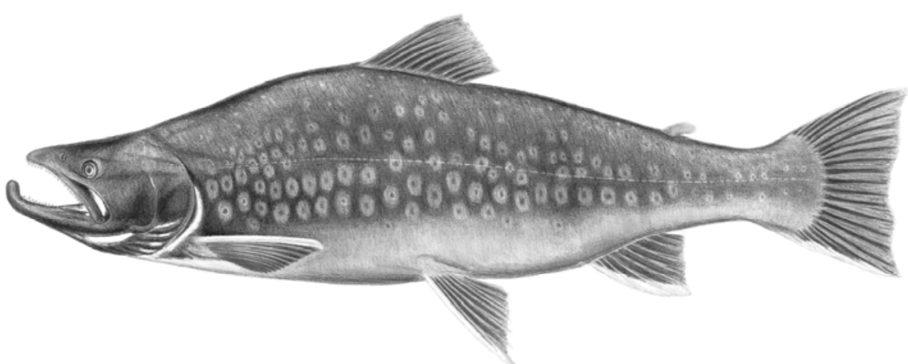
COSEWIC
Assessment and Status Report

on the

Dolly Varden
Salvelinus malma malma

Western Arctic Populations

in Canada



SPECIAL CONCERN
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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

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Production note:
COSEWIC acknowledges Maria C. Leung, James D. Reist, and Nathan P. Millar for writing the provisional status report on the Dolly Varden (northern form), *Salvelinus malma malma,* prepared under contract with Environment Canada. The contractors' involvement with the writing of the status report ended with the acceptance of the provisional report. Any modifications to the status report during the subsequent preparation of the 6-month interim and 2-month interim status reports were overseen by Dr. Eric Taylor, COSEWIC Freshwater Fishes Specialist Subcommittee Co-chair.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le Dolly Varden (*Salvelinus malma malma*) (Populations de l'ouest de l'Arctique) au Canada.

Cover illustration/photo:
Dolly Varden — A male anadromous (sea run) Dolly Varden, *Salvelinus malma.* Illustrations by Gerald Kuehl (with permission).

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COSEWIC
Assessment Summary

Assessment Summary – November 2010

Common name
Dolly Varden - Western Arctic populations

Scientific name
Salvelinus malma malma

Status
Special Concern

Reason for designation
This fish from freshwater and marine habitats of Canada's western Arctic has a very limited area of occupancy associated with a relatively small (17) number of locations that are key for spawning and overwintering. Aboriginal Traditional Knowledge suggests declines in some populations, and the small area and number of key habitats make the species particularly susceptible both to point source (e.g., overexploitation, stochastic events) and broader-scale events (e.g., climate change) that may eliminate or degrade habitats.

Occurrence
Yukon, Northwest Territories

Status history
Designated Special Concern in November 2010.

COSEWIC
Executive Summary

Dolly Varden
Salvelinus malma malma

Western Arctic Populations

Species information

Dolly Varden char belongs to the family of salmon- and trout-like fishes. Two subspecies of Dolly Varden are recognized in Canada, the southern form (“Dolly Varden (Pacific populations)”) and the northern form (“Dolly Varden (Western Arctic populations)”). The latter is the focus of this status report. As they mature, Dolly Varden (Western Arctic populations) change colour and shape, and grow in size, reaching more than 350 mm in length for anadromous (sea-run) adults, and usually 300 mm or shorter for non-anadromous adults. Juveniles are brown with a whitish belly, have small red spots irregularly-distributed on the sides and back, and have eight to twelve rectangular parr marks on the sides. Non-anadromous adults retain the parr marks whereas anadromous individuals lose the marks in sea water. Spawning anadromous males develop a hook or “kype” in the lower jaw and are strikingly coloured, with bright orange-red spots on their sides and an orange-red ventral surface. Female anadromous adults, non-spawners, and non-anadromous adults have a more muted colouration.

Distribution

Dolly Varden (Western Arctic populations) is found in northeastern Eurasia, and northwestern North America. In North America, the northern form of Dolly Varden ranges north from Bristol Bay in Alaska, along the north slope of Alaska and the Yukon Territory, and east to the Mackenzie River. In Canada, Dolly Varden (Western Arctic populations) occur within the Western Arctic National Freshwater Biogeographic Zone.

Habitat

All life history types of Dolly Varden (Western Arctic populations) spawn and overwinter in freshwater associated with perennial groundwater springs where adequate oxygen and suitable temperatures provide high quality habitat for adult and juvenile survival, and egg incubation during the cold winter months. Northwest Territories' Gwich'in say that spawning habitat requires relatively warm water, a fast current providing oxygenated water and plenty of shoreline cover and vegetation in which an abundant source of insect larvae can be fed on. In Canada, anadromous Dolly Varden migrate to sea to feed for the summer and return in the fall to their freshwater wintering grounds. Total area of key habitat for Dolly Varden (Western Arctic populations) is estimated to be less than 1.0 km^2.

Biology

Several different life history types of Dolly Varden (Western Arctic populations) exist. The anadromous type resides in its natal drainage for approximately three years before migrating out to sea to feed for the summer. Non-anadromous "residuals" are males that live alongside the anadromous fish in fall and winter. They reproduce by "sneaking" into redds to spawn with anadromous females, which are otherwise guarded by larger anadromous males. Other non-anadromous types that do not live alongside anadromous types are found above falls, a long distance from the sea, or in lakes. Males and females of this life history type complete their entire life cycle in freshwater.

Population sizes and trends

The population size of Dolly Varden (Western Arctic populations) is largely unknown, with information limited to reconnaissance data for some sites. Dolly Varden were last counted in Big Fish River in 1998 (estimate of 4,026 fish), and are thought to have a low, but stable population size. The population in the Rat River has seen steep declines in recent years, but is currently considered stable or recovering. Rat River Dolly Varden were last enumerated in 2007 when the population size was estimated at 14,897.

Limiting factors and threats

Low water levels, and low groundwater flow in freshwater habitats, especially at spawning/overwintering grounds reduces the amount of habitat suitable to Dolly Varden (Western Arctic populations). This is correlated with the trend of a warmer and drier climate in the Canadian western Arctic. Other threats include overharvesting, offshore industrial infrastructure that impedes movement of anadromous fish, and terrestrial resource extraction that may impact fish directly by altering freshwater habitats or indirectly by increasing access by fishers to freshwater habitats (i.e., building of transportation corridors).

Special significance of the species

Dolly Varden have been a predictable source of food for northern indigenous people. These fish remain a valued part of the Gwich'in and Inuvialuit diets. In the scientific community, Dolly Varden, and similar species (i.e. Arctic Char and Bull Trout) have been the subject of many genetic, evolutionary, and biogeographic studies of fundamental interest to biodiversity and its origins.

Existing protection

Parts of the distribution of Dolly Varden (Western Arctic populations) are within Ivvavik National Park. Other drainages have been identified as sensitive and a priority for protection from development according to the Aklavik Inuvialuit Community Conservation Plan and the Gwich'in Land Use Plan. The Northwest Territories ranks Dolly Varden as "Sensitive", meaning that the species may require special attention or protection to prevent it from becoming at risk. The federal government mandates protection of fish and fish habitat under the *Fisheries Act*.

TECHNICAL SUMMARY

Salvelinus malma malma
Dolly Varden — Dolly Varden
Western Arctic Populations — forme de l'ouest de l'Arctique
Range of Occurrence in Canada : Yukon and NWT: Yukon North Slope drainages flowing into the Beaufort Sea (Fish River, Malcolm River, Firth River, Babbage River), some of the rivers and tributaries flowing into the Mackenzie Delta (Peel River watershed, Big Fish River, Rat River, Vittrekwa River, Gayna River)

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)	6.6 yrs anadromous/ 5.1 yrs non-anadromous excluding male residuals/3.9 yrs male residuals
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown (ATK and DFO surveys both report that some populations have declined, others appear stable)
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown (Big Fish River may have declined by up to 75%, over the last three generations but Rat River appears stable over same total time period)
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown (Big Fish River may have declined by up to 75%, over the last three generations but Rat River appears stable over same total time period)
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Unknown, but serious declines have been observed in some populations (i.e., Big Fish River) in the past both from ATK and fisheries surveys.
Are the causes of the decline clearly reversible and understood and ceased?	Yes in terms of overharvest, unlikely in terms of climate change
Are there extreme fluctuations in number of mature individuals?	Possibly, in some populations (reported both in ATK accounts and fisheries surveys)

Extent and Occupancy Information

Estimated extent of occurrence	227,320 km²
Index of area of occupancy (IAO)	2x2 km = 72 km²
Is the total population severely fragmented?	No
Number of "locations∗"	17
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	No (Slight increase owing to greater survey effort)
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	Unknown

Is there an [observed, inferred, or projected] continuing decline in number of populations?	No (Slight increase owing to greater survey effort)
Is there an [observed, inferred, or projected] continuing decline in number of locations?	No
Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat?	Unknown, but possible owing to climate change
Are there extreme fluctuations in number of populations?	Unknown, but probably not
Are there extreme fluctuations in number of locations∗?	Unknown, probably not
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Population	N Mature Individuals
Big Fish River (estimates from 1972-1990) (includes some non-mature individuals) Rat River (1989-2007) Fish River Malcolm River Firth River Babbage River (1991) Peel River watershed Vittrekwa River (2007) Gayna River (2009)	1,244 – 21,000 2,900 – 14,800 unknown unknown unknown 13,600 unknown minimum 165 small (<1000?)
Total	Unknown, probably 15,000 – 50,000 (variable across years and streams)

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not known (necessary data unavailable)

Threats (actual or imminent, to populations or habitats)

Actual: Climate change and habitat loss due to desiccation of freshwater rivers, overharvest, changes in groundwater recharge at overwintering sites Potential: offshore infrastructure disrupting movement of Dolly Varden out at sea. Resource extraction that may alter habitat. Transportation corridors increasing access to fishing.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? USA: S5 in Alaska	
Is immigration known or possible?	Yes
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Maybe, extent of overwintering and spawning habitat available is unknown.
Is rescue from outside populations likely?	Possible for anadromous forms from streams draining North Slope of Alaska; unlikely for isolated inland populations.

∗ See definition of location in O&P manual

Current Status

COSEWIC: Designated Special Concern in November 2010.

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** N/A
Reason for Designation: This fish from freshwater and marine habitats of Canada's western Arctic has a very limited area of occupancy associated with a relatively small (17) number of locations that are key for spawning and overwintering. Aboriginal Traditional Knowledge suggests declines in some populations, and the small area and number of key habitats make the species particularly susceptible both to point source (e.g., overexploitation, stochastic events) and broader-scale events (e.g., climate change) that may eliminate or degrade habitats.	

Applicability of Criteria

Criterion A: Does not meet any decline criteria.
Criterion B: Meets Endangered for B2 (IAO of only 72 km²), but sub-criteria (a – c) do not apply (e.g., > 10 locations, no inferred continuing decline in habitat quality).
Criterion C: Does not meet any of the criteria.
Criterion D: Does not meet any of the criteria, but the biological AO of crucial overwintering habitat is << 20 km² (~0.5 km²). Aboriginal Traditional Knowledge and fisheries reconnaissance surveys are consistent in the location, area, and vulnerability of these overwintering sites.
Criterion E: Not conducted (required data unavailable).

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
(2010)

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

Dolly Varden
Salvelinus malma malma

Western Arctic Populations

in Canada

2010

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

SPECIES INFORMATION

Name and classification

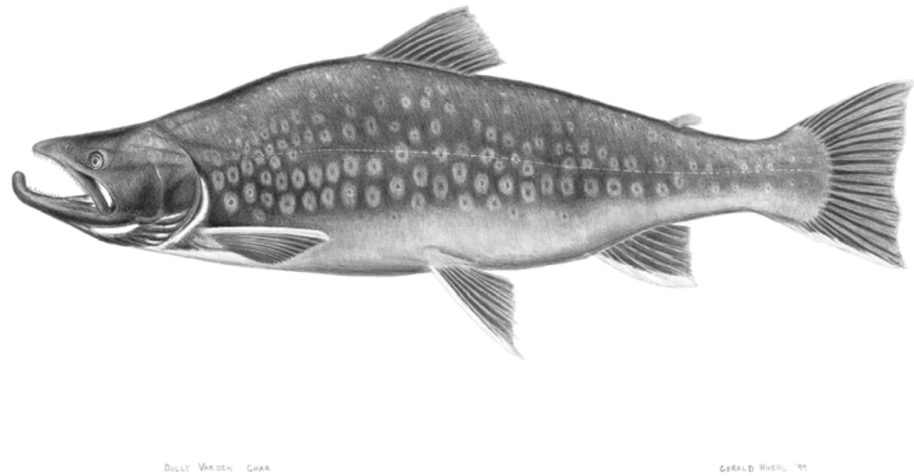
The taxonomic association of Dolly Varden from Nelson (1994) is as follows:

Phylum Chordata
  Subphylum Vertebrata
   Superclass Gnathostomata
     Class Actinopterygii
       Order Salmoniformes
        Family Salmonidae
          Species *Salvelinus malma* (Walbaum 1792)

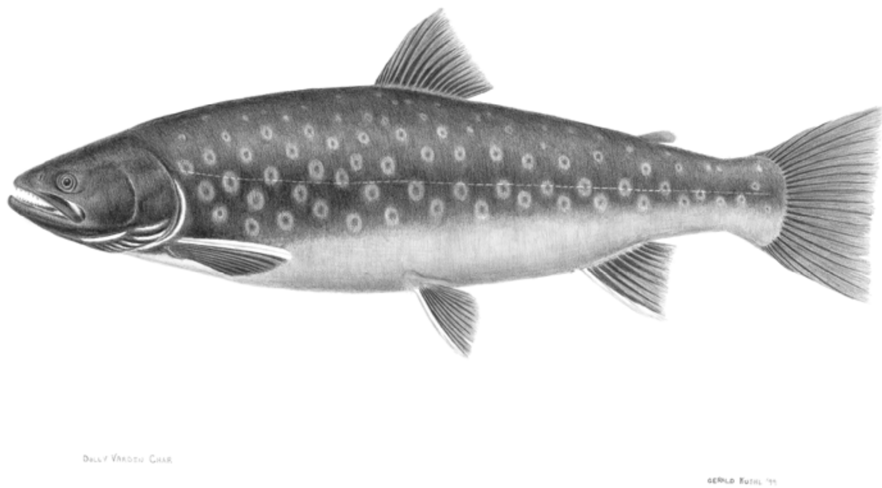
There are two recognized subspecies of Dolly Varden in Canada: *Salvelinus malma malma* (Behnke 1980) and *Salvelinus malma lordi* (Gunther 1866). These two subspecies can be differentiated by morphological traits and genetic attributes, as well as geography. At one time, Dolly Varden were considered as part of the Arctic Char (*Salvelinus alpinus*) "species complex", but the two are now recognized as distinct biological species (e.g., McPhail 1961; Taylor *et al.* 2008). Historically, these two subspecies of *S. malma* have been given unofficial common names that describe their geographic distributions: "northern" Dolly Varden referring to *S. malma malma* which are distributed north of the Aleutian Islands and "southern" Dolly Varden *S. m. lordi* found south of this point in North America. *S. m. malma* is also found in eastern Russia north of the Amur River and in the eastern Asian Arctic basin. In addition, there is another subspecies of southern Dolly Varden found in the western Pacific, *S. m. krascheninnikovi,* that ranges from Hokkaido, Japan, Sakhalin Island, and the mainland of Russia south of the Amur River (Behnke 1984). The French common name of the Dolly Varden (Western Arctic populations) is Dolly Varden (populations de l'ouest de l'Arctique). The Inuvialuit word for Dolly Varden is "qalukpik" (Lowe 1984) and the word in the Gwich'in language is "dhik'ii" (GRRB 1997). Dolly Varden (Western Arctic populations) form a valued component of the diet of these two northern indigenous groups as well as being of tremendous cultural significance (Byers 2010). On the north slope of the Yukon both Dolly Varden and Arctic Char are locally known as "char".

Morphological description

The general morphology of southern and northern Dolly Varden is similar and has been described in detail by Armstrong and Morrow (1980), including the shape and other dimensions of the body. Colouration depends on locality, the age and breeding condition of the individual, and anadromy (Appendix 1; Figure 1). Basic morphological characteristics of Dolly Varden are summarized in Table 1. Young “parr”, also known as pre-smolt juveniles, are brownish with a whitish belly. They have eight to twelve rectangular parr marks and small red spots sprinkled on their sides and backs. For anadromous Dolly Varden, parr marks disappear upon adaptation to seawater (smoltification). Non-breeding Dolly Varden that have undergone smoltification, also called “silvers”, have a silver background colour with pale pink to orange spots scattered along the sides. Anadromous spawning fish develop vivid colouration, with females having a muted, but similar colouration to males. Colouration in spawning anadromous males include: brown-black dorsal surface and orange-red ventral surface, tip of upper and sides of lower jaw are orange, white streaks are present under the maxilla and along the inner edge of the lower jaw, spots on sides are bright orange-red, dorsal and adipose fins are darkly pigmented, and the leading edge of the caudal and ventral fins is white (Bain 1974). Male anadromous Dolly Varden also undergo physical changes preceding the development of spawning colouration. These secondary sexual characteristics include a prominent dorsal ridge developed anterior to the dorsal fin, a prominent “hook” on the lower jaw, known as a kype, with an associated notch on the upper jaw, and enlarged teeth on the lower jaw.



Anadromous Male Dolly Varden (Western Arctic populations) (mature)



Anadromous Female Dolly Varden (Western Arctic populations) (mature)

Residual Male Dolly Varden (Western Arctic populations) (mature)

Figure 1. Anadromous and residual Dolly Varden (Western Arctic populations). Illustrations by Gerald Kuehl (with permission).

Table 1. Morphological characteristics of Dolly Varden at different life stages within different life history types.

Life History Type	Life Stage	Fork Length	Parr Marks	Colouration	Other Distinguishing Characteristics
Anadromous	pre-smolt juvenile	< 250mm	present	brownish with whitish belly; irregularly-distributed small red spots on sides and back	
	smoltified juvenile or non-spawning adult	>100mm	absent	silvery with dark blue to olive green on dorsal surface and white to dusky underparts; dorsal surface has light-coloured yellow spots; orange and pink spots appear on the sides and fade to white or dusky underparts. The spots have a blue halo and are the size of the fish's eye.	
	spawning adult	>300mm	absent	brown-black dorsal surface, orange-red ventral surface, bright orange-red spots on sides	males develop a prominent dorsal ridge, kype, enlarged teeth on lower jaw
Non-anadromous (riverine, residual, and isolated)	juvenile	<175mm	present	same as anadromous pre-smolt juvenile	
	spawner	>175mm	present	dark dorsal surface; yellow orange spots on sides, orange-red belly	generally smaller than anadromous spawners
Lacustrine	juvenile	data deficient	data deficient	data deficient	
	adult (spawning unconfirmed)	260-453mm	absent	as per anadromous spawners but more subdued colouration	Orange-red lips/gums. No kype or dorsal ridge has been observed (data deficient)

Spawning non-anadromous fish are darker than their anadromous counterparts, having a dark chocolate brown dorsal surface, dark fins with white leading edges on pelvic and anal fins, yellow-orange spots and belly, and spots that are smaller than the pupil of the eye. As well, non-anadromous fish retain parr marks throughout their life. During the non-breeding season, non-anadromous Dolly Varden retain a duller version of their spawning colouration. Physical changes such as the development of a kype are not prominent or do not occur at all for spawning non-anadromous Dolly Varden (Sawatsky and Reist in prep.). Mature non-anadromous riverine Dolly Varden are generally smaller than their anadromous counterparts; the latter can weigh up to 6.8 kg (Gwich'in Elders 1997), and measure about 450 mm for mature males and 355 mm for females. Mature fish from a population of lacustrine Dolly Varden in an unnamed lake at the base of Horn Mountain, Yukon (64°28'24.3"N 138°38'20.1"E, herein referred to as "Horn Lake") appear to be comparable in size to the anadromous form, but most other non-anadromous fish are much smaller (< 300 mm) at maturity. The fork length of specimens from Horn Lake ranged from 260 to 453 mm, with an average of 375 mm (n = 4). Numerical details on the size and age of anadromous Dolly Varden are summarized in Roux *et al.* (2009a).

Dolly Varden (Western Arctic populations) are easily confused with Arctic Char (*Salvelinus alpinus*) with which they may be sympatric in western Alaska (see Taylor *et al.* 2008). Externally, both Dolly Varden and Arctic Char have a slightly oblique mouth and small scales. Dolly Varden have a more laterally compressed body and less pronounced fork in the tail fin than anadromous Arctic char. Internally, Dolly Varden can be differentiated from Arctic Char by relatively lower counts of pyloric caeca and total gill rakers (Reist *et al.* 1997; Table 2). The number of gill rakers, combined with the number of vertebrae, is also used to distinguish the northern form of Dolly Varden from its southern counterpart that has fewer gill rakers and vertebrae (DeCicco and Reist 1999). Bull Trout (*Salvelinus confluentus*) occur sympatrically with Dolly Varden (Western Arctic populations) in the Gayna River. Details on how to distinguish Dolly Varden from Bull Trout, including qualitative and quantitative observations, are documented in Reist *et al.* (2002).

Table 2. Morphological differences between northern Dolly Varden and southern Dolly Varden and Arctic Char.

Species/subspecies	# Pyloric Caeca	# gill rakers on lower limb of first arch	# vertebrae
Dolly Varden-northern form	25-30	11-14 (21-23 in total)	66-68
Dolly Varden-southern form	20-30	8-12 (16-18 in total)	62-64
Arctic Char	24-74	12-17	65-71

Spatial population structure and variability

There are both geographical and behavioural barriers to gene flow that likely contribute to the genetic structure of the Dolly Varden (Western Arctic populations) in Canada. There are three different geographical barriers that limit gene flow: First, waterfalls and strong currents / rapids prevent fish from migrating upstream. Occasional downstream movement of fish from upstream of waterfalls does occur although it is not known whether these displaced fish spawn and contribute to the gene pool of the fish native to downstream habitats. Secondly, lacustrine Dolly Varden have a limited opportunity to move out of the lake, especially if the lake is remote and the inflow/outflow to/from the lake is poor habitat. Thirdly, geographical distance can act as a barrier to the movement of individuals, and thus gene flow between populations (Table 3). All of the geographically isolated inland fish are believed to be non-anadromous. Ongoing analysis suggests that non-migratory residents isolated by waterfalls are genetically distinct from fish downstream (Cosens and Martin 2003). The Aberdeen Canyon in the upper Peel River watershed isolates fish upstream from those downstream (Anderton 2006), but Dolly Varden within tributaries either upstream or downstream of the canyon are not geographically isolated from each other.

Table 3. Populations of Dolly Varden (Western Arctic populations) isolated by geography.

Drainage	Waterfall	Distance to Sea	Lake
Big Fish River	X		
Babbage River	X		
Gayna River	X	X	
Vittrekwa[1]		?	
Upper Peel Watershed			
Hart River	X	X	
Black Stone River	X	X	
Other Rivers		X	
Horn Lake			X

[1] A population partially isolated by distance may be present (Sawatzky and Reist in prep.), but has not been confirmed.

The primary behavioural barrier to gene flow is the fidelity of anadromous Dolly Varden to their spawning grounds. Anadromous Dolly Varden are comprised of genetically distinct populations associated with each of the different drainages from which the fish originate (Reist 1989). The behaviour of returning to natal spawning grounds maintains the genetic isolation of each population of Dolly Varden even though members from different populations mix at sea and visit drainages other than their drainages of origin to overwinter (Babaluk and Reist 1996). Genetically distinct anadromous populations occur in the Firth River, Joe Creek, Big Fish River, Babbage River, Rat River and Vittrekwa River (Reist 1989; Fisheries and Oceans Canada (DFO), unpublished data). Male residual and anadromous fish co-occur in these drainages. According to allozyme, mitochondrial DNA and microsatellite evidence, such residual male fish are not genetically distinct from their anadromous counterparts (Reist 1989; Cosens and Martin 2003). Two other drainages, the Fish River and Malcolm River, may have genetically distinct populations of Dolly Varden, but information on the life history and genetics of these fish is lacking. Historical accounts of Inuvialuit catching char from fish holes along Fish River and Malcolm River have been documented, which is consistent with the idea of distinct populations (Papik *et al.* 2003).

Among the sampled anadromous populations in northwestern Canada, there is a trend of greater genetic diversity of the western drainages compared to the eastern drainages (i.e. greatest genetic diversity in the Firth River). This suggests that colonization of the drainages originated from western populations, and occurred several times (Rydderch 2001). Allozyme analysis of anadromous spawners in five drainages found statistically significant differences between each pair of adjacent drainages, except Joe Creek (tributary to Firth River) and the Canoe River, a tributary to the Babbage River (Reist 1989). The other drainages included in the study were the Firth, Big Fish and Rat rivers.

A study of genetic structure of Dolly Varden from drainages entering the Beaufort Sea included samples from the Firth and Babbage rivers in Canada (Figure 4). Estimates of genetic distance using data from allozyme electrophoresis indicated that geographic proximity was not necessarily associated with closer genetic distance, and that more than one genetic population can exist within a drainage. A tributary of the Firth River, Joe Creek, was, however, more similar to the Firth River fish than to fish of other drainages (Department of Fisheries 2002a; Sawatzky and Reist in prep.). Nei's genetic distance between the Babbage and Firth River samples was about 0.013 (Everett *et al.* 1997). Osinov (2002) included Everett's samples of the Babbage and Firth River in a genetic analysis that concluded that genetic divergence of the Dolly Varden (Western Arctic populations) in Asia and North America was low (Nei's D=0.000-0.014), with far more diversity within populations (90.4%) than between populations (2.48%) according to allozyme variation for 17 polymorphic loci.

Comparison of mitochondrial DNA (mtDNA) between Dolly Varden and Bull Trout suggested that Dolly Varden from the Bonnet Plume and Blackstone Rivers are part of a large ("Northern") clade spanning from southern British Columbia to the Kuril Islands in Russia. The other ("Southern") mtDNA clade is distributed from British Columbia to Washington State and has experienced introgression with Bull Trout before the most recent glaciation (Redenbach and Taylor 2002).

Phillips *et al.* (1999) found that Dolly Varden (Western Arctic populations) is distinct from southern (*Salvelinus malma lordi*) using ribosomal DNA and chromosome data. Diploid chromosome count for Dolly Varden (Western Arctic populations) is 76 or 78 (Osinov 2002) whereas for the southern form it is 82. The number of chromosome arms is 98 for both, suggesting a breakage of a four arm chromosome at the centromere that resulted in a higher number of chromosomes in the southern form. A difference in chromosome number suggests that northern and southern Dolly Varden are genetically incompatible and would not produce viable offspring. Ribosomal DNA analysis suggests that the two forms of Dolly Varden diverged from separate subspecies of Arctic Char: *Salvelinus malma malma* from *Salvelinus alpinus alpinus* and *Salvelinus malma lordi* from *Salvelinus alpinus erythrinus* (Phillips *et al.* 1999). The subspecies are sufficiently distinct evolutionary lineages that they merit consideration as distinct biological species.

Designatable units

The identification of several different populations within *Salvelinus malma malma* is supported by genetic and morphological differences, geographic isolation, and differences in limiting factors, but it is debatable as to whether the degree of difference is large enough to warrant identification of separate designatable units. As discussed in the previous section on the genetic description of *Salvelinus malma malma*, sampled drainages flowing into the Beaufort Sea in Canada have populations showing some genetic differences, and several populations are geographically isolated from one another. Discriminant function analysis of morphometric characteristics for Dolly Varden in the Firth, Babbage and Big Fish rivers support the genetic discrimination (Jim Johnson unpublished in Kowalchuk *et al.* 2008). Potentially limiting factors affecting *Salvelinus malma malma* differ between some drainages. Relatively accessible Dolly Varden in rivers such as the Big Fish and Rat rivers are harvested more than remote rivers such as the Babbage and Firth rivers. Thus, population trends recorded in one river do not necessarily reflect the trends in other rivers. Habitats are also not consistent between all rivers; for example, some overwintering sites receive water from shallow, cool, non-thermal springs, while others receive warmer water from deep, thermal springs. Abiotic factors, such as increased precipitation and warmer air temperatures are likely to result in greater short-term changes to ground water above permafrost.

For now, delineating Dolly Varden into separate designatable units will not be done because a comprehensive assessment of genetic distance among a broad sampling of populations is lacking or inconclusive. The Dolly Varden (Western Arctic populations) will be treated as a single designatable unit, *S. malma malma* Western Arctic populations given its geographic distribution in Canada (see **DISTRIBUTION** section below). This issue should, however, be revisited as more genetic information is collected and analyzed. Inland populations, in particular, may require a separate designatable unit, depending on future studies. For instance, the flow of rivers in the Peel River watershed has changed directions historically (Bodaly and Lindsey 1977; Harris and Taylor 2010), so inland populations may have a closer affinity to Dolly Varden in the Yukon River than to the Dolly Varden along the Beaufort Sea. Few populations have been studied in detail, with population information for many sites limited to reconnaissance data (Table 4).

Table 4. Types of information available for different populations of Dolly Varden (Western Arctic populations).

Drainage	Genetic	Habitat Attributes	Harvest/Census/Reconnaisance
Fish River			
Malcolm River			
Firth River and tributaries	x	x	x
Babbage River and tributaries			
upstream of falls			x
downstream of falls	x	x	x
Big Fish River and tributaries			
upstream of falls			x
downstream of falls	x	x	x
Rat River	x	x	x
Vittrekwa River	x	x	x
Upper Peel Watershed			x
above Aberdeen Canyon[1]	x	x	x
below Aberdeen Canyon[2]	x	x	x
"Horn" Lake			x
Gayna River			x

1 Hart and Blackstone Rivers
2 Snake, Bonnet Plume and Wind Rivers

Special significance

Dolly Varden has been and still is part of the traditional diet of the Gwich'in and Inuvialuit. It is a good source of thiamin, calcium and omega-3 polyunsaturated fats (Byers 2010). Harvesting of Dolly Varden takes place at sites along the coast throughout the summer, and along rivers, particularly during the fall migration to spawning and overwintering grounds. Traditionally, Dolly Varden were smoked, dried, and frozen for later use. Non-spawners were deemed tastier, with firmer flesh (see interviews in Benson 2010). Fish became more prominent in the diet of the Inuvialuit of the Mackenzie Delta area in the early 1900s when local caribou herds were decimated by the demands of foreign whaling ships. Elders recall over 200 fish camps and thousands of dogs spread over the Mackenzie Delta in the 1930s. Although fish were harvested for dogs, Dolly Varden were highly valued and kept mainly for human consumption. The Teetl'it Gwich'in people had focused their hunting and fishing activities in the Peel River drainage and the Rat River before European contact. An overland trail from the hunting grounds in the mountains to one of the fishing sites has been in use since the early 1800s and perhaps earlier. When muskrat trapping became lucrative in the 1920s, the Gwich'in began using the Mackenzie Delta extensively alongside the Inuvialuit. An old fishing location along the Firth River had artifacts dating back 8,000 years (Papik *et al.* 2003). The Babbage River Dolly Varden was a source of food for people who travelled to Aklavik or Old Crow. A subsistence harvest still takes place and is self-regulated on the Rat River by the development of a Rat River Char Fishing Plan (Aklavik Renewable Resource Council *et al.* 2000).

There was also a commercial fishery prior to 1985. The Menzies Fish Co. Ltd. operated a small commercial fishery in 1965 and 1966 at Shingle Point. These Dolly Varden are believed to have originated from the Firth, Babbage and Fish rivers, and possibly some Alaskan drainages (DFO 2002).

Dolly Varden has been the subject of many genetic, evolutionary, and biogeographic studies of fundamental relevance to understanding the origins and persistence of biodiversity (e.g., McPhail 1961; Phillips *et al.* 1991; Taylor *et al.* 2008). Its relationship to other *Salvelinus* species and the relationship of Dolly Varden subspecies to each other continue to be incompletely understood.

DISTRIBUTION

Global range

Dolly Varden (Western Arctic populations) occurs in northwestern North America (Figure 2) and northeastern Eurasia. In North America, it ranges from the Bristol Bay drainages of the Alaska Peninsula, west along the coast of Alaska to the north slope of the Yukon and western Mackenzie River delta (Reist 2001). There is a break in the species distribution of approximately 700 km, from Point Hope to the Colville River in Alaska (dashed lines on North Slope of Alaska in Figure 3). Dolly Varden in rivers draining into the Bering Sea south of the Seward Peninsula on the west side of Alaska are currently classified as *Salvelinus malma malma*, but may actually be a form that is intermediate between northern and southern Dolly Varden (Reist *et al.* 2001). In Eurasia, Dolly Varden (Western Arctic populations) ranges from the Amur River estuary in the south to the Kolyma River in the north (Osinov 2002). The subspecies is known from drainages entering the Eastern Chukchi Sea (Chereshnev *et al.* 1989) and was reported from the Pacific coast of Asia from the Chukhotsk Peninsula south at least as far as Petropavlovsk (Morrow 1980).

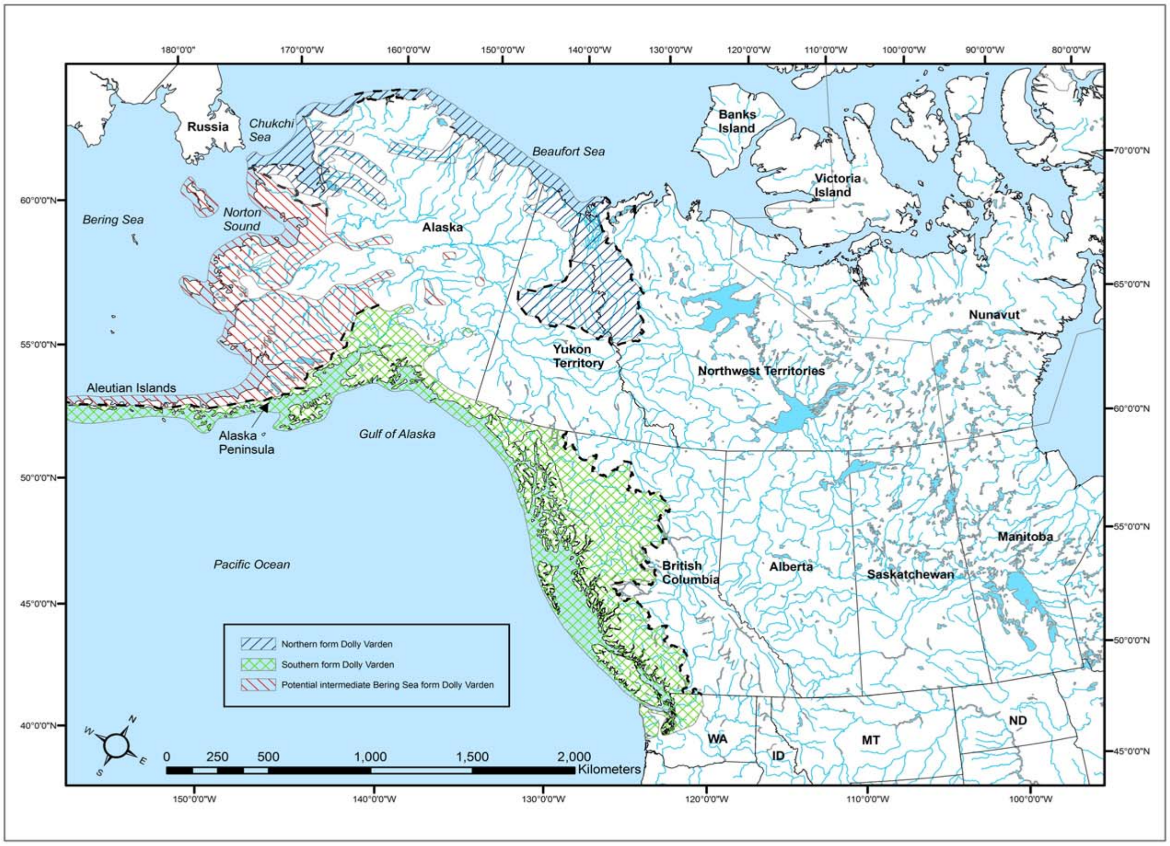


Figure 2. Range of Dolly Varden in North America. The potentially intermediate Bering Sea form on the map is currently regarded as the northern form whose North American range extends from the northern portion of the Alaskan Peninsula to the Mackenzie River basin..

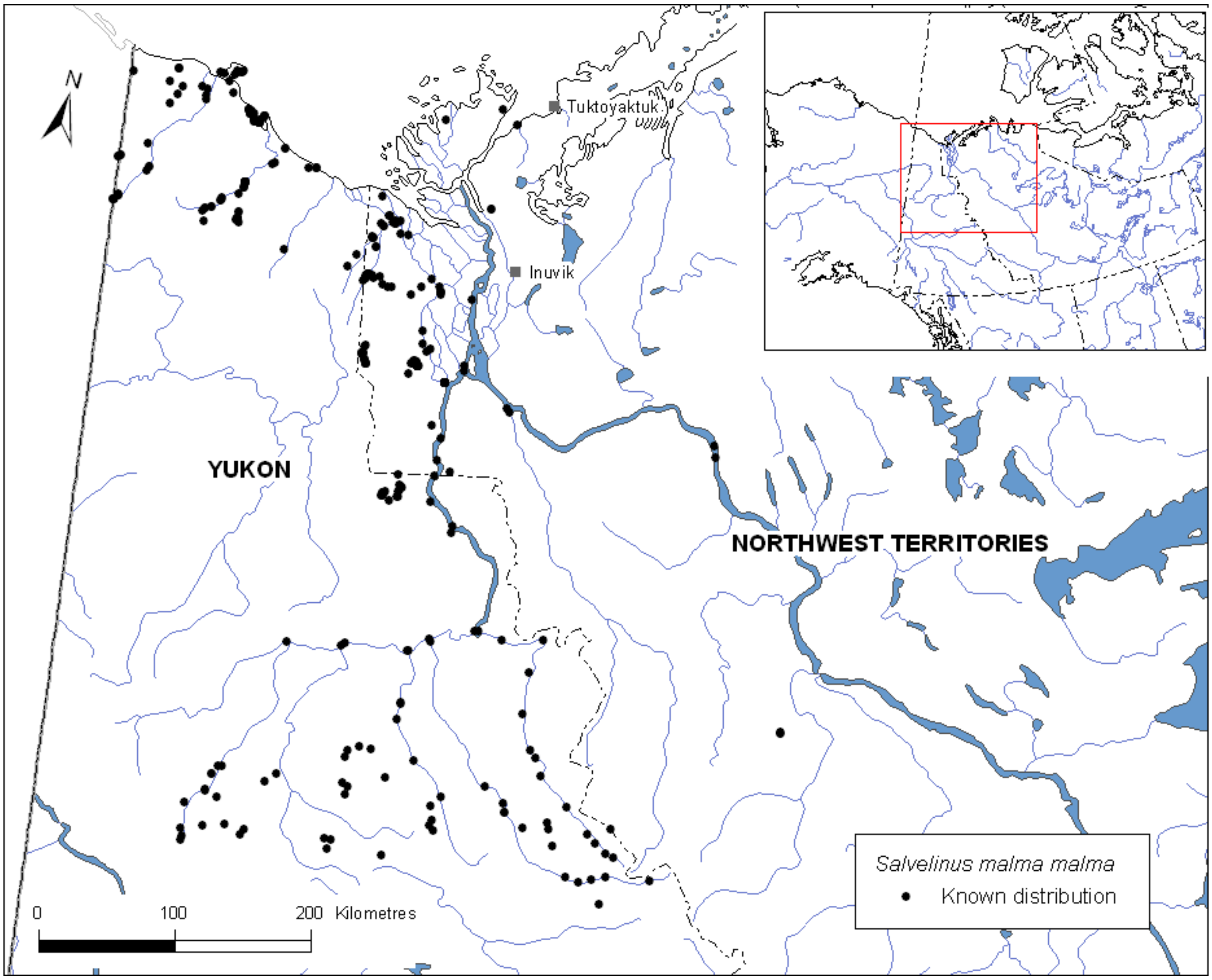


Figure 3. Distribution of Dolly Varden (Western Arctic populations) in Canada.

Canadian range

In Canada, the Dolly Varden (Western Arctic populations) occurs in drainages flowing north into the Beaufort Sea within the Western Arctic National Freshwater Biogeographic Zone (Figure 3). As discussed under **Spatial Population Structure and Variability**, disjunctions in the population exist because of geographic barriers such as waterfalls and distances too far from the sea. Approximately 5 to 10% of the global population of *Salvelinus malma malma* resides in Canada (Kathleen Martin pers. comm. 2008).

On the north slope of the Yukon, Dolly Varden have been found in Fish Creek, Malcolm River, Firth River, Babbage River, and associated tributaries (collectively known as the North Slope populations). Dolly Varden have also been documented in rivers flowing into the Mackenzie Delta including the Big Fish, Rat, and Peel River systems. Tributaries with Dolly Varden within the Peel River watershed include the Vittrekwa (Millar 2006), Snake, Bonnet Plume, Wind, Hart and Blackstone, and Ogilvie rivers, and Stony Creek (Figure 2, 4 in Anderton 2006, Susan Thompson pers. comm., Yukon Government unpublished data, 2009; Gwich'in Renewable Resource Board. Inuvik. unpubl. data 2009). A small outlying population lives in the Gayna River which also eventually drains into the Mackenzie River (Mochnacz and Reist 2007).

There are insufficient data to draw conclusions on expansions and contractions of the subspecies' distribution. Not all drainages within and adjacent to the known Canadian range have been surveyed adequately for Dolly Varden. More recently documented locations for Dolly Varden, in the Gayna River and upper Peel River, are not indications of range expansion, but reflect search effort and stronger criteria for distinguishing between Dolly Varden, Bull Trout and Arctic Char (Table 5). Dolly Varden have been caught out at sea as recently as the summer of 2008, most notably Phillips Bay (J. Johnson Department of Fisheries and Oceans unpublished data), Herschel Island, and Shingle Point (K. Bill, DFO unpublished).

Table 5. The most recent date that Dolly Varden (Western Arctic populations) were found in each of the populations.

Drainage	Date last reported	Reference
Fish River	unknown	Papik *et al.* 2003
Malcolm River	unknown	Papik *et al.* 2003
Firth River and tributaries (Joe Creek)	2008 (2009)	Parks Canada staff member Adriana Bacheschi pers. comm., Neil Mochnacz pers. comm.
Babbage River and tributaries		
upstream of falls	1988	Reist *et al.* 1997
downstream of falls	2001	DFO 2002b
Big Fish River and tributaries		
upstream of falls	1973	McCart and Bain 1974
downstream of falls	2002	Billie Archie pers. comm.
Rat River	2008	Steve Sandstrom pers. comm.
Vittrekwa River	2008	Nathan Millar pers. obs.
Upper Peel Watershed		
Hart	2008	Foos 2008
Blackstone	2008	
Snake	2007	Ferguson 2007
Bonnet Plume	2007	
Wind	2008	Foos 2008
Horn Lake	2004	Thompson pers. comm.
Gayna River	2008	Mochnacz *et al.* 2008.

Dolly Varden have also been documented in the Yukon River system, specifically in the Stewart River. They have been found contiguous to the Peel River drainage in the Rackla River (von Finster 2003) and the Nadaleen River (genetically confirmed as Dolly Varden, Yukon Government files). They have also been found contiguous to the Keele River (Mackenzie River drainage) in Hess River (Weagle and Pearson 1980; EBA Engineering Consultants 2007). These populations are of uncertain genetic affinity, possibly northern or southern form or some intermediate form, and so, for now, have not been included in the range map. Unconfirmed reports of Dolly Varden have been recorded for other parts of the Yukon including the Klondike River (Yukon River system adjacent to the Peel River drainage, Al von Finster pers. comm. 2009).

For Dolly Varden (Western Arctic populations), a location is defined as a spawning and/or overwintering site. The rationale for this is: these are places where all life stages congregate for the winter and thus put all members of that particular population at risk by a single threatening event (e.g. habitat alteration). There are 17 confirmed locations, and several potential locations that require further documentation (Table 6, Figure 4).

Table 6. Index of area of occupancy (IAO) and estimated area of overwinter/spawning habitat of Dolly Varden (Western Arctic populations).

Drainage	IAO (number of 2 km x 2 km grids)	Area[a] of overwintering and spawning habitat (km^2)
Fish River	site needs confirmation	0.00006
Malcolm River	data deficient	data deficient
Firth River and tributaries	sites need confirmation	0.00174 +0.00114 (Joe Ck)
Babbage River and tributaries	1	see below
upstream of falls	-	0.01920
downstream of falls	-	0.05002
Big Fish River and tributaries	2	see below
upstream of falls	-	0.00820
downstream of falls	-	0.04710
Rat River	1	0.08910
Vittrekwa River[1]	6	0.00010
Upper Peel Watershed		
Above Aberdeen Canyon[2]	3	0.183 (Blackstone only)
Below Aberdeen Canyon[3]	4	data deficient
Horn Lake	data deficient	data deficient
Gayna River	1	0.00405

a These numbers are from Schroeder *et al.* (2008), and are tentative.
1 Includes four separate locations
2 Hart and Blackstone Rivers
3 Snake, Bonnet Plume and Wind Rivers

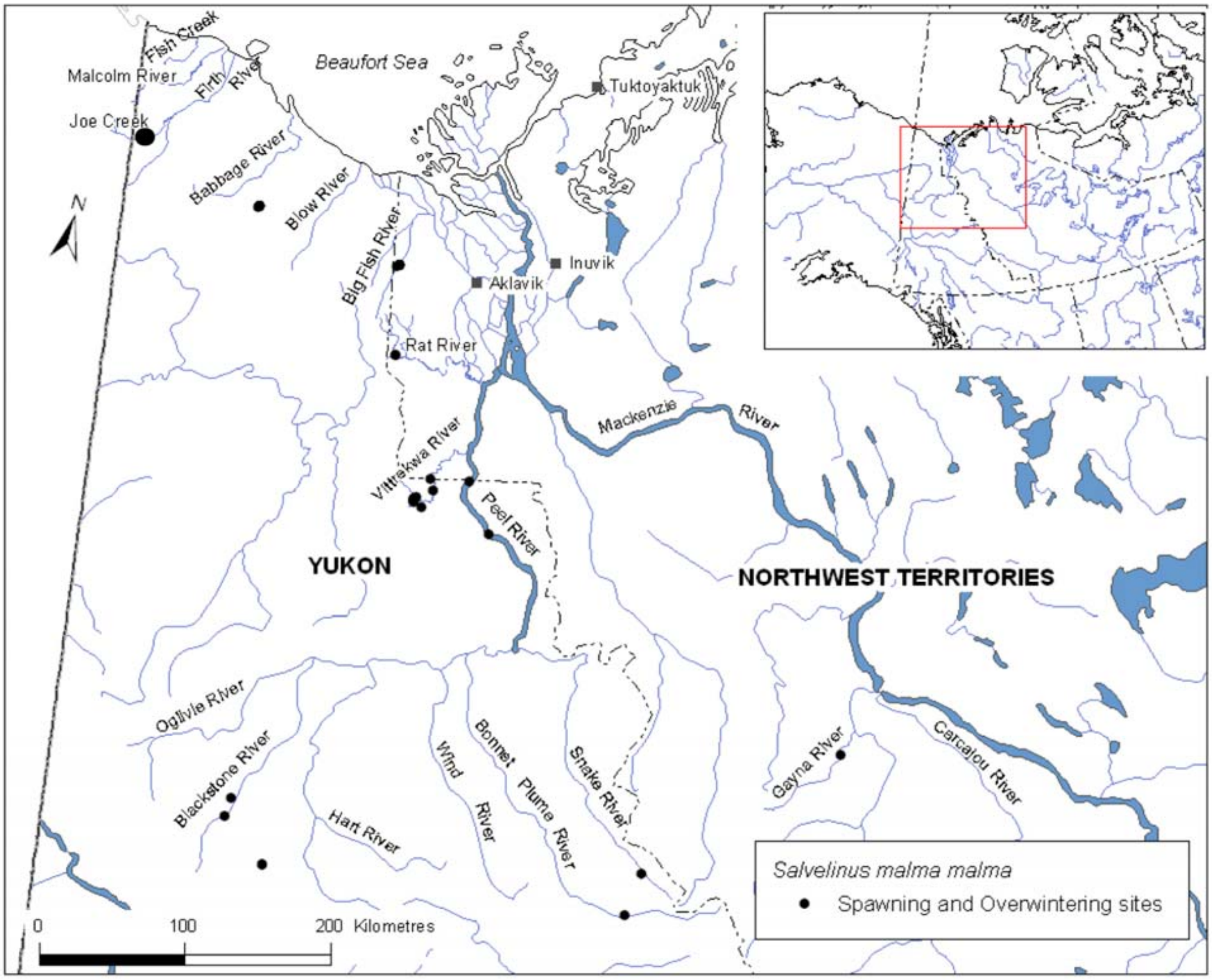


Figure 4. Known spawning/overwintering sites of Dolly Varden (Western Arctic populations) in Canada. Major rivers are labelled.

The extent of occurrence is 227,320 km^2 as calculated following the COSEWIC guidelines for minimum convex polygon (Jenny Wu, Environment Canada pers. comm. 2009). The index of area of occupancy only includes the known spawning/overwintering sites (Figure 4). This amounts to 18 grids of 2 km x 2 km (total = 72 km^2, Table 6). Other suitable overwintering and/or spawning sites have been identified, but confirmation of overwintering or spawning activity are lacking for these locations (Schroeder *et al.* 2008, Table 6). The estimated biological AO of key overwintering habitat is only 0.63 km^2 (Table 6).

HABITAT

Habitat requirements

Dolly Varden (Western Arctic populations) in Canada use coastal estuarine waters in the Beaufort Sea and freshwater drainages that flow northward into the Beaufort Sea. Dolly Varden isolated by geographical barriers or by distance to the sea only use freshwater habitats whereas anadromous Dolly Varden feed out at sea during the summer and are in freshwater habitats for the remainder of the year. Known freshwater habitats vary from wide open braided streams to high elevation, high gradient streams (Nathan Millar pers. obs.; Stewart *et al.* 2010b). The overwintering, spawning and pre-smolt habitat needs are similar for anadromous and non-anadromous Dolly Varden. For anadromous Dolly Varden, additional habitats that provide migration routes to/from feeding areas in the sea, and opportunity for smoltification are required to complete their life cycle. Data on habitat requirements of non-anadromous Dolly Varden are quite limited (Table 7).

Table 7. Habitat use by Dolly Varden (Western Arctic populations) populations with different life history types (modified from Stewart *et al.* 2010b).

Habitat	Life History Type		
	NON-ANADROMOUS[1]		ANADROMOUS
	Stream-resident (isolated)[2]	Residual[3]	
Spring-fed reaches of tributary streams	Year-round use by all life history stages for all activities.	Spawning and rearing habitat. Feeding habitat primarily for fry, but some by juveniles and adults. Migratory corridor for juveniles and adults. Overwintering habitat for all life history stages.	Spawning and rearing habitat. Feeding habitat primarily for fry, but some by juveniles and adults. Migratory corridors for juveniles and adults. Overwintering habitat for all life history stages.
Rivers	Migration corridors and feeding habitat for juveniles and adults.	Migration corridors and feeding habitat for juveniles and adults.	Migration corridors and feeding habitat for juveniles and adults.
Brackish or marine coastal waters			Migration corridors and feeding habitat for juveniles and adults. Rearing habitat for fish as young as age 1, but typically age 3 or older. Estuarine habitat for smoltifying fish.

1 Information is lacking for lacustrine Dolly Varden. They are non-anadromous.
2 Impassable barriers (e.g., waterfalls) prevent access to and from the sea.
3 Residuals are typically small, early-maturing males.

The most specific and limiting habitat for the Dolly Varden is the spawning and overwintering habitat. This habitat is characterized by perennial groundwater upwelling into existing river channels where adequate oxygen and suitable temperatures are conducive to adult and juvenile survival, and egg incubation during the winter months, crucial areas that have long been recognized by Gwich'in and Inuvialuit (Schroeder *et al.* 2008; Byers 2010). These areas of open water, often supporting a growth of filamentous algae throughout the winter, contrast sharply with the rest of the river that typically freezes to the bottom. Downstream, where the upwelling of ground water is forced out over the frozen river, areas of thick layered ice form, features known as *aufeis* that persist into late spring. Meltwater from aufeis creates shallow flows through gravel that is used by non-spawners prior to their ascent to the overwintering sites (DFO 2001; Sandstrom *et al.* 2001). With the exception of the Big Fish River in which fish have been caught in ice tunnels in aufeis, the upstream side of the aufeis usually indicates the lower boundary of the spawning/overwintering site. The Big Fish River overwintering area is fed by warmer thermal springs than other Canadian overwintering sites which are fed by cooler water sources (i.e. Firth, Babbage, Rat rivers). Because of the relatively high temperature of the springs in the Big Fish River, Dolly Varden tend to overwinter further downstream, up to 2 km, rather than at or adjacent to the ground water discharge site. Details of spawning and overwintering sites in individual drainages are described in Mochnacz *et al.* (2010).

Redds are excavated by females in gravel or cobble substrates. Following fertilization, eggs are laid and covered with gravel for the winter (Richardson *et al.* 2001). The water depth at spawning sites is 0.2 m to 1.5 m in currents of 0.3 m/s to 0.6m/s, but aspects of habitat use vary by life stage (Table 8). Moving water cleans the spawning grounds and provides oxygen to the developing embryos. Oxygen levels range from 2.6 to 14.5 mg/L. Water temperature at the spawning grounds ranges from 0 to 8^{o}C (Stewart *et al.* 2010b). Conductivity, which reflects mineralization and salinity in water, ranges from 120 to 350 µmhos/cm at 25^{o}C for areas fed by karst-type groundwater. Some of the overwintering sites have considerably higher concentrations of ions (Table 9). The measured pH of groundwater inflows is mildly alkaline, ranging from 7.6 to 8.8 (Stewart *et al.* 2010b). According to Stabler (1998), the ratio of deep water pools to shallows in a free-stone river system, as measured by frequency of occurrence, is considered healthy for Dolly Varden when it is in the range of 1:1.5 and 1:1.75. In 1995, this ratio was skewed to 1:5.7 in the Big Fish River indicating a dominance of shallow areas and deposition of shale fines and silt following a high water event (Stabler 1998).

Table 8. Rearing habitat preferences by life stage of Dolly Varden (Western Arctic populations), North Slope and NWT, Canada (from Griffith 1979; Schroeder *et al.* 2008).

Life Stage	Velocity (m/s)	Depth (m)	Substrate
Fry	0.1 (0.1-0.3)	0.2-0.4 (0.12-0.8)	Mostly gravel (25% sand/fine, boulders)
Juvenile	0.3 (0.15-0.5)	0.4-1.2 (?-1.5)	Gravel/cobble (mostly sand–mostly boulder
Adult	Fast flow	Deep, riffles/pools	Pools with cover

Table 9. Conductivity measured at various overwintering sites (summarized from various sources in Stewart *et al.* 2010b).

Location	Conductivity (μmhos/cm at 25^{o}C)	Dissolved oxygen
Firth River	446-540	n/a
Fish Creek area of Rat River	411	n/a
Woods Creek Falls on Babbage River	1372	4.6mg/L
Fish Hole on Little Fish Creek (tributary to Big Fish River)	4800	<0.2mg/L at ground water outflow 8.8mg/L 650m downstream

General characteristics of spawning and overwintering habitats identified in the populations are similar; more details are provided in Figure 5, in the following text and in Schroeder *et al.* (2008). On the Firth River, the spawning, nursery and overwintering sites have perennial upwelling sites that provide flowing water year-round. Known spawning and nursery sites in the Firth River drainage occur in spring-fed areas at the headwaters of the Firth River and Joe Creek (Glova and McCart 1974; DFO 2002a). Spawning is later at the Joe Creek site where groundwater temperature is 5^{o}C compared to 1.5 ^{o}C at the other site. The Babbage River spawning and overwintering grounds for anadromous Dolly Varden are comprised of the lower portions of Fish Hole Creek and Wood Creek where water at 4^{o}C flows from groundwater springs, and a 1.5 km section of Canoe River downstream from these springs (DFO 2002b). Babbage River Dolly Varden living above the falls have a different site for spawning and overwintering. Freshwater-resident and anadromous Dolly Varden in the Big Fish River watershed overwinter and spawn in an area called “Fish Hole”. Water with high levels of dissolved solids, and a high temperature (up to 15.5^{o}C), flows from a warm spring, keeping most of the upper areas of the Fish Hole ice-free through the winter months, and forming tunnels containing 0.5 m water in the core of the overflow ice downstream. Rat River Dolly Varden spawn in the tributary known as Fish Creek. Ground water temperature is 4-5^{o}C at these three areas of open water. Only one area, 200 m^2 of Ne’eedilee Creek, has been identified for spawning of Vittrekwa River Dolly Varden. These spawning holes averaged 2 m wide, 5 m long, 1.3 m deep, and were undercut with a gravel bottom and 30% cover of willows. The water is characteristically clear, cold and fast flowing (Millar 2006).

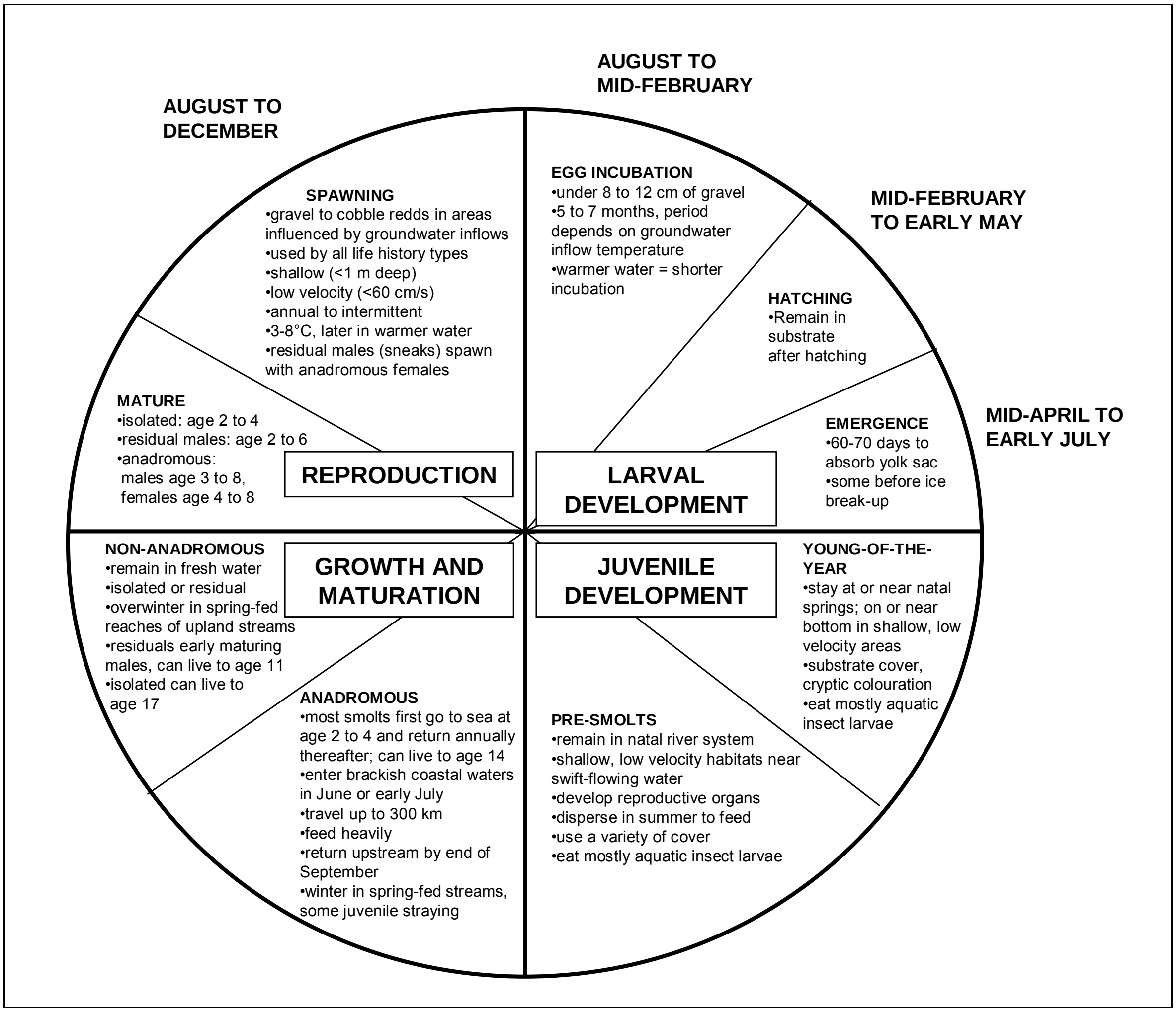


Figure 5. Generic life cycle of Dolly Varden (from Stewart *et al.* 2010b).

Mochnacz *et al.* (2010) defined key habitat as that habitat that if disrupted or lost would have serious implications for the survival of a population or group of populations. Under this definition, the overwintering habitat areas that comprise small groundwater-fed areas (Clark *et al.* 2001) that remain ice-free all year, and typically correspond to spawning habitat, were identified as key for Dolly Varden (Western Arctic populations). The total known amount of such habitat across nine rivers was estimated as only 0.63 km^2 and ranged from a low of 0.0001 km^2 (Vittrekwa River) to 0.01900 km^2 (Firth River) (Mochnacz *et al.* 2010). While other potential areas of such key habitat across the range of Dolly Varden (Western Arctic populations) exist, incorporating estimates of these potential areas only increased the total area of key habitat to 0.98 km^2.

Feeding habitat for juveniles and adults is wider ranging than overwintering sites. For juveniles, feeding is associated with cover in the form of bank vegetation, instream tundra slumps, rocks, and low flows (Sawatzky *et al.* 2007; Stewart *et al.* 2010b). Estuary environments provide a salinity gradient conducive to smoltification, the process by which the young anadromous fish from freshwater become tolerant to salty marine waters. Phillips Bay, at the mouth of the Babbage River, is an example of this type of habitat. In the sea, Dolly Varden are believed to spend most of their summer feeding in coastal areas although dietary studies do suggest that feeding offshore among ice floes also occurs. A small invertebrate, *Apherusa glacialis*, associated with the underside of ice floes was identified in Dolly Varden diets when ice floes were greater than 8 km offshore (BP Exploration 2001). As well, the level of the stable isotope ^{34}Sulphur found in muscle tissue in sampled Dolly Varden indicated that feeding occurred in habitats of higher salinity (Reist unpublished data) than brackish waters. Dolly Varden have been observed feeding off rocks as well as taking stones into their mouths and spitting them out (Byers 2010).

An estuarine band of water, spanning the 750 km length of the coast along the Beaufort Sea, forms for the summer and is absent in winter. This band is usually 2-10 km wide and is relatively warm and brackish compared to adjacent marine water (5-10^{o}C, 10-25% salinity versus -1 to 3^{o}C, 27-32% salinity). An abundant supply of summer food such as mysids and amphipods can be found in this seasonal habitat feature. The use by Dolly Varden of this zone for feeding and as a transportation corridor has been reported by local people (Danny Gordon pers. comm. 2009) and is reported in Craig (1984).

Habitat trends

Quantitative data measuring changes to the area and attributes of suitable habitat are not available; however, qualitative changes have been documented for a few sites, and programs to monitor habitat changes have been initiated. The spawning and overwintering habitat at the Fish Hole on the Little Fish River branch of the Big Fish River degraded in 1996 when high water changed the borders and flow direction within the river system (Joynt *et al.* 2008). Further degradation could be attributed to reduced groundwater flow into the Fish Hole and erosion of steep banks along the spawning areas. Inuvialuit report that the water is lower and is less salty than it was in the 1960s (Byers 1993; Papik *et al.* 2003). The frequency of landslides along the Rat River has increased in the past two decades (Byers 2010). A photographic baseline of known Dolly Varden overwintering and spawning habitat on the Vittrekwa, Big Fish, and Rat rivers was established in 2007 to document habitat changes (Joynt *et al.* 2008). Aerial photographs of the Rat River taken in the summer of 2008 depict some unusually dry creek beds (Steve Sandstrom pers. comm. 2009).

Inuvialuit note that water levels at several other sites are shallower now (Papik 2003). The Firth River delta used to be deep enough for schooners to dock, but this is no longer possible.

Habitat protection/ownership

Habitat for parts of the Dolly Varden range are protected by their inclusion within Territorial parks, while other areas have been identified as important to protect by special designation in the Aklavik Inuvialuit Conservation Plan and the Gwich'in Land Use Plan (Gwich'in Land Use Planning Board 2003). Three of the rivers where Dolly Varden (Western Arctic populations) occur lie within or partially within Ivvavik National Park: Fish River, Malcolm River and Firth River. A portion of the known overwintering and spawning sites on the Firth River lies within the park. Another portion of the Firth River watershed, including part of Joe Creek is within the American Arctic National Wildlife Refuge. The designation of "Refuge" theoretically protects habitat within its boundaries. The protection of fish habitat is mandated under the *Fisheries Act*.

The Babbage River forms the eastern border of Ivvavik National Park. The Babbage River watershed in the park and 1 km east of the river, and the Canoe River, including spawning/overwintering areas upstream, is designated as Management Category D by the Aklavik Inuvialuit Community Conservation Plan (Community of Aklavik *et al.* 2000). This designation identifies the lands and waters where renewable resources are of particular significance and sensitivity throughout the year. Also, under the Aklavik Inuvialuit Community Conservation Plan (Community of Aklavik *et al.* 2000), the riparian areas of the Big Fish River and the Fish Hole are protected from development.

The Rat River watershed and some of the headwaters of the Vittrekwa River are classified as a conservation zone (Conservation Zones A and B: Rat, Husky, Black Mountain and James Creek / Vittrekwa River, respectively). The conservation zone for the Rat River protects most of the watershed. For the Vittrekwa River, however, the conservation zone does not include, and thus does not offer protection to, the only known spawning grounds of Dolly Varden in the river.

Tombstone Territorial (Yukon) Park encompasses 2,200 square kilometres, much of which is in the upper Blackstone River, including Horn Lake. The current designation of "Natural Environment Park" offers protection to Dolly Varden habitat.

The adequacy of the present level of protection to ensure the long-term survival of the species is questionable. The effects of activities not occurring immediately at suitable habitats, such as seismic work which could affect groundwater, are not well documented. Land use plans are being developed for the Peel River watershed which may protect some of the habitat of the Dolly Varden in the region. The Gayna River area is not protected and is a potential mining site for zinc and other minerals (www.eagleplains.com/projects/nwt/gayna/gayna.pdf).

BIOLOGY

The information provided for this section is from several different sources, which are referenced accordingly. Most of the information presented is for anadromous populations, as much less is known about non-anadromous populations. Some information on southern Dolly Varden is mentioned for portions of the biology that have not been documented for Dolly Varden (Western Arctic populations). The biology is generally the same for each population, although variations in specifics do occur. General timing of key events in the life cycle of Dolly Varden for four of the river systems has been documented (Table 10). The general life cycle and seasonal use of habitats by life stage appears in Figure 5.

Table 10. General timing of key events in the life cycle of Dolly Varden (Western Arctic populations), *S. malma malma*, summarized by river system. Numbers in parentheses refer to data sources listed below. (From Sawatzky and Reist in prep.).

Event	Firth River System	Babbage River System	Big Fish River System	Rat River System
Spawning	Joe Creek (anadromous): September - October (1, 2) Upper Mainstem (anadromous): mid-August - early October (1, 2, 3, 4)	Upper Babbage (isolated): September - mid-October (2, 3, 5) Fish Hole Creek (anadromous): September - early October (2, 4, 5, 6)	Cache Creek (isolated): Late fall/early winter (2, 7) Cache Creek (anadromous): September - October (2, 4, 8, 9, 10, 11) late October - November (18)	Fish Creek (anadromous): mid-August - early October (2, 4, 8, 9, 10, 11, 12, 13)
Emergence of Fry	Prior to spring breakup; Joe Creek (anadromous): first observed on May 11 (1)	Fish Hole Creek (anadromous): likely late May (4, 5)	Cache Creek (isolated): Late April - early May (7) Cache Creek (anadromous): Varies by several months depending on water temperature (14)	May - June (for North Slope Dolly Varden in general) (2)
Spring Migration to Sea	May - June (1, 4)	June (15)	Early July (shortly after breakup) (4)	Early to mid-June (non-spawners) (4)
Fall Return Migration	Late summer to fall (1, 4)	July - September (5, 15)	Mid-August - early September (4, 18)	Late July - mid-September (4, 12, 16, 17)

1. Glova and McCart 1974; **2.** McCart 1980; **3.** Craig and McCart 1974; **4.** Baker 1987; **5.** Bain 1974; **6.** Bryan *et al.* 1973; **7.** McCart and Bain 1974; **8.** Dryden *et al.* 1973; **9.** Jessop *et al.* 1974; **10.** Jessop and Lilley 1975; **11.** Stein *et al.* 1973a; **12.** Jessop *et al.* 1973; **13.** Stein *et al.* 1973b; **14.** S. Sandstrom, unpubl. data cited in DFO 2003c; **15.** W. Bond, pers. comm. cited in Baker 1987; **16.** DFO 2001; **17.** Harwood and Sandstrom 2008; **18.** Byers 1993

Life cycle and reproduction

Dolly Varden begin life in headwater streams from eggs laid in fall and buried under gravel by the female in the centre of her redd. The female guards her redd for several days after laying eggs. Larger females tend to produce larger eggs (Armstrong and Morrow 1980), presumably associated with more robust young. Larger males dominate mating opportunities by trying to exclude smaller males. Upon hatching, the alevins remain in the gravel for about 60 to 70 days until the yolk sac has been absorbed. In May or June, free-swimming young-of-the year, or fry, measuring about 25 mm in length, emerge and feed on small crustaceans and aquatic larvae stages of various insects along the margins of the spawning stream (McCart 1980). From this life stage, individuals follow one of several life histories:

<u>Anadromous form</u>

These fish reside in their natal drainage for approximately three years before migrating to the sea to feed for the summer in early to mid-June. Prior to migrating to sea, the life stage is known as "parr", named for the dark rectangular patches on the sides which are characteristic of the Dolly Varden before seaward migration. When the young fish move to sea for the first time, they acquire the ability to cope physiologically with marine waters (smoltification). At this stage they are called smolts and measure approximately 120 mm. Tolerance to full strength sea water may be a gradual process spanning a few years, with individuals building a higher tolerance to salinity and moving further away from brackish waters in successive years (Reist 2001). Compared to the freshwater habitat, the sea offers a greater abundance of food, including various invertebrates and small fishes. Anadromous Dolly Varden attain most of their annual growth during their time at sea and do very little feeding during spawning and overwintering. Each fall, beginning in August, the fish migrate back to freshwater rivers to overwinter. Physiologically, Dolly Varden do not appear capable of surviving in saline or brackish water in winter (Sekerak *et al.* 1992).

Breeding adults return to their natal stream to spawn, as do most non-spawners, although a few non-spawning adults may overwinter in non-natal streams (Glova and McCart 1974; Kowalchuk *et al.* 2008). Traditional knowledge suggests that Dolly Varden will migrate up a river other than their natal one if water conditions are not conducive to spawning or an obstruction prevents them from swimming to their spawning grounds or may use different routes from year to year to reach the same spawning grounds (Byers 2010). This pattern of migrating to and from the sea continues for the rest of the lives of the anadromous form of Dolly Varden except for some spawners that remain in freshwater the year that they spawn (Cosens and Martin 2002). Maturity may begin in the fourth year, but most females mature at age 5 or 6. Males mature, on average, one year later (Roux *et al.* 2009a). Upon reaching maturity, males measure approximately 450 mm and females are about 355 mm long. Measurements for the size and age of Dolly Varden at maturity in the Babbage, Big Fish, Firth and Rat rivers are summarized in Roux *et al.* (2009a, see also Table 11). In the North Slope populations and the Rat River, spawning then occurs every second year for most, except in Big Fish River where many female Dolly Varden appear to spawn every year (Sandstrom and Harwood 2002). The shorter distance to and from sea and earlier access to coastal supplies of food may explain the annual spawning behaviour of fish from the Big Fish River (Stewart *et al.* 2010b). Anadromous Dolly Varden modify their behaviour during winter in order to prolong their body stores accumulated during the summer feeding out at sea. Territoriality, an energetically costly behaviour, is repressed and aggregative behaviour is more evident in overwintering fish (Reynolds 1997).

Table 11. Age and size at maturity of anadromous male and female Dolly Varden among populations (age at maturity was estimated by pooling all available samples over time; from Roux *et al*. 2009a). Age at maturity corresponds to the age class at which ≥ 50% of Dolly Varden were mature. Method of calculations and sample sizes are in Roux *et al.* (2009a).

	Male			Female		
	Age-at-maturity	**mean FL**	**FL_range**	**Age-at-maturity**	**mean FL**	**FL_range**
Babbage R.	7	530	304-631	6	472	324-531
Big Fish R.	6	425	320-533	5	409	340-520
Firth River	7	500	391-598	7	463	456-474
Joe Creek	5	407	301-442	6	441	398-481
Rat River	10	602	582-622	7	501	334-652

Few Dolly Varden live long enough to spawn more than twice (Armstrong and Morrow 1980; Sawatzky and Reist in prep). According to data from 1989 to 2000, more “silvers” (non-spawners) and females were caught than spawners and males in the Rat River (DFO 2001). Assuming all members of the population are equally catchable, this indicates the population structure is skewed to non-spawners and females for the Rat River. On the other hand, no silvers have yet been caught or observed in the Vittrekwa River (Nathan Millar, pers. obs.).

The spawning fish precede the non-spawners by about a month in the upper reaches of the Firth River. Spawning here began in mid-August and continued through to early October. A similar pattern of spawning adults preceding juveniles at the overwintering pools was documented at Fish Creek, tributary of the Rat River (Sandstrom *et al.* 2001). Spawning in Joe Creek was later (Glova and McCart 1974).

Dolly Varden in the Rat River rarely live more than eight years. (DFO 2001). The maximum age observed on the Vittrekwa River is 10 years. Mature anadromous Dolly Varden from the Firth River ranged from 350 mm to 820 mm in length and 4 to 15 years of age. Maturation of anadromous Dolly Varden in the Babbage River tends to be later, with 50% maturity estimated for seven-year-old females and six-year-old males. As with resident males in other rivers, those in the Babbage River generally matured earlier, between 2 and 6 years of age (DFO 2002b).

The sex ratio varies depending on the river drainage and the year of sampling; however, females tend to outnumber males among anadromous populations (Table 12; Roux et al 2009a). Fishing pressures that tend to eliminate anadromous males may explain some of the ratios favouring females, such as the Rat River. Gwich'in have noticed an increase in the number of female spawners compared to male spawners in the Rat River (Benson 2010). Males are more readily caught in nets used in the subsistence fishery because of their larger size and kype (Byers 2010). In one of the rivers, the Vittrekwa, where the sex ratio is skewed towards males; many more males, both anadromous and residuals, are found in the river than females.

Table 12. Average sex ratios (male to female) of anadromous Dolly Varden spawners among populations. From Roux *et al.* (2009a).

	Spawners Sex Ratio (M/F)	Range	Sampling Years*
All available data			
Babbage R.	1.54	0.11-7.00	1986-1987,1990-1993
Big Fish R.	0.92	0.06-6.33	1980,1984,1986-1988,1991-1994,1997-1999
Firth River	0.34	0.21-0.49	1986, 1988, 1995
Joe Creek	0.47	0.39-0.55	1986, 1995
Rat River	0.27	0.02-1.00	1981,1983,1986,1988-1990,1992,1995-2007
Vittrekwa R.	1.71	1.67-1.75	2006, 2007
1990-1995 data only			
Babbage R.	2.03	0.11-7.00	1990-1993
Big Fish R.	0.34	0.23-0.54	1991-1994
Firth River	0.49		1995
Joe Creek	0.39		1995
Rat River	0.15	0.07-0.25	1990,1992,1995

*to avoid possible bias caused by low sample numbers, only years for which sample n ≥10 were included in the average calculation and indicated in the table.

The trend towards the earlier timing of the sea ice breakup is correlated with the observation of greater annual growth of anadromous Dolly Varden from the Rat River (Harwood and Sandstrom 2008). Underwood *et al.* (1997) found that Dolly Varden were in poorer body condition in years when the arctic ice pack did not recede enough from the coast to facilitate coastal upwelling and consequential enhancement of primary production.

<u>Non-anadromous form: residual</u>

This form lives alongside the anadromous form in fall and winter, but, unlike the anadromous form, does not migrate to sea in spring and summer (Figure 6). Residual Dolly Varden have been documented in Firth River (including Joe Creek), Big Fish River, Babbage River, Rat River and Vittrekwa River. Strontium levels found in otoliths from fish provide supporting evidence for the presence of anadromous and non-anadromous forms of Dolly Varden inhabiting the Firth River and its tributary, Joe Creek, and Canoe River (tributary to Babbage River) and the Vittrekwa (John Babaluk / Nathan Millar, unpublished data). Strontium levels are typically much higher in sea water than freshwater and are reflected in the post-smolt bands of otoliths from fish that spend time feeding at sea (Babaluk and Reist 1996).

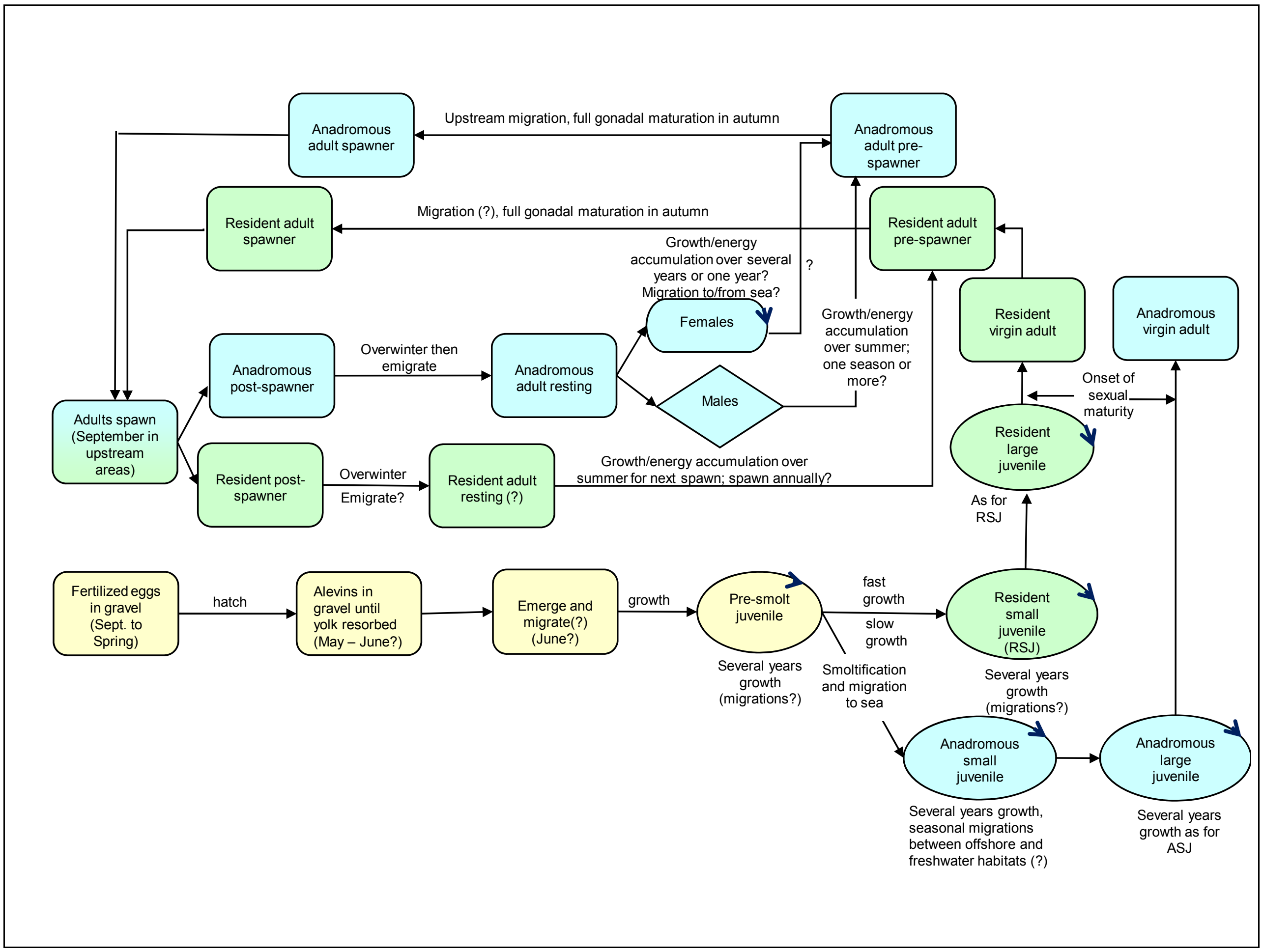


Figure 6. Diagrammatic representation of the linkage between anadromous and residual life history types of Dolly Varden (Western Arctic populations) (from Sawatzky and Reist in prep.).

These Dolly Varden live in the headwater streams their entire lives and are almost exclusively male. They generally have shorter life spans and a smaller maximum size than their anadromous counterparts (Armstrong and Morrow 1980; Roux *et al.* 2009a). For the Babbage, Big Fish, Firth, and Vittrekwa rivers, the fork lengths of residuals compared to anadromous males within a drainage are consistently shorter, and rarely overlap in size (Roux et al 2009a). They mature at a smaller size and younger age (Table 13) than the anadromous form and reproduce by "sneaking" into the redds to spawn with anadromous females. Otherwise larger anadromous males guard females and successfully release milt onto her eggs. Details of how residual males compete to fertilize eggs are unknown for Dolly Varden (Western Arctic populations). In one study for the southern form, residual males were successful at "sneaking" in eight of 13 paired spawnings (Maekawa and Hino 1986).

Table 13. Summary statistics of size and age and maturity information by year for residual male Dolly Varden collected in different river systems. Note that Joe Creek is a tributary to the Firth River. From Roux *et al.* (2009a).

Year	Fork length			Age				Maturity
	n	**mean**	**range**	**n**	**mean**	**mode**	**range**	
Babbage River								
1988	11	186	136-229	11	3	3	2-5	All spawners
Big Fish River								
1986	3	248	228-271	4	4.8	2-8	2-8	All spawners
1988	3	202	149-256	2	3.5	3.4	2-4	All spawners
Firth River								
1988	7	176	133-256	6	2.8	3	2-4	All spawners
1995	9	254	185-322	7	4.6	3.5-6	3-6	7 spawners, 2 resting adults
Joe Creek								
1986	26	192	132-295	23	3.1	3	1-5	22 spawners, 4 juveniles
1995	21	232	149-333	19	5.1	4	3-11	17 spawners, 3 juveniles, 1 resting adult
Rat River								
2004	1	235		0				Not determined
Vittrekwa River								
2006	14	238	180-294	0				All spawners
2007	42	213	116-292	20	4.3	4	3-7	All spawners

Non-anadromous form: "isolates", riverine and lacustrine char

These Dolly Varden do not migrate to the ocean, perhaps due the long distance to sea or a geographical barrier. Unlike residual Dolly Varden, they do not live alongside and breed with the anadromous form. Both males and females reproduce without going out to sea. Sampled populations of non-anadromous isolated Dolly Varden are not consistently represented by more males or females (Table 14).

Table 14. Sex ratios (male to female) among isolated Dolly Varden populations. From Roux *et al.* (2009a).

Year	Location	n	sex ratio (m/f)
1986	Babbage River	27	1.45
1988	Babbage River	32	0.68
1988	Big Fish River	31	0.72
1992	Blackstone River	29	1.23
2006	Gayna River	8	0.60
2007	Gayna River	4	3

There are several types of non-anadromous Dolly Varden. One type, commonly referred to as 'isolates', inhabits the upper portions of rivers that also contain anadromous Dolly Varden downstream. For example, there is a population of fish above the 3 m falls in the Little Fish Creek, a tributary to the Big Fish River (McCart and Bain 1974) and above the falls on the main stem of the Babbage River (DFO 2002b). The Vittrekwa River may also contain isolates because of the distance to the sea (Sawatzky and Reist in prep.), but this needs confirmation.

A second type of non-anadromous Dolly Varden is the riverine type; it inhabits freshwater rivers and streams and is not found close to the anadromous form. For example, the Dolly Varden in the Gayna River live upstream of an impassable barrier which is also a long distance to the sea. Dolly Varden throughout most of the Peel River watershed, including the Ogilvie, Blackstone, Hart, Wind, Snake, and Bonnet Plume rivers, are riverine. Migration to and from the ocean from these rivers may be hindered by swift water in Aberdeen Canyon and/or by long distance. Initially, these non-anadromous fish develop quickly where water from springs is relatively warm, but overall, without the opportunity to feed at sea, these fish tend to be smaller as adults, mature earlier, and have a shorter lifespan (Armstrong and Morrow 1980). Average values for size and age of non-anadromous Dolly Varden are presented in Table 15.

Table 15. Summary statistics of size and age for male and female spawners among isolated Dolly Varden populations. From Roux *et al*. (2009a).

	Male Fork length			Male Age				Female Fork Length			Female Age			
Location	**n**	**Mean**	**Range**	**n**	**Mean**	**Mode**	**Range**	**n**	**Mean**	**Range**	**n**	**Mean**	**Mode**	**Range**
Babbage River	20	166	111-249	14	3.1	3	1-8	18	169	137-210	16	3.4	4	2-5
Big Fish River	7	156	115-239	7	2.1	2	1-4	3	219	140-265	2	6	5,7	5-7
Blackstone River	9	270	172-440	9	5.8	4,5	4-10	4	214	168-257	4	5.0	5	4-6
Gayna River	3	317	293-352	3	8	8	8	5	267	236-288	5	7.2	7,8	6-8

A third type of non-anadromous Dolly Varden is the lacustrine or adfluvial form. To date only several individuals of this type from a single site have been found: Horn Lake, in the Blackstone River system (upper Peel River drainage). Dolly Varden in this lake are unusual in that they are not smaller than anadromous Dolly Varden. The reason for their relatively large size has not been documented, but the large size of Dolly Varden morphs found in Kronotsky Lake on the Kamchatka Peninsula, Russia is partly attributed to a diet of fish (Osterberg *et al.* 2009). Little is known about the habitat use or biology of the Horn Lake Dolly Varden.

Generation time

The generation time, defined by COSEWIC as the average age of parents of the current cohort, differs by population and life history type. For anadromous males, average age of maturity ranged from 5 to 10 years, and for females, average age of maturity ranged from 5 to 7 years (Table 11). Anadromous females reach maturity earlier than males in most studied populations. The average age of maturity of residual males ranges from 3 to 5 years (Table 13). Dolly Varden of other non-anadromous populations mature, on average, at 2 to 8 years for males and 3 to 7 years for females (Table 15). No clear pattern of earlier maturity by either gender for non-anadromous populations is evident from the data collected although the range of ages at maturity is wider for males (1 to 10 years) than for females (2 to 8 years).

Food habits

As scarcity of food does not appear to be a factor currently limiting the population of Dolly Varden, only general food habits are mentioned, and references with more detail are provided. The trend of increased growth of anadromous Dolly Varden from the Rat River is attributed to a trend of warmer temperatures that increase productivity and food availability at sea (Roux *et al.* 2009b). Dolly Varden feed on small fishes and benthic organisms (Figures 6, 7), including molluscs, mysids, amphipods, chironomids, plecopterans and other insect larvae and crustaceans (Palmisano and Helm 1971; Stein *et al.* 1973a; Stevens and Deschermeier 1986). Foraging in the Northwest Territories mostly occurs near the surface of the substrate rather than in midwater or near the surface of the water (Stewart *et al.* 2010a). On the northeastern coast of Alaska, Dolly Varden tend to use shoreline habitats more than open water, and stay in the upper 5 m of the water column. They may go to water warmer than where they had foraged in order to aid digestion (Thorsteinson *et al.* 1991). The wide variety of taxa represented in their diet suggests that Dolly Varden is more opportunistic than specialized in its food habits. Anadromous Dolly Varden feed very little during the spawning and over-wintering period. Stewart *et al.* (2010a) summarized the various food items found in stomachs of Dolly Varden for the Babbage River, Mackenzie River, Rat River and Phillips Bay. This summary has some information that differentiates juveniles from adults, and anadromous from non-anadromous fish.

Mortality

Mortality factors are poorly understood. Post-spawning mortality rates of adults were estimated at 45-50% (Armstrong and Morrow 1980), but the factors contributing to the mortality are not clear. Sandstrom (pers. comm. 2009) stated that Dolly Varden probably reached their lowest mortality as smolts, then experience more stress and mortality as they come into sexual maturity. Predation from several sources contribute to mortality (Figures 6 and 7).

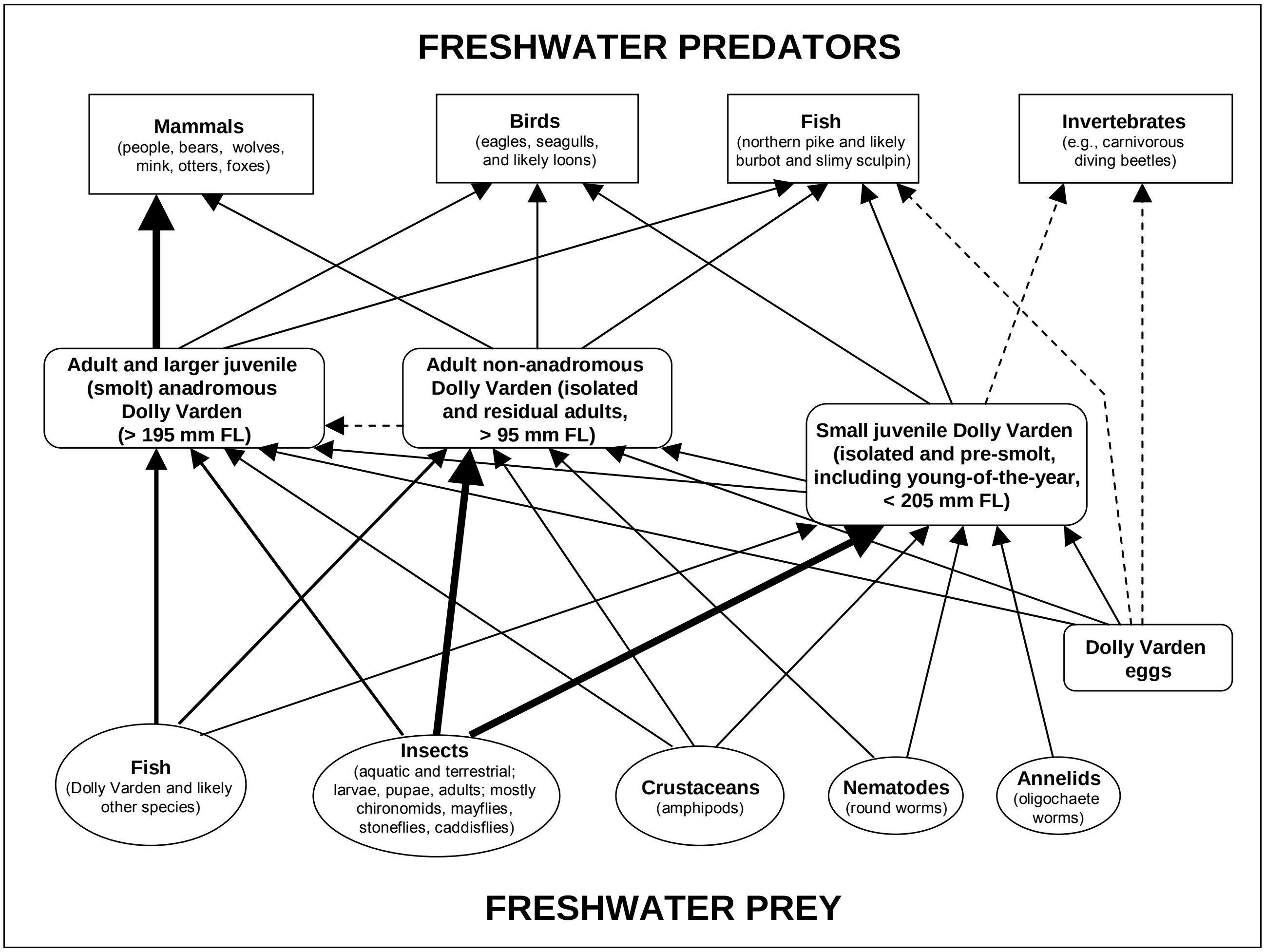


Figure 7. Generalized food web for Dolly Varden in fresh water showing the direction of energy flow. Bold lines indicate major food pathways, in comparison to thinner lines; solid lines indicate demonstrated and dashed lines indicate putative pathways. (From Stewart *et al.* 2010a.)

Fecundity

Information on fecundity (number of eggs/female in a given year) has been documented for the anadromous Dolly Varden of Rat River, Little Fish Creek (tributary to the Big Fish River), Fish Hole Creek (tributary to the Babbage River), and Firth River (Table 16). Fecundity generally increases with the size of the female, but is not consistent between drainages. Sandstrom (1995) found that Big Fish River females had lower fecundity than Babbage River females, but had larger eggs. The larger eggs may be more resilient to the higher and more variable incubation temperatures at the spawning grounds of the Big Fish River. During his study, the fecundity of Big Fish River females averaged 2329 (n=63) in 1991, and 2,313 (n=28) in 1993. When adjusted for the fork length, this value was about 500 fewer eggs than similar size females from the Babbage River (Sandstrom and Harwood 2002). Female Dolly Varden from the Firth River have a similar egg size to the females from the Babbage River (Glova and McCart 1974).

Table 16. Fecundity of Dolly Varden (Western Arctic populations) in Canada (modified from Stewart *et al.* 2010b).

Location	Sample Size	Fork Length (mm)	Fecundity (eggs/female)		Reference
			Mean	Range and/or ±SD	
ANADROMOUS					
Rat River	21		4,221	1,787 - 8,395	Gillman and Sparling 1985
Little Fish Creek, Big Fish River	19	Mean = 435	2,186	1,500 - 2,963	MacDonell 1987
Fish Hole Creek, Babbage River	27	Range = 355 - 525	3,468	1,700 - 5,100 ±936	Bain 1974; ranges taken from Figure 15 in Bain 1974 by McCart 1980
Firth River	20	Mean = 530	4,955	±463	Glova and McCart 1974
Vittrekwa River	3	Mean = 634	4,706	3500 - 6000	Millar unpublished data
STREAM RESIDENT (ISOLATED)					
Upper Babbage River	78	Range = 132 - 251	294	132 - 605; ±119	Bain 1974; ranges taken from Figure 15 in Bain 1974 by McCart 1980

The only Canadian population of non-anadromous Dolly Varden for which fecundity is known is for the population isolated upstream of the falls on the Babbage River. The fecundity of these fish was much lower, with a maximum of 653 eggs, compared to the anadromous form with a maximum of 5,151 eggs (Bain 1975). This pattern of lower fecundity among non-anadromous fish was also noted for southern Dolly Varden in southeastern Alaska; Blackett (1973) documented an average of 1,888 eggs for anadromous Dolly Varden compared to 66 eggs for isolated non-anadromous females. These comparisons, however, do not take into account that female non-anadromous Dolly Varden are generally smaller than anadromous ones.

The actual number of offspring produced by spawners each year is variable. The Rat River population saw a large increase in numbers in 2007, mostly due to one cohort from 2002. Ironically, the population abundance estimate for 2002 was the second lowest in recent history (see **Population Sizes and Trends** section).

Predation

Bears, wolves, otters, mink, foxes, fish-eating birds, larger fish (e.g. pike, burbot) and marine mammals potentially feed on Dolly Varden, but none of these predators are known to specialize on Dolly Varden. Information on the extent of predation by each species of wild animal is not well documented for northern form Dolly Varden. Inuvialuit report more grizzly bears and river otter sightings in recent years in the Mackenzie Delta (Ron Gruben pers. comm. 2009). The observed trend of lowering water levels at some fishing sites may improve access to Dolly Varden by bears and eagles. Gwich'in agree that increased otter activity on the Big Fish River and Rat River may be contributing to the decline of Dolly Varden populations (Byers 2010). Wolves, grizzly bears, mink, golden eagles and possibly black bears feed at the spawning and overwintering site on Fish Creek, tributary to the Rat River (Gwich'in Elders 1997; Stewart *et al.* 2010a). Wolves are known to take Dolly Varden from the Fish Hole Creek spawning area of the Babbage River (Bain 1974). Gwich'in Elders (1997) also report Northern Pike (*Esox lucius*), gulls and foxes catching and eating Dolly Varden. The Arctic Lamprey (*Lampetra japonica*) has also been recorded as parasitizing Dolly Varden (Western Arctic populations) (Sparling and Stewart 1986; Sandstrom *et al.* 1997). Although Dolly Varden is rarely found in seal stomachs, seal scars have been reported on 4 to 6% of Dolly Varden returning to the Big Fish River (Stewart et al 2010a), and Gwich'in suggest that seals contributed to the population decline of Dolly Varden (see interviews in Benson 2010). Simplified food webs (Figures 7 and 8) include predators on Dolly Varden. Only humans are known to take large amounts of Dolly Varden for consumption. Dolly Varden may eat smaller members and eggs of their own species (Stewart *et al.* 2010a).

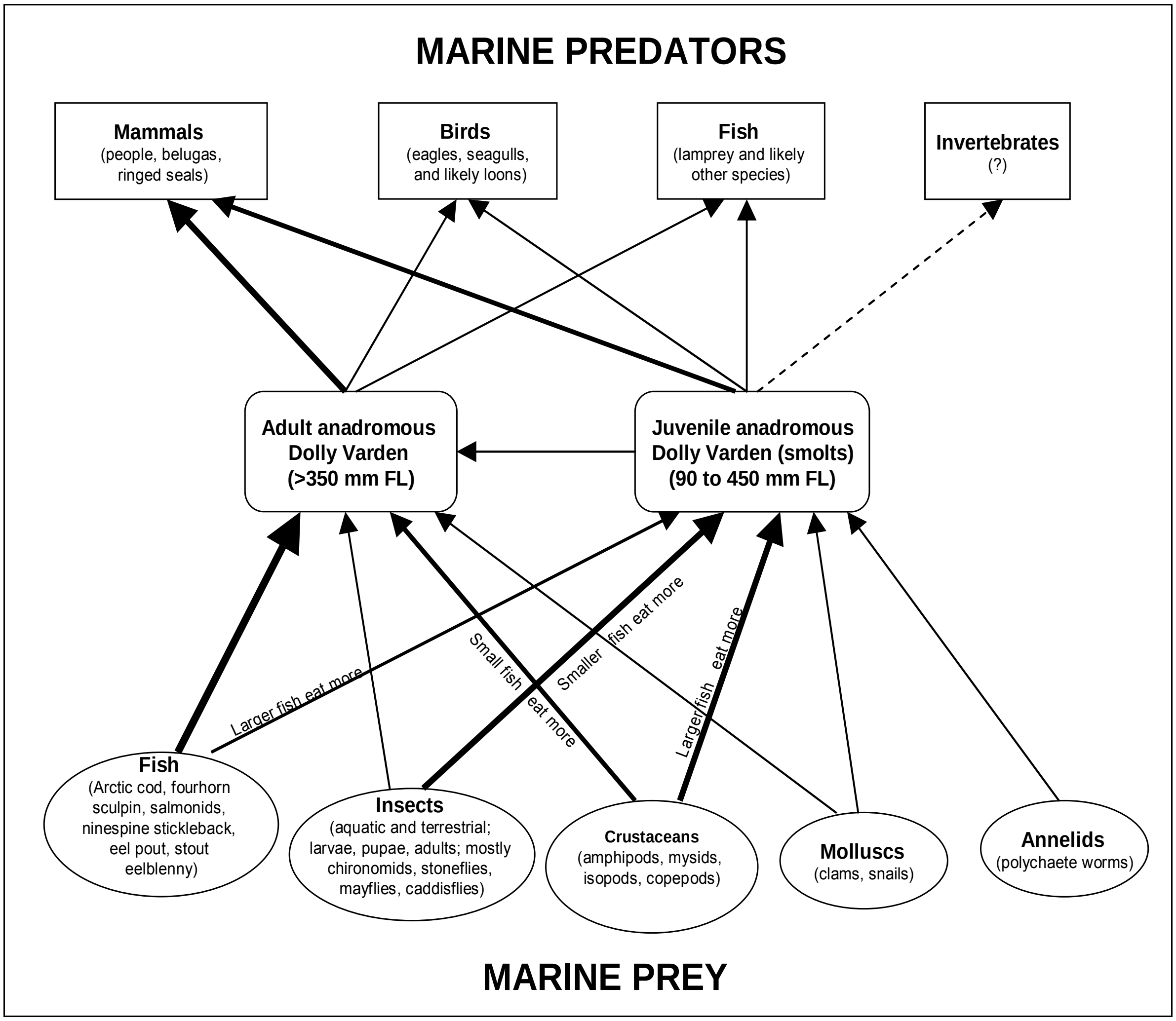


Figure 8. Generalized food web for anadromous Dolly Varden in coastal waters showing the direction of energy flow. Bold lines indicate major food pathways, in comparison to thinner lines; solid lines indicate demonstrated and dashed lines indicate putative pathways (from Stewart *et al.* 2010a).

Physiology

The thermal and conductivity range within which Dolly Varden are found has been documented, but the physiological limits of northern form Dolly Varden are not well studied. At inland overwintering sites, where all life stages spend the winter months, conductivity ranged from 120 to 4800 µmhos/cm (Table 9) and temperature from 0 to 16^{o}C. The pH level of these sites ranged from 7.6 to 8.8. Of note, is the tolerance of low oxygen (0.2mg/L) at the Fish Hole on Little Fish Creek, tributary to Big Fish River (Stewart *et al.* 2010b). Visibility in freshwater habitats is most reduced during the spring melt and can be as little as 2.5 cm compared to 2 m or more in late summer. According to interviews of Elders summarized by Byers (1993), Dolly Varden make their migrations when the water is clear, not murky.

It is believed that anadromous Dolly Varden overwinter inland because they cannot tolerate extreme salinity or temperatures much below 0^{o}C such as supercooled sea water (Reist 2001). They do, however, venture to feed in saline habitats (33 ppt) as shown by the level of 34 Sulphur in their muscle tissue (J. Reist pers. comm. 2009). Thermal death was observed in southern Dolly Varden subjected to 20 ^{o}C (Takami *et al.* 1997). At sea, anadromous Dolly Varden are found in waters with $\leq$ 32% salinity, and 0.5 to 14 ^{o}C, with smaller fish (150 mm to 350 mm fork length) in river deltas and lagoons in lower salinites of < 8% and moderate temperatures (4 to 10^{o}C). Turbidity at sea ranged from 1 to 146 NTU.

Dispersal/migration

Annual movements of Dolly Varden are adaptations to living in a cold Arctic environment with seasonal fluctuations of water conditions and food availability (Craig 1989). Dolly Varden have no physiological defences against freezing (Koenig 2002), so must move to parts of the river that are reliably open throughout the winter, including open areas or areas under ice that are not completely frozen to the bottom. Mochnacz (pers. comm. 2009) observed fish, especially juveniles, holding below ice-covered shelves adjacent to open water areas and in deeper pools. During this period, they are relatively safe from natural predators and feed minimally. The anadromous form of Dolly Varden migrates annually to sea for the summer where food is abundant. They then return back to fresh water to overwinter and spawn. Most growth for Dolly Varden is attained in the summer while winter sees very little growth. A few Dolly Varden are suspected of overwintering somewhere in the Mackenzie Delta as they appeared to move downstream from the Rat River after spawning (Jessop 1973).

In Canada, the movement of Dolly Varden while at sea along the North Slope of the western Arctic is poorly understood. The shorter distance from the overwintering site of the Big Fish River system to the sea could explain why Dolly Varden from that river spawn in subsequent, not alternate, years like the anadromous fish from other drainages. When sampling Dolly Varden at the outlet of four river drainages between June and September along the coast of the Beaufort Sea, Krueger *et al.* (1999) found that fish were of both local and non-local (>100km) origin. This indicates that populations may not be geographically discrete at sea, and mix during the summer. Although Dolly Varden may visit several drainages (Byers 2010), there is no evidence that they spawn in drainages other than their natal one. This fidelity, combined with genetic and phenotypic distinctiveness within populations, suggests that there is a low likelihood that dispersal from Alaskan populations could naturally repopulate any depressed Canadian populations in a timely manner. On a larger time scale, genetic analyses suggest that Dolly Varden in the Firth River have colonized rivers to the east (Rhydderch 2001), and the overall distribution of northern form Dolly Varden likely reflects its ability to colonize marginal, recently deglaciated streams. The anadromous southern form were typically the first fish colonizers in deglaciated streams in southeastern Alaska (Milner *et al.* 2000; Stewart *et al.* 2010b).

In Alaska, long-distance movements up to 1690 km have been documented for Dolly Varden from the Wulik River to Anadyr River in Russia (DeCicco 1992) and have been described as having an affinity to shoreline (Jarvela and Thorsteinson 1997). Non-anadromous Dolly Varden naturally move a much shorter distance than their anadromous counterparts, but do move within the freshwater system in search of food (Table 7).

Non-anadromous Dolly Varden likely move upstream during the open water season and return downstream to overwinter (Yukon Government unpublished data). The distance migrated is unknown.

According to traditional knowledge, smaller fish are impeded by strong winds when travelling through rough coastal waters and may delay migration until winds abate (Byers 2010). Murky water in the Big Fish River also impedes migration. Gwich'in suggest that water temperature, water clarity, water level, and amount of ice in rivers help Dolly Varden decide when to migrate in fall. Elders recall that the fall run coincided with the leaves turning yellow (see interviews in Benson 2010). They say that females migrate first, followed by a more concentrated run of males and immatures. Dolly Varden in the Husky Channel/Rat River system rest in eddies on their way upstream (see interviews in Byers 2010).

Interspecific interactions

Infectious pancreatic necrosis (IPN) virus was found in northern form Dolly Varden sampled from the Firth, Babbage, Big Fish and Rat River systems, and is considered enzootic. It can have a detrimental effect on hatchery-reared fish (Souter *et al.* 1986), but its effect on northern form Dolly Varden is unknown. Scars caused by Arctic Lamprey were reported on Dolly Varden from the Rat River, Big Fish River and Babbage River (Sparling and Stewart 1986; Sandstrom *et al.* 1997). The incidence varied from 1% for Dolly Varden returning to the Babbage River in 1991 (n = 5864) to 23.5% for those on the Rat River (n = 85). The large percentage reported for the Rat River may be due to a relatively small sample size.

The only species of fish to be found consistently at overwintering sites with Dolly Varden is Arctic Grayling (*Thymallus arcticus*). Its interactions with Dolly Varden are not well documented. Declining numbers of Arctic Grayling in Little Fish Creek parallels the decline of Dolly Varden at the same location (Byers 2010). Arctic Grayling are found throughout most of the range of non-anadromous Dolly Varden. A potential predator of Dolly Varden, Northern Pike, has been observed at the Fish Hole of the Big Fish River system (Byers 1993). Interspecific interactions that could be regarded as limiting factors other than predator-prey relationships, which have already been discussed, have not been studied.

Adaptability

Dolly Varden (Western Arctic populations) have not been reared in aquaculture and as they harbour infectious pancreatic necrosis virus, they would be a poor candidate for aquaculture where other fish could be infected. Nevertheless, Dolly Varden (Western Arctic populations) potentially could be reared for transplanting wild fish, given that closely related fish in the *Salvelinus* taxonomic group have been reared in aquaculture and successfully introduced into previously uninhabited sites (e.g. Arctic char introduced into pothole lakes in Yukon).

POPULATION SIZES AND TRENDS

Overall, Gwich'in elders perceive that many more Dolly Varden were harvested in the 1960s to 1970s than in the last two decades (Byers 2010). They also state that not only are Dolly Varden more difficult to catch now, but fewer people are trying to fish them. Factors believed to contribute to the decline in stocks are: overharvest, nets impeding migration of fish along waterways, increase of sandbars and shallow spots in rivers, change in the composition of water, predation by bears and seals, and detrimental effects of tagging on fish (Byers 2010). Observed trends attributed to climate change that may also impact Dolly Varden include: shallower water in rivers and channels, warmer water, increasing number or size of sandbars, more willows, disappearance of eddies, more mudslides or landslides, and drying out of small creeks. Weather is generally thought to be changing, but perceived changes in precipitation were inconsistent among Gwich'in (Byers 2010). Inuvialuit have fished for Dolly Varden along the coast at Herschel Island, King Point and Shingle Point for many generations. More fish were caught in the 1970s than now. Larger fish are caught at Herschel Island, an observation attributed to the clearer and saltier water there. Inuvialuit note that sea ice conditions have been changing (i.e. no ice seen from shore at Shingle Point 2003-2005 [summer]) and may be affecting the harvest at Shingle Point. Dolly Varden migrating further away from shore and out of reach of fishing gear may explain why fewer Dolly Varden are being caught since year 2000.

Population data for many of the populations are limited. The exceptions are the Big Fish River, Babbage River, and Rat River, with the Rat River having the most long-term monitoring effort. The available data preclude an estimate for the total number of individuals of all ages, and number of mature individuals in Canada. The sampling methods used to count Dolly Varden do not include smaller and younger fish; most fish caught were 2 years or older. The information below is discussed by river, generally proceeding from the northwest Yukon, east and south to regions of the NWT (Figure 4).

Fish River

No estimates of population size or trend have been made for these Dolly Varden. The river is used occasionally by people travelling to and from Alaska, but is otherwise too far for most fishers to access (Papik *et al.* 2003).

Malcolm River

No estimates of population size or trend have been estimated for these Dolly Varden. Inuvialuit commented that its long distance from Aklavik and its shallow water deters fishing at this location (Papik *et al.* 2003).

Firth River and tributaries

There are no reliable estimates for the abundance or population trends of Dolly Varden in the Firth River drainage. The contribution of Firth River fish to the mixed stock fisheries at Herschel Island and Phillips Bay is unknown. In 2001, 38 Dolly Varden were taken from the river and another 28 were caught and released (DFO 2002a).

Babbage River and tributaries

<u>Upstream of Falls</u>

No estimates of population size or trend have been made for the Dolly Varden isolated upstream of the falls.

<u>Downstream of Falls</u>

The population size of anadromous Dolly Varden was estimated at 13,600 (95% CI 7,600-19,700) fish in 1991 (Sandstrom *et al.* 1997). This estimate used Bailey's deterministic model, with an adjustment for 11.3% frequency of tag loss. As abundance was only measured once, trends in population numbers cannot be determined. It is noteworthy though, that the age-frequency distribution remained relatively constant from 1990 to 1992 (Figure 9).

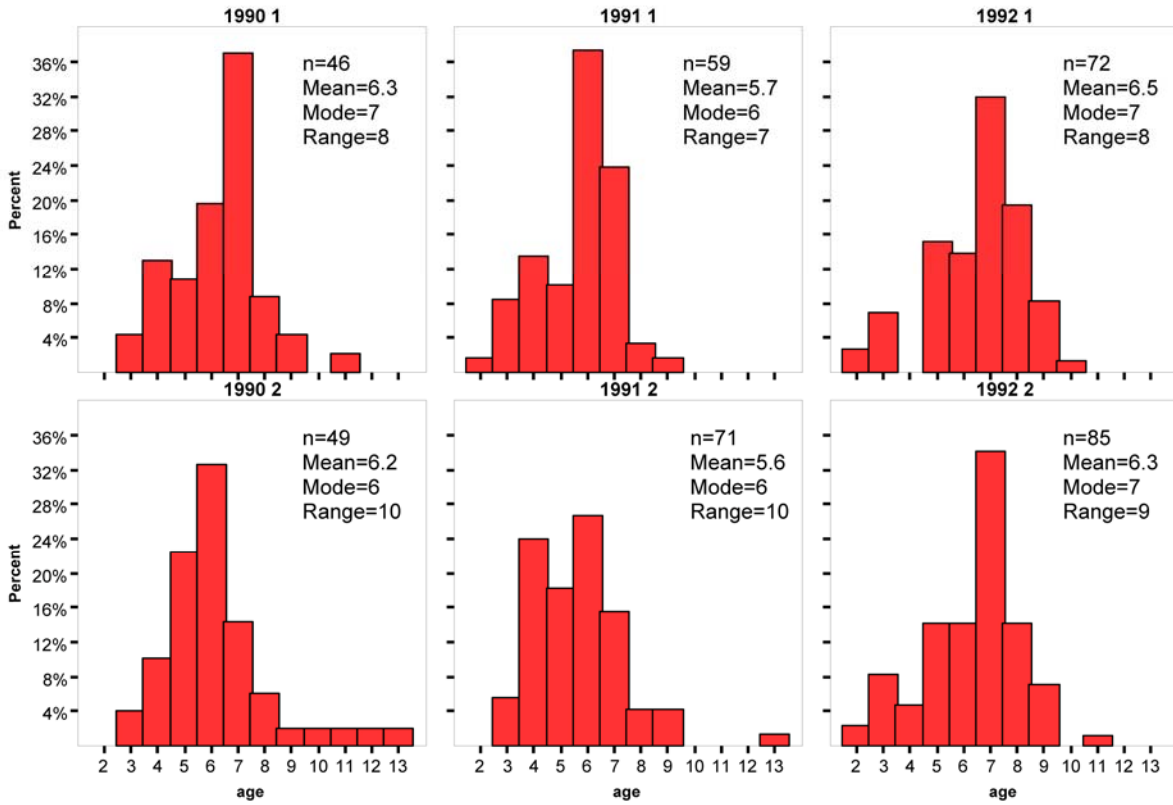


Figure 9. Age frequency distributions for male (top row) and female (bottom row) Dolly Varden caught in river weirs on the Babbage River 1990-1992 (anadromous only). From Roux *et al.* (2009a).

Big Fish River and tributaries

<u>Upstream of Falls</u>

No estimates of population size or trend have been made for the Dolly Varden isolated upstream by the falls.

<u>Downstream of Falls</u>

Abundance was estimated in 1972, 1984, 1987, 1988, 1991, 1993 and 1998. The size of fish included in the counts differed among years, and estimates for portions of the population (e.g. spawners) are given in some years (Table 17). The numbers show a general decline from 1972 to 1998 (up to 75% over three generations), but this estimate of the rate of decline is compromised somewhat because earlier sampling included smaller fish (i.e., non-mature fish) whereas later surveys excluded these (Table 17). More recently, observations made during the subsistence fishery 1998-2000 and 2001-2002 suggest a population decline and recruitment failure (DFO unpublished data). The observation by D.C. Gordon of Aklavik that CPUE declined from the 1970s

(DFO 2002c) also suggests that Dolly Varden in the Big Fish River are at lower numbers. Earlier maturation of Dolly Varden in the Big Fish River, compared to the Babbage River, in the early 1990s was thought to indicate the recovery phase of the stock following its decreased abundance (Sandstrom and Harwood 2002).

Table 17. Summary of available population estimates (± 95% confidence intervals) for anadromous Dolly Varden from the Big Fish River (modified from Gallagher *et al.* in prep. and DFO 2002c).

Year	Population estimate[1]	95% C I	Length of fish	Method	Notes
1972	20,700	15,800-27,600	≥150mm	Petersen	August estimate at river mouth, assuming catch of 4000, tagged same year as recaptured
1972	13,500	11,300-16,000	≥150mm	Petersen	fall estimate at Fish Hole, assuming catch of 6000, tagged same year as recaptured
1984	9,300	6,300-14,300	≥350mm	Petersen	assuming no mortality of tagged fish, tagged 1984 and recaptured 1985
1984	4,600	3,100-7,100	≥350mm	Petersen[a]	adjusted for mortality=0.5, tagged 1984 and recaptured 1985
1987	9,076	6,332-13,790	≥200mm	Petersen	combined, marked and recaptured the same year
1987	7,379	5,479-9,279	≥200mm	Petersen[b]	marked 1987 and recaptured 1988, adjusted for tag loss 11.3%
1988	5,827	4,293-8,122	≥200mm	Petersen	marked and captured Sept 16-18 in Fish Hole, tagged same year as recaptured
1988	8,499	5,846-12,848	≥200mm	Petersen	all fish marked and recaptured in 1988, tagged same year as recaptured
1988	6,766	1,845-11,687	≥200mm	Bailey	tagged in 1987 and 1988 and recaptured in fall 1988 triple-mark-recapture estimate
1991	2,840	2,014-3,666		Petersen	applied at the weir and recaptured at Fish Hole
1991	2,232	1,716-2,748	≥400mm	Petersen	based on visual count of tagged
1993	4,477	2,305-6,649	≥370mm	Petersen[c]	tagged in 1993 recaptured 1994, adjusted for tag loss and immigration
1998	4,026	2,988-5,563	≥320mm	Petersen	combined, marked and recaptured the same year

[1] Population estimates for the anadromous component of the stock (see DFO 2002c, Eddy *et al.* 2001, Sandstrom and Harwood 2002 and Stephenson 2003 for detailed information).
Petersen[a] = adjusted for mortality.
Petersen[b] = adjusted for tag loss.
Petersen[c] = adjusted for tag loss and immigration.

The Big Fish River was closed to all legal harvest for five years, beginning in 1987. This effort did not see the intended outcome of stock recovery. Some fish were likely still harvested in the mixed stock fishery along the coast during the closure. In the early 1980s, fisherpersons observed many young Dolly Varden, but fewer of harvestable size (Papik *et al.* 2003). Earthquake activity in the late 1970s and early 1980s may have adversely affected the quality and quantity of the overwintering/spawning grounds at the Fish Hole by reducing groundwater flow (Sandstrom and Harwood 2002). The replacement of dog teams by snowmobiles beginning in 1959 made fishing at the "Fish Hole" spawning/overwintering site more accessible by reducing travel time to 3 or 4 hours instead of 10 hours to 2 days. This facilitated a greater harvest (Byers 1993). The demand of a large harvest in addition to habitat change may have brought the population level of Dolly Varden in the Big Fish River to a point where it may not recover (Stephenson 2003).

Rat River

The population size of Rat River Dolly Varden was estimated in 1989, 1995, 1997, 2001, 2004 and 2007. The sampling methodology from 1996 onwards is fairly consistent, but the technique used in 1989 was different (Table 18). In 1989, from August 2 to September 12, a hoop net was used to catch and tag migrants returning from the sea in the Destruction City area. Subsistence harvesters provided tag recaptures from their harvest upstream at Destruction City using gill nets. An estimate of the number of fish was calculated with The Schaefer estimate using a six day time interval. From October 4 to 6 of that same year, fish at the spawning grounds along 7 km of Fish Creek were censused by electroshocking during which time the tagged fish were counted, along with the untagged fish. The Petersen formula was used to estimate the population size from this single census (Stephenson and Lemieux 1990). The Petersen estimate was then applied to all counts after 1989. Dolly Varden were captured with seine nets and tagged. The subsistence fishery was the site of recapture the following year.

Table 18. Summary of available population estimates for Dolly Varden (Western Arctic populations) from the Rat River (modified from Roux *et al.* 2009b).

Year	Population estimate	95% C I	Method
1989**	8,928	n/a	Schaefer
1989	11,191	8,532-15,020	Petersen
1995*	9,036	6,931-11,141	Petersen
1997*	10,411	6,558-14,264	Petersen
2001*	7,953	4,547-11,359	Petersen
2004*	2,912	1,934-3,890	Petersen
2007* [a]	14,897	6,206-23,568	Petersen
2007*[b]	9,120	4,430-13,810	Petersen

Note: the length of tagged fish was = 300 mm in all years.
* = estimates were adjusted for a tag loss rate of 8% and for susceptibility to tagging.
** = estimate was adjusted for fishing mortality only.
[a]based on recaptures in the gillnet fishery
[b]based on seined recaptures at Fish Hole

From 1995 to 2008, monitors were hired to record their own and nearest neighbours' catches using gillnets. Five sites were monitored up until 1999, then reduced to four sites, and further reduced to three sites in 2004. The catch-per-unit-effort (CPUE) estimates from 1995 to 2008 for four sites (Table 19 and Figure 10) are believed to have coincided with the timing of the runs, with the exception of 1998 when the run was three weeks earlier than usual and in 2000 when the run was three weeks later than usual. Although general population trends can be inferred from CPUE, it is influenced by changes in recruitment, migration patterns, local environmental conditions and changes in fishing practices and thus should be interpreted with caution. Overall, the trend in CPUE approximates the population trends by mark-recapture estimates.

Table 19. Average daily CPUE by year and location for Dolly Varden (Western Arctic populations) caught in gillnets in the Rat River subsistence fishery, 1995-2008 (from Roux *et al.* 2009b).

	Big Eddy			Mouth of Rat River			Destruction City			Husky Channel		
Year	n	mean CPUE	range	n	mean CPUE	range	n	mean CPUE	range	n	mean CPUE	range
1995										25	21.7	0-105
1996	58	33.9	12-64	95	13.2	0-88	106	51.9	0-180	79	27.6	0-96
1997	61	44.8	4-120	55	66.5	0-328	160	34.5	0-190	59	54	0-244
1998	57	71.1	24-151	26	117.2	0-288	67	87.5	27-196	41	37	0-112
1999	61	37.1	0-90	18	93.1	0-264	106	41.6	0-180	43	14.7	0-36
2000	60	22.6	0-85	97	11.1	0-48	112	22.7	0-144	45	18.8	0-87
2001	142	33.3	0-104	192	17.8	0-107	154	45	0-274	76	28.5	0-114
2002	63	21.9	0-72	88	20.2	0-360	88	12.5	0-60	84	1	0-15
2003	59	18.8	0-48	82	17.9	0-115	56	10.1	0-77	25	29.5	0-78
2004	67	14.9	0-56	87	7.8	0-48	90	10.1	0-60			
2005	60	11.3	0-45	62	13.1	0-70	118	8.9	0-40			
2006	41	7.2	0-30	45	5.5	0-43	92	4.6	0-48			
2007	36	39.7	0-200	24	17.7	4-40	61	7.4	0-43			
2008	27	56.5	0-120	31	152	0-667	25					

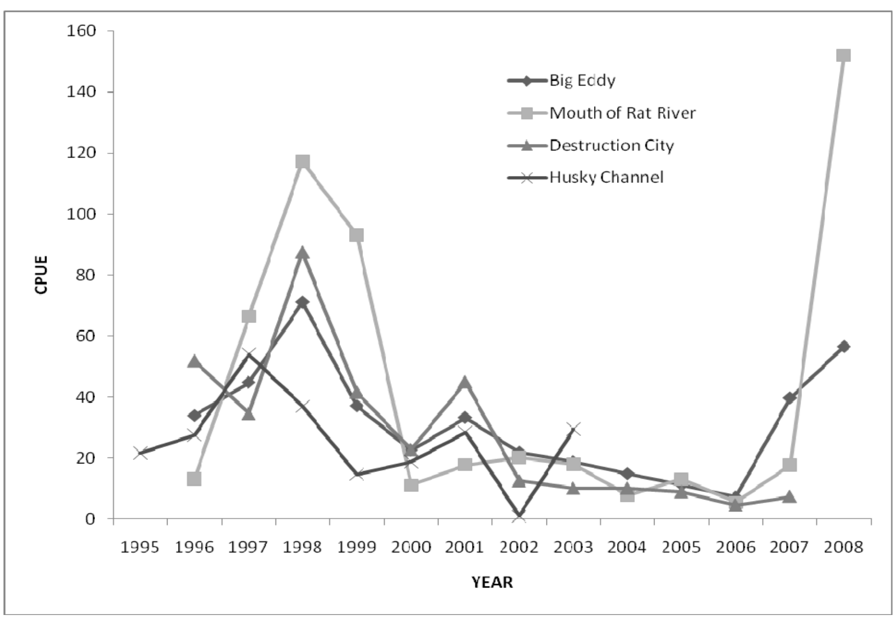


Figure 10. Average daily CPUE for Dolly Varden caught at four sites along the Rat River (data from Roux *et al.* 2009b).

There is no clear explanation for the large fluctuations in population size. Initially, overharvesting was thought to be the main factor. To address this, the communities of Aklavik and Fort MacPherson developed and implemented the “Rat River Char Fishing Plan” which has reduced the harvest of Dolly Varden since 1995 although the quotas are still exceeded from time to time (DFO unpubl. data, 2009). In addition to occasional overharvest. loss of spawning and overwintering habitat through desiccation in unusually warm, dry years may have contributed to general declines (Sandstrom 2003). Gwich’in observed an increasing ratio of silvers to spawners at the spawning/overwintering site. They also recall more abundant Dolly Varden in the 1920s to 1940s, and earlier when catches in the thousands were more common (see interviews in Benson 2010).

Roux *et al.* (2009b) projected that the Rat River population would reach extinction in approximately 80 years if the trend observed between 1997 and 2004 continued and the fishery was re-opened with a quota of 2,000 fish. A population viability analysis for the Rat River found that the probability of extinction would decrease if the initial population is higher and/or the number of female spawners is higher (Tallman *et al.* 2008). A lower percentage of male and female spawners since 2000 suggests a reduction in the reproductive pool and may indicate decreasing fertility (Roux *et al.* 2009b).

Vittrekwa River

There are insufficient data to provide estimates of population abundance or infer population trends in this river. This population is believed to be very small (Millar 2006). In 2007, 165 spawners were counted during a bank-side stream survey along Ne’eedilee Creek, the tributary to the Vittrekwa River where spawning and overwintering habitat has been identified (Nathan Millar pers.obs, 2007).

Upper Peel River Watershed

No estimates of population size or trend have been made for Dolly Varden in any of the rivers in the upper Peel River watershed.

Horn Lake

There are no estimates of population size or trends for these particular Dolly Varden.

Gayna River

Preliminary CPUE and mark recapture results indicate that this population is small (N. Mochnacz, unpublished data). There are insufficient data to determine the population trend.

Rescue effect

Dolly Varden (Western Arctic populations) from Canadian and American (Alaskan) waters intermix at sea; Krueger *et al.* (1999) found that the fish at coastal sites in Alaska were comprised of 20-25% fish of Canadian origin, and coastal sites in Canada had up to 65% fish of Alaskan origin. Dolly Varden are known to travel and overwinter in non-natal river systems (Glova and McCart 1974), but spawning in non-natal rivers systems has not been documented. Immigrants from Alaska could be pre-adapted to survive in Canada as their habitats are similar, but it is unknown to what extent Dolly Varden from individual river systems have genetically adapted to their particular area. If Alaskan lineages are genetically similar to the Canadian ones, then successful re-colonization is more likely. The Firth River crosses the Yukon-Alaskan border and supports anadromous Dolly Varden that regularly cross the international border in their movements to and from the Beaufort Sea.

It is also possible that populations upstream of waterfalls and cascades could disperse downstream and act to rescue populations located below migration barriers. Typically, however, populations of salmonid fishes located above barriers are genetically and behaviourally distinct from those below barriers (e.g., Northcote 1981; Taylor *et al.* 2003) so the effectiveness of such rescue is uncertain.

LIMITING FACTORS AND THREATS

The factors threatening the populations of Dolly Varden (Western Arctic populations) consist of overharvest, climate change, and potential risks from resource extraction (Table 20). Overharvesting has been identified as the primary cause of observed declines in Dolly Varden, but other factors are now being taken into consideration as limits to harvest have been violated in some cases and have not resulted in full recovery of stocks (DFO unpubl. data). Environmental impacts are discussed in Reist *et al.* (2001).

Table 20. Some activities with the potential to affect key aspects of Dolly Varden habitat and their potential effects on the species (from Stewart *et al.* 2010b).

Activity	Potential impact: Habitat	Potential impact: Species	Directly affected life stage(s)
water removal drainage alterations seismic testing	reduced groundwater flow altered base flow and ice and temperature regimes	degradation, reduction or loss of spawning habitat increased winter mortality of eggs, larvae, fry, juveniles, and resident adults	all
construction of roadways, pads, and structures stream crossings	streambed alteration by removal or disturbance of sand, gravel, and cobble substrates sediment mobilization streambed destabilization	egg, larval, fry and juvenile mortality from physical damage, exposure, loss of cover, sediment mobilization degradation, reduction or loss of spawning habitat	all
logging, clearing for right-of-ways, camps, etc. stream crossings	inland clearing loss of riparian and in-stream cover (i.e. shoreline, large woody debris) altered hydrological regime with more abrupt runoff warming, increased sediment inputs	degradation of spawning and rearing habitat higher mortality rates for all life stages	all
culvert installation for stream crossings dam construction in-stream construction	flow impoundment changes in seasonal flow regimes, water depth, water velocity habitat fragmentation	interruption of spawning migrations restricted access to coldwater summer refugia in headwater tributaries inundation or dewatering of spawning areas population extirpation creation of new wintering areas	adults, mainly spawners
road and right-of way construction population growth	improved access to Dolly Varden habitat	increasing harvest pressure on adults and possibly large immature fish visual and physical disturbance of fish and fish eggs increased potential for species introductions population reduction or extirpation	adults and large juveniles by harvesting all life stages by introductions
contaminants releases	chemical pollution	reduction in fish quality increased mortality	all
climate change	changes in the temperature and precipitation regimes warming	decrease in suitable habitat at lower elevations and latitudes increase in suitable habitat at higher elevations and latitudes increasing competition and predation by warmer water species	all

Dolly Varden are particularly vulnerable to harvesting at their spawning and overwintering grounds when a high number of fish are concentrated in a small area. Seining activities at these sites could also impact egg survival by disturbing or destroying redds (Stephenson 1999). The largest breeding males are disproportionately harvested as they can be caught with all mesh sizes of net used. These large males are needed to stimulate spawning. The loss of these prime breeders has been skewing the sex ratio to females in the Big Fish River (Cosens and Martin 2003). There is also general trend towards a lower representation of older age classes in the Rat River since 1999 (Roux *et al.* 2009b). The impact of illegal harvesting by visitors to the Firth River is not well documented or controlled. It is unclear which populations are most impacted by the mixed stock fishery along the coast because the origin of harvested fish is not well monitored.

Global climate models have not been able to accurately simulate trends in precipitation for the western Arctic (Bonsal and Prowse 2006). Nevertheless Sandstrom (pers. comm. 2008) suggests that a decline in precipitation in the last five decades has contributed to the desiccation and reduction of spawning and overwintering habitat in the Rat River. Desiccation of habitat could result from an increase in evaporation with warming temperatures (Wrona *et al.* 2005). Modelling results suggest that an increase of 1 to 4^{o}C in mean annual air temperature could reduce the geographical distribution of Dolly Varden (Western Arctic populations) by 29 to 90% (Stewart *et al.* 2010b). This decrease is based on projected reduction of suitable habitat. There is no evidence that climate change would facilitate a northward range expansion of Dolly Varden, as no Global Climate Models predict an increase in suitable overwintering habitat (i.e., river sites with groundwater springs). Indirect effects of a warmer climate include increased marine traffic as ice recedes in the Arctic. This increases the risk of contaminants in the Dolly Varden that feed along the coast. Exposure to petroleum hydrocarbons due to oil spills can have adverse effects on fish (Hepler *et al.* 1996; Thomas and Rice 1986). Other chemical contaminants such as mercury are a concern of subsistence harvesters (Byers 2010). Marine traffic could also bring in invasive species that may be detrimental to endemic populations.

Climate warming trends have been associated with the northward expansion of more southerly species (e.g., Parmesan and Yohe 2003). Both climate change models and empirical observations suggest that Pacific salmon (*Oncorhynchus* spp.) could become more abundant within the Arctic basin (see discussion in Babaluk *et al.* 2000) where they could have numerous interactions, both positive and negative, with Dolly Varden (Western Arctic populations) (e.g., predation on young, competitor at spawning sites, provide food supply for Dolly Varden).

The coastal band of brackish water used as a transportation corridor and feeding area by Dolly Varden (also known as the “stable buoyancy boundary”) could be disrupted by changes to any of the three factors that stabilize it: 1) dominant easterly winds, 2) freshwater entering the Beaufort sea from Yukon North Slope river systems, and 3) proximity of sea ice in spring. Lower water levels in the Husky Channel, Peel River watershed (Robert Charlie pers. comm., 2008), the Mackenzie River Delta, Philips Bay at the mouth of the Babbage River, Nunaluk Spit, Firth River delta, Malcolm River (Papik *et al.* 2003), and dry stream beds in the Rat River (Steve Sandstrom pers. comm. 2008) all suggest that less freshwater is available for forming the stable buoyancy boundary. There are also noticeably fewer drift logs in rivers compared to the 1970s, indicating that spring high-water levels are not as voluminous (Byers 2010). There is already a trend of reduced sea ice, earlier breakup and recession of sea ice along the Beaufort Sea (Arctic Climate Impact Assessment 2004).

Recent reduced flow rates in the Big Fish River may exacerbate temperature-induced egg mortality (Cosens and Martin 2003). Lower water levels, lower water salinity, and possibly lower groundwater flow at the Fish Hole along the Big Fish River could be limiting the recovery of Dolly Varden (DFO 2002c). Earthquake activity in the late 1970s and early 1980s, combined with a larger harvest than the stock could support may be factors that have brought the population level of Dolly Varden in the Big Fish River to a point where it may not recover (Stephenson 2003). Aklavik residents reported mysterious rapid fluctuations in water level that stranded Dolly Varden in pools on higher ground at the Big Fish River overwintering grounds (Byers 2010).

The thawing of permafrost associated with climate change could accelerate the deposition of materials into spawning areas, smothering redds (Stephenson 2003), and reducing the survival of eggs and fry. Rising temperatures associated with climate change could increase levels of contaminants, such as mercury (Sawatzky and Reist in prep). Other possible effects of climate change are discussed in Reist (1994) and Reist *et al.* (2006). Stressed populations are more adversely affected by parasites and disease, such as infectious pancreatic necrosis virus. Moles (2003) found that Dolly Varden infected with the nematode *Philonema agubernaculum* had reduced foraging ability.

Offshore industrial infrastructure can disrupt the movement of and feeding of Dolly Varden (e.g. Roland Bay; Kavik-Axys Inc. 2008). Fish expend extra energy to move away from marine seismic activity. Inland mining activity in close vicinity to Dolly Varden habitat could have a detrimental effect, for example, diverting water out of rivers would further stress the already reduced water levels reported in several drainages. Transportation corridors could also improve access to remote Dolly Varden and facilitate more fishing of stocks. Potential resource exploitation in the vicinity of Dolly Varden habitat could directly impact the quality of the fish habitat. Sand, gravel and rock material along the Dempster Highway in the James Creek area (tributary to the Vittrekwa River) is valued by the Department of Transportation in the Northwest Territories. Winter seismic activity can destroy or dam creeks by breaking willows (Byers 2010). Water drawn from rivers and lakes to construct the ice road is thought to deplete fish-bearing waters (Byers 2010).

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Existing protection

The federal government's constitutional responsibilities for sea coast and inland fisheries are contained within the *Fisheries Act*. The Act provides DFO with powers, authorities, duties and functions for the conservation and protection of fish and fish habitat (as defined in the *Fisheries Act*) essential to sustaining commercial, recreational and Aboriginal fisheries. The *Fisheries Act* contains provisions that can be applied to regulate flow needs for fish, fish passage, killing of fish by means other than fishing, the pollution of fish-bearing waters, and harm to fish habitat. Environment Canada has been delegated administrative responsibilities for the provisions dealing with regulating the pollution of fish-bearing waters while the other provisions are administered by DFO.

Non-legal status and ranks

The communities of Aklavik and Fort McPherson developed and implemented the "Rat River Char Fishing Plan" in 1995. This plan recommends a limit of 2,000 fish per year and specifies the size of nets and the number of nets per household (DFO 2001). Compliance with the plan has grown since its inception, but violations still occur from time to time (DFO unpubl. data). There was a voluntary closure in the fishery for three years, beginning March 2006, when the population numbers continued to decline (Sawatzky and Reist in prep.). In 2009, the Rat River Working Group decided to allow the collection of 225 fish for monitoring/scientific purposes and a harvest of 1,000 fish for consumption by user groups from local communities.

The government of the NWT considers Dolly Varden a sensitive species under its General Status Ranks of Wild Species in the NWT (RWED 2004). Part of the Firth River drainage is located within Ivvavik National Park, including a portion of the overwintering and spawning sites. Such habitat is protected by Parks Canada. Another portion of the Firth River watershed, including part of Joe Creek is within the United States (US) Arctic National Wildlife Refuge. The designation of "Refuge" theoretically protects habitat within its boundaries; however, a decision to open access to such areas for non-renewable resource development can be made by the US federal government.

Under the Aklavik Inuvialuit Community Conservation Plan (Community of Aklavik *et al.* 2000) and the Gwich'in Land Use Plan (Gwich'in Land Use Planning Board 2003), the riparian areas of the Big Fish River and the Fish Hole are protected from development.

The Babbage River forms the eastern border of Ivvavik National Park. The Babbage River watershed in the park and 1 km east of the river, including the Canoe River, is designated as Management Category D by the Aklavik Inuvialuit Community Conservation Plan (Community of Aklavik *et al.* 2000). This designation identifies the lands and waters where renewable resources are of particular significance and sensitivity throughout the year.

The Big Fish River was closed to all fishing in 1987 when the population witnessed a drastic decline. Some fish are presently harvested by a mixed stock fishery on the coast and a small subsistence harvest which was re-opened in 1992.

Recreational fishing of Dolly Varden is regulated in the Northwest Territories and the Yukon. The Northwest Territories government permits catch and release of Dolly Varden within Gwich'in Settlement Area and Inuvialuit Settlement Region (Northwest Territories Environment and Natural Resources 2009) with the purchase of a territorial fishing licence. In the Yukon, a general daily catch limit of five Dolly Varden applies to recreational fisherpersons with a valid fishing licence (Yukon Environment 2009). Fishing in National Parks is regulated federally, so a Yukon fishing licence does not allow the licensee to fish in Ivvavik National Park. Instead, fishing of Dolly Varden or other fish species in Ivvavik National Park is only permitted with the purchase of a fishing licensc specific to the park.

In the Northwest Territories, Dolly Varden is ranked as "Sensitive", meaning that the species is not considered at risk of extinction or extirpation but may require special attention or protection to prevent them from becoming at risk (Working Group on General Status of NWT Species 2006). In Yukon, the species is ranked as S4 (apparently secure, NatureServe 2010).

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Maria Leung has worked in the field of wildlife biology for many years and currently lives in Whitehorse, Yukon. She completed her Bachelor's degree at the University of Guelph and her Master's degree at the University of British Columbia. She has a special interest in conservation biology, and took on this piece of work on Dolly Varden because of its pertinence to species conservation and focus on northwestern Canada.

Jim Reist is a research scientist at the federal Department of Fisheries and Oceans in Winnipeg. He did his PhD on the systematics and taxonomy of Canadian freshwater fishes. He has been conducting research in Arctic Canada for twenty-five years, including work on sensitive and 'at risk' fish species in support of habitat management, environmental impacts of development, and recovery activities.

Nathan Millar is the Senior Fisheries Biologist for the Yukon Department of Environment. Previously, he worked for the Gwich'in Renewable Resource Board in Inuvik, NT as a fisheries biologist where he was involved in research and management of Dolly Varden in the Rat and Vittrekwa rivers. He holds Bachelor's and Master's degrees in biology (ecology) from McGill University and resides in Whitehorse.

Appendix 1. Photos of Dolly Varden (Western Arctic populations) (*Salvelinus malma malma*) showing a variety of colouration and patterns. a. Small juvenile of anadromous or residual life history from the Firth River; b. Residual spawner from the Firth River; c. Anadromous large juvenile from the Babbage River; d. Anadromous male spawner from the Firth River; e. Anadromous female spawner from the Firth River; f. Anadromous female spawner from Joe Creek; g. non-anadromous mature male from the Little Wind River, Upper Peel Watershed. Photos a. through f. from Department of Fisheries and Oceans; photo g. by Nathan Miller.