COSEWIC
Assessment and Status Report

on the

Bull Trout
Salvelinus confluentus

South Coast British Columbia populations
Western Arctic populations
Upper Yukon Watershed populations
Saskatchewan - Nelson Rivers populations
Pacific populations

in Canada

South Coast British Columbia populations - SPECIAL CONCERN
Western Arctic populations - SPECIAL CONCERN
Upper Yukon Watershed populations - DATA DEFICIENT
Saskatchewan - Nelson Rivers populations - THREATENED
Pacific populations - NOT AT RISK
2012

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:

COSEWIC. 2012. COSEWIC assessment and status report on the Bull Trout *Salvelinus confluentus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. iv + 103 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Production note:
COSEWIC would like to acknowledge Jennifer Gow for writing the status report on the Bull Trout, *Salvelinus confluentus*, in Canada, prepared under contract with Environment Canada. This report was overseen and edited by Dr. John Post, Co-chair of the COSEWIC Freshwater Fishes Specialist Subcommittee.

For additional copies contact:

COSEWIC Secretariat
c/o Canadian Wildlife Service
Environment Canada
Ottawa, ON
K1A 0H3

Tel.: 819-953-3215
Fax: 819-994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur L'omble à tête plate (*Salvelinus confluentus*) au Canada.

Cover illustration/photo:
Bull Trout — Picture courtesy of J.D. McPhail and D.L. McPhail.

Catalogue No. CW69-14/659-2013E-PDF
ISBN 978-1-100-22290-5

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – November 2012

Common name
Bull Trout - South Coast British Columbia populations

Scientific name
Salvelinus confluentus

Status
Special Concern

Reason for designation
This freshwater fish exists in five large river systems in this area. The population sizes are unknown for three of the rivers but are likely not large. This is a slow-growing and late-maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. Therefore the species is particularly vulnerable to habitat degradation, fragmentation of river networks by dams, negative effects from the invasion of non-native Eastern Brook Trout, and overharvest. The anadromous life history form found in these populations is unique within this species.

Occurrence
British Columbia

Status history
Designated Special Concern in November 2012.

Assessment Summary – November 2012

Common name
Bull Trout - Western Arctic populations

Scientific name
Salvelinus confluentus

Status
Special Concern

Reason for designation
This freshwater fish is broadly distributed throughout the Western Arctic drainage although populations are never abundant. There are areas with evidence of decline in numbers and distribution but quantitative estimates for the whole range are lacking. This is a slow-growing and late-maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. Therefore the species is particularly vulnerable to habitat degradation, fragmentation of river networks by dams, negative effects from the invasion of the non-native Eastern Brook Trout, and overharvest, but these threats are localized within its range.

Occurrence
Yukon, Northwest Territories, British Columbia, Alberta

Status history
Designated Special Concern in November 2012.

Assessment Summary – November 2012

Common name
Bull Trout - Upper Yukon Watershed populations

Scientific name
Salvelinus confluentus

Status
Data Deficient

Reason for designation
This freshwater fish is believed to be distributed in the upper Yukon River drainage but information on population sizes and trends is not available. This is a slow-growing and late-maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. In general, the species is vulnerable to habitat degradation, fragmentation of river networks by dams, and overharvest, but specific threats in these populations are largely unknown and likely minor in this remote watershed.

Occurrence
Yukon, British Columbia

Status history
Species considered in November 2012 and placed in the Data Deficient category.

Assessment Summary – November 2012

Common name
Bull Trout - Saskatchewan - Nelson Rivers populations

Scientific name
Salvelinus confluentus

Status
Threatened

Reason for designation
This freshwater fish is broadly distributed east of the Rocky Mountains. It is a slow-growing and late-maturing species that thrives in cold, pristine waters and often requires long unimpeded migratory routes joining spawning to adult habitat. Historical range contractions now limit the populations to the foothills and east slopes of the Rocky Mountains, likely in response to habitat deterioration and reduced habitat connectivity through damming of the larger rivers. No populations are abundant and more than half show evidence of decline. The primary and persistent threats to these populations include competition and hybridization with introduced Eastern Brook Trout and climate-induced increases in water temperature. Although legal harvest has been eliminated, this species is highly catchable and is therefore likely susceptible to catch and release mortality in many areas that are accessible to recreational anglers. Consequently, an aggregate decline in abundance of $\geq$ 30% over the next three generations is projected.

Occurrence
Alberta

Status history
Designated Threatened in November 2012.

Assessment Summary – November 2012

Common name
Bull Trout - Pacific populations

Scientific name
Salvelinus confluentus

Status
Not at Risk

Reason for designation
This freshwater fish is broadly distributed throughout Pacific drainages. Although populations are never abundant, there are many dispersed populations across this area. There is no overall evidence of declines in abundance of mature adults and distribution. Although this is a slow-growing and late-maturing species that thrives in cold, pristine waters, and requires unimpeded migratory routes joining spawning to adult habitat, the risk level is assessed as low in these populations.

Occurrence
British Columbia

Status history
Designated Not at Risk in November 2012.

COSEWIC
Executive Summary

Bull Trout
Salvelinus confluentus

South Coast British Columbia populations
Western Arctic populations
Upper Yukon Watershed populations
Saskatchewan - Nelson Rivers populations
Pacific populations

Wildlife Species Description and Significance

Bull Trout is a large char. This salmonid derives its name from its large head and jaws. Bull Trout are olive-green to blue-grey in colour and pale round spots on their flanks and back distinguish them from most other similar-looking salmonids. It is difficult to visually distinguish them from Dolly Varden char, however, and detailed measurements or genetic analyses are required for accurate identification where their ranges overlap. Because of its very specific habitat requirements, this sportfish is highly sensitive to habitat changes. Bull Trout are, therefore, viewed as an indicator species of general ecosystem health. Based on genetic analysis, range disjunction and distribution across National Freshwater Biogeographic Zones, five designatable units are recognized; *Genetic Lineage 1 (Southcoast BC populations) and Genetic Lineage 2 (Western Arctic, Yukon, Saskatchewan-Nelson* and *Pacific populations)*.

Distribution

Bull Trout is native to western Canada and the U.S. Pacific Northwest. They range north from the Oregon-California border and northern Nevada through British Columbia and Alberta to southern Yukon and southwestern Northwest Territories. The largest portion of their range (about 80%) occurs in western Canada. They are generally restricted to interior drainages but reach the Pacific Coast in southwest British Columbia and northwest Washington. They are concentrated west of the Continental Divide but do extend across it, being found in all of the major eastern slope drainages in Alberta. Their range has become restricted over the last century, particularly in the USA and Alberta, where populations have become more fragmented and isolated. British Columbia, Yukon and the Northwest Territories are the last remaining jurisdictions with wide distributions of Bull Trout.

Habitat

This cold water species' very strict habitat requirements vary across life history stages. In order to maintain their numbers, Bull Trout require habitat that is cold, clean, complex and connected. Structurally complex habitat provides cover for shelter and the right requirements for breeding and rearing young, while connected habitat allows this migratory species to move between the areas it needs to complete its life cycle.

Biology

Bull Trout are voracious predators that eat other fish when given the opportunity. They exhibit considerable diversity in life history traits, including four migratory types; a non-migratory *stream resident* form; a migratory *fluvial* form that occurs in flowing water; a migratory *adfluvial* form that matures in lakes; and an *anadromous* form that migrates to the sea. Each type breeds in headwater or tributary streams at higher elevations but habitat occupied at other times varies. The first three forms are common throughout the Canadian range but the anadromous populations are restricted to the southwestern portion of British Columbia.

Population Sizes and Trends

Typically comprising less than 5% of total catch from broad faunal surveys, adult Bull Trout populations are expected to be smaller than most other freshwater salmonids. A substantial body of qualitative and quantitative data estimates both historical and current Bull Trout population sizes from Alberta, and to a lesser extent British Columbia. However, long-term data sets quantifying Bull Trout abundance are rare, and much of our current knowledge of population trends relies on qualitative expert opinion. In recent decades, Bull Trout populations have experienced declines in abundance across parts of their range, particularly in the USA and Alberta. The full range of life histories is also being lost from some populations. This historical pattern of decline is mirrored in the short-term declining trend of 57% of Alberta Bull Trout populations whereas 29% are stable and 8% increasing. Less is known about Bull Trout populations from the remainder of its Canadian range, although their general trend is considered to be stable to diminishing in British Columbia, and there is no evidence of decline of Bull Trout in Yukon or the Northwest Territories. In both Alberta and British Columbia, some populations appear to be recovering from historical threats.

Threats and Limiting Factors

Bull Trout's specific habitat requirements are their most significant natural limiting factor. The most serious threats to Bull Trout, however, are from human disturbance. The greatest threat is habitat loss through degradation and fragmentation. Commercial forestry, hydroelectric, oil, gas and mining development, agriculture, urbanization, and their associated road development, and climate change may all contribute to this. Interactions with other species strongly influence the local distribution and abundance of Bull Trout. Habitat degradation may exacerbate Bull Trout's susceptibility to displacement and/or hybridization, leaving Bull Trout vulnerable to invasion by non-native species, such as Brook Trout. Misidentification with other char and trout species increases fishing pressure on this species that is vulnerable to overharvesting.

Protection, Status, and Ranks

Bull Trout habitat is protected under both provincial and federal legislation. As a sportfish, populations are subject to National Park and provincial fishing regulations that incorporate a variety of measures to protect fish stocks. Currently, Bull Trout is 'blue-listed' as a *Species of Special Concern* in British Columbia and has also been identified as such in Alberta. The *General Status of Species in Canada* lists Bull Trout as *Sensitive* nationally (N3), in British Columbia the interior lineage is listed as S3S4. It is listed as S3 in Alberta and Yukon. It is listed as *May Be At Risk* (S2) in the Northwest Territories. Populations in the USA are listed as *Threatened* under the *Endangered Species Act*. Its Global Heritage Status rank and its listing under the IUCN Red List of Threatened Species is *Vulnerable* (G3).

TECHNICAL SUMMARY: DU1- Southcoast British Columbia populations

Salvelinus confluentus

Bull Trout — Omble à tête plate

Southcoast British Columbia populations — Populations de la côte sud de la Colombie-Britannique

Range of occurrence in Canada (province/territory/ocean): BC

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used). (see BIOLOGY)	~7 yrs
Is there an observed continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within 5 years or 2 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the last 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the next 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over any period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased? (see THREATS AND LIMITING FACTORS)	No
Are there extreme fluctuations in number of mature individuals? (see POPULATION SIZES AND TRENDS)	No

Extent and Occupancy Information

Estimated extent of occurrence (see DISTRIBUTION)	32 053 km²
Index of area of occupancy (IAO) (see DISTRIBUTION) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	> 2000 km²
Is the total population severely fragmented? (see DISTRIBUTION)	Fragmented, but not severely
Number of locations∗ (see POPULATION SIZES AND TRENDS)	5-10
Is there a continuing decline in extent of occurrence?	Unknown
Is there a continuing decline in index of area of occupancy?	Unknown
Is there a continuing decline in number of populations?	Unknown
Is there a continuing decline in number of locations*?	Unknown
Is there a continuing decline in [area, extent and/or quality] of habitat?	Unknown
Are there extreme fluctuations in number of populations? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in number of locations∗? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in extent of occurrence? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	No

∗ See definition of location.

Number of Mature Individuals (in each population). Abundance estimated as the median from range categories listed in Appendix 2. Refer to Appendix 2 for more detail.

Population	N Mature Individuals
Lillooet, BC	Unknown
Lower Fraser, BC	Unknown
Lower Fraser Canyon, BC	Unknown
Skagit, BC	1750
Squamish, BC	575?
Total	> 2325

Quantitative Analysis

Probability of extinction in the wild.	Not available

Threats (actual or imminent, to populations or habitats)

- Loss of habitat network through degradation and fragmentation (particularly from hydroelectric, agriculture, urbanization, their associated road development, and climate change).
- Interaction (displacement/hybridization) with other species (particularly non-native Brook Trout).
- Vulnerability to overexploitation (particularly by-catch of anadromous Bull Trout from other salmonid fisheries).

(see THREATS AND LIMITING FACTORS)

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Threatened (see PROTECTION, STATUS, AND RANKS)	
Is immigration known or possible? (see POPULATION SIZES AND TRENDS)	Unlikely
Would immigrants be adapted to survive in Canada? (see POPULATION SIZES AND TRENDS)	Possibly
Is there sufficient habitat for immigrants in Canada? (see POPULATION SIZES AND TRENDS)	Probably
Is rescue from outside populations likely? (see POPULATION SIZES AND TRENDS)	No

Status History

COSEWIC: Designated Special Concern in November 2012

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** NA
Reasons for designation*:* This freshwater fish exists in five large river systems in this area. The population sizes are unknown for three of the rivers but are likely not large. This is a slow-growing and late-maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. Therefore the species is particularly vulnerable to habitat degradation, fragmentation of river networks by dams, negative effects from the invasion of non-native Eastern Brook Trout, and overharvest. The anadromous life history form found in these populations is unique within this species.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): No information on decline of the number of mature individuals.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. EO & IAO exceed thresholds (greater than 20 000 km^2 and 2000 km^2, respectively) and no evidence of continuing decline or extreme fluctuations.
Criterion C (Small and Declining Number of Mature Individuals): Small numbers but no evidence of continuing decline
Criterion D (Very Small or Restricted Total Population): Might be close to meeting small population size criterion.
Criterion E (Quantitative Analysis): No quantitative analyses completed.

TECHNICAL SUMMARY: DU2 - Western Arctic populations

Salvelinus confluentus

Bull Trout — Omble à tête plate

Western Arctic populations — Populations de l'ouest de l'Arctique

Range of occurrence in Canada (province/territory/ocean): AB, BC, NT, YK

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2008) is being used). (see BIOLOGY)	~7 yrs
Is there an observed continuing decline in number of mature individuals? (see POPULATION SIZES AND TRENDS)	Yes, in the Alberta portion of the DU, unknown elsewhere
Estimated percent of continuing decline in total number of mature individuals within 5 years or 2 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the last 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the next 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over any period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased? (see THREATS AND LIMITING FACTORS)	No
Are there extreme fluctuations in number of mature individuals? (see POPULATION SIZES AND TRENDS)	No

Extent and Occupancy Information

Estimated extent of occurrence (see DISTRIBUTION)	> 20 000 km²
Index of area of occupancy (IAO) (see DISTRIBUTION) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	> 2 000 km²
Is the total population severely fragmented? (see DISTRIBUTION)	Fragmented, but not severely
Number of locations∗ (see POPULATION SIZES AND TRENDS)	> 45
Is there an observed continuing decline in extent of occurrence? (see POPULATION SIZES AND TRENDS)	Yes, in the Alberta portion of the DU, unknown elsewhere
Is there an observed continuing decline in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	Yes, in the Alberta portion of the DU, unknown elsewhere
Is there an observed continuing decline in number of populations? (see POPULATION SIZES AND TRENDS)	Yes, in the Alberta portion of the DU, unknown elsewhere
Is there an observed continuing decline in number of locations*? (see POPULATION SIZES AND TRENDS)	Yes, in the Alberta portion of the DU, unknown elsewhere
Is there a projected continuing decline in area, extent and/or quality of habitat? (see HABITAT)	Yes, in the Alberta portion of the DU, unknown elsewhere

∗ See definition of location.

Are there extreme fluctuations in number of populations? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in number of locations∗? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in extent of occurrence? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	No

Number of Mature Individuals (in each population)
Refer to Appendices 1 and 2 for more detail.

Population	**N Mature Individuals**
Populations in AB (n ≥ 15)	> 23000
Populations in BC (n ≥ 30)	Unknown
Populations in NT undefined	Unknown
Populations in YK undefined	Unknown
Total	>> 23000

Quantitative Analysis

Probability of extinction in the wild.	Not available

Threats (actual or imminent, to populations or habitats)

- Loss of habitat network through degradation and fragmentation from intense development pressure (particularly from oil, gas and mining development, commercial forestry, their associated road and urban development, and hydroelectric).
- Interaction (displacement/hybridization) with introduced species (particularly non-native Brook Trout).
- Vulnerability to overexploitation exacerbated by misidentification. Overharvest may be associated with increased accessibility.

(see THREATS AND LIMITING FACTORS)

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Threatened (see PROTECTION, STATUS, AND RANKS)	
Is immigration known or possible? (see POPULATION SIZES AND TRENDS)	No
Would immigrants be adapted to survive in Canada? (see POPULATION SIZES AND TRENDS)	Possibly
Is there sufficient habitat for immigrants in Canada? (see POPULATION SIZES AND TRENDS)	Probably
Is rescue from outside populations likely? (see POPULATION SIZES AND TRENDS)	No

∗ See definition of location.

Status History

COSEWIC: Designated Special Concern in November 2012.

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** NA
Reasons for designation: This freshwater fish is broadly distributed throughout the Western Arctic drainage although populations are never abundant. There are areas with evidence of decline in numbers and distribution but quantitative estimates for the whole range are lacking. This is a slow-growing and late maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. Therefore the species is particularly vulnerable to habitat degradation, fragmentation of river networks by dams, negative effects from the invasion of the non-native Eastern Brook Trout, and overharvest, but these threats are localized within its range.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): There is some evidence of decline in numbers but they do not meet criteria
Criterion B (Small Distribution Range and Decline or Fluctuation): Large distribution range with some evidence of decline but does not meet criteria
Criterion C (Small and Declining Number of Mature Individuals): Numbers of mature individuals is not small.
Criterion D (Very Small or Restricted Total Population): Numbers of mature individuals is not small.
Criterion E (Quantitative Analysis): No quantitative analyses completed.

TECHNICAL SUMMARY: DU3 - Upper Yukon Watershed populations

Salvelinus confluentus

Bull Trout	Omble à tête plate
Upper Yukon Watershed populations	Populations de la partie supérieure du bassin versant du fleuve Yukon

Range of occurrence in Canada (province/territory/ocean): YK, BC

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used). (see BIOLOGY)	~7 yrs
Is there an observed continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within 5 years or 2 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the last 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the next 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over any period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased? (see THREATS AND LIMITING FACTORS)	No
Are there extreme fluctuations in number of mature individuals? (see POPULATION SIZES AND TRENDS)	No

Extent and Occupancy Information

Estimated extent of occurrence (see DISTRIBUTION)	Unknown
Index of area of occupancy (IAO) (see DISTRIBUTION) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	Unknown
Is the total population severely fragmented? (see DISTRIBUTION)	Unknown
Number of locations∗ (see POPULATION SIZES AND TRENDS)	Unknown
Is there a continuing decline in extent of occurrence?	Unknown
Is there a continuing decline in index of area of occupancy?	Unknown
Is there a continuing decline in number of populations?	Unknown
Is there a continuing decline in number of locations*?	Unknown
Is there a continuing decline in [area, extent and/or quality] of habitat?	Unknown
Are there extreme fluctuations in number of populations? (see POPULATION SIZES AND TRENDS)	Unknown
Are there extreme fluctuations in number of locations∗? (see POPULATION SIZES AND TRENDS)	Unknown
Are there extreme fluctuations in extent of occurrence? (see POPULATION SIZES AND TRENDS)	Unknown
Are there extreme fluctuations in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	Unknown

∗ See definition of location.

Number of Mature Individuals (in each population)
Refer to Appendix 2 for more detail.

Population	N Mature Individuals
Populations in BC (n ≥ 1)	Unknown
Populations in YK undefined	Unknown
Total	Unknown

Quantitative Analysis

Probability of extinction in the wild.	Not available

Threats (actual or imminent, to populations or habitats)

General threats that apply to all Bull Trout within Canada (loss of habitat network, interaction with introduced species, and vulnerability to overexploitation) apply equally to this DU, although no specific threats have been identified and threat level is assumed to be low in this remote area (see THREATS AND LIMITING FACTORS).

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Threatened (see PROTECTION, STATUS, AND RANKS)	
Is immigration known or possible? (see POPULATION SIZES AND TRENDS)	No
Would immigrants be adapted to survive in Canada? (see POPULATION SIZES AND TRENDS)	Possibly
Is there sufficient habitat for immigrants in Canada? (see POPULATION SIZES AND TRENDS)	Probably
Is rescue from outside populations likely? (see POPULATION SIZES AND TRENDS)	No

Status History

COSEWIC: Species considered in November 2012 and placed in the Data Deficient category.

Recommended Status and Reasons for Designation

Recommended Status: Data Deficient	**Alpha-numeric code:** NA
Reasons for designation: This freshwater fish is believed to be distributed in the upper Yukon River drainage but information on population sizes and trends is not available. This is a slow-growing and late-maturing species that thrives in cold, pristine waters, and many populations require long unimpeded migratory routes joining spawning to adult habitat. In general, the species is vulnerable to habitat degradation, fragmentation of river networks by dams, and overharvest, but specific threats in these populations are largely unknown and likely minor in this remote watershed.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): No information on the total number of mature individuals
Criterion B (Small Distribution Range and Decline or Fluctuation): Large distribution range
Criterion C (Small and Declining Number of Mature Individuals): No information on population sizes and declines
Criterion D (Very Small or Restricted Total Population): No information on population sizes
Criterion E (Quantitative Analysis): No quantitative analysis completed

TECHNICAL SUMMARY: DU4 - Saskatchewan-Nelson Rivers populations

Salvelinus confluentus
Bull Trout — Omble à tête plate
Saskatchewan-Nelson Rivers populations — Populations des rivières Saskatchewan et Nelson
Range of occurrence in Canada (province/territory/ocean): AB

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2008) is being used). (see BIOLOGY)	~7 yrs
Is there an observed continuing decline in number of mature individuals? (see POPULATION SIZES AND TRENDS)	Yes
Estimated percent of continuing decline in total number of mature individuals within 5 years or 2 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the last 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over the next 10 years, or 3 generations.	Unknown
Percent reduction or increase in total number of mature individuals over any period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased? (see THREATS AND LIMITING FACTORS)	No
Are there extreme fluctuations in number of mature individuals? (see POPULATION SIZES AND TRENDS)	No

Extent and Occupancy Information

Estimated extent of occurrence (see DISTRIBUTION)	> 20 000 km²
Index of area of occupancy (IAO) (see DISTRIBUTION) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	> 2 000 km²
Is the total population severely fragmented? (see DISTRIBUTION)	Fragmented but not severely
Number of locations∗ (see POPULATION SIZES AND TRENDS)	> 36
Is there an observed continuing decline in extent of occurrence? (see POPULATION SIZES AND TRENDS)	Yes
Is there an observed continuing decline in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	Yes
Is there an observed continuing decline in number of populations? (see POPULATION SIZES AND TRENDS)	Yes
Is there an observed continuing decline in number of locations*? (see POPULATION SIZES AND TRENDS)	Yes
Is there a projected continuing decline in area, extent and/or quality of habitat? (see HABITAT)	Yes
Are there extreme fluctuations in number of populations? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in number of locations∗? (see POPULATION SIZES AND TRENDS)	No

∗ See definition of location.

Are there extreme fluctuations in extent of occurrence? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	No

Number of Mature Individuals (in each population)

Refer to Appendix 1 for more details.

Population	**N Mature Individuals**
Populations in AB (n ≥ 36)	>10000
Total	>10000

Quantitative Analysis

Probability of extinction in the wild.	Not available

Threats (actual or imminent, to populations or habitats)

- Loss of habitat network through degradation and fragmentation (particularly from oil, gas and mining development, urbanization, hydroelectric, their associated road development, and climate change).
- Interaction (displacement/hybridization) with introduced species (particularly non-native Brook Trout).
- Vulnerability to overexploitation exacerbated by misidentification.

(see THREATS AND LIMITING FACTORS)

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? Threatened (see PROTECTION, STATUS, AND RANKS)	
Is immigration known or possible? (see POPULATION SIZES AND TRENDS)	Unlikely
Would immigrants be adapted to survive in Canada? (see POPULATION SIZES AND TRENDS)	Possibly
Is there sufficient habitat for immigrants in Canada? (see POPULATION SIZES AND TRENDS)	Probably
Is rescue from outside populations likely? (see POPULATION SIZES AND TRENDS)	No

Status History

COSEWIC: none

Status and Reasons for Designation

Status: Threatened	**Alpha-numeric code:** A4de

Reasons for designation:

This freshwater fish is broadly distributed east of the Rocky Mountains. It is a slow-growing and late-maturing species that thrives in cold, pristine waters and often requires long unimpeded migratory routes joining spawning to adult habitat. Historical range contractions now limit the populations to the foothills and east slopes of the Rocky Mountains, likely in response to habitat deterioration and reduced habitat connectivity through damming of the larger rivers. No populations are abundant and more than half show evidence of decline. The primary and persistent threats to these populations include competition and hybridization with introduced Eastern Brook Trout and climate-induced increases in water temperature. Although legal harvest has been eliminated, this species is highly catchable and is therefore likely susceptible to catch and release mortality in many areas that are accessible to recreational anglers. Consequently, an aggregate decline in abundance of ≥ 30% over the next three generations is projected.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Projected declines in abundance of greater than or equal to 30% over the next three generations and the primary threats will persist.
Criterion B (Small Distribution Range and Decline or Fluctuation): Declines in distribution range noted but not a small distribution.
Criterion C (Small and Declining Number of Mature Individuals): Number of mature individuals not small.
Criterion D (Very Small or Restricted Total Population): Number of mature individuals not small.
Criterion E (Quantitative Analysis): Quantitative analysis not completed

TECHNICAL SUMMARY: DU5 – Pacific populations

Salvelinus confluentus

Bull Trout — Omble à tête plate

Pacific populations — Populations du Pacifique

Range of occurrence in Canada (province/territory/ocean): BC

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used). (see BIOLOGY)	~7 yrs
Is there an observed continuing decline in number of mature individuals?	Increasing, stable and decreasing trends are observed across the DU
Estimated percent of continuing decline in total number of mature individuals within 5 years or 2 generations.	No consistent trends
Percent reduction or increase in total number of mature individuals over the last 10 years, or 3 generations.	No consistent trends
Percent reduction or increase in total number of mature individuals over the next 10 years, or 3 generations.	No consistent trends
Percent reduction or increase in total number of mature individuals over any period, over a time period including both the past and the future.	No consistent trends
Are the causes of the decline clearly reversible and understood and ceased? (see THREATS AND LIMITING FACTORS)	No
Are there extreme fluctuations in number of mature individuals? (see POPULATION SIZES AND TRENDS)	No

Extent and Occupancy Information

Estimated extent of occurrence (see DISTRIBUTION)	> 20 000 km²
Index of area of occupancy (IAO) (see DISTRIBUTION) (Always report 2x2 grid value; other values may also be listed if they are clearly indicated (e.g., 1x1 grid, biological AO)).	> 2 000 km²
Is the total population severely fragmented? (see DISTRIBUTION)	Fragmented, but not severly
Number of locations∗ (see POPULATION SIZES AND TRENDS)	> 78
Is there a continuing decline in extent of occurrence?	Unknown
Is there a continuing decline in index of area of occupancy?	Unknown
Is there a continuing decline in number of populations?	Unknown
Is there a continuing decline in number of locations*?	Unknown
Is there a continuing decline in [area, extent and/or quality] of habitat?	Unknown
Are there extreme fluctuations in number of populations? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in number of locations∗? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in extent of occurrence? (see POPULATION SIZES AND TRENDS)	No
Are there extreme fluctuations in index of area of occupancy? (see POPULATION SIZES AND TRENDS)	No

∗ See definition of location.

Number of Mature Individuals (in each population)
Refer to Appendix 1 for more detail.

Population	N Mature Individuals
Populations in BC (n ≥ 78)	>> 39000
Total	>> 39000

Quantitative Analysis

Probability of extinction in the wild.	Not available

Threats (actual or imminent, to populations or habitats)

- Loss of habitat network through degradation and fragmentation (particularly from hydroelectric, forestry, and mining developments, and their associated road development, as well as mountain pine beetle and climate change).
- Interaction (displacement/hybridization) with introduced species (particularly non-native Brook Trout but also localized Lake Trout).
- Vulnerability to overexploitation exacerbated by misidentification.

(see THREATS AND LIMITING FACTORS)

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? (see PROTECTION, STATUS, AND RANKS)	Threatened
Is immigration known or possible? (see POPULATION SIZES AND TRENDS)	Unlikely
Would immigrants be adapted to survive in Canada? (see POPULATION SIZES AND TRENDS)	Possibly
Is there sufficient habitat for immigrants in Canada? (see POPULATION SIZES AND TRENDS)	Probably
Is rescue from outside populations likely? (see POPULATION SIZES AND TRENDS)	No

Status History

COSEWIC: Designated Not at Risk in November 2012

Recommended Status and Reasons for Designation

Recommended Status: Not at Risk	**Alpha-numeric code:** NA

Reasons for designation:
This freshwater fish is broadly distributed throughout Pacific drainages. Although populations are never abundant, there are many dispersed populations across this area. There is no overall evidence of declines in abundance of mature adults and distribution. Although this is a slow-growing and late-maturing species that thrives in cold, pristine waters, and requires unimpeded migratory routes joining spawning to adult habitat, the risk level is assessed as low in these populations.

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals):
No evidence of decline in the overall number of mature individuals

Criterion B (Small Distribution Range and Decline or Fluctuation):
Large distribution range

Criterion C (Small and Declining Number of Mature Individuals):
Large number of mature individuals

Criterion D (Very Small or Restricted Total Population):
Large number of mature individuals

Criterion E (Quantitative Analysis):
No quantitative analysis completed

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
(2012)

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

Bull Trout
Salvelinus confluentus

South Coast British Columbia populations
Western Arctic populations
Upper Yukon Watershed populations
Saskatchewan - Nelson Rivers populations
Pacific populations

in Canada

2012

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Phylum: Chordata

Class: Actinopterygii

Order: Salmoniformes

Family: Salmonidae

Subfamily: Salmoninae

Genus: *Salvelinus*

Species: *Salvelinus confluentus* (Suckley 1859)

English common name: Bull Trout

French common name: Omble à tête plate

The taxonomy of North American char (*Salvelinus*), to which Bull Trout (*Salvelinus confluentus*) belongs, has a tangled history. Many of the systematic uncertainties stem from limitations of morphological analyses in a group of fishes with extensive phenotypic plasticity. This Holarctic genus has been heavily influenced by Pleistocene glaciations, with periodic episodes of range fragmentation also confounding its complex intraspecific relationships. Historical processes, including fragmentation within refugia (Taylor *et al.* 1999; Brunner *et al.* 2001), as well as introgression between species within refugia or in subsequently recolonized deglaciated areas (Bernatchez *et al.* 1995; Wilson and Bernatchez 1998; Phillips *et al.* 1999; Redenbach and Taylor 2002), have likely contributed to conflicting phylogenies from morphological, mitochondrial DNA and nuclear markers (Grewe *et al.* 1990; Phillips *et al.* 1999; Redenbach and Taylor 2002; Crespi and Fulton 2004).

For many years, Dolly Varden (*Salvelinus malma*) and Bull Trout were considered to be geographic variants within the Arctic Char (*Salvelinus alpinus*) species complex. Even when morphological analysis showed them to be sufficiently divergent from Arctic Char to be designated a separate species, *S. confluentus* remained part of the *S. malma* 'species complex' (McPhail 1961). Once often assumed to be the land-locked form of Dolly Varden, subsequent analysis revealed Bull Trout to be sufficiently morphologically diverged from Dolly Varden to warrant designation as an individual species in 1978 (Cavender 1978; Haas and McPhail 1991). Molecular phylogenies now reveal Bull Trout and Dolly Varden are, in fact, not even sister species; the two species probably last shared a common ancestor more than 1 million years ago (Grewe *et al.* 1990; Crane *et al.* 1994; Phillips *et al.* 1994). Subsequent genetic evidence of these two char maintaining distinct gene pools in sympatry, despite some ongoing hybridization and gene flow (Baxter *et al.* 1997; Taylor *et al.* 2001; Redenbach and Taylor 2003), provides the most compelling evidence yet that Dolly Varden and Bull Trout are distinct biological species.

Morphological Description

Bull Trout is a long slender fish with a comparatively large head and jaws (Figure 1), hence the derivation of its common name “bull”. Their body size at maturity depends on life history strategy (average length and range (mm) of: resident is 250 [140-410]; fluvial is >400 [240-730]; and adfluvial >400 [330-900+]; reviewed in Pollard and Down 2001; Rodtka 2009; Mochnacz *et al.* submitted). Although under-reported in the literature, it may be that anadromous Bull Trout attain the largest sizes of all (Brenkman *et al.* 2007).

Figure 1. Bull Trout (*Salvelinus confluentus*). Picture courtesy of J.D. McPhail and D.L. McPhail.

Bull trout are olive-green to blue-grey in colour, with adfluvial fish often displaying silvery sides (Nelson and Paetz 1992). Pale round spots along their flanks and backs that are pink, lilac, yellow-orange or red distinguish them from others: Brook Trout (*Salvelinus fontinalis*) has distinct, light-coloured, worm-like markings on top of the head, back and dorsal fin, while Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*O. clarkii*) and Brown Trout (*Salmo trutta*) have dark spots (Nelson and Paetz 1992; McPhail 2007). Bull Trout usually have pale bellies, which may turn red or orange in spawning males (Nelson and Paetz 1992). Their tail fin is slightly forked, and pelvic or anal fins may have a leading white edge, but this is not followed by black as it is in Brook Trout (Nelson and Paetz 1992). Bull Trout larvae may be distinguished from other larval char by the presence of a prominent fleshy ridge underneath the chin (Gould 1987).

Bull Trout are morphologically very similar to Dolly Varden. Although no single character can consistently distinguish between them, the two species do differ across a suite of several characters. Generally, Bull Trout have larger, broader, and flatter heads than Dolly Varden, with bodies that are more slender and ventrally flattened (Cavender 1978; Haas and McPhail 1991). Together, branchiostegal ray number, anal fin ray number, and the ratio of total upper jaw length to standard body length consistently distinguish between the two species. Bull Trout tend to have larger upper jaws in proportion to their body lengths compared with Dolly Varden. They also have more anal fin and branchiostegal rays (Haas and McPhail 1991). A morphometric identification protocol utilizing these four variables is presented in Haas and McPhail (1991).

Population Spatial Structure and Variability

The phylogeography of Bull Trout has been well studied and provides strong evidence for two major genetic lineages of Bull Trout in northwestern North America: a southern *coastal* group (henceforth called *Genetic Lineage 1*) and an *interior* group (henceforth called *Genetic Lineage 2*). The first genetic evidence came from mitochondrial DNA (mtDNA); a survey of mtDNA variation (115 restriction sites over 410 base pairs) in 47 populations (N = 348) spanning the geographical range revealed a sharp discontinuity in the geographical distribution of haplotypes (sets of alleles of closely linked loci; Taylor *et al.* 1999). While most of *Genetic Lineage 1* based on mtDNA occurs at or west of the Coast and Cascade mountain crests, most of *Genetic Lineage* 2 based on mtDNA is found east of these (Figure 2). The sequence divergence (*d*) between these lineages is comparable to that found in other northern Holarctic fishes (*d* = 0.8% [Taylor *et al.* 1999, 2001] compared to average maximum intraspecific *d* of ~1.2% from 25 other species [Bernatchez and Wilson 1998]). Subsequent surveys of nuclear DNA (microsatellites) across Bull Trout's geographical range have consistently corroborated the presence and distribution of these groupings (Spruell *et al.* 2003; Taylor and Costello 2006). Morphological and comparative life-history (Haas and McPhail 2001; see '**Dispersal and Migration**' section) evidence has also substantiated this major subdivision of Bull Trout into *Genetic Lineage 1* and *2*.

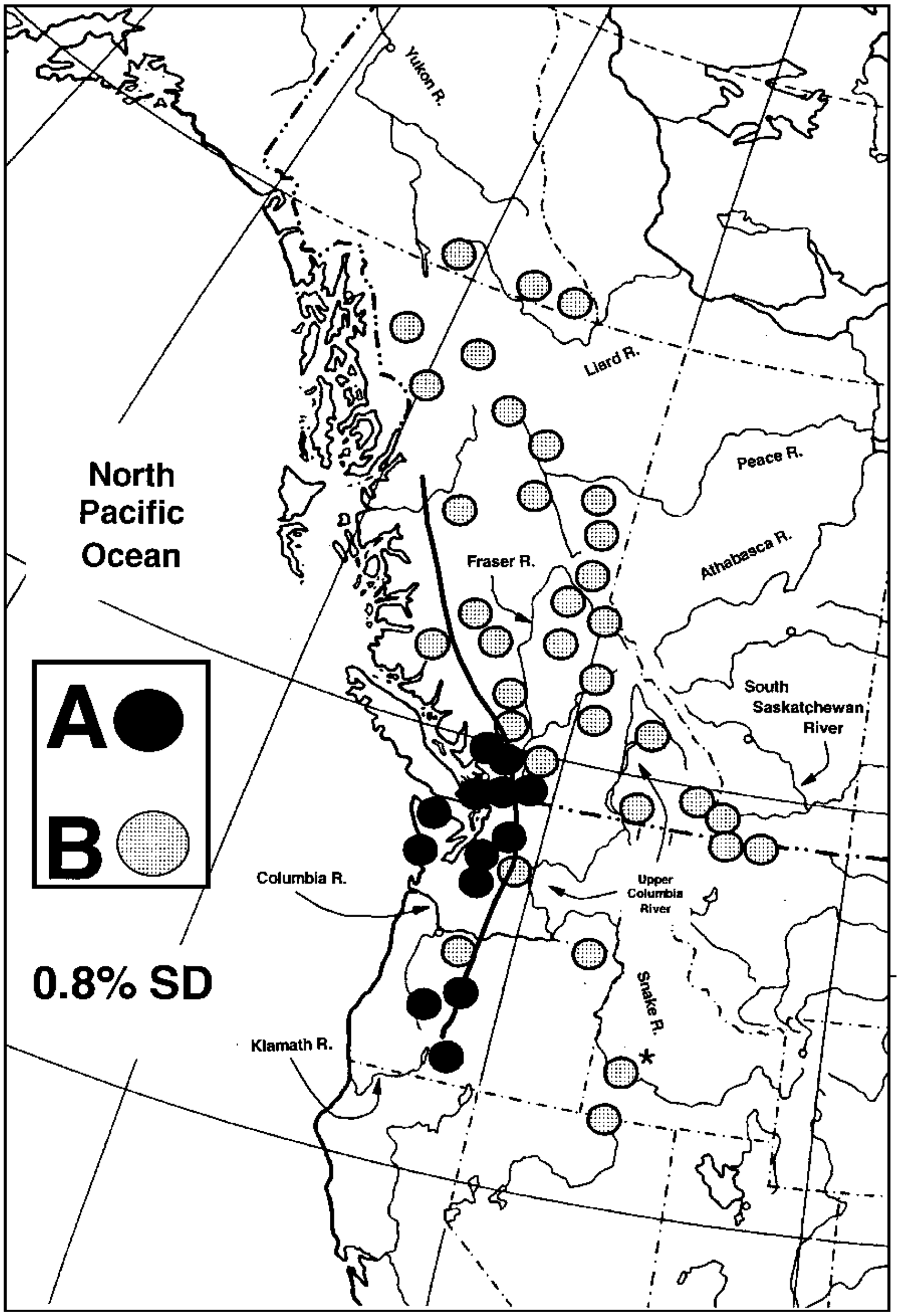

Figure 2. Distribution of two major Bull Trout mitochondrial DNA lineages identified by restriction fragment length polymorphism of 47 Bull Trout populations (N = 348). The solid black line dividing groups A (Genetic Lineage 1) and B (Genetic Lineage 2) is the approximate location of the Cascade/Coast Mountain crest. Sourced from Taylor *et al.* 1999.

This pattern of an inland/coastal genetic split corresponding to the Coast and Cascade mountain ranges is one that is repeated in other northwestern fishes (e.g., Rainbow Trout: McCusker *et al.* 2000; Cutthroat Trout: Allendorf and Leary 1988; Chinook Salmon, *Oncorhynchus tshawytscha*: Teel *et al.* 2000; Coho Salmon, *Oncorhynchus kisutch*: Small *et al.* 1998; and Longnose Suckers, *Catostomus catostomus*: McPhail and Taylor 1999), as well as other taxa (e.g., amphibians: Carstens *et al.* 2005). It is likely explained by the Bull Trout's historical isolation in, and subsequent post-glacial dispersal from, two distinct glacial refugia at the southern edges of the Cordilleran ice sheet during the late Pleistocene: the Chehalis Refuge and the Columbia Refuge (Taylor *et al.* 1999).

The Chehalis Refuge is a region dominated by drainages of the Chehalis River between the Columbia River and Puget Sound that was ice-free during much of the Pleistocene. Based on the distribution of endemic species and differentiated populations in fishes and plants, it was likely independent from the nearby Columbia Refuge (see Taylor *et al.* 1999). It was the probable refuge for *Genetic Lineage 1* Bull Trout, given the localization of this lineage around the southern region of British Columbia (the lower Fraser below Hell's Gate Canyon and Squamish systems), Puget Sound and the Olympic Peninsula in western Washington, the lower Columbia River, and the Klamath River in southwestern Oregon (Figure 2). Postglacial dispersal from this refuge into the lower Fraser or Columbia rivers or adjacent coastal systems may have occurred via freshwater connections through the Puget lowlands (McPhail 1967; Thorson 1980), or even via the sea given this group's anadromous behaviour (see '**Dispersal and Migration**' section). The Columbia Refuge probably served as the source of Bull Trout's *Genetic Lineage 2* postglacial colonists. Well-documented postglacial connections among the upper Columbia in the USA and Canada right through to more northern and eastern draining systems (i.e. Liard River in British Columbia, lower Peace, Athabasca, and South Saskatchewan rivers in Alberta) would have aided the dispersal of this group across the Continental Divide into interior regions (Lindsey and McPhail 1986; McPhail and Lindsey 1986).

Patterns of postglacial dispersal from these refugia can also account for peculiarities in the geographical distribution of the two lineages. For example, headwater faunal exchanges between interior and coastal drainages likely explain why all large coastal-draining systems north of the Squamish River (e.g., Skeena, Stikine, Nass, Klinaklini) carry *Genetic Lineage 2* Bull Trout mtDNA and microsatellite DNA alleles (Figure 3; Figure 4). Interdigitation of these rivers' extensive headwater tributaries is strongly suspected to be the route of past faunal exchanges (Lindsey and McPhail 1986; McPhail and Lindsey 1986) and was the likely conduit for the expansion of *Genetic Lineage 2* west of the Coast mountains' divide at its mid-northern end (Taylor *et al.* 1999; Taylor and Costello 2006).

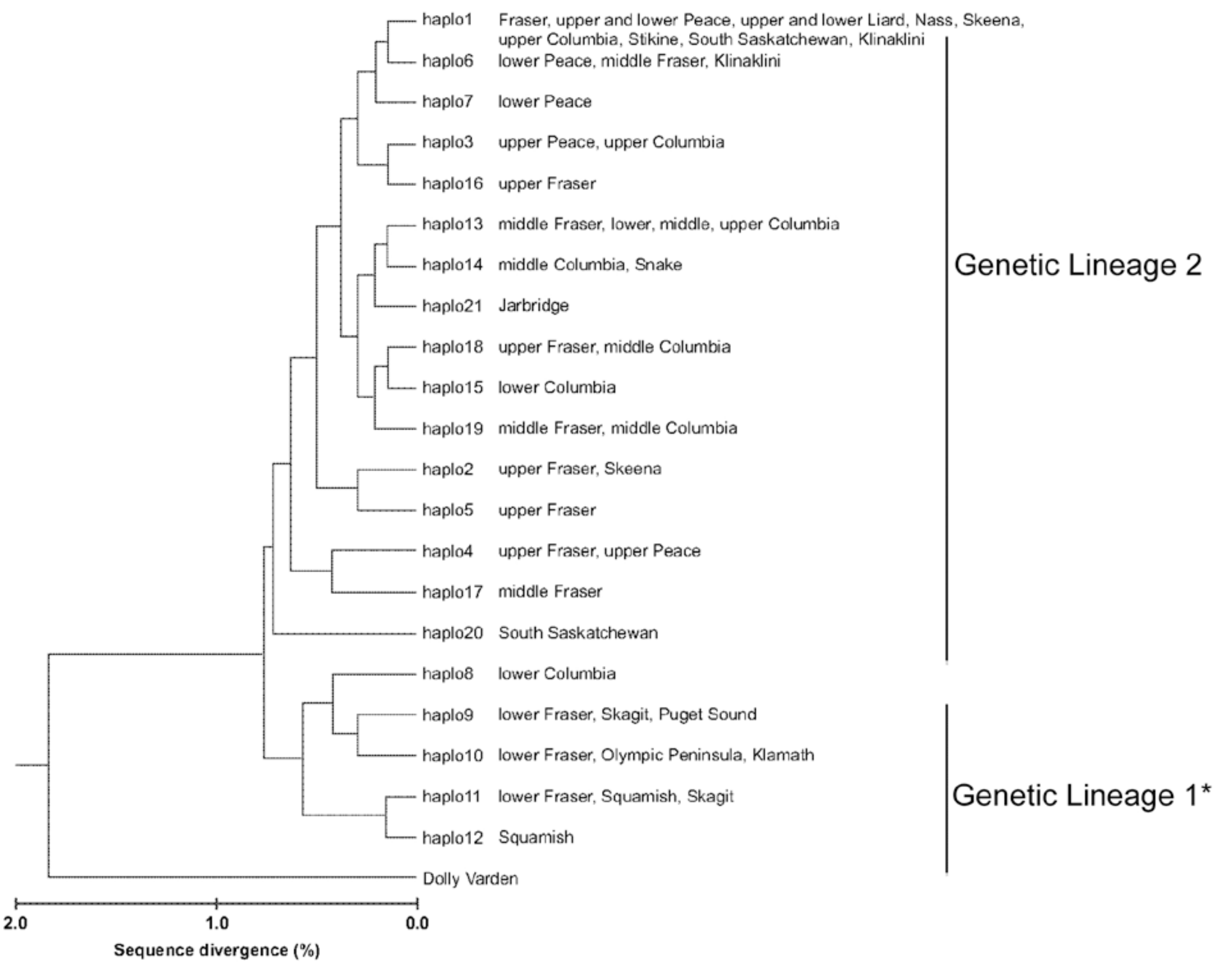

Figure 3. UPGMA dendogram of pairwise sequence divergence estimates from 21 restriction fragment length polymorphism mitochondrial DNA haplotypes. Includes 348 Bull Trout samples analyzed from 47 populations. For each haplotype, geographical locations in which it occurred are listed. Sourced from Taylor *et al.* 1999. Genetic lineages and probable anadromous populations (*) indicated.

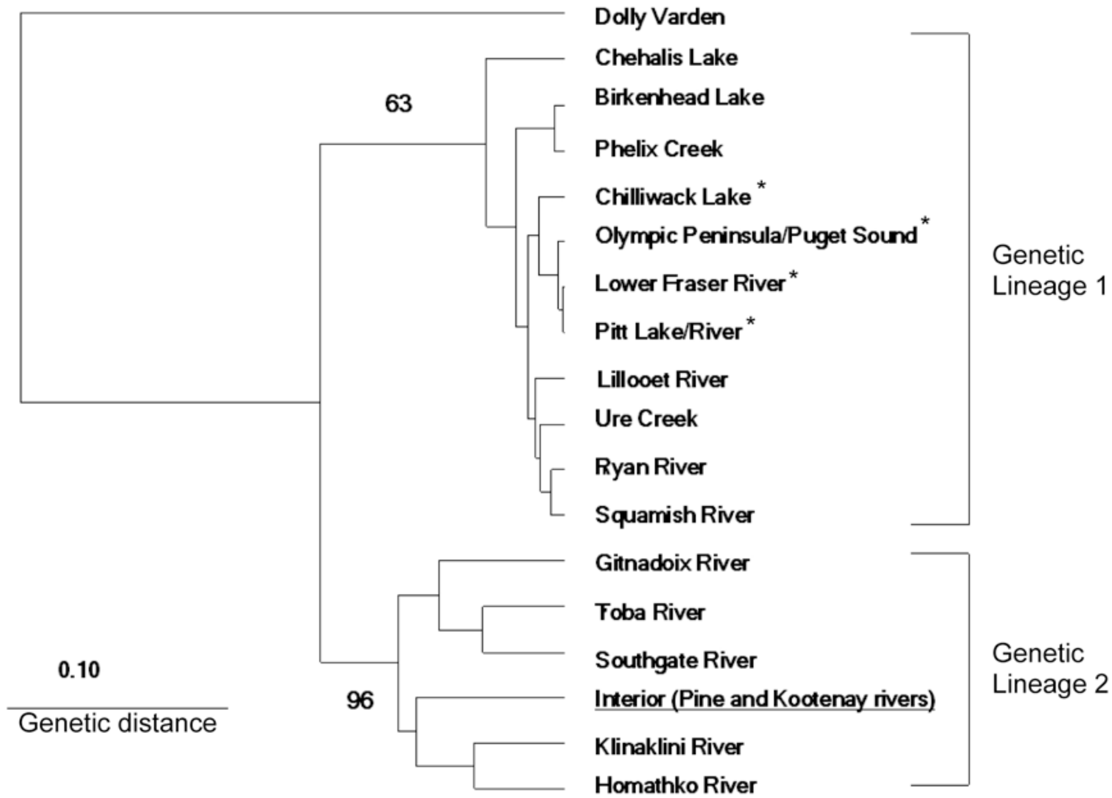

Figure 4. UPGMA dendogram of genetic similarity among 373 samples of Bull Trout from 20 populations estimated from variation across 7 microsatellite loci. Numbers along branches represent bootstrap scores from 1000 pseudoreplicate analyses. Sourced from Taylor and Costello 2006. Genetic lineages and probable anadromous populations (*) indicated.

Another anomaly occurs at the southern end of the Bull Trout's range. Here, *Genetic Lineage 1* predominates in the lower Columbia area at or west of the Cascade Crest (Figure 2; Taylor *et al.* 1999, Spruell *et al.* 2003) despite the presumed role of the Lower Columbia River valley as a glacial refuge for the *Genetic Lineage 2* lineage. Fish in the Columbia refuge likely concentrated east of this divide and dispersed mostly inland into the upper Columbia, Fraser and other northern interior drainages, while Bull Trout from the Chehalis Refuge went on to colonize the lower reaches of the Columbia River valley (Taylor *et al.* 1999). The hypothesis of the lower Columbia River not being a single faunal unit in terms of postglacial dispersal of freshwater fish was, in fact, postulated to account for the curious absence of several other species that occur widely elsewhere in this river system (McPhail and Lindsey 1986).

A further transition between Bull Trout *Genetic Lineage 1* and *2* occurs abruptly in the Fraser River at an area known to be difficult for fish passage, the Fraser Canyon (Figure 3). The Fraser Canyon is associated with abrupt shifts in the distribution of genetic variation within some other fish species (see Taylor *et al.* 1999), as well as changes in the geographical distribution of several others (McPhail and Lindsey 1986). Evidently, this point of biogeoclimatic change from coastal wetlands to dry interior represents a strong natural barrier to fish dispersal and has maintained a bimodal contact zone between the two Bull Trout lineages, which have colonized this river from opposite directions.

In addition to the major division of Bull Trout into two evolutionary lineages, the hierarchical division of genetic variation among local populations contributes to our understanding the extent and origin of diversity within Bull Trout. Throughout Bull Trout's range, most genetic variation resides at the interpopulation and inter-region level. For example, a mtDNA survey (115 restriction sites over 410 base pairs) of 47 populations (N = 348) sampled from across its geographical range revealed that 55% of the variation was found between *Genetic Lineage 1* and *2*, 33% between populations within these groups and only 12% within them ($P < 0.00005$; Taylor *et al.* 1999). Similarly, a comprehensive survey of microsatellites (N = 7) among 57 populations (N = 1561) sampled from across its range found most variation (46%) between the two lineages, 21% among populations within groups and 33% within them ($P < 0.001$; Taylor and Costello 2006).

Not surprisingly, therefore, there is a high degree of substructure within geographical lineages; overall F_{ST} among populations (N = 8-37) within lineages but spanning many hundreds of kilometres have been consistently estimated as lying between 0.30 and 0.39 ($P < 0.005$) in microsatellite ($N \geq 5$) studies (Taylor *et al.* 2001; Costello *et al.* 2003; Whiteley *et al.* 2004; Taylor and Costello 2006). Significant microsatellite differentiation among populations ($P < 0.05$) within localized areas is even common (Spruell *et al.* 1999; Taylor *et al.* 2001; Costello *et al.* 2003; Taylor and Costello 2006). However, caution is warranted in defining Bull Trout populations according to *a priori* stream-of-origin designations. As for other stream-spawning fishes, fine-scale population structure in Bull Trout has traditionally been explored by designating genetic populations according to where individuals were captured. However, not all streams-of-origin may represent genetically distinguishable units and, even though levels of gene flow are considered to be low amongst Bull Trout populations, we cannot assume that each individual sampled at a site was born there.

Rather than assume a certain geographic population structure prior to analysis, a more appropriate approach in systems showing low levels of gene flow may be to define genetic populations statistically, independent of capture location, using model-based genetic clustering methods. A comparison of genetic clustering methods and a traditional stream-of-origin approach applied to Bull Trout in southwestern Alberta found the stream-of-origin approach was prone to overestimating population structure due to genetic and statistical effects (Warnock *et al.* 2010). In contrast, the genetic clustering methods are less likely to generate spurious groupings and define them within a hierarchical structure (Warnock *et al.* 2010). Because the designation of populations has strong implications for management decisions, future genetic studies on Bull Trout should be based on this more objective approach.

The restricted gene flow suggested by the high degree of substructure found within geographical lineages of Bull Trout will favour divergence among different selective environments (Lenormand 2002). Given empirical evidence that estimates of neutral genetic divergence provide conservative estimates of adaptive divergence (Pfrender *et al.* 2000; Morgan *et al.* 2001), microsatellite assays of neutral genetic variation are likely to be conservative estimates of Bull Trout biodiversity. As is common among salmonids (Quinn and Dittman 1990), Bull Trout most likely diverge in quantitative traits important to population persistence in specific environments. Local adaptation will likely be most evident at larger scales, for example among populations inhabiting the four different National Freshwater Biogeographic Zones that the Bull Trout's range straddles (NFBZ 4 [Saskatchewan-Nelson Rivers Watershed], 6 [Yukon River Watershed], 11 [Pacific] and 13 [Western Arctic]; Figure 5). The disjunction between two groupings of these ecozones (Areas 4 and 13, and 11 and 6) by the Rocky Mountains, in particular, is likely to foster adaptive divergence.

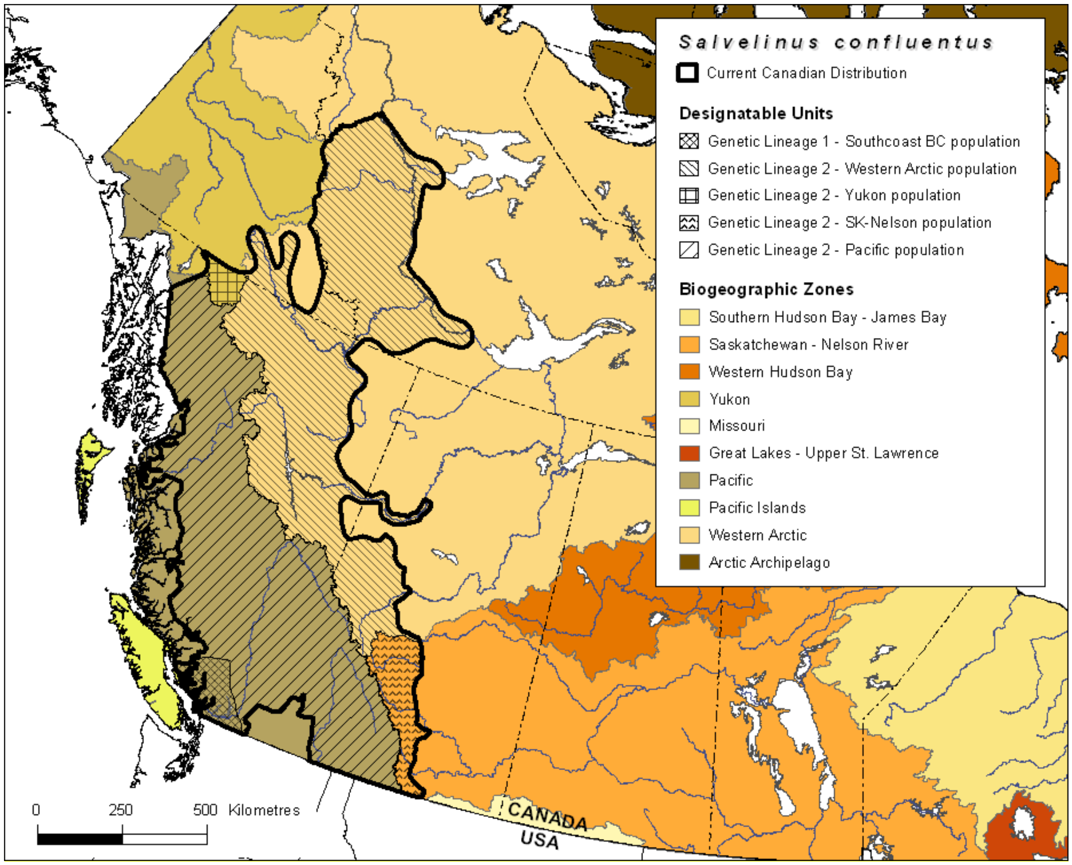

Figure 5. Canadian distribution of Bull Trout. Data from: Province of British Columbia (2007); Rodtka 2009; Laframboise (pers. comm. 2010); Parkinson (pers. comm. 2010); Mochnacz *et al.* (submitted); Reist and Sawatzky (in prep.); Hagen and Decker (2011).

Although the concentration of genetic variation among populations and geographical regions is commonly observed in freshwater fish species (e.g., Ward *et al.* 1994), this pattern is pronounced in Bull Trout, and perhaps char in general (Wilson *et al.* 1996; Angers and Bernatchez 1998) relative to many other salmonids (e.g., Bernatchez and Osinov 1995; Whiteley *et al.* 2004; Harris and Taylor 2010). On the other hand, genetic variability within Bull Trout populations is typically lower than that of many other freshwater salmonids, including other char. Average expected heterozygosity (H_E) from a microsatellite (N = 7) survey of 20 populations (N = 373) spanning the coastal range of Bull Trout in northwestern Washington and southern B.C. (but encompassing both *Genetic Lineages 1* and *2*) was 0.35 (Taylor and Costello 2006). Another survey of the same loci over 37 *Genetic Lineage 2* Canadian populations (N = 1188) found an even lower average H_E of 0.24 (Costello *et al.* 2003). This compares to an average H_E of 0.62 among five other freshwater salmonid species (see Costello *et al.* 2003). This pattern of low genetic diversity is consistently found within Bull Trout populations across its range using other independent genetic markers (allozymes: Leary *et al.* 1993; mtDNA: Taylor *et al.* 1999), as well as microsatellites (Spruell *et al.* 1999, 2003; Taylor *et al.* 2001; Whiteley *et al.* 2006).

While depauperate neutral genetic variation within populations does not necessarily imply low variability at fitness-related traits (Armbruster *et al.* 1998; Pfrender *et al.* 2000), this coupled with high differentiation between populations strongly suggests that Bull Trout have been subjected to large and repeated reductions in effective population size. This will have resulted in part from the influence of postglacial dispersal on stochastic demographic processes such as founder events, bottlenecks, and genetic drift (Hewitt 1996). The influence of historical postglacial recolonization on genetic variation is illustrated by significant reductions ($P < 0.05$) in microsatellite diversity (H_E and number of alleles) in populations that are peripheral to the putative refugia (Costello *et al.* 2003; Whiteley *et al.* 2006). Contemporary factors will also influence these demographic processes, modifying historical patterns of intraspecific genetic variation. For example, microsatellite surveys have shown that migration barriers (both human-constructed and natural) influence distribution of genetic variation among Bull Trout populations (Costello *et al.* 2003; Whiteley *et al.* 2006). The extent of their impact varies spatially, however, and interacts with other important influential factors, such as watershed area and habitat complexity (Costello *et al.* 2003; Whiteley *et al.* 2006).

Life-history characteristics will strongly affect the impact of these demographic processes. As a long-lived, late-maturing top aquatic predator, Bull Trout populations tend to be relatively small (see '**Population and Sizes**' section). This makes them especially vulnerable to the effects of founder events and bottlenecking (Avise 2004). Radiotelemetry shows this largely migratory species displays strong site fidelity to spawning area and overwintering habitat (Swanberg 1997a; Bahr and Shrimpton 2004); a characteristic that is linked to increased population differentiation (Quinn and Dittman 1990). Other intrinsic barriers, such as avoidance of marine waters by most populations, could also constrain gene flow between local populations. Salmonid fishes that make migrations to sea are usually less genetically subdivided than those that are freshwater bound (Ward *et al.* 1994). Nevertheless, there is no compelling evidence to suggest that sea migration affects genetic structure in Bull Trout (although it awaits closer scrutiny); anadromous (see '**Dispersal and Migration**' section) *Genetic Lineage 1* populations ($F_{ST} = 0.33$, $P < 0.001$; Taylor and Costello 2006) are no less structured than non-anadromous *Genetic Lineage 2* ones ($F_{ST} = 0.33\text{-}0.39$, $P < 0.005$; Taylor *et al.* 2001; Costello *et al.* 2003).

Given the plethora of historical, contemporary landscape and biological influences, it is no surprise that there is considerable variation in genetic structure across the range of Bull Trout at the fine scale. Within the broad pattern of low genetic diversity within and high differentiation between populations, there are significant differences in mean H_E, number of alleles, and pairwise F_{ST} among river basins (Whiteley *et al.* 2006). This indicates the varying roles of genetic drift and gene flow at this scale.

Designatable Units

Designatable units (DUs) in Bull Trout within Canada were evaluated in light of the discreteness and significance criteria of COSEWIC (2009). In terms of discreteness, Bull Trout occupy four of Canada's fourteen National Freshwater Biogeographic Zones (NFBZs; Zones 11 [Pacific], 4 [Saskatchewan-Nelson River], 13 [Western Arctic] and 6 [Yukon River Watershed]), resulting in several putative DUs. Recognition of these putative DUs is further supported by various aspects of the zoogeography, ecology, and evolutionary history of Bull Trout.

First, the Pacific NFBZ (Figure 5) encompasses in part, Bull Trout populations east of the Coastal-Cascade Mountain crest that are tributary to the North Pacific Ocean. Their extinction would constitute a loss of approximately 50% of the range of Bull Trout, and the vast majority (> 90%) of the range west of the Continental Divide. This assemblage of populations is also the only one to contain representatives of *Genetic Lineage 1*, the major evolutionary Bull Trout lineage which dominates populations south of about 50 degrees north latitude. *Genetic Lineage 1* contains the only anadromous (sea-going) Bull Trout, a major life history difference with attendant adaptations for survival in marine waters relative to inland populations. Although it awaits closer scrutiny, there is no compelling evidence to suggest that sea migration affects genetic distinctness in Bull Trout (Taylor *et al.* 2001; Costello *et al.* 2003).

The Pacific NFBZ also harbours representatives of the other major evolutionary Bull Trout lineage, *Genetic Lineage 2*. While most river systems within this NFBZ harbour populations belonging to just one of these, one major river system, the Fraser River, holds populations from both. These lineages are distinguished by mtDNA, and corroborated by a diverse and independent set of traits (neutral nuclear DNA markers, other inherited traits and biogeographical patterns). Two putative DUs for the Pacific NFBZ are, therefore, proposed: *Genetic Lineage 1: Southcoast BC populations, and Genetic Lineage 2: Pacific populations*). All other putative DUs contain only representatives of *Genetic Lineage 2*.

Second, the Yukon River Watershed NFBZ (Figure 5) encompasses a proposed DU (*Genetic Lineage 2: Upper Yukon Watershed populations*) whose populations are tributary to the Yukon River drainage. They represent the only assemblage of Bull Trout populations west of the Continental Divide in a system that is tributary to the Bering Sea. The Yukon River watershed in British Columbia (where Bull Trout occur) has a distinctive freshwater fauna (e.g., many species were derived from the Bering Glacial Refuge (Lindsey and McPhail 1986) such that these populations of Bull Trout exist in an ecological setting that is very unusual for the species as a whole.

Third, the Western Arctic NFBZ (Figure 5) encompasses a proposed DU (*Genetic Lineage 2: Western Arctic populations*) whose populations are from the Mackenzie River system (and major tributaries such as the Liard, Peace and Athabasca rivers). These rivers have a distinctive zoogeographic assemblage of fishes (being a variable mix of largely Bering and Great Plains species), and loss of these populations would eliminate approximately 30% of the range of Bull Trout and the few that occur north of the Arctic Circle.

Finally, the Saskatchewan-Nelson Rivers Watershed NFBZ (Figure 5) consists of a proposed DU (*Genetic Lineage 2: Saskatchewan-Nelson populations*) whose populations are tributary to the western headwaters of the North and South Saskatchewan rivers. These systems, particularly the latter are dominated by a Great Plains fish fauna within an environmental setting that is quite distinct compared to other northern-flowing Arctic drainages (which also flow east of the Continental Divide). Loss of these populations would eliminate the only component of the Bull Trout assemblage in Canadian watersheds that are tributary to the Hudson Bay drainage.

In summary, recognition of five DUs in Bull Trout is based on the obvious discreteness inherent in two phylogenetic lineages occupying four NFBZs. Each of these DUs is also significant in terms of the distinctive ecological and zoogeographic settings that they represent (and the realized and inferred attendant phylogeographic and adaptive differences associated with such distinctions), their current demographic independence (all are and have been historically separated by natural watershed divides, and the major gaps in distribution of Bull Trout that would be created should any DU become extinct. Consequently, this report recognizes five DUs for Bull Trout in Canada (Figure 5):

DU1 [*Genetic Lineage 1: Southcoast BC populations*]
DU2 [*Genetic Lineage 2: Western Arctic populations*]
DU3 [*Genetic Lineage 2: Upper Yukon Watershed populations*]
DU4 [*Genetic Lineage 2: Saskatchewan-Nelson River populations*]
DU5 [*Genetic Lineage 2: Pacific populations*]

Special Significance

Bull Trout's worldwide *Vulnerable* status (NatureServe 2009; IUCN 2010) reflects its moderate risk of extinction or elimination. Although there has been a general decline throughout its range during the last century, the Canadian range of Bull Trout is considered to be its stronghold; a general north to south trend in the status of populations describes increasing imperilment near its southern margins (Haas and McPhail 1991). Bull Trout is listed as *Threatened* under the *Endangered Species Act* (USFWS 1999) in the USA, with many of its populations having become extinct or isolated (Rieman and McIntyre 1993). The Bull Trout's narrow tolerance to environmental conditions, combined with its broad distribution in British Columbia, leads it to be used as an indicator species in this province, whose population status may be representative of the health of the watersheds in which it occurs (BCMWLAP 2002).

Although there has been little investigation into Bull Trout's ecological role, its voracious, piscivorous appetite is probably a strong influence on community structure, and ecosystem energy and nutrient flows. This supposition is supported by studies on other piscivorous fishes, including char, which demonstrate their capacity to indirectly regulate organisms at lower trophic levels (e.g., Dolly Varden: Nakano *et al.* 1999; Baxter *et al.* 2004; Brook Trout: Bechara *et al.* 1992). Coupled with their migratory life histories, this characteristic likely leads Bull Trout to link food webs, as well as the flow of energy and nutrients, between different habitats. Again, support for this role comes from descriptions of other migratory fishes (e.g., Gende *et al.* 2002).

Considerable life history diversity characterizes this species. Anadromous *Genetic Lineage 1* populations in the south west of British Columbia (Fraser and Squamish drainages) and northwest of Washington are of particular interest for their unique migratory behaviour (Cavender 1978; Haas and McPhail 1991; Brenkman and Corbett 2005; Brenkman *et al.* 2007). In addition, high levels of genetic diversity residing at the interpopulation and inter-region level typify Bull Trout. A growing understanding of this phylogeography contributes to a broader understanding of the biogeography of northwestern North America (e.g., Taylor *et al.* 1999). Contact sites between Bull Trout and Dolly Varden are of particular scientific interest, where sympatric populations persist as genetically distinct species in the face of ongoing hybridization. This contact zone provides important opportunities for biogeography and evolutionary research, such as:

1. The historical and geographic contexts of past introgression and current hybridization (Rieseberg 1998);
2. The potential role of ecology and genetics in structuring hybrid zones and influencing the evolution of reproductive isolation itself (Jiggins and Mallet 2000);
3. The concordance between aquatic and terrestrial "suture zones", broad areas of contact and hybridization between formally isolated species that are roughly coincident across a broad range of taxa (Remington 1968).

Once considered 'junk' fish because of their tendency to prey on other salmonids (McPhail 2007; Dunham *et al.* 2008), Bull Trout are now valued as sportfish. For example, there are locally important recreational fisheries in the lower Fraser River (especially between New Westminster and Vancouver, Chilliwack Lake, Squamish River, Pitt Lake, and upper Pitt River, Taylor and Costello 2006), as well as in the upper Columbia Basin (Hagen 2008). Misidentification of Bull Trout with other trout and char species (Rodtka 2009) increases the fishing pressure on this species that is particularly sensitive to overharvesting (Paul *et al.* 2003; Post *et al.* 2003).

DISTRIBUTION

Global Range

Bull Trout are endemic to western Canada and the U.S. Pacific Northwest and, like many other taxa that have recolonized formerly glaciated areas, Bull Trout occupy a large geographic range (Figure 5; Figure 6). Their current distribution extends from the Oregon-California border and northern Nevada (42 ^{o}N) north to southern Yukon and southwestern Northwest Territories (65 ^{o}N; Haas and McPhail 1991; Mochnacz *et al.* 2009). Although Bull Trout do reach the Pacific Coast in southwestern British Columbia (Fraser and Squamish drainages) and north west Washington (Skagit drainage and the Olympic Peninsula; Cavender 1978; Haas and McPhail 1991), and extend to approximately 113 ^{o}W, they are generally restricted to interior drainages (Haas and McPhail 1991). Concentrated west of the Continental Divide, Bull Trout extend across the eastern slope of the Continental Divide to their eastern edge (114 ^{o}W); from the upper Columbia and South Saskatchewan systems in western Montana and Alberta north to the Mackenzie River system in the Northwest Territories (Haas and McPhail 1991; Reist *et al.* 2002).

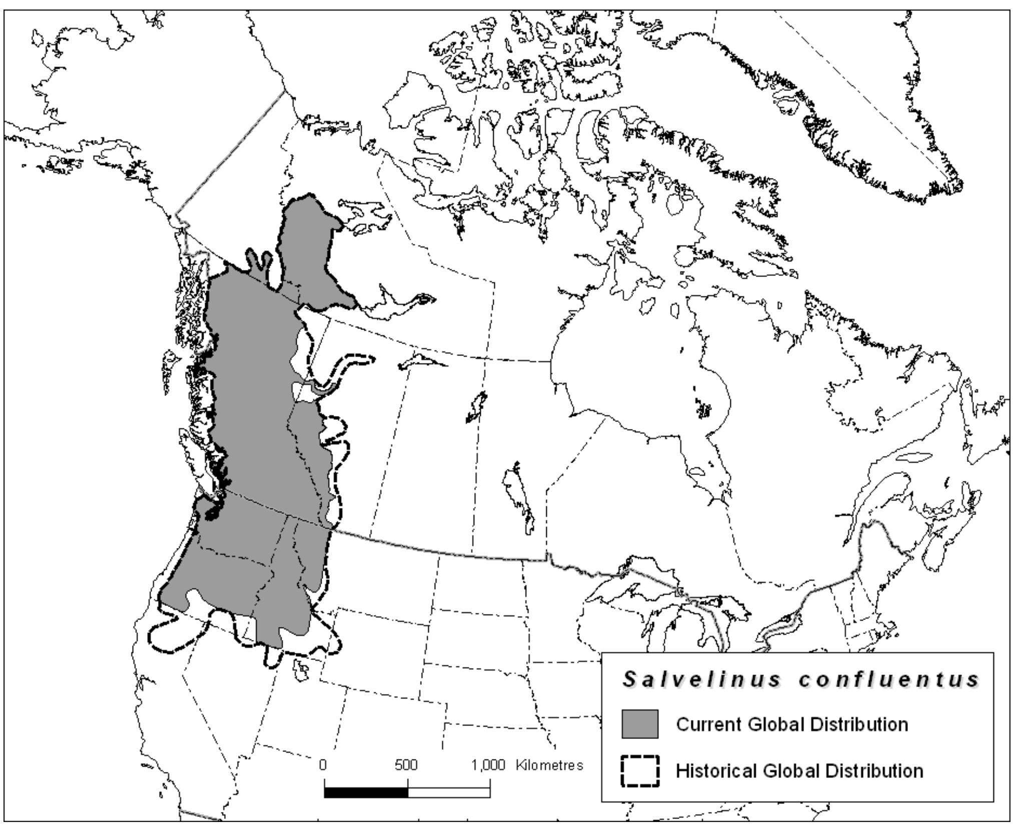

Figure 6. Approximate current and historical global range of Bull Trout. Distribution is not continuous throughout range. Historical range sourced from McPhail and Baxter 1996; current range modified from Figure 5, USFWS2008, Rodtka 2009).

Their range in the contiguous US, however, has become greatly restricted in recent times. Historically, they were considerably more widespread (Rieman *et al.* 1997; USFWS 1999; Figure 6). Originally found in northern California (41^{o}N), they have been extirpated from all but northern parts of Nevada, although they are still to be found in Washington, Idaho, Montana, and Oregon, with the southern extent of their range now lying at the Oregon-California border (42 ^{o}N; Haas and McPhail 1991; USFWS 2008). Populations have been historically fragmented but remnant Bull Trout populations have now likely become even more isolated (Rieman *et al.* 1997). Temperature appears to be an important determinant of the southern limit of cold water fish (Dunham *et al.* 2003) and, as one moves north through its range, Bull Trout appear to increase in the number of sites where they occur (Haas and McPhail 1991; McPhail 2007). This trend is likely due, at least in part, to the more pristine and suitable environments in northerly regions (Haas and McPhail 1991). In recent decades, the distribution of Bull Trout has also declined in eastern parts of its range in Alberta (Rodtka 2009; see below).

Canadian Range

The largest portion of Bull Trout's global range occurs in western Canada (about 80% of its global range; Rieman *et al.* 1997), occurring in British Columbia, Alberta, Yukon and the Northwest Territories across four NFBZs (Figure 5): Zones 4 (Saskatchewan-Nelson River Watershed), 6 (Yukon River Watershed), 11 (Pacific), and 13 (Western Arctic). In fact, the majority of the land base for extant populations of Bull Trout is in British Columbia (Pollard and Down 2001). It is considered the last remaining jurisdiction with wide distribution of Bull Trout (Pollard and Down 2001; McPhail 2007); it is known to occur in 26 of 36 Ecological Drainage Units (EDUs) that have been defined in British Columbia (Hagen and Decker 2011). This classification level represents distinct major water drainages that contain unique fish assemblages based on broad zoogreographic, physiographic and climate patterns (Ciruna *et al*. 2007). Bull Trout are found in the cool waters of most major mainland drainages of this province; they are distributed throughout interior river drainages (e.g., upper Columbia, Peace, Liard, and Yukon River drainages) and in those major coastal drainages that penetrate the Coast Mountains into the interior of the province (e.g., the Fraser, Homathko, Klinaklini, Skeena, Nass, Iskut-Stikine, and Taku rivers (Haas and McPhail 1991; McPhail 2007; Hagen and Decker 2011). They are absent, however, from Vancouver Island, the Queen Charlotte Archipelago, and three adjacent, warm water drainages (Okanagan, Kettle and Similkameen) of the southern interior (Figure 5; Haas and McPhail 1991; McPhail 2007; Hagen and Decker 2011). Coastal populations of *Genetic Lineage 1* found on the British Columbia's south coast (e.g., Squamish River, Lower Fraser River) are isolated from the coastal lineage of *Genetic Lineage 2* by an extensive area of coastline between the Squamish watershed on the south coast and the Homathko watershed on the central coast (McPhail 2007; Hagen and Decker 2011). In the shorter coastal mainland rivers between these rivers, Dolly Varden are thought to be the only native char species present (McPhail 2007; Hagen and Decker 2011).

Detailed knowledge of Bull Trout distribution has been considered inadequate for most areas of British Columbia (Cannings and Ptolemy 1998), and expert opinion has often been relied upon to provide best estimates. Increased efforts in reconnaissance level inventories over the past 15 years have improved our understanding of general Bull Trout distribution in this province (Pollard and Down 2001), although some gaps in Bull Trout records most likely still exist, particularly in remote or pristine areas with low levels of industrial activity e.g., broad areas of the Middle Fraser, and the northernmost parts of BC (reviewed in Hagen and Decker 2011). Gaps in knowledge also occur in coastal headwater streams where recent sampling has identified Bull Trout in systems thought to be fishless (E. Stoddard, pers comm. 2009) In contrast to these sources of error that likely result in underestimation bias, a key source of overestimation bias that needs to be mitigated is the broad zone of Bull Trout sympatry with Dolly Varden, where positive identification is difficult (Hagen and Decker 2011). This issue represents a major source of uncertainty with respect to the distribution and status of both species throughout a large portion of British Columbia (Hagen and Decker 2011).

Bull Trout is the only native char species that can be found in all of the major eastern slope drainages in Alberta (Peace, Athabasca, South Saskatchewan and North Saskatchewan River drainages [Figure 5; Haas and McPhail 2001; Rodtka 2009]). Historically, Bull Trout was even more widely distributed in this province (Figure 6), with anecdotal information and limited historical records suggesting a large decline in distribution in all the river systems occupied in Alberta since the early 1900s. Where Bull Trout were once to be found further downstream, they now tend to occupy only the upstream reaches of the major drainages. Most populations are now found within the Rocky Mountain and Foothills natural regions, as well as a small portion of the Peace River Parkland and Dry Mixedwood subregions (Rodtka 2009). They can, however, be found further inland in the more northerly Peace and Athabasca drainages, albeit in lower abundance (Berry 1994).

Previous taxonomic confusion, combined with generally poor sampling of northern areas (> 60^{o}N), has led to uncertainty in the northern limit of Bull Trout's range. While taxonomic resolution and identifications between Dolly Varden and Bull Trout were addressed for the other provinces and territories in which Bull Trout is found by Haas and McPhail (1991), the situation remained unresolved in the Northwest Territories until 2002 (Reist *et al.* 2002). Their review of historical records and new specimens revealed Bull Trout occurs in the western portion of the Northwest Territories, in Mackenzie River drainages north to the central Sahtu Settlement Area (Reist *et al.* 2002). Work since then has continued to strengthen our knowledge about the northern extent of this species: e.g., Mochnacz *et al.* (2006), Mochnacz and Reist (2007) and Mochnacz *et al.* (submitted) have confirmed that Bull Trout is widely but sparsely distributed throughout much of southern (Deh Cho) and central (Sahtu) Northwest Territories in drainages west of the Mackenzie River (Figure 5). To date the northernmost location known is the Gayna River (Mochnacz *et al.* 2009). While this summarizes our most up-to-date understanding of Bull Trout's distribution in the Northwest Territories, new information from this area will continue to refine our knowledge as it becomes available (Reist and Sawatzky 2010).

In Yukon, Bull Trout occur mainly in the Liard River drainage basin but are also thought to occupy the upper Yukon River watershed (Figure 5). Since a Bull Trout sample from the Liard River (which drains into the Mackenzie River) corroborated its presence in the southeast of this territory (Haas and McPhail 1991), Bull Trout has been confirmed in numerous drainages and lakes of the Liard River watershed in southeast Yukon (Can-nic-a-nick Environmental Sciences 2004). Although the overall distribution of Bull Trout in this remote area remains somewhat unclear, a recent modeling exercise and site visits reveal that Bull Trout is likely widespread in this drainage basin (Miller pers. comm. 2010). On the other hand, little is known about the distribution of Bull Trout in the upper Yukon River watershed drainage. Bull Trout have been found in the extreme headwaters of this drainage in northwestern British Columbia (Haas and McPhail 1991) and a traditional knowledge study undertaken by the Teslin Tlingit Council in the late 1990s indicated that fish of the Dolly Varden/Bull Trout complex could be found in rivers of the Yukon River drainages within their Traditional Territory (Connor *et al.* 1999). Anecdotal reports also report char from this area. However, a thorough survey failed to capture any from this vicinity (Connor *et al.* 1999).

The extent of occurrence (EO) and index of area of occupancy (IAO) were estimated for each DU according to the COSEWIC guidelines (i.e. using the minimum convex polygon method for EO, and using an overlaid grid of cells 2kmX2km for IAO). All index of area of occupancy (IAO) calculations are minimum estimates based on confirmed Bull Trout observations. Although many smaller streams are known to support seasonal adult populations and/or juvenile or resident populations of Bull Trout (Christiansen pers. comm. 2010), the Bull Trout observation data used here is limited to larger order rivers and streams. The IAO estimates are, therefore, likely to be underestimates. In every instance, recorded observations are insufficient to accurately calculate IAO and estimates are provided only as rough guidelines for comparison with threshold values:

- DU1 [*Genetic Lineage 1: Southcoast BC populations*] range includes the Skagit River, Squamish River, Ryan River, Ure Creek, Lillooet River, Pitt Lake/River, Lower Fraser River (below Hell's Gate Canyon), Chilliwack Lake, Phelix Creek, Birkenhead Lake, and Chehalis Lake (Taylor *et al.* 1999; Taylor and Costello 2006). Its EO is estimated to be 32,053 km². The IAO is in excess of the Threatened threshold of 2000 km².
- DU2 [*Genetic Lineage 2: Western Arctic populations*] range includes Mackenzie River drainages including the Liard, Peace and Athabasca River basins. Its EO is estimated to be greater than 20,000 km². The IAO is in excess of the Threatened threshold of 2000 km².
- DU3 [*Genetic Lineage 2: Yukon River Watershed populations*] range includes the upper Yukon River basin. There is a lack of information about Bull Trout distribution for this DU. EO and IAO are unknown for this DU.
- DU4 [*Genetic Lineage 2: Saskatchewan-Nelson Rivers populations*] range includes North and South Saskatchewan River drainages. Its EO is estimated to be greater than 20,000 km². The IAO is in excess of the Threatened threshold of 2000 km².

- DU5 [*Genetic Lineage 2: Pacific populations*] range includes the Upper Columbia, Fraser above Hell's Gate Canyon, Homathko, Klinaklini, Skeena, Nass, Iskut-Stikine and Taku rivers. Its EO is estimated to be greater than 20,000 km². The IAO is in excess of the Threatened threshold of 2000 km².

HABITAT

Habitat Requirements

General

The Bull Trout is a cold water species generally found in water below 18^{o}C, but most commonly in temperatures less than about 12^{o}C (Dunham *et al.* 2003). Indeed, its southern range is limited by temperature (Dunham *et al.* 2003). The Bull Trout's habitat requirements go far beyond temperature, however, being more specific than other salmonids (Rieman and McIntyre 1993). Characteristic requirements are habitat that is cold, clean, complex, and connected (USFWS 2008). Their habitat use is also strongly influenced by the presence, or absence, of other species (see '**Interspecific Interactions**' section).

All life history stages need complex forms of cover, with Bull Trout tending to conceal themselves by remaining near or closely associating with the substrate, submerged wood, or undercut banks (Rieman and McIntyre 1993; Watson and Hillman 1997). Bull Trout also have specific requirements regarding channel and hydrologic stability that include depth, velocity, and substrate parameters (Rieman and McIntyre 1993; Watson and Hillman 1997). The association with substrate appears more important for Bull Trout than for other species (Nakano *et al.* 1992).

Although Bull Trout may be present throughout large river basins, their specific and changing habitat requirements mean that they will only be found in patches of a system (Rieman and McIntyre 1995). Large scale studies of spatial patterns of habitat patch occupancy show that persistence in stream networks is strongly dependent on patch size (stream or watershed size), connectivity, and quality (Rieman and McIntyre 1995; Dunham and Rieman 1999). The importance of habitat size and connectivity is further supported by models of Bull Trout population dynamics investigating the temporal processes driving these patterns, such as dispersal, demographic variation and environmental variability (Rieman and Allendorf 2001). Molecular genetic studies also show that disruption of connectivity can lead to lower effective size of local populations by simultaneously reducing dispersal and local adult population sizes (Costello *et al.* 2003; Taylor and Costello 2006; Whiteley *et al.* 2006).

These specific habitat requirements are, in fact, Bull Trout's most significant natural limiting factor (reviewed in Rieman and McIntyre 1993; Dunham *et al.* 2003). Such specificity makes Bull Trout particularly vulnerable to human induced habitat change and makes it less able to persist in the face of such change (Rieman and McIntyre 1993, 1995). Their habitat utilization varies according to both life-history stage and migratory form of the adult, as well as shifting on a daily and seasonal basis. Major transitions in habitat use over the Bull Trout's life history are illustrated schematically in Figure 7. All of these variations are discussed below. Habitat requirements appear to be largely similar for Bull Trout across their range (Stewart *et al.* 2007a) and the description given herein refers to all Canadian Bull Trout DUs. In addition to specific references cited below, much of the information came from reviews given in Stewart *et al.* (2007a) and Rodtka (2009). Specific statements given without citation refer to these reviews.

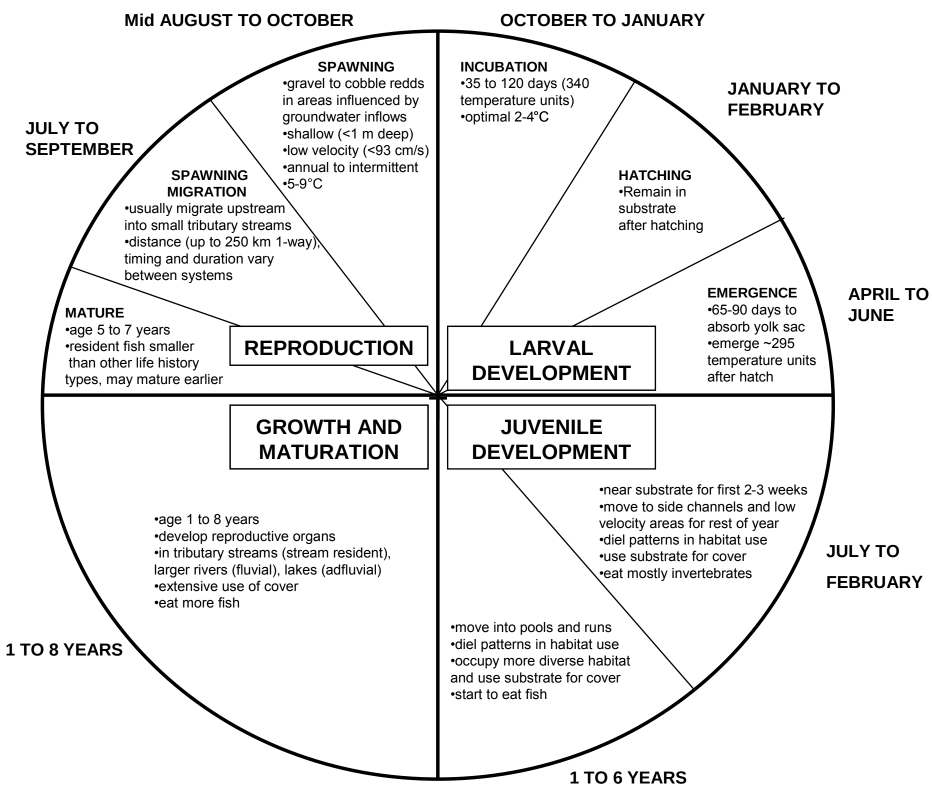

Figure 7. Generic habitat use by Bull Trout throughout their life cycle. Modified from Stewart *et al.* 2007a.

Natal streams and spawning

Bull Trout natal streams tend to be shallow, structurally diverse headwater or tributary streams with stable channels found at higher elevations (Burrows *et al.* 2001; Ripley *et al.* 2005; Decker and Hagen 2008). Their structural diversity not only meets habitat requirements of spawning adults but also provides for the changing habitat needs of rearing juveniles. These natal habitats occur as discrete patches of suitable habitat in a matrix of the larger stream network (Baxter 1997; Dunham and Rieman 1999; Decker and Hagen 2008). Watershed size appears to be a significant factor in providing essential connectivity between these habitats (Rieman and McIntyre 1995).

Once in their natal streams (following migration for adfluvial and fluvial forms), Bull Trout undergo a behavioural transition in habitat use towards a pattern of daytime concealment and nighttime emergence (Jakober *et al.* 2000). Concealment cover includes woody debris and substrate crevices (Jakober *et al.* 2000).

Bull Trout spawn in flowing water. Because eggs incubate over the winter, incubation sites are particularly vulnerable to anchor ice accumulations, as well as scouring and low flows. Females, therefore, often select spawning sites associated with groundwater sources that stabilise temperatures through the winter (Baxter 1997; Baxter and McPhail 1999; Baxter and Hauer 2000; Ripley *et al.* 2005). Within these areas of upwelling, they tend to select localized spots of strong down welling and high intergravel flows (Baxter and Hauer 2000). These occur over coarse gravel-cobble substrates that have low levels of fine sediment, for example, the tail-outs of pools at the heads of riffles (Baxter and Hauer 2000). The specific selection of these characteristics increases aeration of eggs. Successful incubation is dependent on several stream characteristics, including appropriate temperature (see '**Physiology and Adaptability**' section), gravel composition, permeability and surface flow.

Fry and young juvenile rearing

The preference of young Bull Trout for coarser substrate than is used by spawning adults appears to be heavily influenced by avoidance of predation and competition. In the spring, newly emerged young-of-the-year Bull Trout fry are denser than water and seek cover in shallow, slow-flowing stream margins with coarse cobble-boulder substrate (Pollard and Down 2001; Spangler and Scarnecchia 2001). As these juveniles grow, they tend to shift to deeper, faster flowing water, preferring pools over riffles (Bonneau and Scarnecchia 1998; Pollard and Down 2001; Spangler and Scarnecchia 2001). During the early months and years of life, when juvenile Bull Trout are rearing in their natal streams, microhabitat use shifts both daily and seasonally. During all seasons, juveniles are secretive during the day, remaining close to cover, and disperse more at night (Bonneau and Scarnecchia 1998; Jakober *et al.* 2000). This pattern of daytime concealment and nighttime emergence is particularly pronounced in winter (Bonneau and Scarnecchia 1998; Jakober *et al.* 2000). Juveniles tend to shift to deeper, slower-flowing water in the fall, where they stay in contact with coarse substrates and remain closer to cover (Bonneau and Scarnecchia 1998; Spangler and Scarnecchia

2001). This provides ice-free refuges for them throughout winter. Evidently, both shallow stream margins and deep water with low velocities provide important rearing areas for growing juveniles.

Cover use varies with latitude and elevation. As the diversity of cover type diminishes with increasing latitude and/or elevation (e.g., woody debris), juveniles have less opportunity to use shade, undercut banks and large woody debris (Mochnacz *et al.* 2006). Instead they make more use of pocket pools, rootwads, cobbles, boulders and overhanging vegetation for shelter (Mochnacz *et al.* 2006).

<u>Older juvenile and adult foraging and overwintering</u>

Similar to younger fish, maturing and adult Bull Trout tend to use habitat for foraging and overwintering that has the appropriate combination of temperature, shelter, and foraging opportunities. However, while stream habitat use by Bull Trout has been studied in detail, the specifics of habitat use of rivers, lakes, and coastal waters by these fish are poorly understood. Both fluvial and resident Bull Trout prefer low-velocity water, often associating with the tail-outs of pools, and tend to remain close to cover (McPhail 2007). Resident forms find this habitat not far from their spawning grounds.

While radio-telemetry indicates Bull Trout need only move a few kilometers in the fall to find ice-free overwintering sites (Jakober *et al.* 1998), those in northern latitudes may move further into larger tributaries. Just as groundwater upwellings are a preferred location for spawning, these sites that have more stable temperature regimes than areas of surface-water recharge (i.e. warmer during winter, colder during summer) can also provide resident Bull Trout with suitably cold water throughout the year (Baxter and Hauer 2000). In streams at least, Bull Trout undergo a behavioural transition in habitat use during winter towards a pattern of daytime concealment and nighttime emergence. This is negatively correlated to temperature and fish size (Jakober *et al.* 2000).

Migratory forms (fluvial and anadromous) seek suitable habitat out in the larger streams and rivers (or even the sea) that they both migrate through and eventually settle in to forage and overwinter (Burrows *et al.* 2001; Muhlfield and Marotz 2005). Based on fishing patterns, adfluvial adult Bull Trout appear to remain in deeper, cooler water during the day (mostly resting on the bottom) and then move to littoral areas for foraging at night (McPhail 2007).

Habitat Trends

Bull Trout habitat is less well characterized in the more remote reaches of its range although recent surveys in the British Columbia (Pollard and Down 2001), Yukon (Connor *et al.* 1999; Can-nic-a-nick Environmental Sciences 2004) and Northwest Territories (Mochnacz *et al.* 2006, 2009; Mochnacz and Reist 2007) are greatly improving our knowledge about habitat availability and Bull Trout distribution in these regions.

Bull Trout's specific habitat requirements, particularly its requirement for cold, clean tributary or headwater streams and the importance of groundwater springs for spawning and rearing of young, result in a patchy distribution across its broad geographical range (Rieman and McIntyre 1995). This pattern of natural fragmentation has been exacerbated over past decades, especially in the USA where remnant populations have become more isolated (Rieman and McIntyre 1993). The distribution of Bull Trout has declined over the past century, particularly in the southern and eastern parts of its North American range in the USA (Rieman *et al.* 1997; USFWS 1999) and Alberta (Rodtka 2009). For example, many USA strongholds for Bull Trout are now restricted to higher elevation wilderness areas (Rieman *et al.* 1997).

It is difficult to quantify the impact that habitat change has had on this pattern of general decline (see '**Threats and Limiting Factors**' section). Nevertheless, their environmental sensitivity, indicated by their specific habitat requirements, is clearly demonstrated by their consistent association with unmanaged landscapes and low human population influence (e.g., negative correlations with road density, see '**Threats and Limiting Factors**' section). Habitat degradation and fragmentation are considered a primary threat to the persistence of Bull Trout populations (see '**Threats and Limiting Factors**' section for full discussion of anthropogenic threats and DU specific information). Migratory populations that use the largest diversity of habitat throughout their life cycle will be particularly vulnerable to general trends of habitat degradation and fragmentation. The presence of suitable corridors for movement between the different habitats they use for feeding, breeding and refuge is crucial to the persistence of this largely migratory fish (Rieman and McIntyre 1993).

An understanding of the environmental controls on the distribution of suitable Bull Trout habitat could facilitate predictions not only on their occurrence but also on habitat that is unoccupied but suitable for Bull Trout (Rieman and McIntyre 1995; Dunham and Rieman 1999). However, despite (or perhaps because of) the broad distribution of Bull Trout across western Canada, few studies have attempted to quantify trends in Bull Trout habitat across this landscape (BCMWLAP 2004). Activities such as road construction have been used as surrogate measures for Bull Trout habitat disturbance (BC ME 2007), following studies that demonstrated correlations between them. Road density, in particular, has been repeatedly negatively correlated with Bull Trout occurrence (Rieman *et al.* 1997; Dunham and Rieman 1999; Baxter *et al.* 1999), including specifically in Canada (Alberta: Ripley *et al.* 2005; Scrimgeour *et al.* 2008). Given that road length has nearly doubled in British Columbia over the last two decades (82% increase between 1988 and 2005; BC ME 2007), a general decline in the quality of Bull Trout habitat in British Columbia is suggested over that time period. Based on the negative correlation between Bull Trout occurrence and levels of commercial forestry, Ripley *et al.* (2005) forecast the local extirpation of Bull Trout from 24% to 43% of stream reaches that currently support Bull Trout in the Kakwa River basin, Alberta over the next 20 years.

Climate change will also likely play a role in further restricting the availability of habitat for this cold water specialist in the future, as well as reducing connectivity among refuges of suitable coldwater habitat (see '**Threats and Limiting Factors**' section for full discussion). An assessment of the Cariboo-Chilcotin region of British Columbia suggests that the thermal and precipitation effects of global warming will produce a long-term pattern of considerably decreased cold water stream habitat by the 2080s (Porter and Neritz 2009).

BIOLOGY

Information in this section was sourced from several reviews that together represent the most recent comprehensive assessments for Bull Trout across its Canadian range (Alberta: Rodtka 2009; BC: McPhail 2007; BCMWLAP 2004; NT: Stewart *et al.* 2007a, b). A generic life cycle that applies to all Canadian Bull Trout DUs is outlined in Figure 7. The many facets of Bull Trout biology are discussed below, with geographical variations highlighted. The strongest variations are shown among the divergent life history patterns. A general north to south trend may also be evident, with the timing of habitat shifts strongly correlated to water temperature. There are no strong shifts from west to east across Canadian Bull Trout DUs, and the description given herein refers to all DUs unless specified otherwise.

Life History Diversity

Bull Trout's diverse life history patterns can be summarized into four migratory types. A non-migratory *stream resident* form spends its entire life cycle in small rivers and streams and is often isolated by barriers either physical (e.g., waterfalls, dams; Latham 2002), physiological (e.g., unfavourably high temperatures; Rieman and McIntyre 1993; Rieman *et al*. 1997), or biological (e.g., presence of non-native competitor species; Paul and Post 2001; Nelson *et al*. 2002). Migratory forms also spawn and rear in small rivers and streams but as older fish they migrate to other water bodies. The *fluvial* form spends its entire life in flowing water, making migration between spawning and juvenile-rearing natal streams and larger streams and rivers (often the mainstem of large rivers) in which they feed, mature and overwinter between breeding seasons. An *adfluvial* form matures in lakes but migrates up tributaries to natal streams to spawn. These three forms are common throughout Bull Trout's Canadian range (Stewart *et al.* 2007a). In contrast to these three forms, which reside solely in freshwater, a fourth *anadromous* form migrates between freshwater and the sea. It is restricted to the southwestern portion of British Columbia and northwestern Washington. Despite this diversity, there is no evidence of genetic subdivision between different life histories (Homel *et al.* 2008). Indeed, female of one migratory type may produce offspring of a different migratory type indicating plasticity in key life history traits (Brenkman *et al.* 2007).

Reproduction

Bull Trout usually reach sexual maturity between five and seven years of age, with the extreme range between three and eight years. Maximum age is unknown but ages up to 24 years have been recorded. The generation time has been estimated from the average age of spawners from seven Bull Trout populations in British Columbia displaying different life history strategies to be nearly 7 years (Pollard and Down 2001).

Although Bull Trout are iteroparous, there is strong evidence that they display alternate-year spawning or resting periods between consecutive spawning events (Pollard and Down 2001; Johnston and Post 2009). This reproductive strategy, which is often condition and survival dependent, may enable them to accrue sufficient energy for reproduction in colder, less productive systems (reviewed in Johnston and Post 2009). Spawning may occur at 2 to 3 year intervals in the Northwest Territories from all life history types (Mochnacz 2002; Mochnacz *et al.* submitted). This strategy can also show a density-dependent response; the proportion of Bull Trout spawning annually has shown a decline with increasing density as the population in Lower Kananaskis Lake has recovered (Johnston and Post 2009).

Like all char, Bull Trout spawn in the fall, from mid-August to late October. Except for stream-resident populations that spawn locally, this is preceded by a migration. Younger Bull Trout may enter the spawning ground first. Their gonads are usually not fully mature, so gamete development may be completed in their spawning stream over a month or so before breeding at the same time as older fish. At least in some areas, actual spawning does not occur until water temperatures drop below about 10^{o}C, while temperatures below about 5 ^{o}C suspend it. As a result, southern populations appear to have a later, more protracted spawning window than northern ones (Pollard and Down 2001).

Digging of the spawning site, or redd, and spawning is similar to that of other salmonines. Larger females typically use larger substrate toward the centre of the channel when spawning, and bury their eggs deeper. This presumably provides better protection against the impacts of low flows (i.e. sediment deposition) and freezing. A dominant male usually accompanies each spawning female. They vigorously defend her from other satellite males who try to compete for fertilizations (Kitano *et al.* 1994; Baxter 1997). Some populations also have jacks or “sneakers” that dash in at the moment of egg release, often succeeding in fertilizing some eggs. Sometimes these small precocious males mimic females’ colour, behaviour and morphology (lacking a kype), aiding their approach to a spawning pair just before gamete release (Kitano *et al.* 1994; Baxter 1997). Their presence may contribute to the skewed sex ratios that are sometimes observed in spawning runs, although higher rates of repeat spawning amongst females likely also contribute to the pattern of female predominance (McPhail and Baxter 1996; Pollard and Down 2001). The sex ratio of the entire population, on the other hand, is commonly close to 1:1 (McPhail and Baxter 1996; Pollard and Down 2001).

Spawning usually occurs during the day but in some disturbed systems, spawning occurs at night. Like most fish, fecundity (egg number) in Bull Trout depends on female body size; the larger fluvial and adfluvial females produce more eggs (typically 2000-5000+) than the smaller stream-resident females (<1000). Fertilized eggs incubate in the gravel overwinter before fry typically hatch from March onwards (at a total length of about 25mm). The incubation period is temperature dependent and can take anything from 35 days to more than 4 months.

Diet

Bull Trout are opportunistic foragers. While individual prey species may change across Bull Trout's broad range of latitudes and elevations, the general taxonomic groupings preyed upon by each life stage are similar across its range (Figure 8). Throughout their distribution, they feed on a diversity of vertebrate and invertebrate prey, selecting for larger-bodied prey when available. Little is known about the seasonal changes in Bull Trout diet but they most likely alter their diet in response to seasonal abundance of prey, given their opportunistic nature.

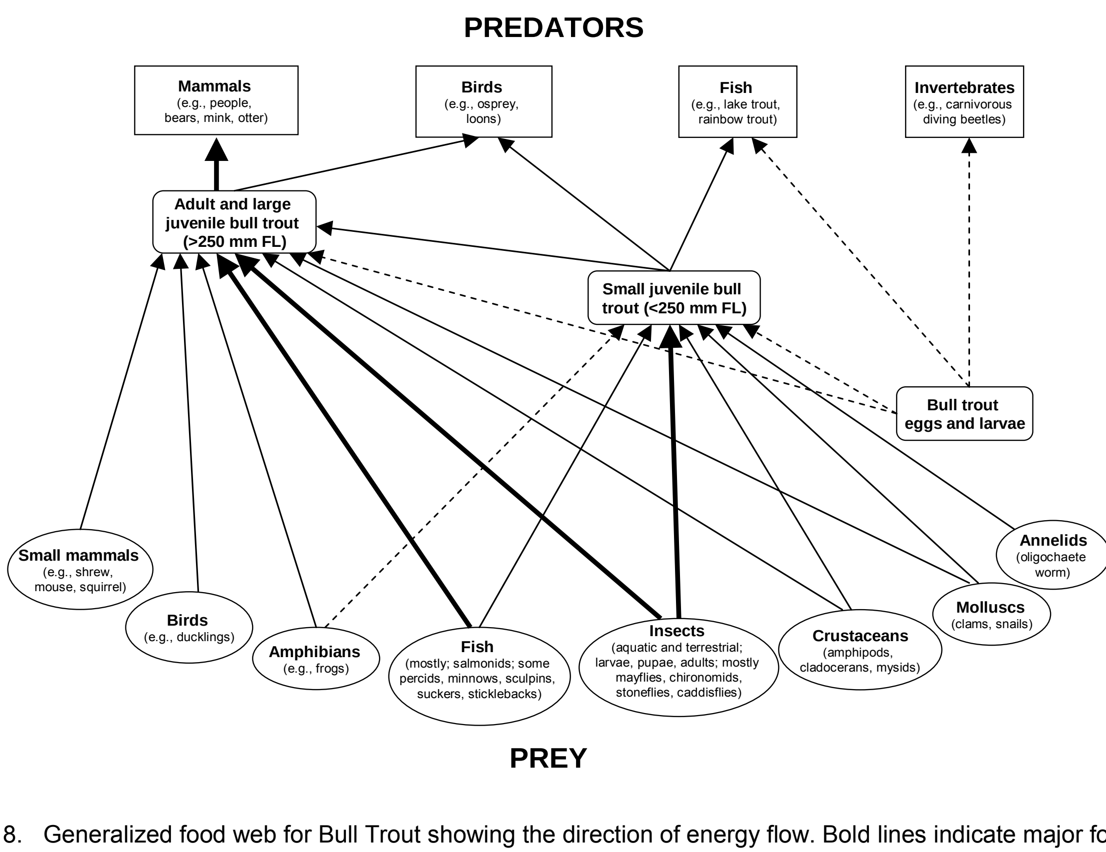

Figure 8. Generalized food web for Bull Trout showing the direction of energy flow. Bold lines indicate major food pathways, in comparison to thinner lines; solid lines indicate demonstrated and dashed lines putative pathways. Sourced from Stewart *et al.* 2007b.

Various life history stages of aquatic and terrestrial insects (mainly mayflies, caddisflies, stoneflies, and chironomids) are commonly consumed by both adults and juveniles. Where other fish species are absent, typically in the highest reaches of the stream habitats or in isolated mountain lakes, juveniles and resident adult Bull Trout feed primarily on these macroinvertebrates. When feeding during the day, juvenile fish are secretive and remain close to the bottom, with most feeding movements directed towards insects drifting nearby (McPhail 2007). At night they will disperse and forage more on benthic organisms. Little if any surface foraging has been observed. Larger juveniles and resident adults will take fish when available (including young of their own species) but their relatively low-piscivorous diet accounts for their low growth rates relative to migratory adult Bull Trout.

Juvenile Bull Trout do, however, become increasingly piscivorous as they approach adulthood. Bull Trout's relatively large gape enables them to consume prey up to 50% of their own length (Beauchamp and Van Tassell 2001). While adults may continue to eat a wide variety of invertebrates, they become increasingly piscivorous with size when opportunity presents in the presence of other fish species. They are often the top aquatic predator where they live and some adfluvial populations are almost exclusively piscivorous. Salmonids are important prey species for both adfluvial and fluvial populations, including smaller juvenile Bull Trout, as well as trout, Kokanee (*Oncorhynchus nerka*), whitefish (especially Mountain Whitefish, *Prosopium williamsoni*), and Arctic Grayling (*Thymallus arcticus*). Other fish, such as a variety of suckers, minnows, sculpins, and sticklebacks are also consumed. When the chance presents, Bull Trout will even consume suitably sized frogs, snakes, ducklings and small mammals. The feeding habits of anadromous Bull Trout at sea are unknown.

Physiology and Adaptability

Bull Trout's pattern of high genetic differentiation between populations and low diversity within them suggests that populations experience limited gene flow. They are, therefore, likely to be locally adapted to their spatially heterogeneous environment (see '**Population Spatial Structure and Variability**' section). This cautions against initiating artificial gene flow between populations (via stocking or hatchery production) as disruption of local adaptations would likely increase a population's vulnerability to extinction. Hatchery production of Bull Trout from Arrow Lakes Reservoir, BC was stopped in 2000, partly over concern about genetic diversity losses (Hagen 2008).

While Bull Trout have many specific habitat requirements, including depth, velocity, substrate, and cover (see '**Habitat**' section), it is its thermal sensitivity that is its most notable physiological characteristic. The influence of temperature on Bull Trout distribution has been recognized more consistently than any other factor (reviewed in Rieman and McIntyre 1993; Dunham *et al.* 2003). Low temperatures are important to the survival and development of all life history stages, from incubation through to breeding, but a narrow range of cold water is particularly critical during incubation and juvenile rearing. High water temperatures, and the resulting low dissolved oxygen levels, increase the rate of yolk absorption and decrease the size of fry. The optimal incubation temperature for survival to hatching is 2-4^{o}C, with survival to hatching declining precipitously above 8^{o}C. Groundwater inflows are important in providing stable temperature for egg development (Baxter and McPhail 1999).

Given a natural thermal gradient (8-15°C), juvenile Bull Trout select the coldest water available (Bonneau and Scarnecchia 1996). Similarly, adult Bull Trout are generally found in water below 18^{o}C, but most commonly in temperatures less than about 12^{o}C (Dunham *et al.* 2003). Laboratory tests of thermal tolerance confirm field reports of Bull Trout having one of the lowest upper thermal limits and growth optima of North American salmonids (Hass 2001; Selong *et al.* 2001). Although the low temperatures typical of Bull Trout habitat lead to relatively low optimum growth rates, such temperature preferences discourage or exclude the invasion of species with higher temperature requirements, which may otherwise compete with Bull Trout.

The specific habitat requirements of Bull Trout result in its patchy distribution within a landscape (Rieman and McIntyre 1993). This, coupled with life history attributes (including top aquatic predator and high site fidelity) that result in relatively low population densities (see '**Population and Sizes**' section) and restricted gene flow (Taylor *et al.* 2001; Taylor and Costello 2006), means that local extinctions through stochastic processes can be considered natural, even common, events for Bull Trout (Rieman and McIntyre 1993, 1995). Bull Trout has evolved strategies that help it to cope with such natural disturbances, including phenotypic plasticity and density dependent changes in life history traits, such as faster maturation and more frequent reproductive events at lower density (Johnston and Post 2009). Nevertheless, the species is at risk from human activities and their impacts (Rieman and McIntyre 1993, 1995). This cold water specialist may be especially vulnerable to climate change (Rieman and McIntyre 1993; Rieman *et al.* 1997, 2007). Populations near its southern limit will be most susceptible, given that this limit is defined by temperature but the thermal and precipitation effects of global warming are likely to exacerbate fragmentation of Bull Trout populations throughout much of the range (Kelehar and Rahel 1996; Rahel *et al.* 1996).

Another notable aspect of the Bull Trout's physiology is the ability of at least some populations to tolerate salt water (see '**Dispersal and Migration**' section).

Dispersal and Migration

The movements of young-of-year and small juveniles are not well described, in part because these secretive fish are difficult to catch or survey. The timing of fluvial and adfluvial juvenile migration appears to be highly variable among systems. While juveniles may inhabit their natal streams from between one to four years, migration at age two or older is most common. Migrations are common during high spring flows in the late spring/summer and when temperatures decline in the fall and winter. This timing may reduce juvenile predation risk and expose them to higher quality food resources at a time when adults occupy spawning grounds. When juvenile adfluvial Bull Trout move into lakes they are rarely taken in the littoral zone, suggesting that they move into deep water.

Often isolated above natural barriers, adult resident Bull Trout typically disperse only short distances to spawn, rear, feed, and overwinter. Migratory forms (fluvial, adfluvial, anadromous) undergo migrations between feeding areas and overwintering habitat, and their distant natal habitat. The timing of spawning migrations differs among populations, being partly dependent on the distance to be travelled, which varies widely (up to several hundred kilometers; Pillipow and Williamson 2004; Pillipow pers. comm. from Hagen and Decker 2011). It is also thought that its onset is triggered by a hierarchy of environmental cues, including changes in river discharge and water temperature. Migratory movements generally occur nocturnally and fluvial populations usually begin spawning migrations when temperatures are relatively high and water levels are declining, from May to August. After spawning, migratory Bull Trout generally move rapidly back to their overwintering habitats by September or October. Bull Trout typically display high fidelity to both natal streams to spawn and overwintering habitat, although there is some evidence of straying, at least at the local scale (Swanberg 1997a; O'Brien 2001; Bahr and Shrimpton 2004).

Upstream pre-spawning migrations are generally slower than the downstream post-spawning movements, with patterns of migration also dependent on age and life-stage; evidence suggests that larger adults consistently migrate quickly, whereas smaller individuals show more diverse and less predictable behaviour (Muhlfield and Marotz 2005; Monnot *et al.* 2008). Bull Trout may congregate at tributary mouths or estuaries before the onset of spawning migrations (Taylor and Costello 2006; Brenkman *et al.* 2007). Coupled with their tendency to gather below barriers before spawning, this habit renders them highly catchable and susceptible to overharvesting (Paul *et al.* 2003; Post *et al.* 2003).

Anadromy

Although not thoroughly investigated, there is evidence of anadromy in Bull Trout in the southwest of British Columbia (Fraser and Squamish drainages), as well as the north west of Washington (Skagit drainage and the Olympic Peninsula). Bull Trout have been collected in the near shore marine areas of Howe Sound, British Columbia and Puget Sound, Washington (Cavender 1978; Haas and McPhail 1991), and anglers refer to sea-run populations in the Squamish River and Pitt River, of which the latter is part of the Fraser drainage.

More recently, radio-telemetry and otolith chemistry have verified that anadromy is a primary life history form in some coastal USA Bull Trout (Brenkman and Corbett 2005; Brenkman *et al.* 2007). More than half of 82 adult Bull Trout radio-tagged on the west side of the Olympic Peninsula were anadromous, migrating to the uppermost portions of rivers to spawn before returning to sea to overwinter and forage (Brenkman and Corbett 2005; Brenkman *et al.* 2007). The life history of anadromous Bull Trout appears variable; some make only single migrations after a prolonged residence in freshwater but many move annually between freshwater and salt water after their first seaward migration around ages 3 or 4 (Brenkman *et al.* 2007). This suggests that they are largely iteroparous like non-anadromous Bull Trout. These anadromous fish co-occur with non-anadromous fish, and life history plasticity results in both types of females being able to produce anadromous progeny (Brenkman *et al.* 2007). Adult dispersal among watersheds using coastal routes can occur; a fish tagged in the Squamish River was recovered in the lower Skagit River in Washington (a marine journey of about 150km) and radio-telemetry revealed dispersal between drainages along the west side of the Olympic Peninsula (Brenkman and Corbett 2005).

Interestingly, this life history feature is not expressed in any of the numerous *Genetic Lineage 2* populations that have access to the sea (Cavender 1978; Haas and McPhail 1991, 2001). Its confinement to (some of) *Genetic Lineage 1* populations suggests that anadromy in Bull Trout originated, or at least persisted, in the Chehalis Refugium, from where Bull Trout (and anadromous Dolly Varden) are thought to have post-glacially recolonized these localities (Haas and McPhail 2001).

Interspecific Interactions

Interspecific interactions strongly influence the local distribution and abundance of Bull Trout. Their distribution may be affected by the availability of prey species, competition for these or other resources, predation or parasitism, or other indirect interactions within their ecosystems. Research on interspecific interactions involving Bull Trout has predominantly focused on just one of these: their potential competition with other native and non-native salmoninae. In fact, it has concentrated on one particular interaction within each of these two categories.

Interspecific Competition with Native Salmonines

Interspecific competition with other native salmonines is likely an important factor in excluding Bull Trout or regulating their coexistence. One example has received particular attention; Bull Trout's interaction with Dolly Varden in areas of sympatry. Dolly Varden is generally more coastal in nature than Bull Trout and ranges further north; it is found from the western Pacific to Alaska, east to the Mackenzie River, and south to the Olympic peninsula, northwest Washington (Haas and McPhail 1991). Their largely parapatric distributions, however, come into contact along the Cascade/Coastal mountain crests from northwestern Washington to Northern BC (Figure 9). This zone of overlap is broadest in Northern British Columbia, where it crosses the Continental Divide north of the Skeena watershed in the headwaters of the Peace and Liard River systems (Taylor *et al*. 1999).

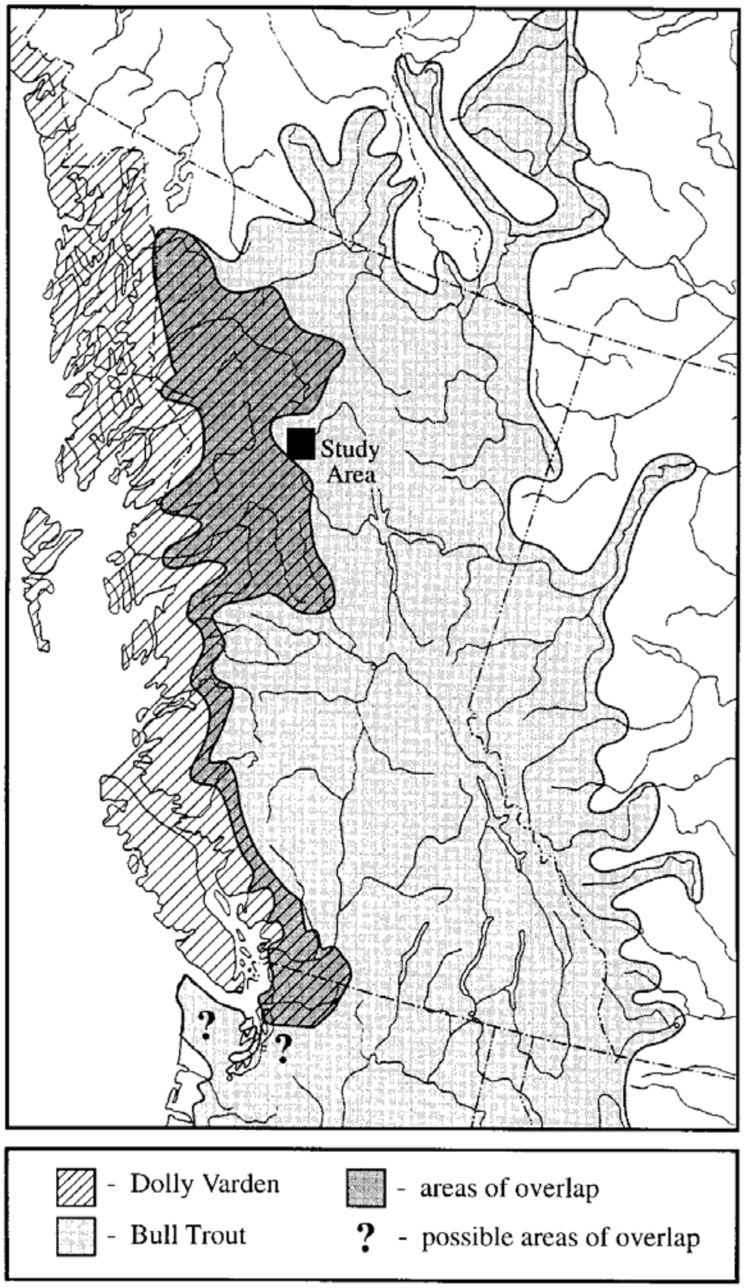

Figure 9. The parapatric species distributions of Dolly Varden (stipled), Bull Trout (shaded), and their overlap (stipled-shaded) in western Canada. Sourced from Baxter *et al.* (1997). Thutade Lake area studied in that manuscript is highlighted.

In part of the two species' southwestern range, this contact has probably been continuous for most of the last 100 000 years. As with Bull Trout, Dolly Varden is composed of two major mtDNA clades (sequence of ~570 base pairs of mtDNA across 207 Dolly Varden samples collected from 50 sites spanning its geographical range revealed haplotype divergence of 1.4-2.2%; Redenbach and Taylor 2002). While one clade encompasses the majority of its range, the second one has a much more limited distribution from Washington State at the southern limit of its range to the middle of Vancouver Island (Redenbach and Taylor 2002). This pattern likely reflects its refuges during the last glacial period in two areas; a northern refuge (Beringia Refuge) and a southern one (Chehalis Refuge), which it likely shared with Bull Trout (Redenbach and Taylor 2002). There is a genetic signature of historical introgression of *Genetic Lineage 1* Bull Trout mtDNA into 'southern' Dolly Varden prior to the most recent glaciation; their mtDNA is paraphyletic, with the 'southern' Dolly Varden clade clustering within Bull Trout from *Genetic Lineage 1*, despite their being reciprocally monophyletic at two nuclear loci (Taylor *et al.* 2001; Redenbach and Taylor 2002).

In addition to historical introgression, genetic analysis has shown these two species currently hybridize across much of this area of sympatry (Baxter *et al.* 1997; Taylor *et al.* 2001; Redenbach and Taylor 2003; Taylor and Costello 2006). Asymmetric introgression of mtDNA shows that this hybridization is typically unidirectional, with most F_1 hybrids resulting from a Bull Trout female mating with a Dolly Varden male (Baxter *et al.* 1997; Redenbach and Taylor 2003). This ongoing hybridization may result from the smaller Dolly Varden males acting as jacks that sneak fertilizations during Bull Trout spawnings (Baxter *et al.* 1997; Hagen and Taylor 2001; Redenbach and Taylor 2003).

Current patterns of sympatry and hybridization are, therefore, due to ancient introgression within, and co-dispersal from, a common refuge, as well as ongoing hybridization resulting from secondary contact between previously allopatric populations across parts of their ranges. While evidence of historical introgression indicates that the most southerly sympatric populations have probably been exchanging genes for 100 000 years, others have come into contact more recently, about 15 000 years ago at the end of the last glaciation (Redenbach and Taylor 2002). Such disparate durations of contact could result in regional differences in levels of reproductive isolation. Longer periods of co-evolutionary history between 'southern' Dolly Varden and *Genetic Lineage 1* Bull Trout may have strengthened reproductive isolation between them through reinforcement, resulting in lower hybridization along the south coast. A quantitative assessment of this awaits more extensive sampling, with preliminary data revealing no significant relationship between areas of secondary contact and range expansion, and the highly variable levels of hybridization detected among sites (e.g., from 2 – 25%; Redenbach and Taylor 2003). There is, however, a qualitative suggestion that present day hybridization may be more extensive in central and northern coast populations than in those along the southern coast; despite being broadly sympatric in southwestern BC and northwestern Washington (e.g., Leary and Allendorf 1997), present day hybridization has only been detected here in the Skagit River (McPhail and Taylor 1995).

Interestingly, it has recently come to light that sympatry between Bull Trout and Dolly Varden extends to the northern most tip of Bull Trout's known distribution, and the most southerly range of a northerly form of Dolly Varden in Northwest Territories: the Gayna River (Mochnacz *et al.* 2009, submitted; Figure 10). Although they co-occur in the same river system they are largely not syntopic, with the Bull Trout occupying downstream areas and the Dolly Varden isolated above barriers (Mochnacz *et al.* 2009, submitted). Not surprisingly then, sequencing of mitochondrial and nuclear genes has not uncovered any genetic evidence of hybridization (Mochnacz *et al.* submitted). If future surveys find Bull Trout's range extends into areas immediately north of the Gayna River, instances of sympatry and hybridization may be uncovered.

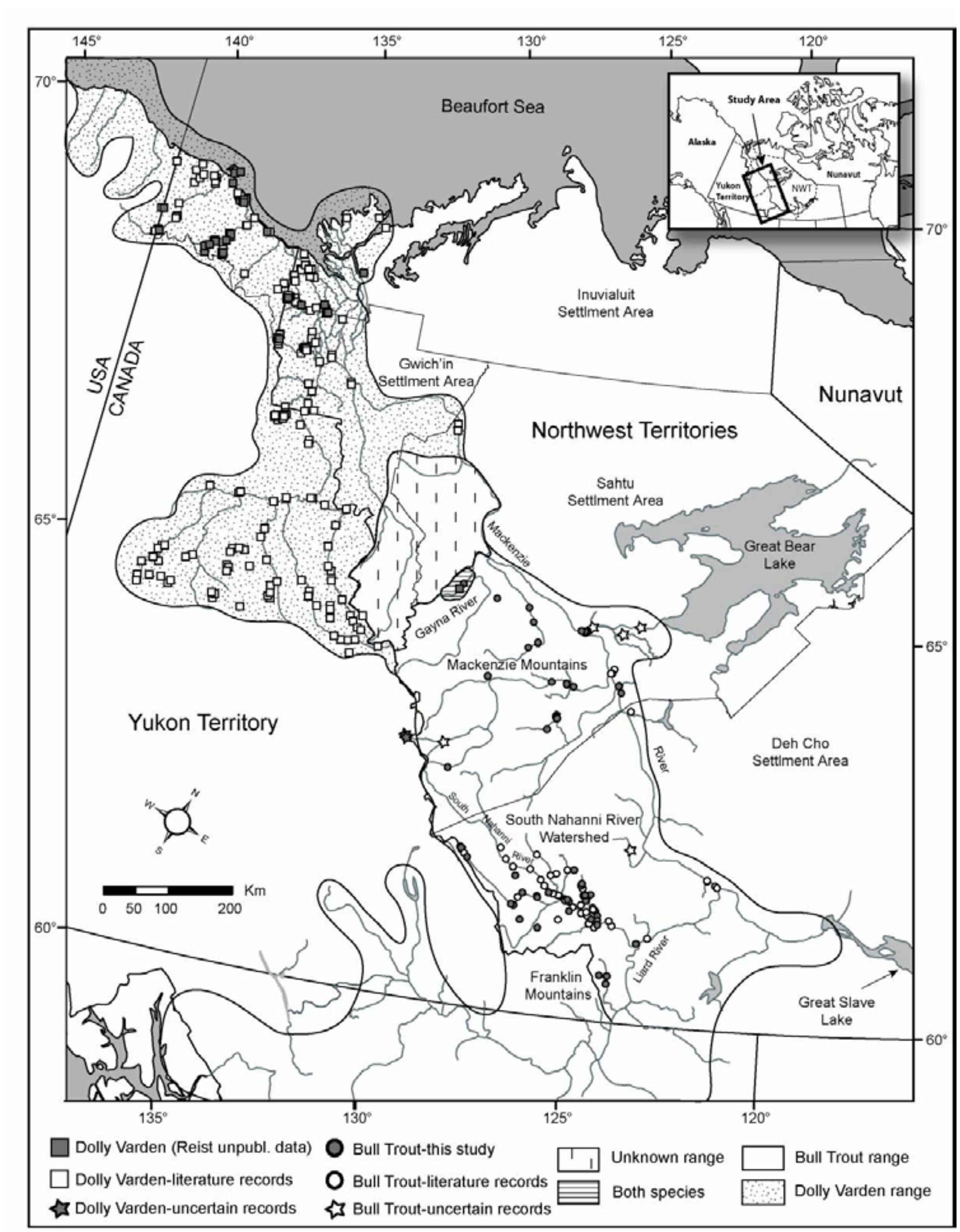

Figure 10. Distribution of northern Bull Trout and Dolly Varden, showing new records from Mochnacz *et al.* (submitted) and point distributions from known and uncertain literature records. General distributions follow drainage basins and known point distributions. Only partial drainages are shown. Sourced from Mochnacz *et al.* (submitted).

Despite this ongoing hybridization and gene flow, Bull Trout and Dolly Varden maintain distinct gene pools in sympatry (Baxter *et al.* 1997; Taylor *et al.* 2001; Redenbach and Taylor 2003). Although postzygotic selection against juvenile hybrids appears to be limited, prezygotic isolation barriers are likely strong thanks to strikingly different adult life histories where they coexist (Hagen and Taylor 2001). Typically, adult Bull Trout are large (40-90cm fork length), migratory or adfluvial, and piscivorous, whereas adult Dolly Varden are small (12-21cm fork length), stream residents, and feed on drift (Hagen and Taylor 2001; Redenbach and Taylor 2003). These disparities in sympatry likely limit interspecific pairings because of size assortative pairing and size-dependent reproductive habitat use (Hagen and Taylor 2001). This contrasts sharply to life-history strategies adopted by each species in allopatry, where each broadens its trophic and habitat niches to include resources that overlap with the other species in sympatry. As has been suggested for other salmonids (e.g., Campton and Utter 1985), life history differences such as these may also contribute to extrinsic post-zygotic selection against later-stage hybrids.

While Bull Trout occur sympatrically with Dolly Varden over only a small part of its range, it is naturally sympatric with either Rainbow Trout or Cutthroat Trout across most of its range. Interactions with these, or Kokanee, may be beneficial to Bull Trout in providing them with high quality food resources (Beauchamp and Van Tassell 2001; Jamieson pers. comm. 2010), although there is also potential for strong competitive interactions (e.g., with Cutthroat Trout; Nakano *et al.* 1992; Jakober *et al.* 2000). Although these interactions have received little research attention compared to those with other char (reviewed in Dunham *et al.* 2008), temperature may affect the ability of Bull Trout to compete with these species (reviewed in Stewart *et al.* 2007b); Bull Trout are more abundant than Rainbow Trout when they occur in sympatry at temperatures below 13°C, but the situation is reversed at higher temperatures. Also, Bull Trout occur allopatrically, rather than sympatrically, with Westslope Cutthroat Trout in warmer water (Pratt 1984). Furthermore, in the coldwater streams of watersheds that have glacial influence, Bull Trout may preferentially select larger, lower gradient tributary reaches for spawning that have abundant gravel and cobble substrates. However, in non-glacial systems dominated by Rainbow Trout or Pacific salmon in their lower reaches, Bull Trout commonly spawn in the furthest upstream reaches they can access, which are often higher gradient, and above obstructions that block the migration of these other species (reviewed by Hagen and Decker 2011).

Bull Trout's interaction with one other native salmoninae, Lake Trout (*Salvelinus namaycush*), has received some attention. Lake Trout, whose adults are piscivorous like Bull Trout, occur over most of continental North America north of 45^{o}N. They overlap with about forty percent of Bull Trout's range, along its eastern and northern parts (Donald and Alger 1993). Competition resulting from substantial niche overlap in food utilization and growth, as well as opportunistic predation upon one another, may contribute to their somewhat disjunct distribution; small northern lakes tend to contain only one of these species, while larger lakes often carry both (Donald and Alger 1993). An exception to this is the large Babine Lake in the Skeena system, BC, which is inhabited only by Lake Trout despite it appearing to be good Bull Trout habitat. Bull

Trout are common, however, in the Babine River immediately below it, indicating that Bull Trout are apparently competitively superior in flowing water but Lake Trout are so in the lake (McPhail 2007). Further evidence that Lake Trout can displace Bull Trout from lakes comes from the southern part of the zone of sympatry. Here, adfluvial Bull Trout tend to be found in higher elevation lakes (>1500m) and Lake Trout in lower ones (<1500m; Donald and Alger 1993), often accompanied by allopatric fluvial or stream resident Bull Trout in tributary streams. When non-native Lake Trout were introduced into two higher elevation lakes in this region, they displaced native Bull Trout (Donald and Alger 1993).

Interspecific Competition with Non-native Salmonines

While ongoing hybridization with native Dolly Varden presents no risk to the integrity of Bull Trout populations, direct interactions (e.g., hybridization, competition) with several species of introduced salmonines may displace Bull Trout populations, and threaten to extirpate them from many habitats throughout broad areas of its range. In western North America, Rainbow Trout, Brown Trout and Brook Trout are the most widespread non-native salmonines (Fuller *et al.* 1999). In particular, Brook Trout is considered a substantial threat to Bull Trout populations (see '**Threats and Limiting Factors**' section). Occupying habitats similar to those used by native trout and char, Brook Trout are commonly found downstream of, or overlapping with, Bull Trout (Paul and Post 2001; Rieman *et al.* 2006; Earle *et al*. 2007). This pattern of segregation is likely influenced by direct interactions. Brook Trout compete with Bull Trout for food and space (Nakano *et al.* 1998; Gunkel *et al.* 2002; McMahon *et al.* 2007). The absence of resource partitioning or a niche shift by Bull Trout in the presence of Brook Trout (Gunkel *et al.* 2002) makes them vulnerable to displacement, especially when resources are scarce. Life history characteristics of Brook Trout (faster maturation, shorter-lived and higher densities compared to Bull Trout; McPhail 2007; Earle *et al*. 2007) will tend to compound this effect. Bull Trout occurrence has been negatively associated with the presence of Brook Trout (Rich *et al.* 2003), and hierarchical analysis supports the hypothesis that Brook Trout displace Bull Trout upstream (Rieman *et al.* 2006). Nevertheless, the ecological impacts of non-native Brook Trout on Bull Trout are highly variable and likely depend on environmental conditions, such as water temperature, as well as the spatial and temporal scales of observation (e.g., Dunham and Rieman 1999; Rich *et al.* 2003; Rieman *et al.* 2006; Earle *et al*. 2007; McMahon *et al.* 2007).

Competitive displacement of Bull Trout by Brook Trout may be exacerbated by gamete wastage resulting from hybridization (Leary *et al.* 1993). Although the geographical extent of hybridization is not well defined, genetic evidence has documented extensive hybridization in British Columbia (McPhail and Taylor 1995) and Montana (Leary *et al.* 1993; Kanda *et al.* 2002). This suggests that it may be widespread and common wherever the two species co-occur. Their F_1 hybrids are predominantly males that are partially sterile (Leary *et al.* 1993; Kanda *et al.* 2002), although some backcrosses identified by molecular analyses indicate that F_1 reproduction does occur (Kanda *et al.* 2002; McPhail and Taylor 1995). Reduced survival and fecundity of these hybrids likely contributes to the prevention of hybrid swarms forming (Kanda *et al.* 2002) but their frequent production represents wasted reproductive effort. In such an instance, one parental species should be favoured over the other, causing displacement or extinction. Not only will Brook Trout's earlier maturation and higher densities be to its advantage, but the predominance of female Bull Trout x male Brook Trout pairings (Leary *et al.* 1993; Kanda *et al.* 2002) results in greater wasted reproductive effort for Bull Trout.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Visual counts of redds have been the primary stock assessment tool for adult Bull Trout populations (Dunham *et al.* 2001; USFWS 2008). This is one of the least expensive and uninvasive adult population assessment methods. The characteristic form and bright, clean appearance of redds, as well as the low water conditions generally present during the early fall mean that they can be a reliable indicator of spawner abundance. Tight correlation of redd counts with independent estimates of population size have verified their usefulness (Dunham *et al.* 2001; Al-Chokhachy *et al.* 2005), although a number of caveats about their reliability and repeatability apply to their use.

Errors (omissions and false identifications) must be reasonably low if redd counts are to accurately indicate the status of a population, and provide an index of population trends. High levels of inter-observer variability can be a significant source of error in redd count accuracy and precision (Dunham *et al.* 2001) and will confound the ability to detect trends in streams over limited time scales (Rieman and Myers 1997). These discrepancies can be greatly reduced, however, when detailed criteria for redd identification and experienced observers are used (Muhlfeld *et al.* 2006; Decker and Hagen 2008).

In addition to inconsistent methodology, variations in detection rate among streams and at different times also contribute to inconsistencies. While a near complete count of redds may be possible under certain environmental conditions, weather and stream type may result in underestimates (Decker and Hagen 2008). For example, high flows may delay redd counts and lead to underestimates, as redds become more difficult to identify with the passing of time after spawning (Decker and Hagen 2008). Also, in areas of limited gravel or high redd abundance, or where spawning site selection is highly specific, superimposition of redds upon one another can occur (Baxter and McPhail 1996). Redd counting in these instances can only be based on a subjective evaluation (Decker and Hagen 2008).

Caution must be applied when estimating the number of adults from the number of redds counted. The Bull Trout's propensity for alternate-year spawning or resting periods between consecutive spawning events (Pollard and Down 2001) means that only the number of spawning adults can be estimated. In addition, the expansion factor from redds to number of spawners can vary among populations as a result of single females constructing more than one redd (Leggett 1980) and sneak fertilizations from inconspicuous satellite and sneaker males in some populations (Kitano *et al.* 1994; Baxter 1997; McPhail 2007). Some males may fertilize more than one redd while some redds may be fertilized by more than one male (Fraley and Shepard 1989). A review of three calibration studies that used independent estimates of population size (two in British Columbia and one in Idaho) found the average number of Bull Trout spawners/redd to be 2.2 (Decker and Hagen 2008), while two other BC rivers yielded expansion factors of 1.5 and 3 (Pollard and Down 2001). This range is confirmed by Al-Chokhachy *et al.* (2005), whose review of five studies in the Columbia River basin suggested an average expansion factor of 2.7 (range of 1.2 - 4.3).

Alternative methods for estimating the spawning population include trapping migratory populations, electro-fishing, snorkel surveys, aerial surveys and, more recently, resistivity counters (Hagen and Decker 2011). All of these methodologies are more labour intensive than redd counting, and each comes with their own potential drawbacks. For example, trap avoidance may bias trapping estimates. Electro-fishing gear is size selective and its capture efficiency diminishes in Bull Trout's preferred habitat of flowing waters with low conductivity and high cover (Bonneau *et al.* 1995; Peterson *et al.* 2004). Day and night snorkel counts can compensate for diel shifts in Bull Trout habitat use but counting errors depend partly upon water clarity and habitat type (Thurow and Schill 1996; Dunham *et al.* 2001; Thurow *et al.* 2006). The deployment of resistivity counters is a costly procedure and their reliability has yet to be evaluated for Bull Trout (Decker and Hagen 2008). Quantitative estimates of adult densities in lakes are rare, but hydroacoustic surveys have been used (McPhail and Baxter 1996). The diel differences in habitat use by adfluvial populations needs to be taken into consideration when selecting sampling locations and techniques.

Electro-fishing and snorkeling surveys are most commonly used to estimate juvenile Bull Trout densities. As with all surveying techniques, their potential drawbacks make them vulnerable to bias. The diel and seasonal shifts in habitat use by juvenile Bull Trout, in particular, will affect the density of fish in sampling locations and the effectiveness of these techniques (Jakober *et al.* 2000). Juvenile Bull Trout's preference for cover during the day makes it difficult to assess their populations from daytime surveys (Jakober *et al.* 2000). Size selection and variable capture efficiency suggest electro-fishing based estimates are more biased than those from night time snorkeling surveys (Decker and Hagen 2005).

Abundance

In order to review current abundance, trends and conservation status of current Bull Trout populations, core area assessments have been conducted in Alberta (Rodtka 2009; Appendix 1, Figure 11) and British Columbia (Hagen and Decker 2011; Appendix 2). These assessments of core areas, which are analogous to meta-populations, used modifications of the methodology employed by the US Fish and Wildlife Service for their Bull Trout core area analysis in the USA (Fredenberg *et al.* 2005). Briefly, a combination of empirical data and expert opinion were used to determine the most likely population abundance using approaches developed by Master *et al.* (2003). This approach was adopted by the US Fish & Wildlife Service and applied to Bull Trout across core areas throughout their US range (Fredenberg *et al*. (2005) and Alberta (Rodtka (2009) and BC (Hagen and Decker 2011) followed the same protocol.

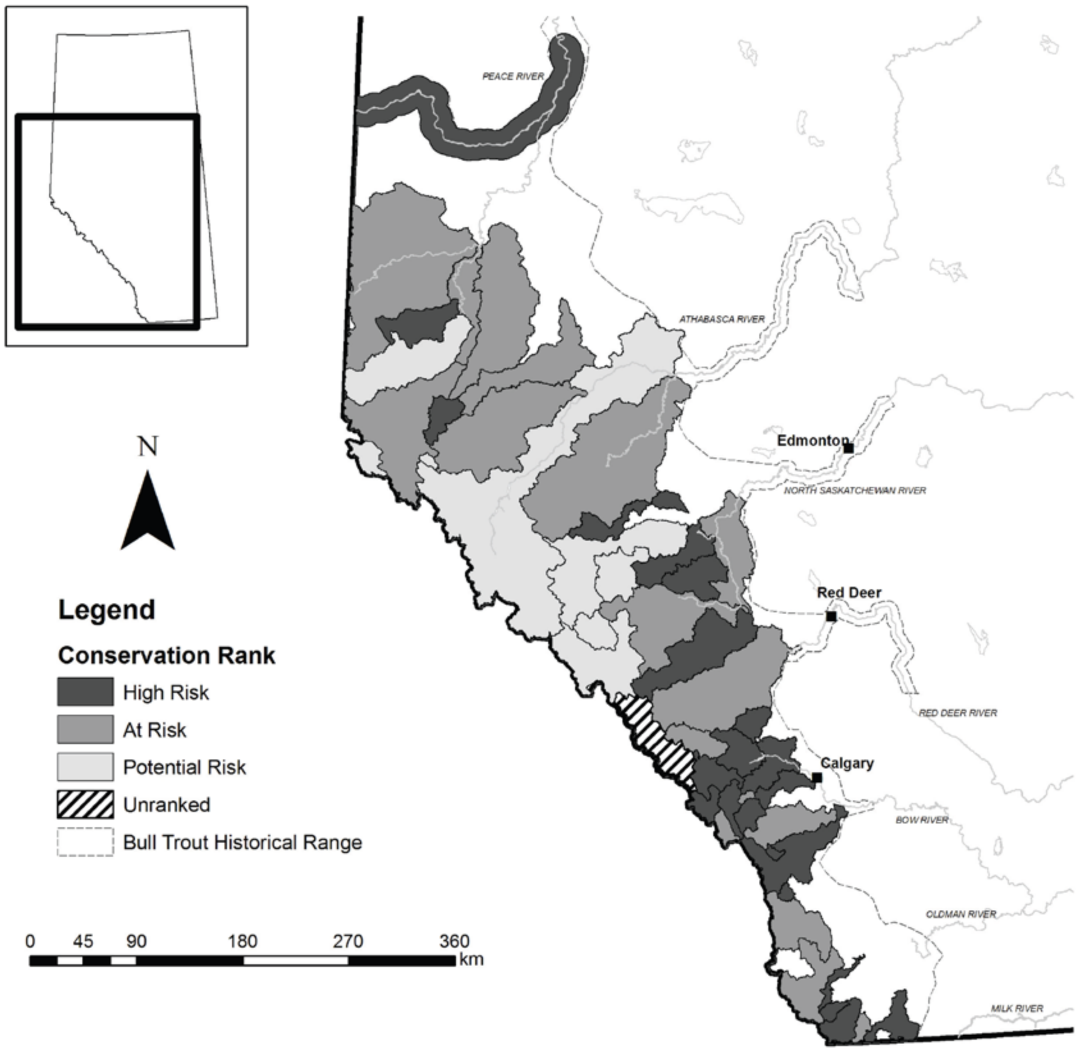

Figure 11. Spatial distributions of Bull Trout core areas in Alberta and their conservation ranking. Assessment was performed by the Fish and Wildlife Division of Alberta Sustainable Resource Development and is based upon a modification of the Natural Heritage Network ranking methodology using NatureServe Conservation Status Assessment Criteria. Extirpated core areas are not shown. Figure prepared by Velma Hudson (Alberta Conservation Association) and sourced from Rodtka (2009).

Several factors were considered when defining the 51 Bull Trout core areas that have been identified in Alberta (Appendix 1, Figure 11), including: historical distribution; abundance of adult fish; barriers to movement, and; the probability of permanently losing (or likelihood of natural re-establishment if extirpated) a population (Girard pers.

comm. 2010). A comprehensive assessment that estimated the abundance of adults within each of the 51 Albertan Bull Trout core areas was based on available data (e.g., population estimates, reconnaissance inventories, fish trapping results, redd surveys; Girard pers. comm. 2010). After data compilation, density estimates were extrapolated from specific habitats to the area of occupancy within a core area (assuming same habitat quality). Some core areas had no data, in which case abundance was estimated as the median from range categories (Fredenberg 2005; Girard pers. comm. 2010).

The delineation of the 115 Bull Trout core areas that have been identified to span 26 Ecological Drainage Units (EDUs) as defined for British Columbia (Appendix 2) and described in full by Hagen and Decker (2011). Briefly, core areas were established using the following guidelines: they contain or have the potential to contain multiple, interconnected local populations; be typically 100-250 km along their longest dimension unless further restricted by migration barriers (or if they can be estimated more reliably from telemetry/genetic studies); provide all critical habitat elements, and; be distributed within the known range of the species in the Province. Expert opinion was then canvassed from a range of biologists to estimate distribution, abundance of mature individuals, trends in abundance, and threats within each of these putative core areas. It is important to note that most of these core areas are considered provisional as availability of data describing Bull Trout distribution, population structure, movement and barriers varies significantly among areas (Hagen and Decker 2011).

The genetic population structure of the vast majority of these core areas has not been defined in either Alberta or British Columbia. Given that genetic differentiation has been detected among Bull Trout populations at the fine scale e.g., within watersheds over distances as small as a few kilometers (Spruell *et al.* 1999; Taylor *et al.* 2001; Costello *et al.* 2003; Taylor and Costello 2006), it is possible, or even likely in some instances, that the number of genetically distinct Bull Trout populations exceeds the core areas identified so far within each DU. A summary of our current knowledge for each of the Canadian DUs is outlined below.

<u>DU1 [Genetic Lineage 1: Southcoast BC populations]</u>

Bull Trout populations from this DU are restricted to British Columbia: only three of the 26 EDUs occupied by Bull Trout within this province are known to contain *Genetic Lineage 1* Bull Trout (Appendix 2). And, of the 115 provisional Bull Trout core areas in this province, just five have been identified with a reasonable level of certainty within this DU (Appendix 2). Some short-term monitoring data exists for three populations (Skagit River, Phelix Creek and Cheakamus River) that represent three of these provisional core areas; in all cases, well over 100 spawners have been counted in most years of monitoring (Table 1). In fact, the most recent snorkel count in the Skagit River (2010) estimated over 1500 adults were present. Based on this information, expert opinion estimates that several thousand spawners (1,000-2,500 or more) may be present in this DU (Hagen and Decker 2011).

Table 1. Summary of 31 adult Bull Trout abundance datasets compiled from 22 core areas from 12 of 26 Bull Trout Ecological Drainage Units (EDUs) identified in British Columbia. Trend data (simple regression analysis) available for 23 of these datasets covering 11 Bull Trout EDUs (datasets with more than five years of data collected using a consistent methodology). Modified from Hagen and Decker (2011).

Core area	Stream or lake	No. years data	Estimated abundance	Short-term trend
DU1 [*Genetic Lineage 1: Southcoast BC populations*]				
EDU Lower Fraser				
Lillooet	Phelix	5	27-185	no
EDU Puget Sound				
Skagit	Skagit	5	159-1650	positive (*P*=0.03)
EDU South Coastal				
Squamish	Cheakamus	13	75-316	multiple trends
DU2 [*Genetic Lineage 2: Western Arctic populations*]				
EDU Upper Peace				
Finlay Reach	Davis	9	37-85	no
Parsnip Reach	Misinchinka	5	35-58	no
	Scott	2	58-106	Unknown
Peace Reach	Point	5	5-39	no
Thutade	Thutade Lake	16	122-288	positive (*P*=0.01)
EDU Lower Peace				
Halfway-Peace	Chowade	6	55-864	positive (*P*=0.01)
	Needham	3	52-103	Unknown
	Cypress	3	18-120	Unknown
Lower Murray	Wolverine	3	25-67	Unknown
DU5 [*Genetic Lineage 2: Pacific populations*]				
EDU Columbia-Arrow				
Pend d'Oreille	Salmo	12	38-109	no
ALR all	Arrow Lakes	23	0.02-0.13 CPUE (fish/hr)	no
ALR southern	Arrow tribs	2	198-260	Unknown
ALR northern	Arrow tribs	2	586-755	Unknown
EDU Lower Kootenay				
Kootenay Lake	Irishman	8	13-32	no
	Duncan	9	202-725	no
	Kaslo	5	716-1219	no
	Crawford	3	336-486	Unknown
	Kootenay Lake	34	0.02-0.15 CPUE (fish/hr)	multiple trends
EDU Upper Kootenay				
Elk	Line	19	28-184	positive (*P*=0.001)
Upper Kootenay R	Skookumchuck	14	64-189	no
	White	10	93-193	no
Koocanusa	Wigwam	17	105-2298	multiple trends
EDU Upper Skeena				
Upper Sustut	Sustut	19	3-70	negative (*P*=0.04)
Mid-Skeena	Kitwanga	7	31-495	no
Lower Sustut/ Skeena	Damshilgwet	11	22-302	positive (*P*=0.01)
EDU Upper Fraser				
Upper Fraser	Goat	5	55-163	no
EDU Middle Fraser				
Chilko	Long Valley	2	433-693	Unknown
EDU Thompson				
Upper Shuswap	Sugar Lake	4	0.01-0.26 CPUE (fish/hr)	*positive(*P*=0.02)

* only four years of data, but included in trend analysis as data spanned a 20-year time period.

DU2 [Genetic Lineage 2: Western Arctic populations]

Bull Trout populations from the vast area of the Mackenzie River drainage basin are found in two Canadian provinces and 2 Territories that harbor this species. Of the 51 Bull Trout core areas that have been identified in Alberta, 15 fall within this DU (in the Athabasca and Peace-Smoky River basins; Appendix 1, Figure 11). Approximately 23,000 adult Bull Trout are estimated to inhabit Alberta's lakes and streams in this DU within the Athabasca and Peace-Smoky River basins (Appendix 1). The mean population size for these 15 core areas is 1545 but population sizes vary widely (standard deviation 1960); extant populations range in size from 25 adults for the Peace River to 7450 for the Kakwa River, both from the northern Peace-Smoky River basin (Appendix 1).

Of the 115 provisional Bull Trout core areas estimated in British Columbia, 30 occur within this DU across four EDUs (Appendix 2). There is, however, significant uncertainty regarding the number of core areas within at least one of these EDUs (Upper Liard; Hagen and Decker 2011). Some monitoring data exists for nine populations that represent six provisional Bull Trout core areas from the Upper and Lower Peace EDUs (Table 1). The Thutade Lake inlets Bull Trout population has been subject to the longest period of monitoring, 16 years. The most recent survey in 2009 recorded 235 redds (Table 1, Hagen and Decker 2011). Although redd counts have varied across time and systems among the eight remaining populations from five other provisional Bull Trout core areas that have received short-term monitoring, fluctuations have been restricted to at or below 100 redds annually with one exception; the Chowade River, where estimates in 2010 exceeded 800 redds (Table 1, Hagen and Decker 2011). There is no information on abundance from either the Upper or Lower Liard EDUs (Hagen and Decker 2011). Expert opinion could only consider 5 of the 30 provisional core areas, with a total estimate of 5,000-10,000 adults. The abundance for 25 provisional core areas remains unknown (Hagen and Decker 2011).

Little is known about the number or size of Western Arctic Bull Trout populations in the Northwest Territories, where recent surveying is only now establishing the northern range of this species distribution. Two recent surveys (electro-shocking, angling and set lines) of 29 streams in the southern (Deh Cho) and central (Sahtu) Northwest Territories found Bull Trout represent 1% (Mochnacz and Reist 2007) and 4% (Mochnacz *et al.* 2009) of the total catch, respectively. This is in line with the general observation that Bull Trout typically comprise less than 5% of the total catch from broad faunal surveys (reviewed in McPhail and Baxter 1996). Given that productivity generally decreases with increasing latitude due to colder temperature and shorter growing seasons, the initial indication of small but wide ranging populations is likely an accurate reflection of Bull Trout populations in their northern reaches.

The single population estimate that is available for Bull Trout from the Northwest Territories comes from Funeral Creek, a suspected resident headwater population (Department of Fisheries and Oceans pers. comm. 2010). Here, four randomly selected reaches (~200 m) were surveyed using electro-shocking (Mochnacz *et al.* 2006). Maximum-likelihood population size estimates at 95% confidence intervals showed adult ranges (N= 17 [95% CI 16-18] and 21 [95% CI 18-23]) to be similar to those for juveniles (17[95% CI 16-18] and 23 [95% CI 20-28]; Mochnacz *et al.* 2006). This suggests that both groups have small populations compared to other fish species, typical of Bull Trout populations throughout their range.

In southeast Yukon, Bull Trout are known to occur in numerous drainages and lakes of the Liard River (Can-nic-a-nick Environmental Sciences 2004) and are likely widespread in this drainage basin (Miller pers. comm. 2010). These northern populations are likely to be small in size, although there is currently no information available on the number or size of these Western Arctic Bull Trout populations.

DU3 [Genetic Lineage 2: Yukon River Watershed populations]

Bull Trout populations from the Yukon River watershed are believed to be found in both Yukon and British Columbia, although there is very little information on their distribution (see '**Distribution**' section).

DU4 [Genetic Lineage 2: Saskatchewan-Nelson Rivers populations]

Bull Trout populations from this DU are restricted to Alberta. Of the 51 Bull Trout core areas that have been identified in this province, 36 fall within this DU (Appendix 1, Figure 11). Approximately 10 000 adult Bull Trout are estimated to inhabit Alberta's lakes and streams in this DU within the Oldman, Bow, Red Deer and North Saskatchewan River basins (Appendix 1). Population sizes for these 36 core areas in southern Alberta tend to be smaller than those from the more northerly Western Arctic populations in Alberta; the mean population size for these 36 core areas is 300. Once again, however, these population sizes vary widely (standard deviation 368); extant populations range in size from 10 adults for the Middle Bow River from the southern Bow River basin, to 1275 in the Brazeau River (Appendix 1).

DU5 [Genetic Lineage 2: Pacific populations]

Bull Trout populations from this DU are widespread throughout British Columbia; they occur in the majority (n = 78) of the 115 provisional Bull Trout core areas identified here, and are spread across 17 EDUs (Appendix 2). Although a number of short and longer-term monitoring initiatives for Bull Trout have been undertaken within this DU, the majority (n = 13) of the 19 abundance datasets available occur within the Columbia drainage (Table 1). These 13 datasets within the Columbia drainage fall across seven provisional Bull Trout core areas in three EDUs. Each of these EDUs has at least one population whose abundance estimates remain below 200 (Table 1). Nevertheless, they all also harbor populations whose abundance estimates consistently exceed this (Table

1). Little information about abundance exists for north coastal watersheds, the Thompson River, or the mid- and upper Fraser River within this DU (Table 1). Expert opinion estimated to be much more than 39,000 adults in this DU, but this was limited to 25 provisional core areas where some abundance information was available (Hagen and Decker 2011).

Effective Population Size

Based on a generalized, age-structured simulation model that incorporated a range of life histories and other conditions characteristic of Bull Trout populations, the effective population size for Bull Trout has been estimated to be approximately 0.5 to 1.0 times the average number of adults spawning annually in a population (Rieman and Allendorf 2001). Achieving the recommendation that Bull Trout populations should include an average of at least 1,000 adults spawning each year for long-term management goals (Rieman and Allendorf 2001) will be challenging given that many Bull Trout populations tend to be smaller (data herein; Rieman and McIntyre 1993). Conserving interconnected populations as groups may be a strategy that can meet this suggested minimum, while simultaneously providing for the full expression of life history variation and the natural processes of dispersal and gene flow (Rieman and Allendorf 2001).

Fluctuations and Trends

In recent decades, Bull Trout populations have experienced declines in abundance across their range but particularly in southern and eastern parts in the USA (Rieman *et al.* 1997; USFWS 1999, 2008) and Alberta (Rodtka 2009). For the most part, this range reduction is comprised of localized extinctions, although it is known to have become extinct in two systems in the USA (McCloud, California; Willamette, Oregon; McPhail and Baxter 1996). The status of Bull Trout populations appears to show a general north to south trend, with decreasing abundance towards its southern margins (Haas and McPhail 1991; McPhail 2007). This trend is likely due, at least in part, to the more pristine and suitable environments in northerly regions (Haas and McPhail 1991).

In addition to this general trend of declining abundance, there is evidence to suggest that the full range of life histories is also being lost from populations. There is particular concern that migratory Bull Trout may be especially susceptible to declines in larger, highly fecund, individuals (Nelson *et al.* 2002; Post *et al.* 2003). For example, large-bodied fluvial or adfluvial Bull Trout were common in southwestern Alberta prior to 1950, but many extant populations are now comprised of small-bodied residents that only occupy a fraction of their former range (Fitch 1997). It has also been noted that adfluvial Bull Trout populations in the upper Columbia Basin frequently include individuals that are larger and older than those found in more southerly populations, suggesting these more northerly populations experience less exploitation as well as lower growth rates (Hagen 2008).

Although this general pattern of decline in abundance is clear, two factors make it difficult to assess its extent in populations. Firstly, broad natural fluctuations in abundance (Paul *et al.* 2000) make it difficult to assess population trends over short periods of time. This natural variation, combined with the limitations of surveying methods (Rieman and Myers 1997; Dunham *et al.* 2001; Al-Chokhachy *et al.* 2009), means that considerable resource and temporal commitments are required to detect moderate changes in abundance of Bull Trout. Evidence from long-term studies conducted in the USA suggests that more than a decade of Bull Trout monitoring may be required to detect a large population decline statistically (Rieman and Myers 1997; Al-Chokhachy *et al.* 2009). Given this sensitive species' tendency towards naturally low population sizes, it may not be possible to prove significant trends for many monitored Bull Trout populations before they drop below a critically low level (Rieman and Myers 1997).

Despite these hurdles, monitoring is often proposed as a mechanism to assess trends in abundance in order to recognize and mitigate land management effects. Standardized quantitative information gathered from a number of Bull Trout populations over a period of decades will be necessary for a thorough evaluation of the trends and status of Bull Trout in each DU. However, few long-term monitoring efforts on the abundance of Bull Trout exist in Canada, and the limited long-term quantitative data that is available is often confounded by non-standardized sampling techniques. Much of our current knowledge of population trends actually relies on qualitative expert opinion (Rodtka 2009; Girard pers. comm. 2010; Hagen and Decker 2011).

Nevertheless, more monitoring and baseline assessments are now being established. For example, 31 abundance datasets have been compiled for Bull Trout populations in British Columbia (which have two or more years of information collected using a consistent methodology; Table 1). Of these datasets, 15 have at least seven years of data (which is a reasonable approximation of one generation for Bull Trout in British Columbia; Westover and Conroy 1997), seven have 14 or more years of data (i.e. two generations), and two have 21 or more years of data (i.e. three generations). Coupled with core area assessments (Rodtka 2009; Hagen and Decker 2011), abundance assessments such as these should provide useful data to assess trends in population size for future Bull Trout status assessments. Even so, substantial gaps remain. For example, the 31 abundance datasets compiled for Bull Trout populations in British Columbia are found in just 22 of the 115 provisional Bull Trout core areas, spanning only 12 of the 26 Bull Trout EDUs identified in this province (Table 1).

A summary of our knowledge about trends in Bull Trout populations for each of the Canadian DUs is outlined below.

DU1 [Genetic Lineage 1: Southcoast BC populations]

Short-term trend data are available for three local populations in this DU (Skagit River, Phelix Creek and Cheakamus River, Table 1). They are from three of five identified provisional Bull Trout core areas, and represent each of the three EDUs within this DU. A positive trend was observed for the Skagit River with most recent counts (2010) almost six times greater than earliest counts (1998); this trend largely reflects population recovery following the implementation of more restrictive fishing regulations (Hagen and Decker 2011). A similar response was observed in the Cheakamus dataset until 2006, a year after a caustic soda spill into the river. Since this time, adult numbers steadily declined but most recent counts (2010-2011) indicate the population is increasing (Hagen and Decker 2011). A similar response to altered angling regulations was not observed in Phelix Creek (where no trend was observed), and further regulatory restrictions may still be required (Jesson pers. comm. 2011).

An expert opinion assessment found that trend varied between each of the five provisional core areas in this DU, ranging from increasing to stable, to decreasing and unknown (Appendix 2). In summary, no consistent trend is apparent from either the limited quantitative data or expert opinion assessment for this DU; status appears to vary by major watershed according to local pressures and threats.

DU2 [Genetic Lineage 2: Western Arctic populations]

Anecdotal information and limited historical records suggest that there has been a large decline in the abundance (as well as distribution) of Bull Trout in all river systems in Alberta where it has been found since the early 1900s, including in the drainages of the Peace and Athabasca rivers that fall within this DU (Rodtka 2009, Figure 6). As is the case in the USA (Rieman *et al.* 1997), most Albertan self-sustaining populations are now restricted to less accessible headwater areas (Rodtka 2009).

This historical pattern of decline is mirrored in today's short-term trends in Alberta (Appendix 1). Although current population size estimates vary widely across the 15 Bull Trout core areas in this DU, their short-term trends are dominated by declines (N = 11, 73%; Appendix 1). Only three (20%) of them are considered to be stable and one to be increasing (6.7%; Appendix 1). These trends have been based on both quantitative data (multi-year abundance estimates) and qualitative, expert opinion using a modification of the Natural Heritage Network ranking methodology using NatureServe Conservation Status Assessment Criteria (Rodtka 2009; Girard pers. comm. 2010).

While monitoring and baseline assessments have now been established in all river systems in Alberta where Bull Trout is found, including the drainages of the Peace and Athabasca rivers within this DU, there is currently a lack of long-term trend data. Most monitoring efforts have been applied to populations in the southwest of Alberta, within DU4 [*Genetic Lineage 2: Saskatchewan-Nelson populations*] (reviewed in Rodtka 2009). An exception to this is Eunice Creek in the Athabasca River drainage, whose monitoring reveals valuable insight into Bull Trout population dynamics under relatively unaltered conditions. Closed to angling since 1966 and protected from most development until 1985 (Hunt *et al.* 1997), the abundance of Bull Trout fluctuated here by two orders of magnitudes over just fifteen years (Paul *et al.* 2000), reflecting the broad natural fluctuations that may occur in Bull Trout abundance.

There is evidence that some less closely monitored adfluvial populations appear to be increasing as a result of conservative angling regulations in Alberta, including Pinto Lake within this DU (reviewed in Rodtka 2009). The trend for resident and fluvial populations in this province is less consistent. Within this DU, electro-fishing and angling surveys of Kakwa River have found no evidence of change in abundance in this system since the provincial wide, zero-harvest regulation implemented in 1995 and the total closure of angling on Lynx Creek, the key spawning stream for Bull Trout from the Kakwa River (reviewed in Rodtka 2009).

Adult trend data for Bull Trout populations in British Columbia exists for five populations in this DU (Table 1). They are from five of 30 identified provisional Bull Trout core areas. Four are found within the Upper Peace EDU, and one within the Lower Peace EDU but there is no trend data from either the Upper or Lower Liard EDUs (Hagen and Decker 2011). As in Alberta, there is a case of a previously exploited British Columbian Bull Trout population that has expanded once threats have been mitigated; the explosive increasing trend observed from six years of redd count data over 15 years for the Chowade River in the Lower Peace EDU is considered to represent the recovery of a depleted population following the implementation of more restrictive angling regulations in the 1990s (Hagen and Decker 2011). The more modest increase in spawner numbers observed during 16 years of monitoring of Bull Trout from the Thutade Lake watershed (assumed to represent a meta-population) from the Upper Peace EDU may simply reflect a range of normal variation, although compensation measures associated with the Kemess open-pit copper and gold mine (including fishway construction, spawning habitat creation and the removal of impassible beaver dams) have likely been beneficial (Bustard and Associates 2010). Angling regulation restrictions have likely had less impact on this remote watershed, which is subject to relatively little angling effort (Hagen and Decker 2011). The other three local populations within this EDU (Davis River, Misinchinka and Point), which are tributaries of Williston Reservoir, were more or less stable over time.

No data exists, however, for the large majority of provisional core areas regarding either abundance or distribution for Bull Trout. In summary, stable or increasing trends are evident from the limited quantitative data and expert opinion assessment although the status of the majority of provisional Bull Trout core areas in British Columbia remains unknown.

There is no information available on the trend of Bull Trout populations in either the Northwest Territories, where recent surveying is only now establishing the northern range of this species distribution (Mochnacz *et al.* in review), or Yukon, where its distribution remains unclear. However, these northerly populations (which generally inhabit less productive habitat than their more southerly counterparts) are likely to be smaller, and hence more susceptible to perturbations, than those found further south. Indeed, Bull Trout are thought to be the most sensitive species in the upper Liard River basin (Can-nic-a-nick Environmental Sciences 2004).

DU3 [Genetic Lineage 2: Yukon River Watershed populations]

There is no information available on the trend of Bull Trout populations within this DU.

DU4 [Genetic Lineage 2: Saskatchewan-Nelson Rivers populations]

Historical patterns of decline in Bull Trout populations in Alberta have been most severe in southern areas of the province within this DU, with many areas in the South and North Saskatchewan River basins no longer supporting Bull Trout (Rodtka 2009). Brook Trout introductions in southwestern Alberta are thought to have contributed to this trend, where about 70% of native Bull Trout populations have been extirpated (Fitch 1997).

This historical pattern of decline is mirrored in today's short-term trends in Alberta (Appendix 1). Although current population size estimates vary widely across the 36 identified Bull Trout core areas in this DU, the short-term trends of extant populations are dominated by declines (N = 19, 53%; Appendix 1). Fourteen are considered to be stable or increasing (48%; Appendix 1). This general pattern of decline is particularly pronounced in the south; in the South Saskatchewan River basin, both core areas in the Red Deer River basin are declining, 11 of the 15 in the Bow River basin are either extirpated or declining, as are five of the ten from the Oldman River basin.

Most of the monitoring efforts that have been established in Alberta have been applied to populations within this DU (reviewed in Rodtka 2009). The most comprehensive data set exists for the adfluvial population in Lower Kananaskis Lake, which has been monitored annually for adult numbers in a spawning creek from trapping data and redd counts over 12 years (Johnston *et al*. 2009). These data show a rapid recovery of a previously heavily exploited population since the introduction of strict angling regulations in 1992; a population low of fewer than 100 adults increased almost 28 fold by 2000 (Johnston *et al*. 2009). Other less closely monitored adfluvial populations also appear to be increasing as a result of conservative angling regulations (e.g., Jacques and Harrison Lakes) (reviewed in Rodtka 2009), although the trend for resident and fluvial populations in this DU is less consistent. There is no indication of change in some other rivers (e.g., Elbow and Highwood rivers, and Quirk Creek), although others do seem to be increasing (Clearwater and Sheep rivers). Lack of consistent methodology and long intervals between some assessments, however, inhibit robust interpretations (reviewed in Rodtka 2009).

DU5 [Genetic Lineage 2: Pacific populations]

Although this DU contains more provisional core areas for Bull Trout than any other DU in British Columbia (78 of 115 total), the number of adult trend datasets is very limited and mostly short-term; there are only 15 datasets representing just 12 provisional core areas from six of the 17 EDUs believed to harbor Bull Trout from this DU (Table 1). The majority (n = 10) of these datasets are from the Columbia drainage (Table 1).

The positive trend observed in Line Creek within this drainage reflects population recovery following the implementation of more restrictive fishing regulations (Hagen and Decker 2011). A strong positive trend from 1994-2006 in the Wigwam River from the Columbia drainage was followed by a decline (considered acceptable and within routine management zone for this healthy population). This reflects changes in regulations; a limited harvest has occurred in recent years (i.e. 2004-2010) following a decade of more restrictive fishing regulations (Hagen and Decker 2011). Some other systems within the Columbia drainage exhibited more or less stable trends (e.g., Salmo River watershed and Upper Kootenay River), while datasets from two other regulated systems (Kootenay Lake and Arrow Lake Reservoir) reflect more complex patterns, showing both positive and negative trends (Table 1). Fluctuations over a decade in Duncan Reservoir within the Kootenay Lake core area are thought to reflect nutrient levels and response to forage base (i.e. Kokanee; Hagen and Decker 2011). Trends in a long-term (nearly 50 yrs) catch-per-unit effort (CPUE) dataset from Kootenay Lake (assumed to represent a meta-population) also track nutrient loading patterns influenced historically by a fertilizer plant and its closure, and the damming of rivers, and more recently by an annual whole-lake fertilization program. However, CPUE survey design varied over time and may not be sensitive to decreases in abundance (Hagen and Decker 2011). Arrow Lakes Reservoir CPUE data, which is also assumed to represent a meta-population, is similarly varied and responsive to manipulations associated with nutrient additions, but is considered more or less stable over the past three decades (Hagen and Decker 2011).

There is little information available for north coastal watersheds, the Thompson River, or the mid- and upper Fraser River within this DU (Table 1). Within the Upper Skeena EDU of the north coast, there are three datasets from salmon counting fences; one (Sustut River) indicates a consistent negative trend, one (Damshilgwet Creek) a positive trend, and the other no trend. However, there is concern that these observations may be, at least in part, artifacts of a methodology (Hagen and Decker

2011). The positive trend observed from CPUE data in Sugar Lake in the Upper Shuswap drainage of the southern interior Thompson EDU (assumed to represent a meta-population) is considered to be a response to the implementation of more restrictive fishing regulations (Hagen and Decker 2011). Within the Upper Fraser EDU, population trend can only be evaluated over the relatively short-term (5 years) for one system, the Goat River, where abundance appears stable.

An expert opinion assessment found that trend appears to vary by major watershed according to local pressures and threats, ranging from increasing to stable, to decreasing and unknown (Appendix 2). In summary, no consistent trend is apparent from either the limited quantitative data or expert opinion assessment for this DU. Given the lack of quantitative data for most core areas within this DU, however, it would be inappropriate to consider existing trend data as representative of larger geographic areas. That said, the greatest concerns occur in the Flathead, Pend d'Oreille and Columbia (downstream of Arrow Lakes Reservoir) rivers where expert opinion considers both low abundance and declining trends to be of significant concern in all three core areas (Hagen and Decker 2011). In contrast, other core areas in the Columbia basin (upper Kootenay River and Kookanusa) are considered to be stable to increasing with large numbers of adults.

Rescue Effect

In theory, a diminished or extirpated population of Bull Trout could experience a rescue effect from neighbouring populations, be they within Canada or from the USA. The potential for such a rescue effect will, however, depend on several factors, including the amount of migration between populations, the viability of immigrants in their new environment and the status of neighbouring populations.

Genetic studies indicate low levels of gene flow between populations. Significant genetic differentiation among Bull Trout populations is common even within watersheds (Spruell *et al.* 1999; Taylor *et al.* 2001; Costello *et al.* 2003; Taylor and Costello 2006), although the degree of divergence is more pronounced at a more regional scale (Taylor *et al.* 2001; Costello *et al.* 2003; Whiteley *et al.* 2004; Taylor and Costello 2006). The Bull Trout's typically strong site fidelity to spawning area and overwintering habitat revealed by radiotelemetry studies (Swanberg 1997a; Bahr and Shrimpton 2004) further suggests that migration between populations is low. This diminishes the likelihood of immigration providing a significant rescue effect for Bull Trout populations. Significant dispersal between watersheds seems particularly unlikely, although some evidence of straying at the local level (Swanberg 1997a; O'Brien 2001; Bahr and Shrimpton 2004) and at least one account of dispersal between watersheds (Brenkman and Corbett 2005) does suggest a potential role for dispersal from nearby sources in the repopulation of a declining or extirpated population.

While local adaptation of Bull Trout will reduce the viability of immigrants in new environments (Nosil *et al.* 2005) and diminish the possibility of rescue effects from neighbouring populations, phenotypic plasticity may counterbalance this to some extent. Divergence in quantitative traits will likely be most evident across different environments at larger scales, for example, among populations inhabiting the different DUs. However, local adaptation may exist even at the fine scale, given that microsatellite-based differentiation, which likely provides conservative estimates of adaptive divergence (Pfrender *et al.* 2000; Morgan *et al.* 2001), has commonly been detected among populations within localized areas (Spruell *et al.* 1999; Taylor *et al.* 2001; Costello *et al.* 2003; Taylor and Costello 2006).

Any rescue effects to be had will, therefore, most likely occur between close, adjacent populations that are connected by contiguous habitat suitable for Bull Trout migration. This could include several watersheds that have transboundary Bull Trout populations, such as the Flathead River, upper Kootenay River, Kootenay Lake, Salmo River, Skagit River and Chilliwack watershed. The direction of any transboundary rescue effect is most likely to be from Canadian populations to USA waters because Canadian Bull Trout are likely much more numerous in both the number of populations and abundance than their USA counterparts. The vast majority of Bull Trout's range occurs in Canada (Rieman *et al.* 1997) and Canadian Bull Trout populations are generally considered to be more stable than *Threatened* (USFWS 2008) populations in the USA. The majority of Bull Trout populations in the northern USA range are considered to be depressed (Rieman *et al.* 1997). With very few strong or protected populations near the US-Canada boundary (Rieman *et al.* 1997), it is very unlikely that a USA Bull Trout population could contribute to a rescue effect for a Canadian one.

THREATS AND LIMITING FACTORS

A number of factors combine to limit the abundance of Bull Trout in Canada. Some of these are naturally occurring limiting factors but the most serious threats to Bull Trout come from anthropogenic disturbance.

Naturally Occurring Limiting Factors

The natural limiting factors for Bull Trout discussed herein are universal across their range and, therefore, relevant to all DUs. Any geographical trends in the extent of their influence are highlighted in the following DU-specific subsections.

Bull Trout's specific habitat requirements are its most significant natural limiting factor (reviewed in Rieman and McIntyre 1993; Dunham *et al.* 2003). Its need for cold water (most commonly less than 12^{o}C) in particular, as well as the very specific habitat required for spawning and rearing, strongly influence its occurrence and result in its characteristic patchy distribution (Rieman and McIntyre 1993; Dunham *et al.* 2003; see '**Habitat Requirements**' section). A warmer climate in the southern margins of its global range influences Bull Trout's spotty distribution here (Dunham *et al.* 2003). This sensitivity makes it an excellent indicator of environmental disturbance. Interactions with other fish species are likely another important determinant of Bull Trout distribution and abundance; interference competition from other species, such as Rainbow or Cutthroat Trout, also appears to be mediated by water temperature, while the abundance of prey species, such as Kokanee, likely also impacts Bull Trout growth and survival (see '**Interspecific Interactions**' section).

Bull Trout are also limited by their low reproductive potential. Within suitable reaches, density-dependent survival appears to limit production of age-1+ Bull Trout parr to mean densities of about 8 fish/100 m^2 or less (Hagen 2008 and references therein). This density-dependent survival at the juvenile life stage can be an important determinant of abundance at later life stages (Johnston *et al.* 2007). Other life history attributes, such as it being a top aquatic predator and showing high site fidelity, can contribute to relatively low densities (see '**Population and Sizes**' section). Together with its restricted gene flow (Taylor *et al.* 2001; Taylor and Costello 2006) and natural pattern of fragmentation, these factors make Bull Trout vulnerable to local extinctions through stochastic processes. Such natural extinctions may even be common (Rieman and McIntyre 1993, 1995). The pattern of depauperate neutral genetic variation within Bull Trout populations and high differentiation between them (see '**Population Spatial Structure and Variability**' section) indicates a historical demographic pattern of bottlenecks and local extinctions.

These limiting factors render Bull Trout vulnerable to human activities and their impacts (Rieman and McIntyre 1993, 1995). On the other hand, strategies that Bull Trout has evolved to persist in the face of variable environmental conditions may also offer some compensation when dealing with human-induced changes. For example, phenotypic plasticity and density dependent changes in life history traits, such as faster maturation and more frequent reproductive events at lower density, may offer some resilience to perturbations (Johnston and Post 2009).

Anthropogenic Threats

While the gradual demise of Bull Trout in developed areas over the last century (Rieman *et al.* 1997; USFWS 1999, 2008; Rodtka 2009) clearly indicates their environmental sensitivity, the reasons underlying this vulnerability are not clearly understood. Most evidence is correlative in nature and identification of causal mechanisms is needed. Nevertheless, three main anthropogenic factors are likely responsible for their decline: loss of habitat network through degradation and fragmentation, interaction (hybridization and competition) with introduced species and overexploitation (Rieman and McIntyre 1993; BCMWLAP 2004; Brewin 2004; Rodtka 2009). These broad categories apply to Bull Trout across its range, and the descriptions given in each category's subsection are relevant to all Canadian Bull Trout DUs. However, the type and extent of specific threats will vary at regional and local scales; information that is available for individual Bull Trout DUs is outlined in the subsequent DU-specific subsections.

It can be extremely difficult to predict and quantify the influences of anthropogenic specific threats, and their interactions with other threats and natural limiting factors. For example, increasing connectivity in landscapes that have become fragmented through human disturbance may reduce extinction risk by facilitating movement. However, it may simultaneously foster invasion by other non-native species (Fausch *et al.* 2008) or threaten previously isolated resident populations with replacement by larger, migratory ones (Hagen 2008). In another example, the Bull Trout's ability to resist invasion and persist in watersheds may be strengthened where intact habitat allows the expression of a full range of life histories, including large, highly fecund, migratory individuals (Nelson *et al.* 2002). When these migratory individuals are lost (e.g., through habitat loss or fragmentation, or overfishing), non-native fishes may be better able to displace or replace remaining resident Bull Trout (Dunham *et al.* 2008). Although we have a limited understanding of such interactions, it is undisputed that this battery of anthropogenic threats forms a formidable obstacle to the persistence of many Bull Trout populations (Rieman and McIntyre 1993; BCMWLAP 2004; Brewin 2004; Rodtka 2009).

Loss of Habitat Network

The degradation and fragmentation of freshwater habitat associated with disruptive land use practices, such as commercial forestry, hydroelectric, oil, gas and mining development, agriculture, urbanization, and all of their associated road development has been widely documented (reviewed in Rieman and McIntyre 1993; Ripley *et al.* 2005; Rodtka 2009). The gradual demise of Bull Trout in developed areas over the last century (Rieman *et al.* 1997; USFWS 1999, 2008; Rodtka 2009) suggests a trend of negative biological response to this environmental disruption. Indeed, road density, as a general, indirect measure of habitat disturbance, has frequently been found to significantly negatively correlate ($P < 0.05$) with Bull Trout occurrence (Rieman *et al.* 1997; Baxter *et al.* 1999; Dunham and Rieman 1999; Ripley *et al.* 2005; Scrimgeour *et al.* 2008).

<u>Habitat degradation:</u>

The environmental sensitivity of Bull Trout should come as no surprise, given their very specific habitat requirements. Variables such as temperature, depth, velocity, substrate and cover are critical to the persistence of this cold water specialist (see '**Habitat Requirements**' section). The Bull Trout's long overwinter incubation and rearing phase make these particularly vulnerable stages during Bull Trout's development. For example, the occurrence of Bull Trout is negatively correlated to the percentage of fine sediment filling interstitial spaces (Weaver and White 1985; Ripley *et* *al.* 2005). Groundwater is key to providing the high quality habitat required for this stage, as well as overwintering, in many Bull Trout populations (Baxter 1997; Baxter and McPhail 1999; Baxter and Hauer 2000; Ripley *et al.* 2005). As well as direct impacts, habitat degradation that impacts the availability and abundance of prey species will also likely have a trickle-up effect on this top aquatic predator.

The exact mechanisms by which disruptive land use practices adversely affect the occurrence and abundance of Bull Trout are not well understood. Their impacts on habitat quality are likely related to changes in forest composition and age that alter the input of groundwater and woody debris, loss of deep pools, channel simplification, decreased vegetation cover, and increase surface runoff, sediment inputs and nutrient pulses. These effects can lead to diminished water quality, reduced cover, increased thermal and light regimes, increased sedimentation, and altered flow regimes that destabilize streambeds (reviewed in Rieman and McIntyre 1993; Ripley *et al.* 2005; Rodtka 2009). For example, increased stream temperatures are a common result of watershed developments when they result in loss of riparian vegetation (Holtby 1988; Johnson and Jones 2000; Post and Johnston 2002).

Bull Trout's susceptibility to increasing water temperatures extends beyond the localized effects of altered patterns of forest cover, to global climate change (Rieman and McIntyre 1993; Rieman *et al.* 1997, 2007). Climate change and associated global warming in North America is likely to exceed global means in most areas, with mean projected warming ranges lying between 3°C and 5°C over most of the continent (Christensen *et al.* 2007). Such temperature changes would limit the availability of suitable Bull Trout habitat, and increase the risk of invasion, and displacement, by other species that require warmer water (Kelehar and Rahel 1996; Rahel *et al.* 1996; Porter and Neritz 2009). An increase in winter precipitation and a decrease in summer rainfall are also expected in western regions (Christensen *et al.* 2007). Subsequent winter flooding caused by heavy precipitation or glacial floods could damage Bull Trout spawning and rearing habitat. Changes like these are likely to have their biggest impact on Bull Trout populations in the south of its range, where temperature already defines its southern limit (Dunham *et al.* 2003). Here, simulations of predicted 5°C warming result in a 69% decrease in the length of streams having thermally suitable habitat for cold water salmonids in a Wyoming drainage of the Rocky Mountains (Rahel *et al.* 1996), and a loss of 92% of thermally suitable Bull Trout natal habitat area over 50 years in the interior Columbia River basin of the USA (Rieman *et al.* 2007). There has been no consideration of potential impacts, including potential range extensions, at the northern limits of the species' range.

<u>Habitat fragmentation:</u>

As well as having very specific habitat requirements, migratory populations need uninterrupted migratory corridors that connect spawning grounds with feeding and overwintering habitats. The viability of these populations, therefore, is linked to their need to access this diversity of habitat at different stages throughout their life cycle (Rieman and McIntyre 1993). Several activities can fragment Bull Trout's habitat.

Hydroelectric dams are obvious barriers to movement that can threaten the viability of Bull Trout populations across their range (USA: Neraas and Spruell 2001; BC: Decker and Hagen 2008; Hagen 2008; AB: reviewed in Rodtka 2009). They can isolate populations and prevent migration between productive juvenile and adult rearing environments (Swanberg 1997b; Neraas and Spruell 2001; Decker and Hagen 2008; Hagen 2008), as well as alter and degrade Bull Trout habitat (Brown 1995; Decker and Hagen 2008; Hagen 2008).

Road construction can also lead to fragmentation of Bull Trout habitat via numerous smaller blockages and hanging culverts (reviewed in Rieman and McIntyre 1993; Ripley *et al.* 2005; Rodtka 2009). Other obstructions to movement can be more subtle than these obvious physical impacts; degraded habitat resulting from, for example, increased water temperatures and velocities, can also ruin and fragment suitable habitat patches (Rieman and McIntyre 1993; BCMWLAP 2004; Hagen 2008).

Existing fragmentation restricts gene flow, making isolated populations more susceptible to local extinction from stochastic and deterministic risks (Lande 1993; Dunham and Rieman 1999). With less chance of recolonization through regional connectivity, extinction at the regional scale becomes more likely (Rieman *et al.* 1997). As a result of such fragmentation, Bull Trout's distribution may diminish in a way that is not directly proportional to the loss of habitat area. Rather, rates of extinction may accelerate beyond rates of habitat loss (Rieman and McIntyre 1995).

Interaction with Introduced Species

Although population declines may be largely attributed to the effects of land management and development (reviewed in reviewed in Rieman and McIntyre 1993; BCMWLAP 2004; Rodtka 2009), the expansion of introduced fish species also poses a significant threat to Bull Trout (Donald and Alger 1993; Leary *et al.* 1993). Introduced species, such as Lake Trout, Yellow Perch (*Perka flavescens*), Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*), Walleye (*Sander vitreus*) and Northern Pike (*Esox Lucius*), may pose a threat to Bull Trout populations. The greatest threat, however, may come from non-native Brook Trout populations, given the known potential negative consequences of their direct interactions with Bull Trout (see '**Interspecific Interactions**' section), and their widely overlapping range. Introduction of this recreational fish across the Pacific Northwest from its native eastern North America range began in the late 1800s. Ongoing introductions and its subsequent invasion have led to its wide establishment throughout much of Bull Trout's range (Fuller *et al.* 1999), and its presence in many of the same basins (Rieman and McIntyre 1993).

Anecdotal evidence of Bull Trout's occurrence being negatively associated with the presence of Brook Trout strongly implicates this non-native fish in the decline in Bull Trout populations across much of its range (Paul and Post 2001; Rich *et al.* 2003; Rieman *et al.* 2006; McCleary and Hassan 2008). Hierarchical analysis confirms that Brook Trout can influence upstream displacement of Bull Trout, although the extent of displacement is strongly influenced by environmental conditions (including elevation and temperature; Rieman *et al.* 2006). While complete elimination of Bull Trout is not a foregone conclusion of Brook Trout invasion, even partial upstream displacement of Bull Trout by Brook Trout may pose a serious threat to these low density fish. Bull Trout occurrence decreases with stream width (Rieman and McIntyre 1995; Earle *et al*. 2007; McCleary and Hassan 2008) so, as Bull Trout are displaced upstream, smaller and more isolated Bull Trout populations will become more vulnerable to local extinction through other causes (Lande 1993; Dunham and Rieman 1999).

The potentially devastating and unpredictable impact of non-native species on Bull Trout is illustrated by the crash in the early 1990s of Bull Trout in Flathead Lake and the Flathead River system in northwest Montana. The collapse of these Bull Trout populations that were previously considered to be abundant and secure resulted from the introduction of the combination of Lake Trout and the non-native invertebrate, the Opossum Shrimp (*Mysis relicta;* Spencer *et al.* 1991). These species caused major ecosystem changes and cascading food web interactions (Spencer *et al.* 1991).

Overexploitation

Bull Trout were once considered 'junk' fish because of their tendency to prey on other salmonids (McPhail 2007; Dunham *et al.* 2008). Active eradication plans combined with easy road access resulted in Bull Trout being "fished out" of some areas, including parts of southern Alberta and British Columbia (McPhail 2007; Dunham *et al.* 2008). Changing attitudes and management practices (see 'Legal Protection and Status' section), however, mean that the threat of extirpation from overharvesting has been reduced for many Canadian Bull Trout populations (McPhail 2007). Nevertheless, not all populations that have been subject to strict angling regulations have shown signs of recovery (reviewed in Rodtka 2009; Hagen and Decker 2011). The lack of change in some systems may be partly attributed to Bull Trout's high catchability. Angler-mediated mortality from hooking, poaching and non-compliance to fishing regulations still poses a significant threat in some areas (Post *et al.* 2003; Earle *et al*. 2007; Rodtka 2009; Hagen and Decker 2011). The infrastructure of road networks developed to support urban and industrial activities can exacerbate this threat by increasing accessibility (reviewed in Rieman and McIntyre 1993; Ripley *et al.* 2005; Rodtka 2009). Simulations using reasonable estimates of fishing effort, mortality from catch-and-release, and illegal harvest, demonstrate that many Bull Trout populations will continue to require restrictive angling regulations if they are to be sustained (Post *et al.* 2003).

Although there is no published information on the extent of mortality of Bull Trout in rivers where intensive fisheries exist for other Pacific salmonids, incidental by-catch mortality from commercial and recreational fisheries directed at these other fish poses a risk to Bull Trout. This may be borne out not just through increased hooking mortalities (Paul *et al.* 2003), but also through misidentification with other char and trout species (Rodtka 2009); many anglers remain unaware of a key distinguishing morphological feature in Bull Trout, the absence of spotting on the dorsal fin (Rodtka 2009). The introduction of sport fish, such as Brook Trout, adds to this threat (Paul *et al.* 2003).

Features of Bull Trout life history, including late age-at-maturity, low fecundity and a tendency towards non-consecutive year spawning, will hamper recovery from anthropogenic disturbances (Paul *et al.* 2003; Post *et al.* 2003; Johnston *et al*. 2007; Johnston amd Post 2009). Its high catchability also renders Bull Trout particularly vulnerable to overharvesting, even when angling effort and harvest limits are low (Paul *et al.* 2003; Post *et al.* 2003; Brenkman *et al.* 2007).

DU1 [Genetic Lineage 1: Southcoast BC populations]

The assigned overall threat impact to this DU is High-Low (IUCN Threats Calculator - Table 2). The lack of a general trend among populations in this DU is reflected in inconsistent designations of conservation status to provisional core areas; while one is considered to be ‘At Risk’ and another as “Low Risk’ of extirpation, three others remain ‘Unranked’ (Appendix 2). Considerable gaps in our knowledge about Bull Trout populations in this area make it challenging to identify threats in a DU where potential threats are diverse and location-specific (Hagen and Decker 2011). The most significant threats that have been identified include:

Table 2. Summary of threats assessment for Bull Trout within each designated unit (DU). Threats recorded according to the IUCN classification system. Impacts calculated from recorded scope and severity values (‘Not Calc.’ refers to values not calculated because they lay outside of the assessment timeframe). Assigned overall threat impact may vary from the calculated value based on best professional judgment.

Threat	Impact				
	DU1	DU2	DU3	DU4	DU5
1.Residential & commercial dev.	Medium	Low	Unknown	Low	Low
2.Agriculture & aquaculture	Medium	Unknown	Unknown	Low	Unknown
3.Energy production & mining	Not Calc.	Medium	Unknown	Low	Low
4.Transportation & service corridors	Medium	Low	Unknown	Low	Not Calc.
5.Biological resource use	Low	Low	Unknown	Low	Low
6.Human intrusions & disturbance	Not Calc.	Medium	Unknown	Low	Low
7.Natural system modifications	Medium	Low	Unknown	Low	Low

Threat	Impact				
	DU1	**DU2**	**DU3**	**DU4**	**DU5**
8.Invasive & other problematic species & genes	Medium	Not Calc.	Unknown	High	Medium
9.Pollution	Unknown	Unknown	Unknown	Unknown	Unknown
10.Geological events	Not Calc.	Not Calc.	Not Calc.	Not Calc.	Not Calc.
11.Climate change & severe weather	Medium	Not Calc.	Not Calc.	Medium	Medium
Calculated Overall Threat Impact	**High**	**High**	**Low**	**High**	**High**
Assigned Overall Threat Impact	**High-Low**	**High-Low**	**Low**	**High-Medium**	**High-Low**

Loss of habitat network:

The numerous hydroelectric projects and their associated dams in the Lower mainland (BCME 2011), as well as extensive urbanization, agricultural, and transportation system development (and, to a lesser extent, forestry) may degrade and/or fragment Bull Trout habitat within this DU (Hagen and Decker 2011).

Introduced species:

Brook Trout in Canada are concentrated in south-eastern British Columbia, as well as southwestern Alberta (Fuller *et al.* 1999; McPhail 2007). British Columbia's Brook Trout Stocking Program supplies these fish to less than 100 lakes lakes (as of 2001; Pollard and Down 2001). Several initiatives in British Columbia attempt to address concerns about the threat Brook Trout pose to Bull Trout. For example, BC's draft Brook Trout Stocking Policy, developed in 1998, calls on no further expansion of its stocking program, sterilization of all stocked fish, and pilot projects investigating their replacement with less risky stocking practices (Pollard and Down 2001).

Overexploitation:

Anadromous Bull Trout may be particularly susceptible to incidental by-catch, given their multiple migrations between freshwater and salt water, and their tendency to congregate in estuaries (Taylor and Costello 2006; Brenkman *et al.* 2007). Incidental by-catch of anadromous Bull Trout has been documented in terminal gill-net fisheries directed at Pacific salmon in north-west Washington State (Brenkman *et al.* 2007). Although protective regulations are in place, illegal harvest is thought to be a potential threat to Bull Trout populations in the Lillooet provisional core area in particular (Hagen and Decker 2011).

<u>DU2 [Genetic Lineage 2: Western Arctic populations]</u>

The assigned overall threat impact to this DU is High-Low (Table 2). The general trend of decline among Albertan populations in this DU is reflected in the designation of 11 (73%) of these core units as 'High Risk' or 'At Risk' of extirpation (Figure 11, Appendix 1). Ripley *et al.* (2005) also identified a significant threat of extirpation to Albertan Bull Trout populations in this DU; using road density and levels of commercial foresting as indirect measures of habitat disturbance, they forecast the local extirpation of Bull Trout from 24% to 43% of stream reaches that currently support Bull Trout in the Kakwa River basin over the next 20 years. Due to the limited information available on British Columbian Bull Trout populations within this DU, the majority of its provisional core units (n = 26, 87%) remain 'Unranked' for conservation status (Appendix 2). Three of the four remaining provisional core areas are from the Lower Peace EDU, and are all considered to be 'At Risk' of extirpation (Appendix 2). The fourth one from the Upper Peace EDU has been assessed as being at 'Potential Risk' (Appendix 2). As in other DUs, threats are location-specific, and vary here depending on major watershed. For example, much of the Upper Liard is considered remote and pristine, whereas the Lower Peace faces considerable pressure from rapid development (Hagen and Decker 2011). Significant threats that have been identified include:

Naturally occurring limiting factors:

The lower productivity of the colder waters in Bull Trout's northern extent likely limits its population density (Mochnacz and Reist 2007; Mochnacz *et al.* 2009). In addition, the more northerly populations within this DU may recover more slowly from adverse impacts compared to their more southerly counterparts, given their tendency for slower growth and less frequent mating (Stewart *et al.* 2007a; Mochnacz *et al. in review*). Given this likely susceptibility to perturbations, there is concern about the potential impact of development activities (Cott *et al.* 2008) on Bull Trout habitat in the Northwest Territories (Mochnacz *et al. in review*).

Loss of habitat network:

Habitat disturbances from intense development pressure in the Lower Peace River basin within British Columbia and Alberta warrant particular attention for this DU. Exploration for and extraction of oil and gas, as well as mining developments and timber harvesting, and their accompanying developments (e.g., roads, urbanization) are of the most concern (Rodtka 2009; Hagen and Decker 2011). To a lesser extent, similar concerns extend to the Lower Liard River basin within British Columbia (Hagen and Decker 2011) and Yukon (Connor *et al.* 1999). The proposed Site C dam on the Peace River if developed can be included as a threat to the populations in the Halfway-Peace, Murray, Moberly, and Pine/sukunka core areas. Conversion of river to reservoir habitas and associated changes in species assemblages, and changes to life history strategies are likely. Fish passage facilities at the dam site may not be built.

Despite their significant potential to be detrimental to Bull Trout populations, however, little evidence of this has been documented. Scrimgeour *et al.* (2008) is an exception to this; they found the occurrence of Bull Trout in the Kakwa and Simonette watersheds of west central Alberta negatively related to percent disturbance from exploration and extraction of oil and gas resources, as well as forest harvesting. Ripley *et al.* (2005) also found the level of commercial foresting (cumulative area of the subbasin harvested) in the Kakwa River Basin negatively correlated to Bull Trout occurrence. Both of these studies also found that road density acted as a general, indirect measure of habitat disturbance that significantly negatively correlated ($P < 0.05$) with Bull Trout occurrence (Ripley *et al.* 2005; Scrimgeour *et al.* 2008).

The susceptibility of Bull Trout to detrimental changes in water quality from heavy metal contaminants released from mining activities is also poorly understood (but see Hansen *et al.* 2002a, b, c). There is, however, concern about the contribution of mining activity in Alberta's northeast slopes region to declining Bull Trout stocks in the area. Elevated levels of selenium, which can reduce recruitment in fish populations by increasing rates of deformities during early development (Hodson *et al.* 1980; Hodson and Hilton 1983), occur in the region (Casey and Siwik 2000). Muscle biopsies indicate that selenium concentrations do, in fact, exceed toxicity threshold values for negatively impacting reproductive success in most Bull Trout captured downstream of coal mining activity (Palace *et al.* 2004). However, further analysis of Bull Trout eggs is needed to understand the impact of selenium on Bull Trout survival and recruitment in these coal impacted waters (Palace *et al.* 2004). Coal mine development planned for the Murray river area in the lower Peace River watershed may pose a risk to Bull Trout spawning in this area.

Although hydroelectric dams can pose a risk to Bull Trout populations, there are relatively few such developments in Northern British Columbia or in Alberta. Those that exist within this DU are clustered around the Upper Peace River (BCME 2011; Hagen and Decker 2011), although the proposed Site C Dam on the Peace River has the potential to profoundly affect Bull Trout populations in the Lower Peace EDU (Hagen and Decker 2011).

Introduced species:

Although Brook Trout in Canada are most prevalent in southern British Columbia and southwestern Alberta (Fuller *et al.* 1999; McPhail 2007), Bull Trout's occurrence has been negatively associated with the presence of Brook Trout within this DU (McCleary and Hassan 2008). While most Brook Trout stocking within Bull Trout's range in Alberta has stopped (see '**Protection, Status, and Ranks**' section), an ongoing Provincial Brook Trout Stocking Program continues to supply these fish to less than 100 lakes across British Columbia (as of 2001; Pollard and Down 2001). As listed under DU1 [*Genetic Lineage 1: Southcoast BC populations*] subsection, several initiatives attempt to address concerns about the threat to Bull Trout from this continuing Brook Trout stocking program (Pollard and Down 2001). An increasing abundance of Lake Trout in Williston Reservoir (Upper Peace EDU) is also a growing but low severity threat at present (Hagen and Decker 2011).

Overexploitation:

There is a curious pattern of increases in some Bull Trout populations within this DU (e.g., Pinto Lake) but no change in others (e.g., Kakwa River) that have been subject to strict angling regulations (reviewed in Rodtka 2009). The lack of change in some systems may be partly attributed to Bull Trout's high catchability, with hooking mortality, poaching and non-compliance to fishing regulations still posing a significant threat in some areas (reviewed in Rodtka 2009). The potential for overexploitation of Bull Trout is recognized as a moderately severe threat in specific locations in the Upper Peace EDU (Hagen and Decker 2011). In addition, the increase in angler-mediated mortality that may be associated with increased accessibility (Ripley *et al.* 2005) will likely be a threat in remote areas of this DU that have experienced recent increases in road development for primary resource extraction but where enforcement remains difficult.

<u>DU3 [Genetic Lineage 2: Yukon populations]</u>

The assigned overall threat impact to this DU is Low (Table 2). Very little is known about the distribution of Bull Trout in this DU, let alone abundance and trends for this species (Appendix 2). Despite their expected vulnerability, very few anthropogenic threats exist in this remote area. Their estimated threat level is, therefore, assumed to be low (Hagen and Decker 2011). This suggests a relatively low level of conservation concern for this DU.

Naturally occurring limiting factors:

As for the northerly populations of DU2 [*Genetic Lineage 2: Western Arctic populations*], Bull Trout populations within this northerly DU are likely to have lower population densities and exhibit slower recovery from adverse impacts compared to their more southerly counterparts.

Loss of habitat network:

Unlike the other DUs, there are no hydroelectric dams within this DU that threaten Bull Trout habitat (BCME 2011). Furthermore, there is very minimal road access and little (historical) mining activity (Hagen and Decker 2011).

DU4 [Genetic Lineage 2: Saskatchewan-Nelson Rivers populations]

The assigned overall threat impact to this DU is High-Medium (Table 2). The general trend of population decline identified in this DU is reflected in the designation of 30 (91%) of its extant core units as ‘High Risk’ or ‘At Risk’ of extirpation (Figure 11, Appendix 1). Significant threats that have been identified include:

Loss of habitat network:

All of the land use practices that have been identified as general threats to the integrity of Bull Trout habitat throughout their Canadian range have been associated with the demise of Bull Trout in southwestern Alberta during the mid-20th century (e.g., commercial forestry, hydroelectric, oil, gas and mining development, agriculture, urbanization, their associated road development, and climate change; see Appendix 3). However, little quantitative evidence of their impact on Bull Trout populations has been documented within this DU.

Although hydroelectric dams can pose a risk to Bull Trout populations, there are few such developments in Alberta compared to British Columbia. Nevertheless, the potential for the developments that do exist within this DU to fragment Bull Trout habitat is illustrated by the congregation of Bull Trout attempting spawning migration below Oldman Dam, which has no provision for fish passage (Fernet and O’Neil 1997).

The anticipated effects of global climate change (Christensen *et al.* 2007) on Bull Trout habitat within its Canadian range can be expected to be exacerbated in the rain-dominated habitat of this DU, although there are currently no modeling simulations to support this.

Introduced species:

Brook Trout are particularly prevalent in southwestern Alberta, (Fuller *et al.* 1999; McPhail 2007). Brook Trout introductions in southwestern Alberta are thought to have contributed to the historical pattern of decline in Bull Trout populations in this DU (Paul and Post 2001; Fitch 1997). In recognition of this, most Brook Trout (as well as Brown Trout) stocking within Bull Trout's range in Alberta has either stopped for more than 8 years or, in a few cases, been replaced by stocking of only sterile, triploid fish (see '**Protection, Status, and Ranks**' section).

A Brook Trout removal research project in Quirk Creek, southwestern Alberta (Paul *et al.* 2003; Earle *et al*. 2007; see '**Protection, Status, and Ranks**' section) provides a cautionary note on the difficulty of removing or suppressing introduced species to promote Bull Trout recovery. Here, Brook Trout have been found to be relatively resilient to even selective harvesting, thanks to their fast growth and early maturation, and their lower catchability (i.e., proportion of vulnerable population caught per unit of angling effort) compared to native salmonids, including Bull Trout (Paul *et al.* 2003; Earle *et al*. 2007). On the other hand, Bull Trout, with their higher catchability, slower growth and later maturity, are extremely sensitive to overexploitation, and may even be negatively impacted from incidental mortalities resulting from such initiatives (Paul *et al.* 2003; Earle *et al*. 2007).

Overexploitation:

The diminished threat of extirpation from overharvesting within this DU is reflected in the expansion of some previously exploited Bull Trout populations since the introduction of strict angling regulations (e.g., Lower Kananaskis, Jacques and Harrison lakes, and Clearwater and Sheep rivers; Johnston *et al.* 2007; and reviewed in Rodtka 2009). Nevertheless, not all Bull Trout populations in southwestern Alberta that have been subject to strict angling regulations have shown change (e.g., Elbow and Highwood rivers, and Quirk Creek; reviewed in Rodtka 2009). The lack of change in some systems may be partly attributed to Bull Trout's high catchability, with hooking mortality, poaching and non-compliance to fishing regulations still posing a significant threat in some areas (reviewed in Rodtka 2009).

DU5 [Genetic Lineage 2: Pacific populations]

The assigned overall threat impact to this DU is High-Low (Table 2). As for most of the other Bull Trout DUs, considerable gaps in our knowledge about Bull Trout populations make it difficult to fully assess threats in this DU; the majority of its provisional core units (n = 52, 67%) and many of its EDUs (n = 7, 41%) remain 'Unranked' for conservation status (Appendix 2). Nevertheless, threats are known to vary by major watershed in this very broadly distributed DU (Hagen and Decker 2011) and, not surprisingly, those provisional core areas that have been designated a conservation status range widely from 'High Risk' (n = 4) and 'At Risk' (n = 7) of extirpation to 'Potential Risk' (n = 3) and 'Low Risk' (n = 12, Appendix 2). One EDU, the

Upper Kootenays, is considered to be ‘Low Risk’, seven other EDUs are thought to be at ‘Potential Risk’, while the greatest concerns occur in the Flathead and Upper Skeena EDUs, which have core areas listed as ‘At Risk’ of extirpation (Appendix 2). The most significant threats that have been identified include:

Loss of habitat network:

Hydroelectric dams within this DU are concentrated in a southern central area that covers the Upper Columbia basin, the Thompson-Okanagan region, and the interior of the Cariboo-Chilcotin region (BCME 2011; Hagen and Decker 2011). Evidence from this DU indicates that hydroelectric dam projects can degrade Bull Trout habitat, as well as potentially isolating resident populations and preventing migratory fishes from moving between their spawning and feeding grounds. The inundation of streams and lakes can ruin spawning and rearing grounds, and adult habitat can be degraded, and the reduced flow can degrade adult habitat downstream through sedimentation (Brown 1995; Decker and Hagen 2008; Hagen 2008). The spawning preference of Bull Trout for colder, higher elevation headwaters will, however, reduce this impact relative to other salmonids (Hagen 2008). While riparian restoration along streams and the removal of migration barriers can correct for these losses in habitat and connectivity, care must be taken to not create other negative impacts, such as threatening previously isolated resident populations with replacement by larger, migratory ones (Hagen 2008).

While risks to Bull Trout associated with dam developments should not be underplayed, the reservoirs that they hold may positively impact adfluvial Bull Trout populations that can readily shift from a fluvial to adfluvial life history; in the headwaters of the Kootenay and Columbia Rivers, reservoirs have supported the large expansion of Kokanee populations over the last 30 years, with subsequent increases in the abundance of Kokanee’s predators, including Bull Trout (Jamieson pers. comm. 2010).

Another serious threat to Bull Trout across parts of this DU (especially the Middle Fraser EDU but also including parts of the Homathko-Klinaklini, Bella Coola-Dean, and Thompson EDUs) is the recent massive loss of pine forest cover to the mountain pine beetle, which could lead to significantly warmer thermal regimes (Hagen and Decker 2011) While these impacts will likely be lessened in the long term as forests regenerate, climate change will likely exert an increasingly negative influence on thermal regimes for Bull Trout. Although detrimental habitat changes associated with global warming are likely to have their biggest impact on Bull Trout populations in the US, where temperature already defines its southern limit (Dunham *et al.* 2003), an assessment of the snowmelt-dominated watersheds in the Cariboo-Chilcotin region of the Middle Fraser EDU in British Columbia suggests that the thermal and precipitation effects of global warming will produce a long-term pattern of considerably decreased cold water stream habitat by the 2080s (Porter and Neritz 2009). Indeed, the potential of climate change to be a major threat to the long-term persistence of Bull Trout is recognized for a number of provisional core areas in the Middle Fraser, Thompson and Columbia-Arrow Lakes EDUs (Hagen and Decker 2011). It is also recognized as a potential threat to areas of the Upper and Lower Kootenays, Bella Coola-Dean, and Upper Fraser

EDUs (Hagen and Decker 2011). Bull Trout streams downstream of heavily glaciated headwaters that are found in some areas of this DU (e.g., some areas in the Homathko-Klinaklini, Thompson, Columbia-Arrow Lakes, and Middle Fraser EDUs) will likely be buffered against such degradation of thermal regimes (Hagen and Decker 2011).

Habitat threats related to other watershed development are also recognized in EDUs across this DU (Hagen and Decker 2011). In places these threats are potentially widespread e.g., mining in the Upper Kootenays, and forestry in the Upper Columbia and Lower Kootenays EDUs (Hagen and Decker 2011). Potentially significant threats to Bull Trout populations posed by some proposed watershed developments (e.g., hydroelectric projects in the Homathko-Klinaklini EDU; mining in the Upper Nass, Upper Stikine, and Nakina and Taku EDUs, and; recreation resort in the Thompson EDU) are recognized as requiring immediate attention (Hagen and Decker 2011).

Introduced species:

Brook Trout in this DU are concentrated in southeastern British Columbia (Fuller *et al.* 1999; McPhail 2007). The potential threat posed by this species is recognized for several areas in this DU (Upper Columbia, Columbia-Arrow Lakes, and Upper Fraser EDUs, Hagen and Decker 2011). While British Columbia's ongoing Provincial Brook Trout Stocking Program supplies these fish to less than 100 lakes (as of 2001; Pollard and Down 2001), several initiatives attempt to address concerns about the threat to Bull Trout from this continuing Brook Trout stocking program (listed under DU1 [*Genetic Lineage 1: Southcoast BC populations*] subsection, Pollard and Down 2001). Lake Trout incursion in the Flathead EDU is considered to be a major threat (Hagen and Decker 2011).

Overexploitation:

Overexploitation is likely the most significant historical impact on Bull Trout in the Middle Fraser EDU, alongside hydroelectric development (Hagen and Decker 2011). As is the case elsewhere (e.g., Wigwam River, Pollard and Down 2001), at least some Bull Trout populations within this EDU have recovered from past exploitation following stricter angling regulations (e.g., Quesnel Lake, Porter and Nelitz 2009). Nevertheless, concern about localized overharvest still exists for some provisional core areas in this and other EDUs (e.g., Thompson, Lower and Upper Skeena, Upper Nass, Iskut-Lower Stikine and Upper Stikine EDUs, Hagen and Decker 2011).

PROTECTION, STATUS, AND RANKS

Legal Protection and Status

Bull is listed by the United States Fish and Wildlife Service (USFWS) as *Threatened* throughout its range in the contiguous United States under the *Endangered Species Act*. After listing certain populations of Bull Trout as *Threatened*, the USFWS added the remaining population segments within Bull Trout's range in the United States in 1999 (USFWS 1999). This classification was maintained following a five-year review of the listing in 2004 (USFWS 2008).

The Canadian federal *Fisheries Act* delegates authority to the provinces and territories to establish and enforce fishing regulations. Under this Act, each jurisdiction within Bull Trout's range has designated this species as a game or sportfish (DJC 1996, 1998, 2005, 2008). These regulations incorporate a variety of measures to protect fish stocks, including stream and lake closures, catch and release fisheries, size and catch limits, and gear restrictions. Alberta currently has the most conservative Bull Trout angling regulations, which includes a province-wide zero-bag-limit (Rodtka 2009). Sport harvesters in the Northwest Territories and Yukon are allowed to catch 2 Bull Trout per day; those in Northwest Territories can have three in their possession at any one time, while those in Yukon can have four (FOC/YE 2010; NTENR 2010). Increasingly conservative angling regulations in British Columbia vary across the province; the least restrictive region for daily catch quota (DCQ) is the Okanagan for lakes (DCQ = 6 but zero for streams), and the Skeena for streams (DCQ = 2 from streams, 3 total). The most conservative regulations in place are in the Lower mainland and Omineca, where there is a DCQ of 1 from lakes and 0 from streams (BCME 2010).

The Canadian federal *Wildlife Act* enables provincial and territorial authorities to license anglers and angling guides, and to supply scientific fish collection permits. Under this Act, Bull Trout is afforded some protection in Alberta and British Columbia. Alberta's Endangered Species Conservation Committee (ESCC) has identified Bull Trout as a *Species of Special Concern* under its *Wildlife Act* since 2002 (Gutsell *et al.* 2008). This means that it is a species that may soon become threatened with extinction if there is no human intervention.

At the provincial level, growing concerns about Bull Trout's declining populations in Alberta led to the establishment of the Bull Trout Task Force in 1993. This facilitated recovery efforts in subsequent years and helped the development of Alberta's 'Bull Trout Management and Recovery Plan' (Berry 1994), which recognized Bull Trout as a species of Special Concern and was implemented in 1995 (Brewin 2004). A provincial status report was first published in 2002 (Post and Johnson 2002). This has been recently updated, with the status of various populations currently under review (Rodtka 2009). The management plan is currently being updated (Rodtka 2009). A number of recovery actions that have already been undertaken include (Christiansen pers. comm. 2010):

1. A province-wide no-harvest regulation implemented in 1995 that will be enforced until such time as there is a harvestable surplus. This was also implemented by the National Parks (Brewin 2004).
2. The elimination of bait use in waters containing Bull Trout since 1988 (with several highly restricted seasonal exceptions).
3. The establishment of permanent, as well as some seasonal, angling closures in known key Bull Trout spawning areas.
4. An extensive campaign undertaken since 1995 to educate anglers in fish identification to help reduce the chances of misidentification and accidental harvest of Bull Trout.
5. A public education program about Bull Trout and their habitat requirements designed to encourage responsible decision-making where impacts on Bull Trout habitat could result.
6. “Class A” designation of many of the most significant known Bull Trout spawning areas under the *Alberta Water Act*. This affords a high level of protection to these key areas, excluding almost all new road and pipeline crossings from within the area, and limiting the extent of disturbance that can occur in the riparian zone.
7. Provincial Enforcement staff place a high priority on enforcement of the Bull Trout harvest closures throughout the species range since 1995, directed by enforcement advisories.
8. Two assessment and remediation projects of stream crossings in NW Alberta, initiated by a consortium of groups including government, industry and regulators. Work aims to identify and correct crossings that may block fish movements or contribute to sedimentation.
9. A review of all stocking programs within the Bull Trout range followed by their discontinuation or modification. Most Brook Trout and Brown Trout stocking within Bull Trout range has either stopped for more than 8 years or, in a few cases, been replaced by stocking of only sterile, triploid fish.
10. A Brook Trout removal research project in Quirk Creek, southwestern Alberta, which has examined the use of angling to selectively remove Brook Trout from a mountain stream that harbours remnant populations of native Bull Trout and West Slope Cutthroat Trout.

Some similar actions have occurred in British Columbia. In 1995, the British Columbia Fisheries Program developed a ‘Strategic Plan for the Conservation and Management of Char in British Columbia’ (BCME 1994). Bull Trout was identified as a priority species in this plan. This reflected its provincial blue-listing as a species of *Special Concern* (i.e. are considered to be particularly vulnerable to human activities or natural events) in 1994 (BCCDC 2010), and recognized that the majority of intact Bull Trout populations in the species’ range occur in British Columbia (Pollard and Down 2001). This plan has since focused ongoing provincial inventory, assessment and research efforts towards a better understanding of the species’ general distribution, patterns of genetic diversity, seasonal movements, critical habitat and interspecific interactions (Pollard and Down 2001).

Bull Trout is afforded limited protection in British Columbia from the provincial *Fish Protection Act*, as well as being protected under BC's *Wildlife Act*. The *Fish Protection Act* provides some legislative authority for water managers to consider impacts on fish and fish habitats before approving new water licenses or amendments to existing licenses, or issuing approvals for works in and about streams. Bull Trout is also one of four fish listed under the 'Identified Wildlife Management Strategy' of the 'Forest and Range Practices Code of British Columbia', which recommends special management attention for such species under the *Forest and Range Practices Act*.

Non-Legal Status and Ranks

Bull Trout is assessed as *Vulnerable* under the IUCN Red List of Threatened Species (IUCN 2010). Its Global Heritage Status rank is *Apparently Secure* (G4, NatureServe 2011). Bull Trout is ranked as *Sensitive* nationally (N3), in British Columbia the interior lineage is ranked as S3 and also S3 in Alberta and Yukon. It is ranked as *May Be At Risk* (S2) in the Northwest Territories. Populations in the USA are listed as *Threatened* under the *Endangered Species Act*.

Habitat Protection and Ownership

Recent controversial changes to the *Fisheries Act* reduce the degree of protection of Bull Trout and their habitat, but it could be afforded some protection as a species of interest for recreational angling with economic implications. This species is also found within several National Parks (Jasper, Yoho, Kootenay, Banff, Glacier, Nahanni and Waterton Lakes National Parks), which are managed by Parks Canada and are regulated in accordance with the *National Parks Act*. Development is prohibited to varying degrees in the various other park systems and protected areas that exist throughout the Canadian range of Bull Trout (PDAC 2008).

All of the jurisdictions within Bull Trout's Canadian range surpassed the target recommended in the 1988 Brundtland Report to reach 12% of the land base dedicated to protected areas (WCED 1987); current area protected ranges from about 13% in Alberta and Yukon, and nearly 14% in British Columbia, to approximately 22% in Northwest Territories (BCME 2007; PDAC 2008). The majority of land in Bull Trout's Canadian range is Crown or public (BC ~ 94%; AB ~72%; NT; ~100%; YK 98%) with the minority being privately owned (PDAC 2008).

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

Many people contributed to the information contained in this report. The report writer would like to extend her gratitude to all of the following people for generously sharing published reports and manuscripts, and/or other invaluable information and advice: Tom Brown, Holly Cleator, Neil Mochancz, Dave O'Brien, Raymond Ratynski, Jim Reist, Chantelle Sawatzky, Christie Whelan, Paul Welch, Timber Whitehouse (Department of Fisheries and Oceans); Patrick Nantel (Parks Canada); Steve Brechtel, Isabelle Girard, Robin Gutsell (Alberta Fish and Wildlife); Ted Down, Susan Pollard (BC Ministry of Environment); Suzanne Carrière (Wildlife Division ENR NT); Bruce Bennett, Lars Jessup, Lars Jessup (Environment Yukon); Meherzad Romer (British Columbia Conservation Data Centre); Lorna Allen (Alberta Natural Heritage Information Centre); Noel Alfonso, Lynn Gillespie, Sylvie Laframboise (Canadian Museum of Nature); Sue Peters (Alberta Conservation Association); Harry Nyce Sr (Nisga'a Wildlife Committee [NWC] and Joint Fisheries Management Committee); Bruce Stewart (Arctic Biological Consultants); Bob Jamieson (Kinbasket Development Corporation); Don McPhail, Eric Parkinson, Eric Taylor (University of British Columbia); Bruce Rieman (USFS Rocky Mountain Research Station). Neil Mochancz and David O'Brien generously shared unpublished manuscripts. The report writer would also like to thank Jenny Wu (COSEWIC Secretariat) for her collegiality in creating the distribution map and calculating extent of occurrence and area of occupancy. A request was made for ATK related to Bull Trout in Canada but no information was received prior to submission of this report. All authorities contacted by the author in the making of this report are listed in Table 3.

Table 3. Authorities contacted during the preparation of this report.

Name	Title	Affiliation	City, Province/ State (Country)
Sonia Schnobb/ COSEWIC sectretariat	Administrative Assistant	COSEWIC Secretariat	Ottawa, ON
Jenny Wu	Scientific Project Officer	COSEWIC Secretariat	Gatineau QC
Rhonda L. Millikin	A/Head Population Assessment	Canadian Wildlife Service (Pacific & Yukon Region)	Delta, BC
Shelagh Bucknell	Administrative Services Assistant	Canadian Wildlife Service (Pacific & Yukon Region)	Delta, BC
Dave Duncan		Canadian Wildlife Service (Prairie & Northern Region, AB)	Edmonton, AB
Dave Ingstrup		Canadian Wildlife Service (Prairie & Northern Region, AB)	Edmonton, AB
Bruce MacDonald		Canadian Wildlife Service (Prairie & Northern Region, NT)	Yellowknife, YK
Vanessa Charlwood		Canadian Wildlife Service (Prairie & Northern Region, NT)	Yellowknife, YK
Christie Whelan	Science Advisor	Department of Fisheries and Oceans	Ottawa, ON
Simon Nadeau	Senior Advisor	Department of Fisheries and Oceans	Ottawa, ON
Dave O'Brien	Science Advisor	Department of Fisheries and Oceans	Nanaimo, BC
Tom Brown	SARA Biologist	Department of Fisheries and Oceans	Nanaimo, BC

Name	Title	Affiliation	City, Province/ State (Country)
Sean MacConnachie		Department of Fisheries and Oceans	
Karen Calla		Department of Fisheries and Oceans	
Kathleen Martin		Department of Fisheries and Oceans	
Holly Cleator	Science Advice Liaison	Department of Fisheries and Oceans	Winnipeg, MB
Jim Reist	Research Scientist and Head	Department of Fisheries and Oceans	Winnipeg, MB
Neil Mochancz	Fisheries Research Biologist	Department of Fisheries and Oceans	Winnipeg, MB
Chantelle Sawatzky	Arctic Aquatic Research Biologist	Department of Fisheries and Oceans	Winnipeg, MB
Paul Welch	Sockeye Biologist	Department of Fisheries and Oceans	Kamloops, BC
Timber Whitehouse		Department of Fisheries and Oceans	
Brian Young		Department of Fisheries and Oceans	
Gilles Seutin	Coordinator of Species at Risk Program	Parks Canada	Gatineau, QC
Patrick Nantel	Conservation Biologist	Parks Canada	Gatineau, QC
Shelley Humphries	Aquatics Specialist	Parks Canada	Field, BC
Gordon Court	Provincial Wildlife Status Biologist	Alberta Fish & Wildlife	Edmonton, AB
Steve Brechtel		Alberta Fish & Wildlife	
Richard Quinlan	Provincial Species at Risk Specialist	Alberta Fish & Wildlife	
Isabelle Girard	Senior Fisheries Biologist	Alberta Fish & Wildlife	Rocky Mountain House, AB
Donna Rystephanuk		Alberta Fish & Wildlife	
Robin Gutsell		Alberta Fish & Wildlife	
Susan Pollard	Aquatic Species At Risk Specialist	BC Ministry of Environment	Victoria, BC
Ted Down	Manager, Fisheries Science Section, Ecosystem Branch,	BC Ministry of Environment	Victoria, BC
Suzanne Carrière	Biologist (Biodiversity)	Wildlife Division ENR NT	Yellowknife, YK
Tom Lakusta	Manager, Forest Resources	Forest Management Division ENR NT	Hay River, NT
Thomas Jung	Senior Biologist	Environment Yukon	Whitehorse, YT
Bruce Bennett		Environment Yukon	Whitehorse, YT
Lars Jessup	Fisheries Technician	Environment Yukon	Whitehorse YT
Nathan Miller	Senior Fisheries Biologist	Environment Yukon	Whitehorse YT
Meherzad Romer		British Columbia Conservation Data Centre	Victoria, BC
Lorna Allen	ANHIC Coordinator	Alberta Natural Heritage Information Centre	Edmonton, AB
Lynn Gillespie	Research Scientist	Canadian Museum of Nature	Ottawa, ON
Sylvie Laframboise	Assistant Collections Manager	Canadian Museum of Nature	Ottawa, ON
Noel Alfonso	Research Services	Canadian Museum of Nature	Ottawa, ON
Sue Peters	Species At Risk Biologist	Alberta Conservation Association	Sherwood Park, AB

Name	Title	Affiliation	City, Province/ State (Country)
Harry Nyce Sr	Director of Fisheries & Wildlife	Nisga'a Wildlife Committee (NWC) & Joint Fisheries Management Committee	New Aiyansh, BC
Bob Jamieson	Project Manager	Kinbasket Development Corporation	Invermere, BC
John Post	Co-chair	COSEWIC Freshwater Fishes Specialist Subcommittee	Calgary, AB
Bruce Stewart	Head	Arctic Biological Consultants	Winnipeg, MB
Eric Taylor	Professor	University of British Columbia	Vancouver, BC
Eric Parkinson	Professor	University of British Columbia	Vancouver, BC
Don McPhail	Professor Emeritus	University of British Columbia	Vancouver, BC
Bruce Rieman	Research Scientist (Emeritus)	USFS Rocky Mountain Research Station	Seeley Lake, MT, USA

INFORMATION SOURCES

Al-Chokhachy, R., P. Budy, and M. Conner. 2009. Detecting declines in the abundance of a Bull Trout (*Salvelinus confluentus*) population: understanding the accuracy, precision, and costs of our efforts. Canadian Journal of Fisheries and Aquatic Sciences 66:649–658.

Al-Chokhachy, R., P. Budy, and H. Schaller. 2005. Understanding the significance of redd counts: a comparison between two methods for estimating the abundance of and monitoring Bull Trout populations. North American Journal of Fisheries Management 25:1505-1512.

Allendorf, F.W., and R.F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species: the Cutthroat Trout. Conservation Biology 2:170–184.

Angers, B., and L. Bernatchez. 1998. Combined use of SMM and non-SMM methods to infer structure and evolutionary history of closely-related Brook Charr (*Salvelinus fontinalis*, Salmonidae) populations from microsatellites. Molecular Biology and Evolution 15:143–159.

Armbruster, P., W.E. Bradshaw, and C.M. Holzapfel. 1998. Effects of Postglacial Range Expansion on Allozyme and Quantitative Genetic Variation of the Pitcher-Plant Mosquito, *Wyeomyia smithii.* Evolution 52:1697-1704.

Avise, J.C. 2004. Molecular Markers, Natural History and Evolution. 2nd edition. Chapman and Hall, New York. 684 pp.

Bahr, M.A., and J.M. Shrimpton. 2004. Spatial and quantitative patterns of movement in large Bull Trout (*Salvelinus confluentus*) from a watershed in north-western British Columbia, Canada, are due to habitat selection and not differences in life history. Ecology of Freshwater Fish 13:294–304.

Baxter, J.S. 1997. Aspects of the reproductive ecology of Bull Trout (*Salvelinus confluentus*) in the Chowade River, British Columbia. M.Sc. dissertation, University of British Columbia, Vancouver, British Columbia, Canada. 97 pp.

Baxter, C.V., K.D. Fausch, M. Murakami, and P.L. Chapman. 2004. Fish invasion restructures stream and forest food webs by interrupting reciprocal prey subsidies. Ecology 85:2656-2663.

Baxter, C.V., C.A. Frissell, and F.R. Hauer. 1999. Geomorphology, logging roads, and the distribution of Bull Trout spawning in a forested river basin: implications for management and conservation. Transactions of the American Fisheries Society 128:854–867.

Baxter C.V., and F.R. Hauer. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by Bull Trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57:1470-1481.

Baxter, J.S., and J.D. McPhail. 1996. Bull Trout spawning and rearing habitat requirements: summary of the literature. Fisheries Technical Circular No. 98, British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia. 25 pp.

Baxter, J.S., and J.D. McPhail. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of Bull Trout (*Salvelinus confluentus*) from egg to alevin. Canadian Journal of Fisheries and Aquatic Sciences 77:1233-1239.

Baxter, J.S., E.B. Taylor, R.H. Devlin, J. Hagen, and J.D. McPhail. 1997. Evidence for natural hybridization between Dolly Varden (*Salvelinus malma*) and Bull Trout (*Salvelinus confluentus*) in a northcentral British Columbia watershed. Canadian Journal of Fisheries and Aquatic Sciences 54:421–429.

Baxter J.S., W.T. Westover, and J.R. Roome. 2000. Wigwam River Bull Trout - Habitat Conservation Trust Fund Progress Report (1999). Fisheries Project Report KO 57, British Columbia Ministry of Environment, Lands and Parks, Cranbrook, British Columbia. 39 pp.

Beauchamp, D.A., and J.J. van Tassell. 2001. Modeling seasonal trophic interactions of adfluvial Bull Trout in Lake Billy Chinook, Oregon. Transactions of the American Fisheries Society 130:204-216.

Bechara, J.A., G. Moreau, and D. Planas. 1992. Top-down effects of Brook Trout (*Salvelinus fontinalis*) in a boreal forest stream. Canadian Journal of Fisheries and Aquatic Sciences 49:2093-2103.

Bernatchez, L., H. Glemet, C.C. Wilson, and R.G. Danzmann. 1995. Introgression and fixation of Arctic char (*Salvelinus alpinus*) mitochondrial genome in an allopatric population of Brook Trout (*Salvelinus fontinalis*). Canadian Journal of Fisheries and Aquatic Sciences 52:179–185.

Bernatchez, L., and A. Osinov. 1995. Genetic diversity of trout (genus *Salmo*) from its most eastern native range based on mitochondrial DNA and nuclear gene variation. Molecular Ecology 4: 285-297.

Bernatchez, L., and C.C. Wilson. 1998. Comparative phylogeography of Nearctic and Palearctic fishes. Molecular Ecology 7:431–452.

Berry, D.K. 1994. Alberta’s Bull Trout management and recovery plan. Alberta Environmental Protection, Fish and Wildlife Services, Fisheries Management Division, Edmonton, Alberta. 22 pp.

Bonneau, J. L., and D. L. Scarnecchia. 1996. Distribution of juvenile Bull Trout in a thermal gradient of a plunge pool in Granite Creek, Idaho. Transactions of the American Fisheries Society 125:628–630.

Bonneau J.L., and D. L. Scarnecchia. 1998. Seasonal and diel changes in habitat use by juvenile Bull Trout (*Salvelinus confluentus*) and Cutthroat Trout (*Oncorhynchus clarki*) in a mountain stream. Canadian Journal of Zoology 76:783–790.

Bonneau, J.L., R.F. Thurow, and D.L. Scarnecchia. 1995. Capture, marking, and enumeration of juvenile Bull Trout and Cutthroat Trout in small, low-conductivity streams. North American Journal of Fisheries Management 15:563-568.

Brenkman, S.J., and S.C. Corbett. 2005. Extent of anadromy in Bull Trout and implications for conservation of a threatened species. North American Journal of Fisheries Management 25:1073 -1081.

Brenkman, S.J., S.C. Corbett, and E.C. Volk. 2007. Use of otolith chemistry and radiotelemetry to determine age-specific migratory patterns of anadromous bull trout in the Hoh River, Washington. Transactions of the American Fisheries Society 136:1-11.

Brewin, M.K. 2004. Bull Trout management and recovery in Alberta. Pp. 1-22 in T.D. Hooper (eds.). Proceedings of the Species at Risk 2004 Pathways to Recovery Conference, Species at Risk 2004 Pathways to Recovery Conference Organizing Committee, Victoria, British Columbia.

British Columbia Conservation Data Centre (BCCDC). 2010. British Columbia Species and Ecosystems Explorer. Web site: http://a100.gov.bc.ca/pub/eswp/ [accessed March 2010].

British Columbia Ministry of Environment (BCME). 1994. A Strategic Plan for the Conservation and Management of Char in British Columbia. British Columbia Ministry of Environment, Fisheries Program, Victoria, British Columbia.

British Columbia Ministry of Environment (BCME). 2007. Environmental Trends in British Columbia. Web site: http://www.env.gov.bc.ca/soe/et07/EnvironmentalTrendsBC_2007.pdf [accessed March 2010].

British Columbia Ministry of Environment (BCME). 2010. Freshwater Fishing Regulations. Web site: http://www.env.gov.bc.ca/fw/fish/regulations/synopsis/printed.html [accessed May 2010].

British Columbia Ministry of Environment (BCME). 2011. Dams of British Columbia displayed in iMapBC. Web site: http://webmaps.gov.bc.ca/imfx/imf.jsp?session=268746869657 [accessed February 2011].

British Columbia Ministry of Water, Land and Air Protection (BCMWLAP). 2002. Environmental Trends in British Columbia. Web site: http://www.env.gov.bc.ca/soe/et02/ET2002.pdf [accessed April 2010].

British Columbia Ministry of Water, Land and Air Protection (BCMWLAP). 2004. Bull Trout (*Salvelinus confluentus*) in Accounts and Measures for Managing Identified Wildlife – Accounts V. 2004. Web site: http://www.env.gov.bc.ca/wld/frpa/iwms/accounts.html [accessed April 2010].

Brown, T.G. 1995. Stomach contents, distribution, and potential of fish predators to consume juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in the Nechako and Stuart Rivers, B.C. Canadian Technical Report of Fisheries and Aquatic Sciences 2077. Department of Fisheries and Oceans, Science Branch, Nanaimo, British Columbia. 39 pp.

Brunner, P.C., M.R. Douglas, A. Osinov, C.C. Wilson, and L. Bernatchez. 2001. Holarctic phylogeography of Arctic Charr (*Salvelinus alpinus* L.) inferred from mitochondrial DNA sequences. Evolution 55:573–586.

Burrows, J., T. Euchner, N. Baccante. 2001. Bull Trout movement patterns: Halfway River and Peace River Progress. Pp.153-157 in M.K. Brewin, A.J. Paul and M. Monita (eds.). Bull Trout II Conference Proceedings. c/o Trout Unlimited Canada, Calgary, Alberta.

Bustard, D., and Associates Ltd. 2010. Kemess South Project Fish Monitoring Studies 2009. Northgate Minerals Corp. Kemess Mines Inc., Smithers, British Columbia. 176 pp.

Campton, D.E., and F.M. Utter. 1985. Natural hybridization between Steelhead Trout (*Salmo gairdneri*) and coastal Cutthroat Trout (*S. clarki*) in two Puget Sound streams. Canadian Journal of Fisheries and Aquatic Sciences 42:110–119.

Canadian Endangered Species Conservation Council (CESCC). 2001. Wild Species 2000: The General Status of Species in Canada. Ottawa: Minister of Public Works and Government Services Canada. Web site: http://www.wildspecies.ca [accessed April 2010].

Canadian Endangered Species Conservation Council (CESCC). 2006. Wild Species 2005: The General Status of Species in Canada. Ottawa: Minister of Public Works and Government Services Canada. Web site: http://www.wildspecies.ca [accessed April 2010].

Can-nic-a-nick Environmental Sciences. 2004. Review of fish resources of the Liard River basin in the Southeast Yukon. Yukon Department of Environment Kaska Forest Resources Stewardship Council, Watson Lake, Yukon.

Cannings, S.G., and J. Ptolemy. 1998. Rare freshwater fish of British Columbia. British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia. 214 pp.

Carstens, B.C., S.J. Brunsfeld, J.R. Demboski, J.M. Good, and J. Sullivan. 2005. Investigating the evolutionary history of the Pacific Northwest mesic forest ecosystem: hypothesis testing within a comparative phylogeographic framework. Evolution 59: 1639–1652.

Casey, R., and P. Siwik. 2000. Overview of selenium in surface waters, sediment and biota in river basins of west central Alberta. Pp. 184–194. in R. Rosentreter and K. Bittman (eds.) Proceedings of the 24th Annual British Columbia Mine Reclamation Symposium, Williams Lake, British Columbia.

Cavender, T. M. 1978. Taxonomy and distribution of the Bull Trout, *Salvelinus confluentus* (Suckley), from the American Northwest. California Fish and Game 64:139–74.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kollii, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr, and P. Whetton. 2007. Regional climate projections. Pp. 848-926 in S. Solomon, D. Quin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Climate Change 2007: the Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, UK.

Christiansen, D., pers. comm. 2010. *Correspondence via review to J.L. Gow.* December 2010. Fish & Wildlife Manager, Clearwater Area, Government of Alberta, Rocky Mountain House, Alberta.

Ciruna, K. A., B. Butterfield, J. D. McPhail, and BC Ministry of Environment. 2007. EAU BC: Ecological Aquatic Units of British Columbia. Nature Conservancy of Canada, Toronto, Ontario.

Committee on the Status of Endangerd Wildlife in Canada (COSEWIC). 2009. Status Reports: Guidelines for Recognizing Designatable Units, Government of Canada. Web site: http://www.cosewic.gc.ca/eng/sct2/sct2_5_e.cfm [accessed January 2011].

Connor, M., P. Sparling, and G. Sidney.1999 Fisheries investigations into Bull Trout distribution in the Swift and Morley Rivers, Yukon Territory 1999. Yukon Fish and Wildlife Enhancement Trust, Whitehorse, Yukon. 6 pp.

Costello, A.B., T. Down, S. Pollard, C.J. Pacas, and E.B. Taylor. 2003. The influence of history and contemporary stream hydrology on the evolution of genetic diversity within species: an examination of microsatellite DNA variation in Bull Trout, *Salvelinus confluentus* (Pisces: Salmonidae). Evolution 57: 328–344.

Cott, P.A., P. Sibley, A. Gordon, R.A. Bodaly, K. Mills, M. Somers, and G. Fillatre. 2008. The effects of water withdrawal from ice-covered lakes on oxygen, temperature and fish. Journal of the American Water Resources Association 44:328-342.

Crane, P.A., L.W. Seeb, and J.E. Seeb. 1994. Genetic relationships among *Salvelinus* species inferred from allozyme data. Canadian Journal of Fisheries and Aquatic Sciences 51(S1):182–197.

Crespi, B.J., and M.J. Fulton. 2004. Molecular systematics of Salmonidae: combined nuclear data yields a robust phylogeny. Molecular Phylogenetics and Evolution 31: 658–679.

Decker, S., and J. Hagen. 2005. Feasibility of juvenile and adult bull trout abundance monitoring in selected tributaries of the arrow lakes reservoir. Fish and Wildlife Compensation Program - Columbia Basin, Nelson, British Columbia; BC Hydro and Power Authority, Columbia Basin Generation, Castlegar, British Columbia. 81 pp.

Decker, S., and J. Hagen. 2008. Adfluvial Bull Trout spawner abundance in tributaries of the arrow lakes reservoir (2004-2007). Fish and Wildlife Compensation Program - Columbia Basin, Nelson, British Columbia; BC Hydro and Power Authority, Columbia Basin Generation, Castlegar, British Columbia. 38 pp.

Department of Fisheries and Oceans, pers. comm. 2010. *Correspondence via review to J.L. Gow.* December 2010.

Department of Justice Canada (DJC). 1996. British Columbia Sport Fishing Regulations, 1996 (SOR/96-137). Web site: http://laws.justice.gc.ca/en/SOR-96-137/FullText.html [accessed April 2010].

Department of Justice Canada (DJC). 1998. Alberta Fishery Regulations, 1998 (SOR/98-246). Web site: http://laws.justice.gc.ca/en/SOR-98-246/FullText.html [accessed April 2010].

Department of Justice Canada (DJC). 2005. Northwest Territories Fishery Regulations (C.R.C., c. 847). Web site: http://laws.justice.gc.ca/en/C.R.C.-c.847/FullText.html [accessed April 2010].

Department of Justice Canada (DJC). 2008. Yukon Territory Fishery Regulations (C.R.C., c. 854). Web site: http://laws.justice.gc.ca/en/C.R.C.-c.854/FullText.html [accessed April 2010].

Donald, D.B., and D.J. Alger. 1993 Geographic distribution, species displacement, and niche overlap for Lake Trout and Bull Trout in mountain lakes. Canadian Journal of Zoology 71:238-247.

Dunham, J., C. Baxter, K. Fausch, W. Fredenberg, S. Kitano, I. Koizumi, K. Morita, T. Nakamura, B. Rieman, K. Savvaitova, J. Stanford, E.B. Taylor, and S. Yamamoto. 2008. Evolution, ecology, and conservation of Dolly Varden, White-Spotted Char, and Bull Trout. Fisheries 33:537 -550.

Dunham, J.B., and B.E. Rieman. 1999. Metapopulation structure of Bull Trout: influences of habitat size, isolation, and human disturbance. Ecological Applications 9:642–655.

Dunham, J.B., B.E. Rieman, and G.L. Chandler. 2003. Influences of temperature and environmental variables on the distribution of Bull Trout at the southern margin of its range. North American Journal of Fisheries Management 23:894–904.

Dunham, J., B. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts for Bull Trout. North American Journal of Fisheries Management 21:343-352.

Earle, J.E., J.D. Stelfox and Meagher, B.E. 2007. Quirk Creek brook trout suppression project, 2004-2006. Unpublished report, Alberta Fish and Wildlife Division, Cochrane, AB.

Fausch, K.D., B.E. Rieman, J.B. Dunham, M.K. Young, and D.P. Peterson. 2008. Invasion versus isolation: trade-offs in managing native salmonids with barriers to upstream movement. Conservation Biology 23: 859–870.

Fernet, D.A., and J.O. O'Neil. 1997. Use of radio telemetry to document seasonal movements, and spawning locations for bull trout in relatio0n to a newly created reservoir. Pp. 427-434 in W.C. Mackay, M.K. Brewin, and M. Monita (eds.) Friends of the Bull Trout conference proceedings, Bulltrout task force (Alberta), c/o Trout Unlimited Canada, Calgary, Alberta.

Fisheries and Ocean Canada/Yukon Environment (FOC/YE). 2010. Fishing Regulations Summary 2010-2011. Web site: www.environmentyukon.gov.yk.ca [accessed April 2010].

Fitch, L.A. 1997. Bull Trout in southwestern Alberta: notes on historical and current distribution. Pp. 147-160 in W.C. Mackay, M.K. Brewin, and M. Monita (eds.) Friends of the Bull Trout conference proceedings, Bulltrout task force (Alberta), c/o Trout Unlimited Canada, Calgary, Alberta.

Fraley, J.J., and B.B. Shepard. 1989. Life history, ecology and population status of migratory Bull Trout (*Salvelinus confluentus*) in the Flathead Lake and River System, Montana. Northwest Science 63:133–143.

Fredenberg, W., J. Chan, J. Bowerman, B. Streif, C. Allen, B. Goehring, P. Lickwar, J. O'Reilly, A. Mauer, P. Bridges, J. Stephenson, G. Sausen, C. Myler, C. Reighn, J. Wood, M. Hemker, S. Deeds, S. Spalding, J. De La Vergne, and S. Werdon. 2005. Bull Trout core area templates. An unpublished compilation of Bull Trout core area analysis to support the five-year review. U.S. Fish and Wildlife Service, Portland, OR. 662 pp.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication Number 27, U.S. Geological Survey, Florida Integrated Science Center, Gainesville, FL. 622 pp.

Gende, S.M., E.D. Edwards, M.F. Willson, and M.S. Wipfli. 2002. Pacific salmon in aquatic and terrestrial ecosystems. BioScience 52:917-928.

Girard, I., pers. comm. 2010. *Email correspondence to J.L. Gow.* May 2010. Senior Fisheries Biologist, Alberta Fish and Wildlife, Rocky Mountain House, Alberta.

Gould, W.R. 1987. Features in the early development of Bull Trout (*Salvelinus confluentus*). Northwest Science 61:264-268.

Grewe, P.M., N. Billington, and P.D.N. Hebert. 1990. Phylogenetic relationships among members of *Salvelinus* inferred from mitochondrial DNA divergence. Canadian Journal of Fisheries and Aquatic Sciences 47:984-991.

Gunckel, S.L., A.R. Hemmingsen, and L.L. Judith. 2002. Effect of Bull Trout and Brook Trout interactions on foraging habitat, feeding behavior, and growth. Transactions of the American Fisheries Society 131:1119 -1130.

Gutsell, R., L. Matthias, and K. Kissner. 2008. Report of Alberta's Endangered Species Conservation Committee: June 2006. Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, Alberta. 44 pp.

Haas, G.R., and J.D. McPhail. 1991. Systematics and distributions of Dolly Varden *(Salvelinus malma)* and Bull Trout *(Salvelinus confluentus)* in North America. Canadian Journal of Fisheries and Aquatic Sciences 48:2191 -2211.

Hass, G.R.. 2001. The mediated associations and preferences of native bull trout and rainbow trout with respect to maximum water temperature, and its measurement standards, and habitats. Pages 53-55 in M.K. Brewin, A.J. Paul and M. Monita (eds.). Bull Trout II Conference Proceedings. c/o Trout Unlimited Canada, Calgary, Alberta.

Haas, G.R., and J.D. McPhail. 2001 The post-Wisconsinan glacial biogeography of Bull Trout (*Salvelinus confluentus*): a multivariate morphometric approach for conservation biology and management. Canadian Journal of Fisheries and Aquatic Sciences 58:2189–2203.

Hagen, J. 2008. Impacts of dam construction in the upper Columbia Basin, British Columbia, on Bull Trout (*Salvelinus confluentus*) production, fisheries, and conservation status (draft). Fish and Wildlife Compensation Program – Columbia Basin, Nelson, British Columbia. 73 pp.

Hagen, J. and S. Decker. 2011. Bull trout population 'health' in British Columbia: distribution, abundance, trends and threats. British Columbia Ministry of Environment, Victoria, British Columbia. 104 pp.

Hagen, J., and E.B. Taylor. 2001. Resource partitioning as a factor limiting gene flow in hybridizing populations of Dolly Varden char (*Salvelinus malma*) and Bull Trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 58:2037–2047.

Hansen, J.A, J. Lipton, P. Welsh. 2002a. Relative sensitivity of Bull Trout (*Salvelinus confluentus*) and Rainbow Trout (*Oncorhynchus mykiss*) to acute copper toxicity. Environmental Toxicology and Chemistry 21:633-639.

Hansen, J.A., P.G. Welsh, J. Lipson, D. Cacela, and A.D. Dailey. 2002b. Relative sensitivity of Bull Trout (*Salvelinus confluentus*) and Rainbow Trout (*Oncorhynchus mykiss*) to acute exposures of cadmium and zinc. Environmental Toxicology and Chemistry 21:67–75.

Hansen, J.A, P.G. Welsh, J. Lipton, and M.J. Suedkamp. 2002c. The effects of long-term cadmium exposure on the growth and survival of juvenile Bull Trout (*Salvelinus confluentus*). Aquatic Toxicology 58:165–174.

Harris, L.N., and E.B. Taylor. 2010. Pleistocene glaciations and contemporary genetic variation in a Beringian fish, the Broad Whitefish, *Coregonus nasus (*Pallas): inferences from microsatellite DNA variation. Journal of Evolutionary Biology 23:72-86.

Hewitt, G.M. 1996. Some genetic consequences of ice ages, and their role in divergence and speciation. Biological Journal of the Linnean Society 58: 247–276.

Hodson, P.V., and J.W. Hilton. 1983. The nutritional requirements and toxicity to fish of dietary and waterborne selenium. Ecological Bulletins 35:335–340.

Hodson, P.V., D.J. Spry, and B.R. Blunt. 1980. Effects on Rainbow Trout (*Salmo gairdneri*) of a chronic exposure to waterborne selenium. Canadian Journal of Fisheries and Aquatic Sciences 37: 233–240.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Homel, K., P. Budy, M.E. Pfrender, T.A. Whitesel, and K. Mock. 2008. Evaluating genetic structure among resident and migratory forms of Bull Trout (*Salvelinus confluentus*) in Northeast Oregon. Ecology of Freshwater Fish 17:465–474**.**

Hunt, C.W., R. Hawryluk, and D. Hildebrandt. 1997. Bull Trout status in Fish Management Area Four, Alberta. Pp. 171-186 in W.C. Mackay, M.K. Brewin, and M. Monita (eds.) Friends of the Bull Trout conference proceedings, Bulltrout task force (Alberta), c/o Trout Unlimited Canada, Calgary, Alberta.

International Union for Conservation of Nature (IUCN). 2010. IUCN Red List of Threatened Species, version 2010.1. Web site: www.iucnredlist.org. [accessed March 2010].

Jakober, M.J., T.E. McMahon, and R.F. Thurow. 2000. Diel habitat partitioning by Bull Charr and Cutthroat Trout during fall and winter in Rocky Mountain streams Environmental Biology of Fishes 59:79-89.

Jakober, M.J., T.E. McMahon, R.F. Thurow, and C.G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by Bull Trout and Cutthroat Trout in Montana headwater streams. Transactions of the American Fisheries Society 127: 223–235.

Jamieson, B., pers. comm. 2010. *Email correspondence to J.L. Gow.* December 2010. Project Manager, Kinbasket Development Corporation, Invermere, British Columbia.

Jesson, D., pers. comm. 2011. *Email communication to S. Pollard.* 2011. Senior Fisheries Biologist. Ministry of Environment, Fish & Wildlife - South Coast, Surrey, British Columbia.

Jiggins, C.D., and J. Mallet. 2000. Bimodal hybrid zones and speciation. Trends in Ecology and Evolution 15:250–255.

Johnson, S. L., and J. A. Jones. 2000. Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 57(Suppl. 2):30-39.

Johnston, F.D., and J.R. Post. 2009. Density-dependent life-history compensation of an iteroparous salmonid. Ecological Applications 19:449–467.

Johnston, F.D., J.R. Post, C.J. Mushens, J.D. Stelfox, A.J. Paul, and B. Lajeunesse. 2007. The demography of recovery of an overexploited Bull Trout, *Salvelinus confluentus*, population. Canadian Journal of Fisheries and Aquatic Sciences 64:113–126.

Kanda, N., R.F. Leary, and F.W. Allendorf. 2002. Evidence of introgressive hybridization between Bull Trout and Brook Trout. Transactions of the American Fisheries Society 131:772-782.

Keleher, C.J., and F.J. Rahel. 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: a geographic information system (GIS) approach. Transactions of the American Fisheries Society 125:1–13.

Kitano, S., K. Maekawa, S. Nakano, and K.D. Fausch. 1994. Spawning behavior of Bull Trout in the upper Flathead River drainage, Montana, with special reference to hybridization with Brook Trout. Transactions of the American Fisheries Society 123:988-992.

Laframboise, S., pers. comm. 2010. *Email correspondence to J.L. Gow.* March 2010. Assistant Collections Manager, Vertebrate Section, Canadian Museum of Nature, Ottawa, Ontario.

Lande, R. 1993. Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142:911-927.

Latham, S. J. 2002. Historical and anthropogenic influences on genetic variation in bull trout (*Salvelinus confluentus*) in the Arrow Lakes, British Columbia. M.Sc. dissertation, University of British Columbia, Vancouver, British Columbia, Canada. 104 pp.

Leary, R.F., and Allendorf, F.W. 1997. Genetic confirmation of sympatric Bull Trout and Dolly Varden in western Washington. Transactions of the American Fisheries Society 126:715–720.

Leary, R.F., F.W. Allendorf, and S.H. Forbes. 1993. Conservation genetics of Bull Trout in the Columbia and Klamath River drainages. Conservation Biology 7:856–865.

Leggett, J. W. 1980. Reproductive ecology and behaviour of Dolly Varden charr in British Columbia. Pp. 721-737 in E.K. Balon (ed.) Charrs, salmonid fishes of the genus *Salvelinus*. W. Junk, The Hague, Netherlands.

Lenormand, T. 2002. Gene flow and the limits to natural selection. Trends in Ecology and Evolution 17:183–189.

Lindsey, C.C., J.D. McPhail. 1986. Zoogeography of fishes of the Yukon and McKenzie Basins. Pp. 639–674 in C.H. Hocutt, E.O. Wiley (eds.) Zoogeography of North American Freshwater Fishes, Wiley and Sons, New York.

Master, L.L., L.E. Morse, A.S. Weakley, G.A. Hammerson and D. Faber-Langendoen. 2003. NatureServe Conservation Status assessment Criteria. NatureServe, Arlington, Virginia, USA.

McCleary, R.J., and M.A. Hassan. 2008. Predictive modeling and spatial mapping of fish distributions in small streams of the Canadian Rocky Mountain foothills. Canadian Journal of Fisheries and Aquatic Sciences 65: 319-333.

McCusker, M.R., E. Parkinson, and E.B. Taylor. 2000. Mitochondrial DNA variation in Rainbow Trout (*Oncorhynchus mykiss*) across its native range: testing biogeographical hypotheses and their relevance to conservation. Molecular Ecology 9: 2089–2108.

McMahon, T.E., A.V. Zale, F.T. Barrows, J.H. Selong, and R.J. Danehy. 2007. Temperature and competition between Bull Trout and Brook Trout: a test of the elevation refuge hypothesis. Transactions of the American Fisheries Society 136:1313-1326.

McPhail, J. D. 1961. A systematic study of the *Salvelinus alpinus* complex in North America. Journal of the Fisheries Research Board of Canada 18:793–816.

McPhail, J.D. 1967. Distribution of freshwater fishes in western Washington. Northwest Science 41:1–11.

McPhail, J.D. 2007. Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton, Alberta.620 pp.

McPhail, J.D., and J.S. Baxter. 1996. A review of Bull Trout (*Salvelinus confluentus*) life-history and habitat use in relation to compensation and improvement opportunities. Fisheries Management Report No. 104, British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia. 35 pp.

McPhail, J.D., and C.C. Lindsey. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia system and rivers north to the Stikine). Pp. 615–637 in C.H. Hocutt and E.O. Wiley (eds.) Zoogeography of North American Freshwater Fishes., Wiley and Sons, New York.

McPhail, J.D., and E.B. Taylor. 1995. Skagit char. Project No. 94-1, Skagit Environmental Endowment Commission, North Vancouver, British Columbia. 39 pp.

McPhail, J.D., and E.B. Taylor. 1999. Morphological and genetic variation in northwestern longnose suckers, *Catostomus catostomus*: the Salish Sucker problem. Copeia 1994:884–893.

Miller, N., pers. comm. 2010. *Correspondence via review to J.L. Gow.* December 2010. Senior Fisheries Biologist, Environment Yukon, Whitehorse, Yukon.

Mochnacz, N.J. 2002. Bull Trout distribution, life history, and habitat requirements in the southern and central Mackenzie River Valley, Northwest Territories. Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba. 52 pp.

Mochnacz, N.J., S.M. Backhouse, R. Bajno, and J.D. Reist. 2009. Biological and habitat data for fish collected during stream surveys in the southern (Deh Cho) and central (Sahtu) Northwest Territories, 2007. Canadian Data Reports of Fisheries and Aquatic Sciences No. 1209. Central and Arctic Region, Fisheries and Oceans Canada, Winnipeg, Manitoba. 29 pp.

Mochnacz, N.J., and J.D. Reist. 2007. Biological and habitat data for fish collected during stream surveys in the Sahtu Settlement Region, Northwest Territories, 2006. Canadian Data Reports of Fisheries and Aquatic Sciences No. 1189. Central and Arctic Region, Fisheries and Oceans Canada, Winnipeg, Manitoba. 40 pp.

Mochnacz, N.J., J.D. Reist, P. Cott, G. Low, and R. Wastle. 2006. Biological and habitat data for Bull Trout (*Salvelinus confluentus*) and associated species from stream surveys conducted in the southern and central Mackenzie River Valley, Northwest Territories, 2000 to 2001. Canadian Manuscript Reports of Fisheries and Aquatic Sciences No. 1131. Central and Arctic Region, Fisheries and Oceans Canada, Winnipeg, Manitoba. 38 pp.

Mochnacz, N.J., J.D. Reist, G. Low, R. Bajno, and J.A. Babaluk. *In review*. Distribution and Biology of Sympatric Bull Trout (*Salvelinus confluentus*) and Dolly Varden (*Salvelinus malma*) in the Mackenzie Mountains, Northwest Territories.

Monnot, L., J. B. Dunham, T. Salow, and P. Koetsier. 2008. Influences of body size and environmental factors on autumn downstream migration of Bull Trout in the Boise River, Idaho. North American Journal of Fisheries Management 28:231-240.

Morgan, K.K., J. Hicks, K. Spitze, L. Latta, M.E. Pfrender, C.S. Weaver, M. Ottone, and M. Lynch. 2001. Patterns of genetic architecture for life-history traits and Molecular Markers in a Subdivided Species. Evolution 55:1753-1761.

Muhlfield, C.C., and B. Marotz. 2005. Seasonal movement and habitat use by subadult Bull Trout in the Upper Flathead River system, Montana. North American Journal of Fisheries Management 25:797–810.

Muhlfeld, C. C., M.L. Taper, D.F. Staples, and B.B. Shepard. 2006. Observer error structure in Bull Trout redd counts in Montana streams: implications for inference on true redd numbers. Transactions of the American Fisheries Society 135:643-654.

Nakano, S., K.D. Fausch, T. Furukawa-Tanaka, K. Maekawa, and H. Kawanabe. 1992. Resource utilization by Bull Char and Cutthroat Trout in a mountain stream in Montana, U.S.A. Japanese Journal of Ichthyology 39:211-216.

Nakano, S., S. Kitano, K. Nakai, and K.D. Fausch. 1998. Competitive interactions for foraging microhabitat among introduced Brook Charr, *Salvelinus fontinalis*, and native Bull Charr, *S. confluentus*, and westslope Cutthroat Trout, *Oncorhynchus clarki lewisi*, in a Montana stream. Environmental biology of fishes, 52:345–355.

Nakano, S., H. Miyasaka, and N. Kuhara. 1999. Terrestrial-aquatic linkages: riparian arthropod inputs alter trophic cascades in a stream food web. Ecology 80:2435-2441.

NatureServe. 2009. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. Web site: http://www.natureserve.org/explorer [accessed February 2010].

Nelson, M.L., T.E. McMahon, and R.F. Thurow. 2002. Decline of the migratory form in Bull Charr, *Salvelinus confluentus*, and implications for conservation. Environmental Biology of Fishes 64:321-332.

Nelson, J.S., and M.J. Paetz. 1992. The Fishes of Alberta, 2nd edition. The University Press and the University of Calgary Press, Edmonton and Calgary, Alberta. 437 pp.

Neraas, L.P., and P. Spruell. 2001. Fragmentation of riverine systems: the genetic effects of dams on Bull Trout (*Salvelinus confluentus*) in the Clark Fork River system. Molecular Ecology 10:1153–1164.

Northwest Territories Environment and Natural Resources (NTENR). 2010. Sport Fishing Regulations Guide. Web site: http://www.enr.gov.nt.ca/_live/pages/wpPages/sport_fishing_regulations_guide.aspx [accessed April 2010].

Nosil, P., T.H. Vines, and D.J. Funk. 2005. Reproductive isolation caused by natural selection against immigrants from divergent habitats. Evolution 59: 705–719.

O'Brien, D.S. 2001. Bull Trout (*Salvelinus confluentu*s) spawning migrations in the Duncan River: insights from telemetry and DNA. M.Sc. dissertation, University of British Columbia, Vancouver, British Columbia, Canada. 82 pp.

Palace, V.P., C. Baron, R.E. Evans, J. Holm, S. Kollar, K. Wautier, J. Werner, P. Siwik, G. Sterling, and C.F. Johnson. 2004. An assessment of the potential for selenium to impair reproduction in Bull Trout, *Salvelinus confluentus*, from an area of active coal mining. Environmental Biology of Fishes 70:169–174.

Parkinson, E., pers. comm. 2010. *Email correspondence to J.L. Gow.* May 2010. Fisheries Scientist, Adjunct Professor UBC Fisheries Center, Vancouver, British Columbia.

Paul, A.J., and J.R. Post. 2001. Spatial distribution of native and non-native salmonids in streams of the eastern slopes of the Canadian Rocky Mountains. Transactions of the American Fisheries Society 130:417–430.

Paul, A.J., J.R. Post, and J.D. Stelfox. 2003. Can anglers influence the abundance of native and non-native salmonids in a stream from the Canadian Rocky Mountains? North American Journal of Fisheries Management 23:109-119.

Paul, A.J., J.R. Post, G.L. Sterling, and C. Hunt. 2000. Density-dependent intercohort interactions and recruitment dynamics: models and a Bull Trout (*Salvelinus confluentus*) time series. North American Journal of Fisheries Management 57:1220-1231.

Peterson, J.T., R.F. Thurow, and J.W. Guzevich. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462–475.

Pfrender, M.E., K. Spitze, J. Hicks, K. Morgan, R.L. Latta, and M. Lynch. 2000. Lack of concordance between genetic diversity estimates at the molecular and quantitative-trait levels. Conservation Genetics 1:263–269.

Phillips, R. B., L.I. Gidex, K.M. Westrich, and A.L. DeCicco. 1999. Combined phylogenetic analysis of ribosomal ITS1 sequences and new chromosome data supports three subgroups of Dolly Varden char (*Salvelinus malma*). Canadian Journal of Fisheries and Aquatic Sciences 56:1504–1511.

Phillips, R.B., S.A. Manley, and T.J. Daniels. 1994. Systematics of the salmonid genus *Salvelinus* inferred from ribosomal DNA sequences. Canadian Journal of Fisheries and Aquatic Sciences 51(S1):198–204.

Pillipow, R., and C. Williamson. 2004. Goat River Bull Trout (*Salvelinus confluentus*) biotelemetry and spawning assessments 2002–03. British Columbia Journal of Ecosystems and Management 4: 29-37.

Pollard, S., T. Down. 2001. Bull Trout in British Columbia – a provincial perspective on status, management and protection. Pp. 207-214 in M.K. Brewin, A.J. Paul and M. Monita (eds.). Bull Trout II Conference Proceedings. c/o Trout Unlimited Canada, Calgary, Alberta.

Porter, M., and M. Nelitz. 2009. A future outlook on the effects of climate change on Bull Trout (*Salvelinus confluentus*) habitats in the Cariboo- Chilcotin. Fraser Salmon and Watersheds Program, British Columbia Ministry of Environment, and Pacific Fisheries Resource Conservation Council, British Columbia.

Post, J.R., and F.D. Johnston. 2002. Status of Bull Trout *(Salvelinus confluentus)* in Alberta. Alberta Wildlife Status Report No. 39, Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, Alberta; Alberta Conservation Association, Edmonton, Alberta. 40 pp.

Post, J.R., C. Mushens, A. Paul, and M. Sullivan. 2003. Assessment of Alternative Harvest Regulations for Sustaining Recreational Fisheries: Model Development and Application to Bull Trout. North American Journal of Fisheries Management 23:22-34.

Pratt, K.L. 1984. Habitat use and species interactions of juvenile Cutthroat (*Salmo clarki lewisi*) and Bull Trout (*Salvelinus confluentus*) in the upper Flathead River Basin. M.Sc. dissertation, University of Idaho, Moscow, Idaho, USA. 95 pp.

Prospectors and Developers Association of Canada (PDAC). 2008. Protected Areas. Web site: http://pdac.ca/pdac/advocacy/land-use/protected-areas.html [accessed May 2010].

Province of British Columbia. 2007. GeoBC: Data Distribution Service. Web site: http://pdac.ca/pdac/advocacy/land-use/protected-areas.html [accessed April 2010].

Quinn, T.P., and A.H. Dittman. 1990. Pacific salmon migrations and homing: mechanisms and adaptive significance. Trends in Ecology and Evolution 5:174–177.

Rahel, F.J., C.J. Keleher, and J.L. Anderson. 1996. Potential habitat loss and population fragmentation for cold water fish in the north platte river drainage of the rocky mountains: response to climate warming. Limnology and Oceanography 41:1116-1123.

Redenbach, Z., and E.B. Taylor. 2002. Evidence for historical introgression along a contact zone between two species of char (Pisces: Salmonidae) in northwestern North America. Evolution 56:1021–1035.

Redenbach, Z., and E.B. Taylor. 2003. A bimodal hybrid zone between two species of char (*Salvelinus*) in northwestern North America. Journal of Evolutionary Biology 16:1135–1148.

Reist, J.D., and C. Sawatzky. 2010. Diversity and distribution of chars, genus *Salvelinus*, in northwestern North America in the context of northern Dolly Varden (*Salvelinus malma malma* (Walbaum 1792)). Department of Fisheries and Oceans Canadian Science Advisory Secretariat Research Document 2010/014. 18pp.

Reist, J.D., G. Low, J.D. Johnson, and D. Mcdowell. 2002. Range extension of Bull Trout, *Salvelinus confluentus*, to the central Northwest Territories, with notes on identification and distribution of Dolly Varden, *Salvelinus malma*, in the western Canadian Arctic. Arctic 55:70–76.

Remington, C.L. 1968. Suture-zones of hybrid interaction between recently joined biotas. Evolutionary Biology 2:321–428.

Rich, C., T. McMahon, B. Rieman, and W. Thompson. 2003. Local habitat, watershed, and biotic features associated with Bull Trout occurrence in Montana streams. Transactions of the American Fisheries Society 132:1053–1064.

Rieman, B.E., and F.W. Allendorf. 2001. Effective population size and genetic conservation criteria for Bull Trout. North American Journal of Fisheries Management 21:756–764.

Rieman, B.E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D.L. Myers. 2007. Anticipated climate warming effects on Bull Trout habitats and populations across the interior Columbia River basin. Transactions of the American Fisheries Society 136:1552–1565.

Rieman, B.E., D.C. Lee, and R.F. Thurow. 1997. Distribution, status, and likely future trends of Bull Trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17:111-1125.

Rieman, B.E., and J.D. McIntyre. 1993. Demographic and habitat requirements for conservation of Bull Trout. Forest Service General Technical Report INT-302, USA Department of Agriculture, Ogden, Utah. 38 pp.

Rieman, B.E., and J.D. McIntyre. 1995. Occurrence of Bull Trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Rieman, B.E., and D.L. Myers. 1997. Use of redd counts to detect trends in Bull Trout populations. Conservation Biology 11:1015-1018.

Rieman, B.E., J.T. Peterson, and D.L. Myers. 2006. Have Brook Trout displaced Bull Trout along longitudinal gradients in central Idaho streams? Canadian Journal of Fisheries and Aquatic Sciences 63:63–78.

Rieseberg, L.H. 1998. Molecular ecology of hybridization. Advances in Molecular Ecology 306:243–265.

Ripley, T., G. Scrimgeour, and M.S. Boyce. 2005. Bull Trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed. Canadian Journal of Fisheries and Aquatic Sciences 62: 2431–2442.

Rodtka, M. 2009. Status of the Bull Trout (*Salverlinus confluentus*) in Alberta: Update 2009. Alberta Wildlife Status Report No. 39, Alberta Sustainable Resource Development, Edmonton, Alberta; Alberta Conservation Association, Edmonton, Alberta. 48 pp.

Scrimgeour, G.J., P.J. Hvenegaard, and J. Tchir. 2008. Cumulative industrial activity alters lotic fish assemblages in two boreal forest watersheds of Alberta. Canada Environmental Management 42:957–970.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of Bull Trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026–1037.

Small, M.P., T.D. Beacham, R.E. Withler, and R.J. Nelson. 1998. Discriminating Coho Salmon (*Oncorhynchus kisutch*) populations within the Fraser River, British Columbia, using microsatellite DNA markers. Molecular Ecology 7:141–155.

Spangler, R.E., and D.L. Scarnecchia. 2001 Summer and fall microhabitat utilization of juvenile Bull Trout and Cutthroat Trout in a wilderness stream, Idaho. Hydrobiologia 452: 145–154.

Spencer, C. N., B. R. McClelland, and J. A. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement: cascading interactions in the food web of a large aquatic ecosystem. BioScience 41:14-21.

Spruell, P., A.R. Hemmingsen, P.J. Howell, N. Kanda, and F.W. Allendorf. 2003. Conservation genetics of Bull Trout: geographic distribution of variation at microsatellite loci. Conservation Genetics 4:17–29.

Spruell, P., B.E. Rieman, K.L. Knudsen, F.M. Utter, and F.W. Allendorf. 1999. Genetic population structure within streams: microsatellite analysis of Bull Trout populations. Ecology of Freshwater Fish 8:114–121.

Stewart, D.B., N.J. Mochnacz, C.D. Sawatzky, T.J. Carmichael, and J.D. Reist. 2007a. Fish life history and habitat use in the Northwest Territories: Bull Trout (*Salvelinus confluentus*). Canadian Data Reports of Fisheries and Aquatic Sciences No. 2801. Central and Arctic Region, Fisheries and Oceans Canada, Winnipeg, Manitoba. 46 pp.

Stewart, D.B., N.J. Mochnacz, C.D. Sawatzky, T.J. Carmichael, and J.D. Reist. 2007b. Fish diets and food webs in the Northwest Territories: Bull Trout (*Salvelinus confluentus*). Canadian Data Reports of Fisheries and Aquatic Sciences No. 2800. Central and Arctic Region, Fisheries and Oceans Canada, Winnipeg, Manitoba. 18 pp.

Stoddard, E. pers.comm. 2012. August 2012. Fish Biologist, BC MFLNRO.

Swanberg, T.R. 1997a. Movements of and habitat use by fluvial Bull Trout in the Blackfoot River, Montana. Transactions of the American Fisheries Society 126:735–746.

Swanberg, T.R. 1997b. Movements of Bull Trout (*Salvelinus confluentus*) in the Clark Fork River system after transport upstream of Milltown Dam. Northwest Science 71:313-317.

Taylor, E.B., and A.B. Costello. 2006. Microsatellite DNA analysis of coastal populations of Bull Trout (*Salvelinus confluentus*) in British Columbia: zoogeographic implications and its application to recreational fishery management. Canadian Journal of Fisheries and Aquatic Sciences 63:1157–1171.

Taylor, E.B., S. Pollard, and D. Louie. 1999. Mitochondrial DNA variation in Bull Trout (*Salvelinus confluentus*) from northwestern North America: implications for zoogeography and conservation. Molecular Ecology 8:155–170.

Taylor, E.B., Z. Redenbach, A.B. Costello, S.M. Pollard, and C.J. Pacas. 2001. Nested analysis of genetic diversity in northwestern North American char, Dolly Varden (*Salvelinus malma*) and Bull Trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 58:406–420.

Teel, D.J., G.B. Milner, G.A. Winans, and W.S. Grant. 2000. Genetic population structure and origin of life history types in Chinook Salmon in British Columbia, Canada. Transactions of the American Fisheries Society 129:194–209.

Thorson, R.M. 1980. Ice-sheet glaciation of the Puget lowland, Washington, during the Vashon state (late Pleistocene). Quaternary Research 13: 303–321.

Thurow, R.F., J.T. Peterson, and J.W. Guzevish. 2006. Utility and Validation of Day and Night Snorkel Counts for Estimating Bull Trout Abundance in First- to Third-Order Streams. North American Journal of Fisheries Management 26:217–232.

Thurow, R.F. and D.J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate Bull Trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16:314-323.

US Fish and Wildlife Service (USFWS). 1999. Determination of threatened status for Bull Trout in the coterminous United States. Final Rule Federal Register 64: 58909–58933.

US Fish and Wildlife Service (USFWS). 2008. Bull Trout (*Salvelinus confluentus*) 5-year review: summary and evaluation. U.S. Fish and Wildlife Service, Portland, Oregon. 53 pp.

Ward, R.D., M. Woodwark, and D.O.F. Skibinski. 1994. A comparison of genetic diversity levels in marine, freshwater, and anadromous fishes. Journal of Fish Biology 44:213–232.

Warnock, W.G., J.B. Rasmussen, and E.B. Taylor. 2010. Genetic clustering methods reveal Bull Trout (*Salvelinus confluentus*) fine-scale population structure as a spatially nested hierarchy. Conservation Genetics 11:1421–1433.

Watson, G., T.W. Hillman. 1997. Factors affecting the distribution and abundance of Bull Trout: an investigation at hierarchical scales. North American Journal of Fisheries Management 17:237-252.

Weaver, T.M., and R.G. White. 1985. Coal Creek fisheries monitoring study number III. Quarterly progress report to United States Department of Agriculture, Forest Service, Montana State Cooperative Fisheries Research Unit, Bozeman, Montana. 94 pp.

Westover, W. T., and D. Conroy. 1997. Wigwam River bull trout: Habitat Conservation Trust Fund progress report (1996). Fisheries Project Report KO 51, BC Ministry of Environment, Cranbrook, British Columbia. 19 pp.

Whiteley, A.R., P. Spruell, and F.W. Allendorf. 2004. Ecological and life history characteristics predict population genetic divergence of two salmonids in the same landscape. Molecular Ecology 13:3675–3688.

Whiteley, A.R., P. Spruell, B.E. Rieman, and F.W. Allendorf. 2006. Fine-scale genetic structure of Bull Trout at the southern limit of their distribution. Transactions of the American Fisheries Society 135:1238–1253.

Wilson, C., and L. Bernatchez. 1998. The ghost of hybrids past: fixation of Arctic Charr (*Salvelinus alpinus*) mitochondrial DNA in an introgressed population of Lake Trout (*S. namaycush*). Molecular Ecology 7:127–132.

Wilson, C.C., P.D.N. Hebert, J.D. Reist, and J.B. Dempson. 1996. Phylogeography and postglacial dispersal of Arctic Charr, *Salvelinus alpinus,* in North America. Molecular Ecology 5: 187–197.

World Commission on Environment and Development (WCED). 1987. Our Common Future, Report of the World Commission on Environment and Development. Web site: http://www.un-documents.net/wced-ocf.htm [Accessed April 2010].

BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Jennifer Gow, M.Res., PhD, is a science writer at the University of British Columbia. She has worked in the field of conservation biology and molecular ecology for more than a decade. Jennifer began applying her expertise in molecular ecology to freshwater fish native to Canada in 2003 when she started postdoctoral work at the University of British Columbia. Her research there has given insight into the ecological and evolutionary forces that shape patterns of genetic diversity in a broad range of fish species, which include Bull Trout but extend from stickleback to steelhead.

COLLECTIONS EXAMINED

No collections were examined in the preparation of this report.

Appendix 1. Conservation rank, estimated adult population abundance, stream occupancy (km), short-term trend, and the severity, scope and immediacy of threats to the 51 identified Bull Trout core areas in Alberta. Assessment was performed by the Fish and Wildlife Division of Alberta Sustainable Resource Development and is based upon a modification of the Natural Heritage Network ranking methodology using NatureServe Conservation Status Assessment Criteria (estimated adult population abundances (using quantitative data and/or expert opinion) are accompanied by appropriate NatureServe Range Categories in parenthesis, and were subject to a core areas status exercise based on methodology of Fredenberg *et al.* (2005). The focus of the review was on core areas currently occupied by Bull Trout, and therefore this is not a comprehensive list of extirpated core areas. Modified from Rodtka (2009) and Girard (pers. comm. 2010).

Core Area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
DU2 [*Genetic Lineage 2: Western Arctic populations*]					
Athabasca River Basin					
Pembina River	80 (50-250)	200-1000	Declining	Substantial, imminent threat	High Risk
McLeod River	1275(1000-2500)	1000–5000	Declining	Substantial, imminent threat	At Risk
Athabasca River	2500(1000-2500)	1000–5000	Declining	Localized, substantial threat	Potential Risk
Berland River	1000(250-1000)	1000–5000	Declining	Moderate, imminent threat	At Risk
Peace-Smoky River Basin					
Little Smoky River	750 (250-1000)	200–1,000	Stable	Moderate, imminent threat	At Risk
Upper Smoky River	4500(2500-10000)	1000–5000	Stable	Moderate, imminent threat	At Risk
Muskeg River	625 (250-1000)	200-1000	Declining	Substantial, imminent threat	High Risk
Jackpine River	625 (250-1000)	200-1000	Stable	Widespread, low-severity threat	Potential Risk
Sulphur River	1000(250-1000)	40-200	Increasing	Slightly threatened	Potential Risk
Middle Smoky River	150 (50-250)	200–1000	Declining	Moderate, imminent threat	At Risk
Wapiti River	1100(1000-2500)	200–1000	Declining	Moderate, imminent threat	At Risk
Peace River	25 (1-50)	40–200	Declining	Substantial, imminent threat	High Risk
Cutbank River	175 (50-250)	200–1000	Rapidly declining	Moderate, imminent threat	High Risk
Kakwa River	7450 (2500-10000)	200–1000	Declining	Localized, substantial threat	Potential Risk
Simonette River	1925 (1000-2500)	200–1000	Declining	Moderate, imminent threat	At Risk
DU4 [*Genetic Lineage 2: Saskatchewan-Nelson populations*]					
Oldman River Basin					
Belly River	250 (250-1000)	4–40	Stable	Widespread, low-severity threat	At Risk
St. Mary River	550 (250-1000)	40–200	Stable	Substantial, imminent threat	High Risk
Upper Crowsnest R.	0	–	–	–	Extirpated
Castle River and Oldman Reservoir	310 (250-1000)	200–1000	Stable	Moderate, imminent threat	At Risk
Upper Oldman R.	410 (250-1000)	40–200	Stable	Moderate, imminent threat	At Risk
Upper Livingstone River	280 (250-1000)	4–40	Stable	Moderate, imminent threat	High Risk

Core Area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
Lower Oldman R.	60 (50-250)	40–200	Declining	Substantial, imminent threat	High Risk
Waterton River	40 (1-50)	4–40	Declining	Localized, substantial threat	High Risk
Drywood Creek	40 (1-50)	4–40	Declining	Substantial, imminent threat	High Risk
Willow Creek	0	—	—	—	Extirpated
Bow River Basin					
Lower Bow River	0	—	—	—	Extirpated
Highwood River	190 (50-250)	40–200	Declining	Substantial, imminent threat	High Risk
Flat Creek	40 (1-50)	4–40	Declining	Widespread, low-severity threat	High Risk
Sheep River	445 (250-1000)	40–200	Increasing	Moderate, imminent threat	At Risk
Lower Elbow River	105 (50-250)	40–200	Rapidly declining	Substantial, imminent threat	High Risk
Canyon Creek	20 (1-50)	4–40	Stable	Widespread, low-severity threat	At Risk
Upper Elbow River	115 (50-250)	40–200	Declining	Moderate, imminent threat	High Risk
Jumpingpound Cr.	15 (1-50)	4–40	Declining	Substantial, imminent threat	High Risk
Ghost River	385 (250-1000)	40–200	Declining	Moderate, imminent threat	High Risk
Middle Bow River	10 (1-50)	<4	Declining	Substantial, imminent threat	High Risk
Middle Kananaskis R.	Unknown	4–40	Severely declining	Substantial, imminent threat	High Risk
Upper Kananaskis R.	1200(1000-2500)	40–200	Increasing	Widespread, low-severity threat	Potential Risk
Upper Spray River	40 (1-50)	4–40	Declining	Moderate, imminent threat	High Risk
Lake Minnewanka	58 (50-250)	4–40	Declining	Slightly threatened	At Risk
Upper Bow River*	Unknown	Unknown	Unknown	Unknown	Unranked
Red Deer River Basin					
Red Deer River	530 (250-1000)	200–1000	Declining	Moderate, imminent threat	At Risk
Little Red Deer River	10 (1-50)	4–40	Declining	Substantial, imminent threat	High Risk
North Saskatchewan River Basin					
Brazeau River	1275(1000-2500)	200–1000	Stable	Widespread, low-severity threat	Potential Risk
Blackstone River	720 (250-1000)	200–1000	Stable	Widespread, low-severity threat	Potential Risk
Nordegg River	105 (50-250)	40–200	Declining	Moderate, imminent threat	High Risk
Baptiste River	50 (1-50)	40–200	Declining	Moderate, imminent threat	High Risk
Upper North Saskatchewan River	950 (250-1000)	40–200	Increasing	Slightly threatened	Potential Risk
Pinto Lake & Cline R.	1150(1000-2500)	40–200	Stable	Slightly threatened	Potential Risk
Middle North Saskatchewan River	400 (250-1000)	40–200	Stable	Moderate, imminent threat	At Risk
Lower North Saskatchewan River	75 (50-250)	40–200	Stable	Moderate, non-imminent threat	At Risk
Clearwater River	390 (250-1000)	40–200	Declining	Moderate, imminent threat	High Risk
Total	33398				

*Bull Trout occur within this core area; however, insufficient information was available to derive a conservation rank.

Appendix 2. Conservation rank, estimated adult population abundance, stream occupancy (km), short-term trend, and threats to the 115 identified Bull Trout core areas in British Columbia. Assessment was performed by the British Columbia Ministry of Environment and is based upon a modification of core areas assessment methodology of Fredenberg *et al.* (2005) using quantitative data where available (see * below) and expert opinion. The severity, scope, and immediacy of threats identified is listed for each core area. Conservation status rank given for each core area, as well as overall for each of the 26 identified Bull Trout Ecological Drainage Units (EDUs) using the weighted average of assigned status ranks for each EDU's core areas. * Indicates one of 31 available adult Bull Trout abundance datasets (number in parenthesis when more than one dataset for a core area). See Table 1 for more details. Modified from Hagen and Decker (2011).

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
DU1 [*Genetic Lineage 1: Southcoast BC populations*]					
EDU Lower Fraser					Unranked
Lillooet *	Unknown	200-1000	Stable	Substantial, mod.-severe, imminent threat	Unranked
Lower Fraser	Unknown	200-1000	Declining	Widespread, low-severity threat	Unranked
Lower Fraser Canyon	Unknown	Unknown	Unknown	Restricted, low-severity threat	Unranked
EDU Puget Sound					Low Risk
Skagit *	1000-2500	4-200	Increasing	Restricted, low-severity threat	Low Risk
EDU South Coastal					At Risk
Squamish *	250-1000?	40-200	Declining	Substantial, mod.-severe, imminent threat	At Risk
DU2 [*Genetic Lineage 2: Western Arctic populations*]					
EDU Upper Peace					Potential Risk
Thutade *	250-1000	40-200	Increasing	Restricted, low-severity threat	Potential Risk
Finlay Reach *	Unknown	200-1000	Stable	Unthreatened	Unranked
Peace Reach *	Unknown	200-1000	Unknown	Restricted, mod.-severe threat	Unranked
Parsnip Reach *(n=2)	Unknown	1000-5000	Unknown	Widespread, low-severity threat	Unranked
Upper Parsnip	Unknown	200-1000	Unknown	Widespread, low-severity threat	Unranked
Upper Finlay	Unknown	200-1000	Unknown	Unthreatened	Unranked
Lower Finlay	Unknown	200-1000	Unknown	Widespread, low-severity threat	Unranked
Omineca	Unknown	200-1000	Unknown	Unthreatened	Unranked
Dinosaur Reservoir	Unknown	4-40	Unknown	Restricted, mod.-severe threat	Unranked
EDU Lower Peace					At Risk

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
Halfway-Peace *(n=3)	250-1000?	200-1000?	Increasing?	Widespread, mod.-severe, imminent threat	At Risk
Lower Murray *	250-1000	200-1000?	Unknown	Substantial, mod.-severe, imminent threat	At Risk
Moberly	50-250?	200-1000?	Unknown	Widespread, low-severity threat	At Risk
Pine/Sukunka	Unknown	200-1000?	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Upper Sukunka	250-1000?	200-1000?	Unknown	Restricted, low-severity threat	Unranked
Upper Murray	Unknown	200-1000?	Unknown	Restricted, low-severity threat	Unranked
West Kiskatinaw	Unknown	200-1000?	Unknown	Widespread, low-severity threat	Unranked
Upper Wapiti	Unknown	200-1000?	Unknown	Restricted, low-severity threat	Unranked
Upper Narraway	Unknown	200-1000?	Unknown	Restricted, low-severity threat	Unranked
EDU Upper Liard					Unranked
Lower Dease	Unknown	Unknown	Unknown	Unknown	Unranked
Upper Dease	Unknown	Unknown	Unknown	Unknown	Unranked
Rancheria	Unknown	Unknown	Unknown	Unknown	Unranked
Upper Liard	Unknown	Unknown	Unknown	Unknown	Unranked
Upper Ketchika	Unknown	200-1000?	Unknown	Unthreatened	Unranked
Turnagain	Unknown	200-1000?	Unknown	Unthreatened	Unranked
Ketchika/Liard	Unknown	200-1000?	Unknown	Unthreatened	Unranked
EDU Lower Liard					Unranked
Lower Liard	Unknown	200-1000?	Unknown	Unthreatened	Unranked
Upper Toad	Unknown	200-1000?	Unknown	Unthreatened	Unranked
Muskwa	Unknown	200-1000?	Unknown	Widespread, low-severity threat	Unranked
Prophet	Unknown	200-1000?	Unknown	Restricted, low-severity threat	Unranked
Upper Fort Nelson	Unknown	200-1000?	Unknown	Widespread, mod.-severe, imminent threat	Unranked
DU3 [*Genetic Lineage 2: Yukon populations*]					
EDU Lewes	Distribution in question				Unranked
Atlin Lake	Unknown	Unknown	Unknown	Unknown	Unranked
EDU Teslin					Unranked
Teslin	Unknown	Unknown	Unknown	Unthreatened	Unranked
DU5 [*Genetic Lineage 2: Pacific populations*]					
EDU Columbia-Arrow					Potential Risk
Pend d'Oreille *	1-250	4-40	Declining	Widespread-substantial, mod.-severe, imminent threat	High Risk
Columbia River	1-50	4-40	Declining	Substantial, mod.-severe, imminent threat	High Risk
ALR southern * (1 + 1 w/ALR-N)	250-1000	4-40	Stable	Widespread, low-severity threat	At Risk

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
Whatshan	50-250?	4-40	Stable	Widespread, low-severity threat	At Risk
ALR northern * (1 + 1 w/ALR-S)	1000-2500	40-200	Stable	Restricted, low-severity threat	Low Risk
EDU Lower Kootenay					Potential Risk
Slocan	250-1000	40-200	Declining	Substantial, mod.-severe, imminent threat	At Risk
Kootenay Lake *(n=5)	2500-10000	200-1000	Stable	Widespread, low-severity threat	Potential Risk
EDU Upper Kootenay					Low Risk
Upper Kootenay R *(n=2)	1000-2500	200-1000	Increasing	Restricted, low-severity threat	Low Risk
Koocanusa *	1000-10000	200-1000	Increasing	Restricted, low-severity threat	Low Risk
Elk *	Unknown	40-200	Increasing	Restricted, low-severity threat	Unranked
Bull	Unknown	40-200	Unknown	Restricted, low-severity threat	Unranked
EDU Upper Skeena					At Risk
Morice	250-1000	40-200	Unknown	Substantial, mod.-severe, imminent threat	At Risk
Upper Sustut *	Unknown	Unknown	Unknown	Restricted, low-severity threat	Unranked
Mid-Skeena *	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Lower Sustut/Skeena *	Unknown	Unknown	Unknown	Restricted, low-severity threat	Unranked
Upper Skeena	Unknown	Unknown	Unknown	Unknown	Unranked
Lower Babine/Skeena	Unknown	Unknown	Unknown	Unthreatened	Unranked
Upper Babine	Unknown	Unknown	Declining?	Restricted, mod.-severe threat	Unranked
Babine Lake	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
Kispiox	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Bulkley	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Zymoetz	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Kitsumkalum	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
EDU Upper Fraser					Potential Risk
Upper Fraser *	1000-2500	200-1000	Stable?	Widespread, low-severity threat	Potential Risk
Robson	Unknown	Unknown	Unknown	Substantial, mod.-severe, imminent threat	Unranked
McGregor	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
Bowron	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
EDU Middle Fraser					Potential Risk
Chilko *	250-1000	40-200	Stable	Widespread, low-severity threat	At Risk
Upper Bridge	250-1000	40-200	Unknown	Substantial, mod.-severe, non-imminent threat	At Risk
Seton/Anderson/Lower Bridge	250-1000	200-1000	Unknown	Substantial, mod.-severe, non-imminent threat	Potential Risk
Fraser Canyon	Unknown	40-200	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Quesnel Lake	Unknown	40-200	Stable	Restricted, low-severity threat	Unranked
Cariboo	Unknown	200-1000	Unknown	Restricted, low-severity threat	Unranked
Cottonwood	Unknown	200-1000	Unknown	Substantial, mod.-severe, imminent threat	Unranked
West Road	Unknown	200-1000	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Churn	Unknown	40-200	Unknown	Widespread, low-severity threat	Unranked
Upper Big Creek	Unknown	40-200	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Little Chilcotin	Unknown	40-200	Unknown	Substantial, mod.-severe, imminent threat	Unranked
Taseko	Unknown	200-1000	Unknown	Widespread, low-severity threat	Unranked
Prince George	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
Upper Stuart	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
Francois	Unknown	Unknown	Unknown	Unknown	Unranked
Nechako Reservoir	Unknown	Unknown	Unknown	Unknown	Unranked
EDU Homathko-Klinaklini					Potential Risk
Lower Klinaklini	Unknown	Unknown	Unknown	Restricted, mod.-severe threat	Unranked
Upper Klinaklini	1000-2500?	200-1000	Stable	Restricted, low-severity threat	Unranked
Lower Homathko	250-1000?	40-1000	Stable	Unthreatened	Potential Risk
Upper Homathko	1000-2500?	200-1000	Stable	Restricted, low-severity threat	Unranked
EDU Bella Coola-Dean Distribution in question					Unranked
Upper Dean	Unknown	40-200	Unknown	Widespread, low-severity threat	Unranked
Upper Atnarko	Unknown	4-40	Unknown	Unknown	Unranked
EDU Thompson					Potential Risk
Upper Shuswap *	250-1000	40-200	Increasing	Widespread, low-severity threat	Potential Risk
Middle Shuswap	1-50	4-40	Very rapidly declining	Widespread, mod.-severe, imminent threat	High Risk

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
Adams Lake	250-1000	40-200	Unknown	Widespread, low-severity threat	Potential Risk
Shuswap Lake	1000-2500	200-1000	Unknown	Widespread, low-severity threat	Potential Risk
Mabel Lake	250-1000	200-1000	Unknown	Substantial, mod.-severe, non-imminent threat	Potential Risk
Nicola	1-250	4-40	Very rapidly declining	Widespread, mod.-severe, imminent threat	High Risk
North Thompson	1000-2500	200-1000	Unknown	Widespread, low-severity threat	Potential Risk
EDU Upper Columbia					Potential Risk
Revelstoke Reservoir	250-2500	200-1000	Stable/ Increasing	Widespread, low-severity threat	Potential Risk
Kinbasket Reservoir	1000-10000	200-1000	Stable/ Increasing	Widespread, low-severity threat	Potential Risk
Upper Columbia	250-2500	200-1000	Unknown	Widespread, low-severity threat	Potential Risk
Spillimacheen	Unknown	4-40	Unknown	Restricted, mod.-severe threat	Unranked
EDU Flathead					At Risk
Upper Flathead	250-1000	40-1000	Declining	Substantial, mod.-severe, imminent threat	At Risk
EDU Lower Skeena					Unranked
Lower Skeena	Unknown	Unknown	Unknown	Restricted, low-severity threat	Unranked
EDU Upper Nass					Unranked
Upper Naas	Unknown	Unknown	Unknown	Unknown	Unranked
Middle Naas	Unknown	Unknown	Unknown	Unknown	Unranked
Meziadin	Unknown	Unknown	Unknown	Unknown	Unranked
Cranberry-Kiteen	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
Bell-Irving	Unknown	Unknown	Unknown	Widespread, low-severity threat	Unranked
EDU Iskut-Lower Stikine				Unknown	Unranked
Tuya	Unknown	Unknown	Unknown	Unknown	Unranked
Tahitan	Unknown	Unknown	Unknown	Unknown	Unranked
Middle Iskut	Unknown	Unknown	Unknown	Unknown	Unranked
EDU Upper Stikine				Unknown	Unranked
Upper Stikine	Unknown	Unknown	Unknown	Unknown	Unranked
Spatsizi	Unknown	Unknown	Unknown	Unknown	Unranked
Klappan	Unknown	Unknown	Unknown	Unknown	Unranked
Tanzilla	Unknown	Unknown	Unknown	Unknown	Unranked
EDU Nakina				Unknown	Unranked
Nakina	Unknown	Unknown	Unknown	Unknown	Unranked

Core area	Estimated abundance	Occupancy (stream km)	Short-term trend	Threats	Conservation rank
EDU Taku				Unknown	Unranked
Inklin	Unknown	Unknown	Unknown	Unknown	Unranked
Sheslay	Unknown	Unknown	Unknown	Unknown	Unranked
Nahlin	Unknown	Unknown	Unknown	Unknown	Unranked

Appendix 3. Land-use events and Bull Trout declines in the Oldman River Basin, southwestern Alberta. Sourced from Rodtka (2009).

Drainage	Type of Habitat Disturbance (Watershed)	Date	Period of Bull Trout decline/ disappearance
St. Mary River and tributaries	Reservoir construction (St. Mary River)	1946	1960s
	Irrigation agriculture, irrigation diversion, timber harvest (Lee Creek)	1950s	
Belly River and tributaries	Three irrigation diversion weirs (Belly River)	1920s	1960s
	Reservoir construction (Waterton River)	1964	
	Reservoir construction (North Drywood Creek, Drywood Creek)	1960s	
	Gas exploration, development, and processing (Drywood drainage)	1950s	
Castle River and tributaries	Timber harvest (West Castle, South Castle, Carbondale drainages)	1940s	1960s–1970s
	Road improvement (South Castle)	1953	
	Timber harvest, road improvement (Carbondale drainage, South and West Castle drainages)	1960s,1970s	
	Gas exploration	1960s,1970s	
Crowsnest River and tributaries	CPR construction	1897–1898	1950s–1960s
	Coal mine developments	1902–1970s	
	Timber harvest	1902–1960s	
	Road improvements	1920s–1970s	
	Urban development	1902–now	
Oldman River and tributaries	Road improvement (Forestry Trunk Road) (Upper Oldman drainage)	1953	1960s–1970s
	Timber harvest (Upper Oldman drainage)	1960s–now	
	Reservoir construction (Willow Creek)	1966	
	Irrigation diversion (Willow Creek drainage)	1960s	
	Gas exploration (Upper Oldman, Porcupine Hills)	1960s–1970s	