for Athabasca Rainbow Trout were present (n=131), 63.3% of the streams were considered to have fish densities in the high risk category, 16.8% in the moderate risk category and only 19.8% in the low risk category. In the Berland / Wildhay drainage, 78.6% of streams are in the high risk category. It is hypothesized that populations in this area are at reduced abundances due to natural low productivity, habitat degradation from resource extraction and historical over fishing (Sterling, pers. comm. 2012). The proportion of streams by risk category varied among river systems, and the majority of the sampled streams were in the high risk category for all systems (Table 8). Specific population density estimates for the 131 sampled streams are given in Appendix 1. Of the 131 streams with population assessments 10 streams contained populations of non-native Rainbow Trout and of these 10 streams Chance Creek was the only stream not in the “high-risk” category. Based on population estimates in reference streams and suitable habitat area, the estimated total population of Athabasca Rainbow Trout is between 15,000 and 25,000 mature individuals (Rasmussen and Taylor 2009).

Table 8. Percentage of streams in each risk category by tributaries. Source: Rasmussen and Taylor (2009). Low-, moderate- and high-risk streams are defined as >50 fish·0.1 ha^{-1}, 30-50 fish·0.1 ha^{-1} and <30 fish·0.1 ha^{-1} respectively.

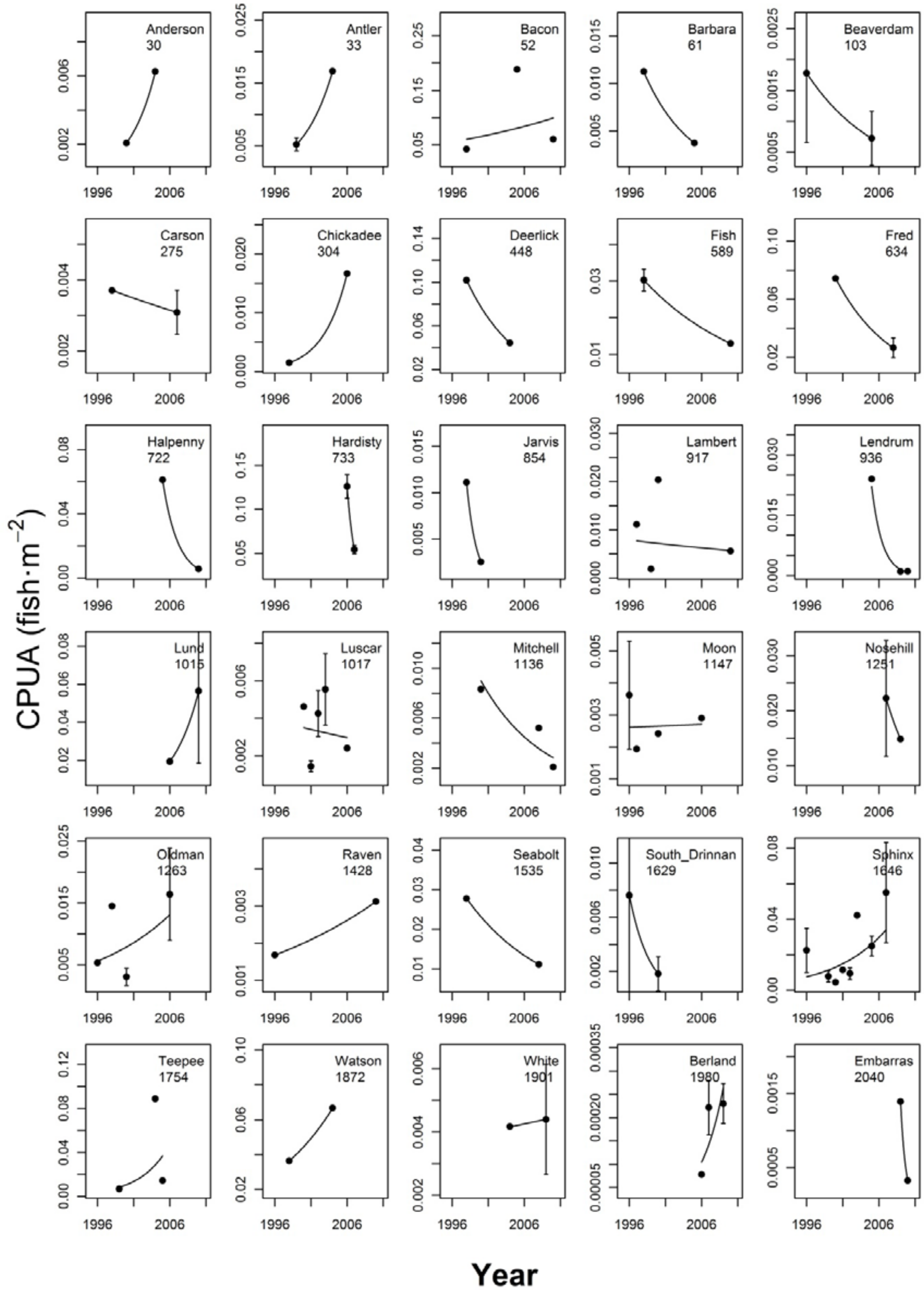
Region	Number Sampled	% Low Risk	% Moderate Risk	% High Risk
Athabasca Tributaries	28	25.0	14.3	60.7
Berland / Wilday Tributaries	28	3.5	17.9	78.6
McLeod Tributaries	71	25.4	18.3	56.3
Freeman Tributaries	4	0.0	0.0	100.0
Total	131	19.8	16.8	63.3

Fluctuations and Trends

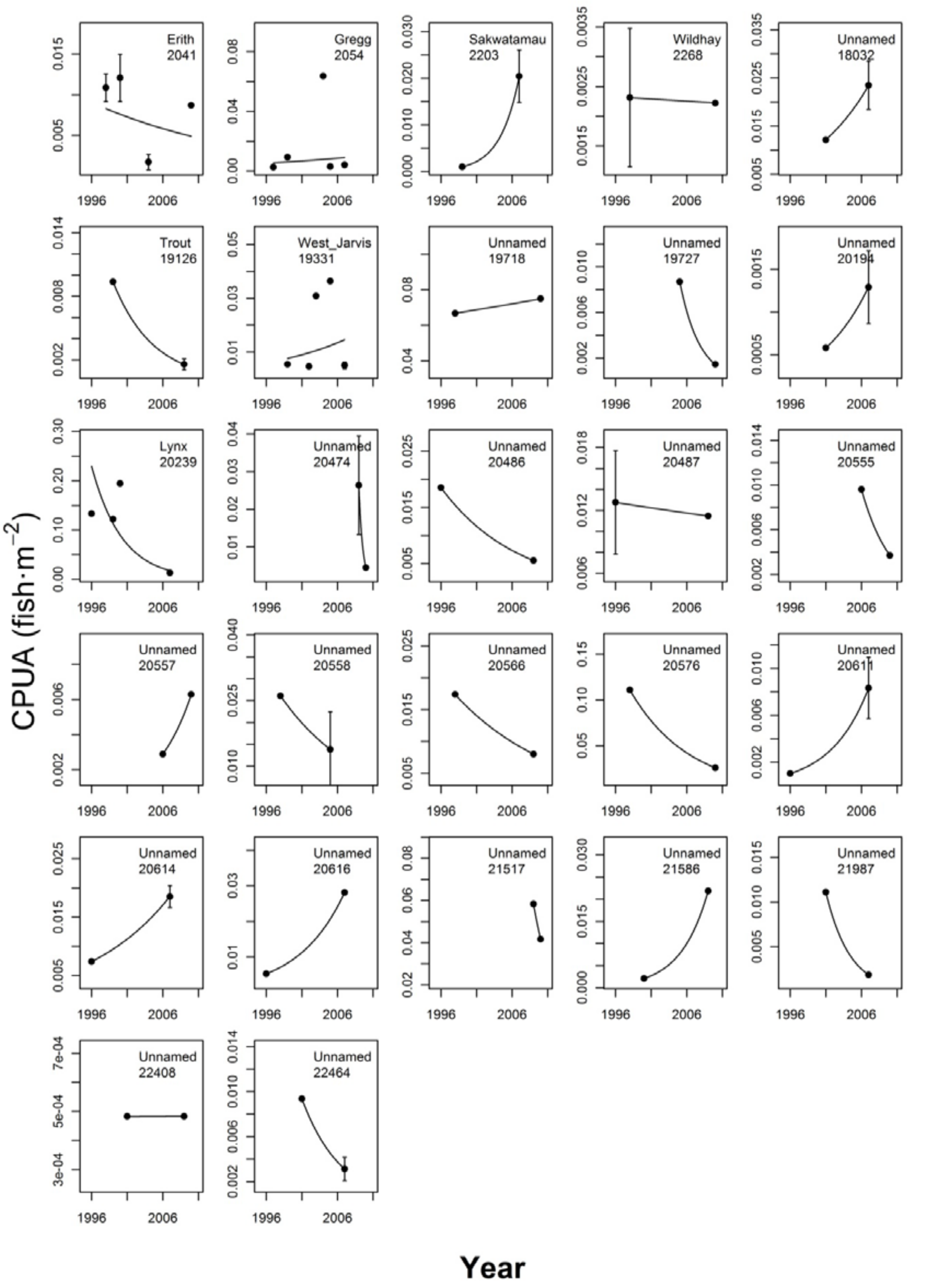
Backpack electrofishing data from three streams (Eunice, Deerlick and Wampus) in the Tri-Creeks Experimental Watershed compose the longest data set for Athabasca Rainbow Trout. First-pass CPUA varied substantially for these streams (Figure 8). Two capture locations existed for both Deerlick and Wampus creek, and these have been separated into upper and lower reaches for analysis and interpretation. Road development began in this area in the mid-1970s, and significant flood events (1/100 year events) occurred in 1969 and 1980 and a lesser magnitude flood in 1996.

Both capture locations in Wampus and Deerlick creek show large fluctuations in CPUA over time. In Wampus Creek, CPUA varied approximately 18-fold and 40-fold, and in Deerlick creek, CPUA varied approximately 14-fold and 33-fold in the lower and upper sections respectively. Wampus and Deerlick creek showed declines in CPUA in the late 1970s which likely correspond to road development in the area. The populations in these creeks appeared to recover by the mid-1980s.

Analysis of trends in CPUA over time suggested that Athabasca Rainbow Trout have decreased in abundance recently in many streams. For tributaries in the Athabasca drainage that met the criteria for a trend-analysis, 31 (approximately 54%) streams showed evidence of declines in CPUA over the past 15 years (3 generations) or less, based on the length of the time series available (Figure 9, Figure 10). Across streams, streams with high CPUA (and assuming high fish density) in the first year of data showed large rates of declines (Figure 11). Therefore, across all streams, the rate of change for Athabasca Rainbow Trout was estimated at -96.5% (95% probability interval: -99.3% to -88.0%) over 15 years (for a time period that included both the past and present; as applicable to COSEWIC (2013) criteria A4) (Figure 12a). Many of the high-density streams showed dramatic declines over this period and although uncertainty in CPUA was included, this estimate was very precise and suggests an overall decline in CPUA over this 15-year period. Similarly, the projected rate of change into the future for the next 15 years (COSEWIC (2013) criteria A3) across all streams was estimated to be -44.4%, with 95% probability interval between -92.5% and 229% (Figure 12b).


CPUA (fish·m⁻²)
Year
Anderson 30
Antler 33
Bacon 52
Barbara 61
Beaverdam 103
Carson 275
Chickadee 304
Deerlick 448
Fish 589
Fred 634
Halpenny 722
Hardisty 733
Jarvis 854
Lambert 917
Lendrum 936
Lund 1015
Luscar 1017
Mitchell 1136
Moon 1147
Nosehill 1251
Oldman 1263
Raven 1428
Seabolt 1535
South_Drinnan 1629
Sphinx 1646
Teepee 1754
Watson 1872
White 1901
Berland 1980
Embarras 2040
1996
2006

a)



b)

Figure 9(a-b). Variation in CPUA over time (error bars refer to 1 standard error) for tributaries in the Athabasca drainage. Numbers below tributary names refer to stream identity numbers. Source: FWMIS (2012).

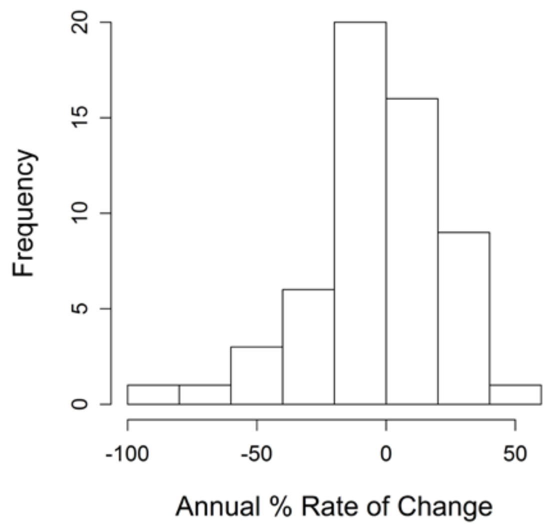


Figure 10. Frequency distribution of annual % rate of change for streams used in the trend analysis.

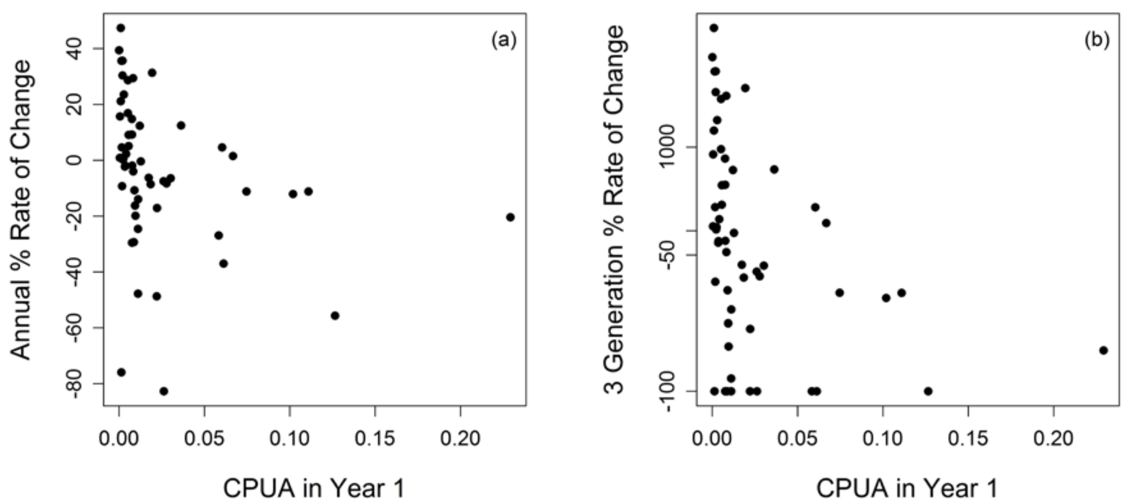


Figure 11. Relationship between (a) annual % rate of change and (b) % rate of change over 3 generations as a function of CPUA in the first year of data.

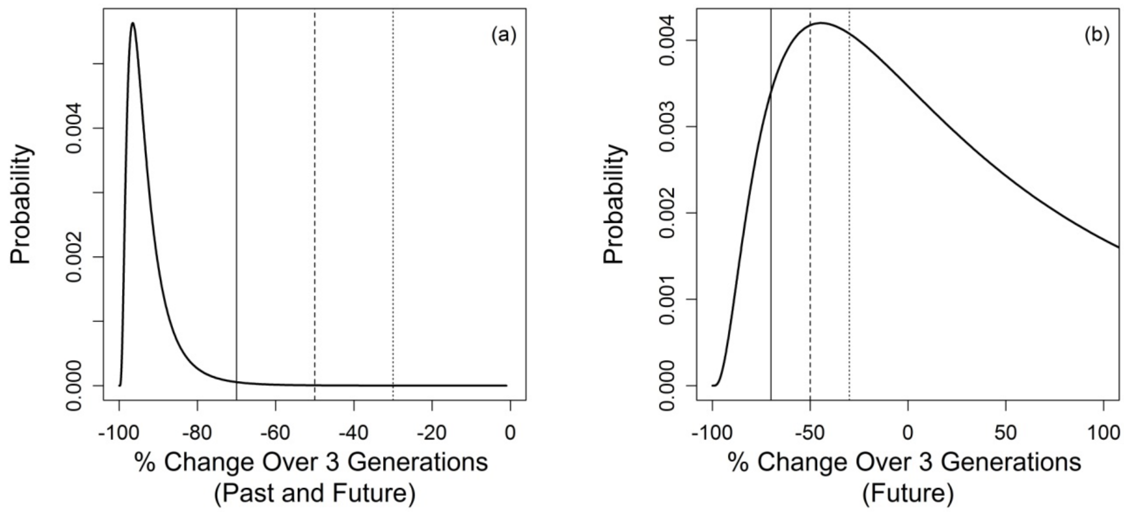


Figure 12. Probability distribution for estimated rate of change in Athabasca Rainbow Trout over (a) 15 years, including past and future, (b) the next 15 years. Dotted, dashed and solid lines refer to thresholds of -30%, -50% and -70% respectively.

Although there is no quantitative data to determine how much, and at what rate, the native genome of Athabasca Rainbow Trout is being eroded by introgression of hatchery fish. In the Athabasca drainage, a large number of naturalized populations of non-native Rainbow Trout occur in Jasper National Park and these populations continue to provide propagule pressure downstream, especially to the mainstem Athabasca River. Genetic data on the degree of introgression of hatchery fish over time exists for three paired sites in the main stem of the Athabasca River (Table 9). Paired sites for each location were less than 10km apart. Between 2000 and 2011, Q_i values (admixture coefficient, representing the proportion of the genome that is of indigenous origin) decreased between 0.5 and 4.3% per year, leading to an average decrease of 29.2% over 3 generations (15 years).

Table 9. Trend over time in admixture coefficient (Q_i) for paired sampling locations in the main stem of the Athabasca River. Sampling locations were considered pairs if less than 10km apart. Source: Taylor and Yau (2013).

Pair	Location	Year	Mean Q_i	SD	N
1	Main stem Athabasca	2000	0.94	0.05	7
1	Mouth of Muskuta River	2011	0.88	0.15	8
2	Mouth of Beauvert Creek	2000	0.58	0.58	29
2	Mouth of Maligne River	2011	0.10	0.11	17
3	Mouth of Emerson Creek	2000	0.91	0.09	9
3	Main stem Athabasca from Baseline to Nosehill Creek	2011	0.79	0.28	17

Rescue Effect

It is possible for extirpated populations of Rainbow Trout within portions of the Athabasca drainage to experience re-colonization from fish elsewhere in the drainage. However, this is strongly dependent on habitat connectivity between populations and competition with introduced Brook Trout in the Athabasca drainage. At least seven drainages with watershed areas ranging from approximately 14,000 ha to 170,000 ha (mean 77,145 ha) are thermally isolated (see Habitat Requirements) from populations in the upper regions, and therefore, immigration of fish into the lower regions is unlikely. However, there is no possibility for Rainbow Trout populations in the Athabasca drainage to be re-colonized by fish in other river systems within the Western Arctic Biogeographic zone. Although other populations of Rainbow Trout exist within this area, movement of fish between these river systems is impossible.

Athabasca Rainbow Trout are uniquely adapted to small, cold and unproductive headwater streams (see Biology). These local adaptations suggest that fish from extra-regional populations would not be well-suited to the Athabasca drainage and that any rescue introductions would be unsuccessful. Rainbow Trout (Alberta populations) are currently limited by habitat fragmentation and watershed disturbances associated with resource extraction, recreational fishing, and competition with Brook Trout and other non-native fish (see Threats and Limiting Factors). Therefore, introductions from extra-regional populations would also be affected by these factors.

THREATS AND LIMITING FACTORS

The primary factors limiting populations of Athabasca Rainbow Trout include (1) introgression with hatchery fish and competition with non-native species, (2) industrial and agricultural pollution. Additional threats include: climate change and other natural factors, habitat fragmentation and watershed disturbances associated with road development and resource extraction. Detailed information on human activities that are thought to result in habitat destruction is given in Table 10 and summarized in a formal Threats Assessment (Appendix 3).

Table 10. Human activities likely to result in the destruction of essential habitat for Athabasca Rainbow Trout. The effect pathway for each activity is provided as well as the potential links to the biophysical functions, features and attributes of essential habitat. Source: Sterling (unpub.).

Habitat Modifications	Effect – Pathway	Function Affected	Feature Affected	Attribute Affected
Channel diversions (including impoundment, road building, stream crossings)	Changes in channel morphology following the introduction of fine sand, silt and clay Sedimentation	Spawning Nursery Feeding Cover Over-wintering	Pool tail-outs Stream margins Pools Runs Riffles	Gravel beds Water depth Fine sands, silts and clays Optimum dissolved oxygen Migration of fluvial adults Optimum water temperatures Invertebrate production Pools >75 cm deep Large cobble and hyporheic flow
Construction of poorly designed culvert stream crossings	Fragmented habitat caused by accelerated water velocities in crossing structure resulting in creation of plunge pool, degradation of stream channel and elevated culvert outlet Sedimentation	All	All	Localized in-stream movement of residents to spawning habitat Migration of fluvial populations to spawning habitat in small to medium perennial streams
Water extraction	Reduced pool volumes and availability of stream habitat Sedimentation	All	All	All
Resource use (removal of riparian vegetation, timber harvesting, grazing)	Increased water temperatures because of direct solar radiation Stream flow increases leading to a greater frequency and magnitude of spate and streambed scour Nutrient enrichment Sedimentation	All	All	Optimum stream flows during spawning and incubation Optimum water temperatures Optimum dissolved oxygen Invertebrate production

Introgression of Hatchery Fish and Competition with Non-native Species

The native genome of Athabasca Rainbow Trout is, and continues to be, threatened by introgression of non-native hatchery fish (see Hatchery Populations of Rainbow Trout). The occurrence of several naturalized populations of non-native Rainbow Trout in Jasper National Park that provide a continuous propagule pressure emanating from headwater lakes and streams, significant introgression of non-native alleles in some areas where stocking has occurred, and evidence of introgression of non-native alleles in unstocked populations in Alberta suggest that genetic introgression is a serious threat to the long-term persistence of the native genome (Sterling, pers. comm. 2012).

Athabasca Rainbow Trout are also directly threatened by introduced Brook Trout. In streams where introduced Brook Trout have established naturalized populations, they have become competitors for food and space with Athabasca Rainbow Trout (see Interspecific Interactions). There is a small hybridization threat with Cutthroat Trout in two small watersheds in the Athabasca drainage: Rock Creek and Fiddle River (see Interspecific Interactions).

Industrial and Agricultural Pollution

Industrial effluents (especially airborne pollutants) and agricultural effluents pose a significant threat to Athabasca Rainbow Trout populations. In some tributaries of the McLeod River in the Athabasca drainage, there has been a significant decline in habitat quality as a result of open pit coal mining (see Habitat Trends). Selenium is naturally occurring in soils derived from black shales and phosphate rocks (Haygarth 1994). However, coal mining can release previously unavailable selenium into aquatic environments, and produces toxicity symptoms in fish (Hamilton 2004). Alberta Environment sampled several stream sites in the McLeod River drainage (upstream and downstream of mining activities) between 1998 and 2003 and found that selenium concentrations downstream of the Cardinal Rivers Coal Mine exceeded the Canadian guidelines for the protection of freshwater aquatic life. Between 2000 and 2002, Holm *et al.* (2005) collected Rainbow Trout and Brook Trout fry from Luscar and Gregg creeks (downstream of the Cardinal Rivers Coal Mine near Hinton, Alberta) to study the effects of selenium concentrations on fry development (fish were also collected from Deerlick and Wampus creeks as reference sites). Tissues from collected fish were analyzed for selenium, eggs were fertilized and embryos were raised in a laboratory setting to evaluate the type and proportion of deformities. Holm *et al.* (2005) found that Brook Trout were less sensitive to selenium and that Rainbow Trout fry demonstrated a significant relationship between selenium levels in eggs and developmental abnormalities, leading to impaired reproduction (Figure 13). This species-specific difference in response to selenium concentrations may help to explain why Brook Trout have replaced Rainbow Trout in several streams in the upper McLeod watershed (see Interspecific Interactions). The Luscar Coal Valley and Cheviot mines are currently in operation within the current habitat of Athabasca Rainbow Trout, and several other mines are proposed in the area.

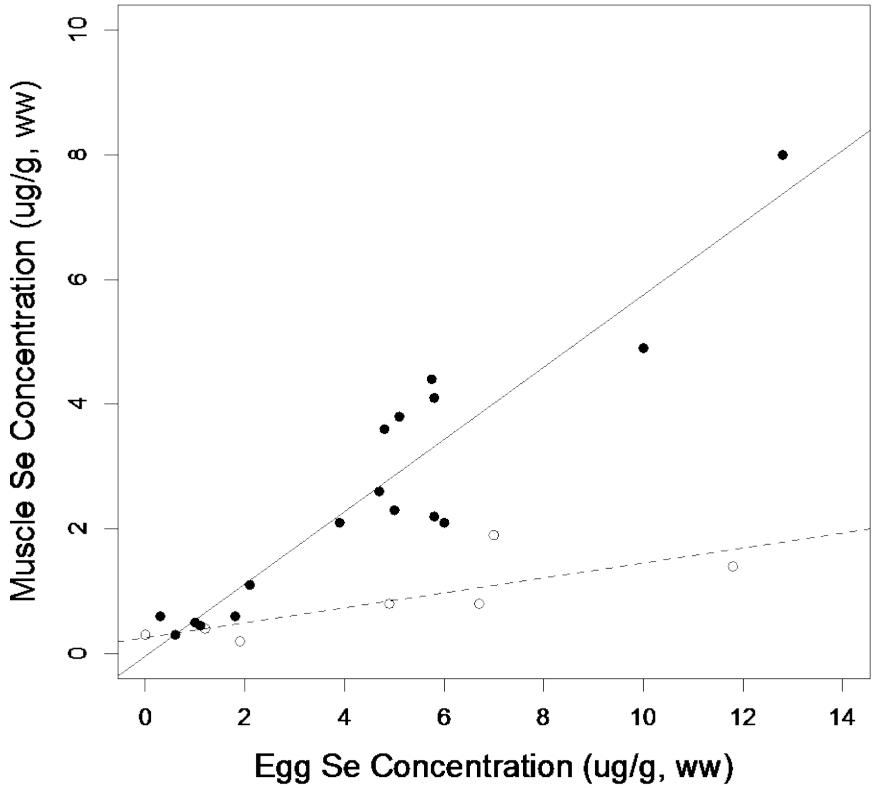


Figure 13. Correlation between muscle and egg selenium (Se) concentrations in Rainbow Trout (open symbols; r = 0.864; p = 0.012) and Brook Trout (closed symbols; r = 0.954; p < 0.01) collected from Se-exposed and reference sites in southeastern Alberta, Canada. Each symbol represents data from tissues obtained from one female. Source: Holm *et al.* (2005)

Climate Change and Other Natural Factors

The specific habitat requirements for Rainbow Trout are important factors that when combined with the effects of climate change can threaten populations. In particular, Rainbow Trout have strong water temperature preferences (between 7 and 18 $^{\circ}$C) and very specific habitat requirements for spawning and rearing (see Habitat Requirements). Athabasca Rainbow Trout are most common in 3rd- and 4th-order streams that remain cool during the summer and have sufficient oxygen (Rasmussen and Taylor 2009). These habitat requirements strongly influence the distribution of Rainbow Trout in the Athabasca River system. Data on habitat occupancy from FWMIS (2012) showed a decline in the proportion of occupied habitat in downstream reaches of the watershed (Table 4). This decline is likely a reflection of warmer downstream water temperatures. These unique habitat requirements make Athabasca Rainbow Trout particularly susceptible to the effects of climate change.

Climatic variability and change affects Athabasca Rainbow Trout in three main ways: (1) altered thermal regimes in streams (and corresponding oxygen levels), (2) altered water volume and delivery schedules that affect snow pack (winter delivery and/or spring freshet) and/or heavy precipitation events that result in flooding (and habitat scouring) and (3) effects of late summer flows as a result of glacial drawdown over sequential seasons (Sterling, pers. comm. 2012).

Major flood events associated with freshet often occur during the month of June. Floods increase fine sediments and because floods often coincide with egg deposition in gravel, these fine sediments cover incubating eggs and alevin, resulting in suffocation. However, bed scour (as a result of erosion and deposition) during flood events significantly impacts fish habitat. Minor flood events do not have enough power to transport particles; whereas major flood events produce sufficient velocities to transport fine particles and other bed material. Sterling (1992) examined critical flow rates for Athabasca Rainbow Trout and found that spawning particles were transported when flows exceeded 0.731 m^3s^{-1}. Following major flood events, Sterling (1992) found that the quality of spawning substrates actually increased (due to scour) and this likely contributed to the observed increased recruitment and quick population recovery following the flood in 1980. Additionally, a sudden increase in fine sediments can also severely decrease the habitat required for invertebrate production (the main food source for both adult and juvenile fish). Populations with low abundance levels are particularly sensitive to flood events and in some cases, flood events correspond well to large changes in abundance (Sterling 1990).

Habitat Fragmentation and Resource Extraction

Outside the boundary of Jasper National Park, the prevalence of timber harvesting, oil and gas production (including exploration and development), coal mining, and agriculture (primarily grazing) uses are increasing rapidly. These developments result in an increase in road construction, and directly impact streams through erosion and siltation, and channel alterations (for bridge and culvert construction). In addition to the direct effects of industrial exploitation, these industries also create new roads that lead to increased access for recreationalists into previous undisturbed habitats.

Channel alterations as a result of bridge construction and improper installation of culverts increase habitat fragmentation by restricting upstream fish movement. Improper installation of culverts (by placing culverts above the existing stream grade) often results in water velocities that exceed the speed at which fish can swim against (Furniss *et al.* 1991). Additionally, it has been shown that increasing water velocity (resulting in increased erosion and downcutting of stream bed) from bridge and culvert construction can have significant effects on stream habitat (Peterson 1993). The Foothills Stream Crossing Program database shows that 123 out of 427 crossings (29%) in the Hinton area are likely to have Athabasca Rainbow Trout (Sterling, pers. comm. 2012). Of the 1230 crossings audited by the Alberta Environment and Sustainable Resource Development between 2009 and 2012, 167 of the 823 culvert crossings (21%) were considered to be likely barriers to fish movement.

The effects of logging on Athabasca Rainbow Trout populations were studied in-depth for creeks in the Tri-Creeks watershed (Sterling 1990; Sterling 1992). The results of this study showed an increase in discharge following logging, which led to an increase in both siltation and scouring. However, logging resulted in no changes to annual minimum water flows, which is essential for providing over-wintering habitat (see Habitat Requirements). The effects of logging on abundance of Athabasca Rainbow Trout were inconclusive; large flood events masked any other effect that logging may have had on growth and/or survival. The increase in siltation and scouring as a result of logging is hypothesized to have similar impacts on egg and alevin survival as floods, discussed above. It has been well documented that timber harvest causes an increase in water temperatures. Nip (1991) reported that mean August water temperatures in Wampus and Deerlick creeks increased 3.4 and 5.7 °C, respectively following logging. Increases in water temperature can result in a loss of suitable habitat, especially for cold-water adapted fish such as Athabasca Rainbow Trout. Changes in water temperature following timber harvest are strongly dependent on post-logging riparian zone management, and in some extreme cases, increases in water temperature have remained for up to 10 years following logging (Beschta and Taylor 1988). Additionally, it has been suggested that water temperature changes as a result of logging could be further increased when compounded with the effects of climate change and lead to a further decrease in suitable habitat (Isaak *et al.* 2012).

Number of Locations

For Athabasca Rainbow Trout, a location is defined as a spawning site. River migrant and stream resident populations spawn in small tributaries in the spring (see Habitat Requirements), and therefore these areas are places where a single threatening event (e.g. habitat alteration) could put the population at risk. Data on the number of spawning streams in the Athabasca River drainage is unavailable, but the number of spawning streams (and locations) is likely much greater than 50. In Alberta, there are seven tertiary watersheds that encompass the range of Athabasca Rainbow Trout. Of these seven watersheds, three tertiary watersheds contain nine drainages where populations exist in isolation from other populations (Sterling pers. comm. 2012). If populations in these areas went extinct, they would not become re-established without human intervention.

There is also evidence of a reduction in the number of locations over time in the Athabasca drainage. No Rainbow Trout have been captured in Eunice creek over the past five years, suggesting that this population is now extinct (FWMIS 2012). Additionally, historical records suggest that Rainbow Trout were present in Carrot and Bench creeks, but no Rainbow Trout have been captured in these locations for several decades (FWMIS 2012).

PROTECTION, STATUS AND RANKS

Legal Protection and Status

The Canadian federal *Fisheries Act* assigns the ability to the provinces and territories to establish and enforce fishing regulations. In Alberta, Rainbow Trout are managed provincially under Eastern Slopes - ES3 angling regulations and the Freeman River is in the Northern Boreal - NB2 area. Major changes to East Slope (Zone 1) regulations occurred in 1995, including size and bag limits, and gear restrictions that are watershed specific. Historically, aggregate bag limits were 10 fish with no size limits or bait bans. The use of bait, specifically maggots, is permitted in the major main stem rivers (Athabasca, lower Berland, and lower McLeod) within the ES3 management area for a portion of each year. A total ban is only stipulated for streams and secondary rivers, and a total catch-and-release regulation for ES3 applies only for Athabasca Rainbow Trout (although several specific watersheds, Wildhay, Embarras, and Gregg, have a catch-and-release regulation for all species).The Tri-Creeks experimental streams (Wampus, Deerlick and Eunice creeks) in the McLeod drainage are closed year-round to angling.

Internationally, Rainbow Trout have a global conservation status of G5 (secure) and a similar national status in Canada and the United States (N5, secure) (IUCN 2012). Athabasca Rainbow Trout are listed under the NatureServe conservation status as “Critically Imperilled” (S1). However, these global ranks do not account for the risk of extinction in specific designatable units.

Non-legal Status and Ranks

Athabasca Rainbow Trout have long been recognized as a unique native strain (Alberta Sustainable Resource Development 2012). In 2005, it was determined that the native stocks of Rainbow Trout within the Athabasca River and tributaries “May Be At Risk” as a result of introgression with introduced Rainbow Trout and anthropogenic habitat changes (Alberta Sustainable Resource Development 2012).

The provincial government of Alberta has responded to growing concerns regarding the status of Athabasca Rainbow Trout. A Conservation Action Statement was recommended to the Minister of Sustainable Resource Development by the Provincial Endangered Species Conservation Committee (dated June 2009) to list Athabasca Rainbow Trout provincially as “threatened”, but this document remains unsigned. The first provincial status report was published in 2009 (Rasmussen and Taylor 2009) and a provincial recovery team for Athabasca Rainbow Trout now exists. Additionally, the provincial government created the Alberta Selenium Working Group in 1999 to coordinate efforts to assess and manage selenium impacts from coal mines in west-central Alberta.

Habitat Protection or Ownership

Several rivers and streams containing Athabasca Rainbow Trout are located in protected areas. The main stem of the Athabasca River and tributaries are within the boundaries of Jasper National Park and a portion of the Berland and McLeod River drainages are within Willmore and Whitehorse Wilderness Park respectively. Outside the boundaries of these parks, the area is subjected to a wide variety of land-use practices. Additionally, fish habitat is protected under provincial government legislation.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Hillary Ward completed a Bachelor's degree in Environmental Science at the University of British Columbia and is now a PhD candidate at the University of Calgary. Her research is focused on understanding trade-offs in harvest and angler dynamics for small lake Rainbow Trout fisheries in British Columbia.

COLLECTIONS EXAMINED

No collections were examined in the preparation of this report.

Appendix 1. Rainbow Trout density (# fish·0.1ha^{-1}) from single-pass electrofishing surveys in streams of the Upper Athabasca river system, an assessment of their risk status based on fish density and location specific land-use practices. Source: Rasmussen and Taylor (2009).

* Low (L), moderate (M) and high (H) risk streams are defined as >50 fish·0.1 ha-1, 30-50 fish·0.1 ha-1 and <30 fish·0.1 ha-1 respectively.
† L= Logging; M= mining; F = recreational fishing

Waterbody	Fish Density	SE	n	Years	Risk *	Land Use†
Athabasca River Drainage						
Baseline Creek	11.8	2.5	13	1996-98	H	L, F
Canyon Creek	11.1	2.1	9	1996-98	H	L, F
Centre Creek	24.6	12.8	2	1997	H	L, F
Chickadee Creek	14.7	4.3	9	1993-03	H	L, F
Emerson Creek*	20.4	4.3	8	1998-01	H	L, F
Felix Creek	38.6		1	1998	M	L, F
Fish Creek	21.4	3.9	23	1996-00	H	L, F
Gorge Creek	70.9	17.1	9	1996-98	L	L, F
Hardisty Creek	4.7		1	1999	H	L, F
Hunt Creek	3.2		1	1995	H	L, F
Lynx Creek	67.1	14	12	1996-01	L	L, F
Marsh Creek	45	21	3	1996-98	M	L, F
Maskuta Creek	4.8		1	1996	H	L, F
Nosehill Creek	1.3		1	1997	H	L, F
Obed Creek	16.6		1	1997	H	L, F
Oldman Creek	16.1	4.8	7	1996-99	H	L, F
Oldman Creek	77	31.5	6	2000-03	L	L, F
Plante Creek	12.4	6.8	4	1996-98	H	L, F
Ponoka Creek	22.4		1	1995	H	L, F
Roundcroft Creek	208.9	237.1	2	1993-98	L	L, F
Seabolt Creek	6.6	4.5	4	1995-99	H	L, F
Solomon Creek	2.6	0.7	11	1996-01	H	L, F
Two Creek	2.4	1.3	3	1999	H	L, F
Unnamed	41.7	8.1	7	1999-03	M	L, F
Unnamed	44.8	17.7	5	2000-02	M	L, F
Unnamed	55.8	24.3	7	1999-02	L	L, F
Unnamed	197.4	154	6	1999-02	L	L, F
Unnamed	203.3	64.1	5	1999-02	L	L, F
Berland / Wildhay Drainage						
Barbara Creek	5.5	3.6	2	1996-97	H	L, F
Berland River	11.8	1	2	1998	H	L, F
Big Creek	11.1	4.4	4	1993-98	H	L, F
Cabin Creek	9.3	2.2	2	1993-97	H	L, F
Carson Creek	2.2		1	1999	H	L, F
Collie Creek	39.2	12.4	2	1993-96	M	L, F
Fox Creek	12.3	8.9	2	1993-96	H	L, F
Fred Creek	143.2	140.5	2	1997-01	L	L, F

Waterbody	Fish Density	SE	n	Years	Risk *	Land Use[†]
Hendrickson Creek	12.1	5.4	2	1993-97	H	L, F
Hightower Creek	2.2	1.5	2	1993-96	H	L, F
Little Berland River	4.7	3.5	6	1993-98	H	L, F
Maria Creek	37.5		1	1998	M	L, F
Moberly Creek	17.8	7.4	3	1993-98	H	L, F
Moon Creek	5.1	1.4	11	1998-01	H	L, F
Moon Creek	6.7	1.9	7	1993-97	H	L, F
Pinto Creek	2	0.4	7	1993-01	H	L, F
Teitge Creek	3.9		1	1996	H	L, F
Twelve Mile Creek	32	7	6	1993-99	M	L, F
Unnamed	1.4		1	1998	H	L, F
Unnamed	3.2	0.3	2	1996-97	H	L, F
Unnamed	14.7	6.8	3	1982-96	H	L, F
Unnamed	26.5	11.5	3	1997-03	H	L, F
Beaver Creek	1.5	0.8	3	1993-98	H	L, F
Grizzly Creek	2.6	0.4	3	1993-95	H	L, F
Vogel Creek	8.7	2.7	2	1993-97	H	L, F
Wildcat Creek	32.2	29.4	2	1996	M	L, F
Wildhay River	1.7	0.8	8	1993-99	H	L, F
Wroe Creek	32.7	17	6	1982-01	M	L, F
Freeman River Drainage						
Louise Creek	1.8		1	1996	H	L, F
Unnamed	0.7		1	1996	H	L, F
Unnamed	2.2	0.5	2	1992-02	H	L, F
Unnamed	9.1	6.2	3	2002	H	L, F
McLeod River Drainage						
Anderson Creek	5.6	0.5	4	2003-04	H	L, F
Anderson Creek	14.2	3	14	1999	H	L, F
Anderson Creek	14.8	8.8	4	2001	H	L, F
Anderson Creek	15.2	4.3	3	2000	H	L, F
Anderson Creek	72.5	20.5	8	1993-98	L	L, F
Antler Creek	25.4	5.9	8	1996-98	H	L, F
Antler Creek	36.4	23.5	9	1999-03	M	L, F
Bacon Creek	49.2	10	3	1996-99	M	L, F
Baril Creek	6.7	5.4	2	1998-01	H	L, F
Beaverdam Creek	34.5	23	8	1993-00	M	L, F
Berry's Creek	1.8	10.3	3	1996-97	H	M,L,F
Bryan Creek	52.1	42.1	3	1998-01	L	L, F
Change Creek*	46.1		1	1996	M	L, F
Chief Creek	18.3		1	1995	H	L, F
Corral Creek	24.8		1	1983	H	L, F
Deerlick Creek	156.2	40.2	12	1998-99	L	L
Deerlick Creek	158.3	29.7	12	2000-04	L	L
Deerlick Creek	238.5	76.4	6	1996-97	L	L
Dummy Creek	10.6	7.8	2	1996-97	H	L, F
Embarras River*	16.6	5.5	7	1997-99	H	L, F
Erickson's Creek	20.8		1	1982	H	L, F

Waterbody	Fish Density	SE	n	Years	Risk *	Land Use[†]
Eunice Creek	6.5	3	6	2000-03	H	L
Eunice Creek	7	1.8	10	1993-99	H	L
Gregg River	5.5	2.3	12	1996-04	H	M,L,F
Halpenny Creek	163.1	100.1	5	1996-01	L	L, F
Hanlan Creek	18.9	17.8	2	1996-97	H	L, F
Hay Creek	145.7	92.9	2	1982-04	L	L, F
Lambert Creek	8.8	2.4	10	1998-02	H	L, F
Little MacKenzie Creek*	19.5	8.6	5	1998-01	H	F
Lost Creek*	11.4	3.2	3	1982-00	H	L, F
Lund Creek	88.1	47.2	2	1996	L	L, F
Luscar Creek	6.6		1	1996	H	M
MacKenzie Creek*	11	5.2	9	1983-01	H	F
Mary Gregg Creek	46	8.7	10	1993-03	M	M, F
McCardell Creek	4.8	1.1	2	1982-98	H	L, F
McLeod River	1.1	0.2	48	1998-01	H	L, F
McNeil Creek	7.4	5.3	2	1982	H	L, F
McPherson Creek	19.5	7.5	4	1993-98	H	L, F
Meadow Creek*	1.7		1	1998	H	L, F
Mercoal Creek	44.6	24.5	3	1983-98	M	L, F
Mitchell Creek	9	6.1	7	1995-04	H	L, F
Moose Creek*	5.4	3.5	2	1998	H	L, F
Quigley Creek	11.4	6	4	1982-03	H	L, F
Rainbow Creek*	8.5	5.2	4	1995-99	H	L, F
Raven Creek	2.4	0.7	2	1997-98	H	L, F
Rodney Creek	1.2	0.4	2	1996-00	H	L, F
Taylor Creek	22.5	15.8	5	1993-99	H	L, F
Teepee Creek	48.4	35.7	6	1996-00	M	M,L,F
Thompson Creek*	23.8	8.5	3	1997-00	H	L, F
Trapper Creek	130.3	47.6	4	1993-97	L	L, F
Unnamed	3.6	0.6	5	2002	H	L, F
Unnamed	9.1	6.1	3	2002	H	L, F
Unnamed	11.5		1	1996	H	M,L,F
Unnamed	24.1	0.5	2	1995	H	L, F
Unnamed	32	28	3	1997-98	M	L, F
Unnamed	43.2	13.2	5	1995-03	M	L, F
Unnamed	99.2	14.6	4	2001-02	L	L, F
Unnamed	117.6	37	7	1996-01	L	L, F
Unnamed	125.6	49.7	3	1998-00	L	L, F
Unnamed	187.8	59.4	5	1996-01	L	L, F
Unnamed/Nice Creek	32.2	6.3	8	1982-02	M	L, F
Unnamed/Trout Creek	22.2	9.6	8	2000-02	H	L, F
Wagwam Creek	43.3	16.4	6	1982-01	M	M,L,F
Wampus Creek	149.4	49.8	12	1998-99	L	L
Wampus Creek	262.3	86.2	18	2000-04	L	L
Wampus Creek	310.6	67	8	1990-97	L	L
Warden Creek	30.6	19.2	2	1996-98	M	M,L,F
Watson Creek	56.4	19.5	5	1982-00	L	F

Waterbody	Fish Density	SE	n	Years	Risk *	Land Use†
White Creek	20.1	8.9	5	1995-04	H	F
Wickham Creek	80.6	44	2	1998	L	L, F

Appendix 2. Psuedocode to calculate the rate of change in abundance across all streams.

Subscripts

t = year of data; year 1 = 1998
i = stream

Probability Distributions

N = normal distribution with parameters mean and precision (τ), $\tau = \frac{1}{\sigma^2}$

Observations

$A_{i,t}$ = relative abundance (catch per unit area (fish/ha) in stream i and year t)
$\overline{LA_i}$ = mean of $\ln(A_i)$

CV = -0.1379 (mean coefficient of variation in ln(CPUA), from streams with >1 observations per year)

Initial Values

c_i = parametric linear regression estimate of slope: $\ln(\overline{A_{i,t}}) = d_i + c_i t$
d_i = parametric linear regression estimate of intercept

Model

$\ln(\hat{A}_{i,t}) = \beta_i + \alpha_i t$ #Model to describe rate of change

$\ln(A_{i,t}) \sim N(\ln(\hat{A}_{i,t}), \tau_i)$ #Probability of data

$\tau_i = \frac{1}{(CV \cdot \overline{LA_i})^2}$ #Precision of data

$\alpha_i \sim N(c_i, 1)$ #Hyperprior for slope

$\beta_i \sim N(d_i, 0.1)$ #Hyperprior for intercept

$\hat{A}_{i,t} = exp(\beta_i + \alpha_i t)$ #Predicted abundance in year t

$\hat{A}_{i,t+1} = exp(\beta_i + \alpha_i [t+1])$ #Predicted abundance in year t +1

$\%\Delta_1 = \frac{\sum_i^I \hat{A}_{i,t+1} - \sum_i^I \hat{A}_{i,t}}{\sum_i^I \hat{A}_{i,t}}$ #Rate of change across all streams in 1 year

$\%\Delta_{15} = (1 + \%\Delta_1)^{15} - 1$ #Rate of change across all streams in 3 generations (15 years)

Appendix 3. Threats Assessment Worksheet

THREATS ASSESSMENT WORKSHEET				
Species or Ecosystem Scientific Name	Athabasca Rainbow Trout			
Element ID			**Elcode**	
Date (Ctrl + ";" for today's date):				
Assessor(s):				
References:				
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	3	2
	C	Medium	4	4
	D	Low	0	1
		Calculated Overall Threat Impact:	Very High	Very High
		Assigned Overall Threat Impact:		
		Impact Adjustment Reasons:		
		Overall Threat Comments		

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
2	Agriculture & aquaculture		Negligible	Negligible (<1%)	Serious (31-70%)	High (Continuing)	
2.3	Livestock farming & ranching		Negligible	Negligible (<1%)	Serious (31-70%)	High (Continuing)	grazing in some watersheds but negligible.
3	Energy production & mining	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	
3.1	Oil & gas drilling	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	drilling affects all populations except Jasper. Fracking.
3.2	Mining & quarrying	C	Medium	Restricted (11-30%)	Serious (31-70%)	High (Continuing)	loss of habitat converted from lotic to lentic. Lots of new mining projected within species range.
3.3	Renewable energy		Negligible	Negligible (<1%)	Unknown	Low (Possibly in the long term, >10 yrs)	hydro limited. Dam sites of Athabasca River negligible. Some projected dam sites but not in near future.
4	Transportation & service corridors	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
4.1	Roads & railroads	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	stream crossing from road development blocking fish passage.
4.2	Utility & service lines	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	habitat removal from gas pipelines
5	Biological resource use		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	
5.4	Fishing & harvesting aquatic resources		Negligible	Pervasive (71-100%)	Negligible (<1%)	High (Continuing)	bycatch. Only one population not under pressure of harvesting. Closed stream for Bull Trout. Some illegal fishing but not for undersized fish.
6	Human intrusions & disturbance	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	
6.1	Recreational activities	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	quading and recreational activity causing some sedimentation and loss of habitat integrity.
7	Natural system modifications	BD	High - Low	Large - Restricted (11-70%)	Serious - Moderate (11-70%)	High (Continuing)	
7.1	Fire & fire suppression		Negligible	Negligible (<1%)	Serious (31-70%)	High (Continuing)	very limited but toxic and therefore serious when it happens
7.2	Dams & water management/use	BD	High - Low	Large - Restricted (11-70%)	Serious - Moderate (11-70%)	High (Continuing)	big fracking, proposal to build four new water reservoirs. Push to build them in low lying Muskeg areas. Threat severity is dependent on negotiations.
8	Invasive & other problematic species & genes	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	
8.1	Invasive non-native/alien species	B	High	Large (31-70%)	Serious (31-70%)	High (Continuing)	Cutthroat Trout. Brook Trout outside Jasper. Hybridization and competition issues in the Athabasca and McLeod.
8.2	Problematic native species		Unknown	Unknown	Unknown	High (Continuing)	Pathogens. Didimo blooms in Jasper associated with nutrient loading.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
8.3	Introduced genetic material	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	Hatchery Rainbow Trout stocking has ceased but introduced genetic material is a major problem. Jasper largely stocked. Having non-native allelles has negative effect. Introgression in populations in some sites but they are so heavily compromised. 48% of population sampled show some introgression. all of Jasper. coming downstream into McLeod where 3 places found non-native allelles worse than 0.95. Only Parson Creek dumps into Squatima. All others into Athabasca.
9	Pollution	B	High	Pervasive (71-100%)	Serious (31-70%)	High (Continuing)	
9.1	Household sewage & urban waste water		Negligible	Negligible (<1%)	Slight (1-10%)	High (Continuing)	downstream in Hinton
9.2	Industrial & military effluents	B	High	Large (31-70%)	Serious (31-70%)	High (Continuing)	closer to the upper limit. Coal fines in the air. Some streams adjacent to coal mines. Small threat. Involves only a few systems. Includes selenium from coal mines. And salt water spills from pipelines.
9.3	Agricultural & forestry effluents	C	Medium	Pervasive (71-100%)	Moderate (11-30%)	High (Continuing)	effluent from agriculture
10	Geological events						
11	Climate change & severe weather	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	
11.1	Habitat shifting & alteration	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	1/3 of watershed affected from habitat alteration outside Jasper. Under a stage of regrowth, altered stream flow regimes, significant impact to recruitment.
11.3	Temperature extremes	C	Medium	Large (31-70%)	Moderate (11-30%)	High (Continuing)	main tributaries to lower McLeod where water temperatures isolated. Temperature extremes. Majority of population affected.