Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*)

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FISH LIFE HISTORY AND HABITAT USE IN THE NORTHWEST TERRITORIES: BULL TROUT (*Salvelinus confluentus*)

by

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Bull trout occur in the Mackenzie River Valley south of Great Bear Lake, and possibly also in some rivers north of this area. The species requires cold, clean water and populations can be resident or migratory. The latter can follow fluvial, adfluvial or anadromous life histories. Differences in habitat use by these populations and in the seasonal requirements of eggs, fry, juveniles, and adults are summarized. Spawning occurs in shallow, fast-flowing tributary streams with stable channels and gravel to boulder substrates, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. To support the assessment, avoidance and mitigation of environmental impacts in the Mackenzie Valley, the potential impacts of development activities and climate change on survival of the species are reviewed. The species' narrow habitat requirements for spawning and rearing make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators, bull trout are also vulnerable to overharvesting and other stressors that target the older segment of the population. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Key words: distribution; life history; habitat requirements; seasonal movements; reproduction; spawning; rearing; life cycle; Mackenzie watershed; hydrological integrity; fresh water; Salmonidae.

RÉSUMÉ

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2801: vi + 46 p.

L'omble à tête plate se trouve dans les eaux de la vallée du Mackenzie au sud du Grand lac de l'Ours et habite probablement certaines rivières au nord de cette région. L'espèce requiert des eaux froides et propres. Les populations peuvent être sédentaires ou migratrices. Les populations migratrices peuvent être de nature fluviale, adfluviale ou anadrome. Nous résumons ici les différences dans l'utilisation des habitats par ces populations et les différences dans les besoins saisonniers des œufs, des alevins, des juvéniles et des adultes. La fraie se produit dans les tributaires peu profonds et à fort courant comportant des chenaux stables et des substrats graveleux à rocheux, souvent aux endroits alimentés par des eaux souterraines qui assurent des conditions favorables à l'incubation et à l'alevinage tout au long de l'hiver. Nous examinons les incidences éventuelles des activités humaines et du changement climatique sur la survie de l'espèce en appui de l'évaluation, de l'évitement ou de l'atténuation des incidences environnementales dans la vallée du Mackenzie. Les exigences strictes en matière d'habitat de fraie et d'alevinage rendent ces populations vulnérables à la disparition en raison de la fragmentation et de la perturbation des habitats. Bien qu'il vieillisse lentement et qu'il soit un prédateur vorace, l'omble à tête plate est également vulnérable à la surpêche et à d'autres agents stressants qui touchent la strate la plus âgée de la population. Il ne rivalise pas bien avec les autres espèces d'omble à des températures supérieures à 12°C et il est vulnérable à l'introduction d'autres espèces d'omble.

Mots clés : répartition; cycle vital; exigences en matière d'habitat; déplacements saisonniers; reproduction; fraie; alevinage; bassin versant du Mackenzie; intégrité hydrologique; eau douce; Salmonidés.

1.0 INTRODUCTION

Renewed interest in natural gas pipeline development along the Mackenzie Valley has raised the prospect that fish species in the watershed may be impacted by changes to their habitat. The proposed pipeline would extend from near the Beaufort Sea coast to markets in the south (http://www.mackenziegasproject.com/). Fishes in the Mackenzie River depend upon the integrity of their aquatic habitats, so it is important to summarize knowledge that can be used to assess potential impacts of this development proposal and others, and to facilitate efforts to avoid and mitigate these impacts.

This report reviews knowledge of the bull trout, *Salvelinus confluentus* (Suckley, 1859), an attractive but sensitive sportfish. It includes information on the species' distribution, habitat use during the various stages of its life history, and about threats posed to the species and its habitat by development activities. Knowledge gaps are also identified. This information was compiled to assist developers, habitat managers, and researchers. Similar reports have been prepared for other fishes that inhabit the Mackenzie River watershed.

The distribution and life history of bull trout in the Northwest Territories (NT) are poorly known, so the discussion that follows is based largely on populations from other regions.

1.1 Taxonomic units

Prior to 1991, bull trout in the Mackenzie Valley were identified as Dolly Varden (*Salvelinus malma*). This has led to confusion of the species' life histories, and the need to reassess literature from studies conducted in the 1970s and 1980s (e.g., Stein *et al*. 1973; McCart *et al*. 1974; Porter *et al*. 1974; Sigma Resource Consultants Ltd. 1976; Wickstrom 1977, 1979; Chang-Kue and Cameron 1980; Wickstrom and Lutz 1981; McCart 1982). Fish from the Great Bear River and further upstream in the Mackenzie River watershed that were originally identified as Arctic charr (*S. alpinus*) or Dolly Varden are now believed to be bull trout (Reist *et al*. 2002).

Genetic variability within bull trout populations is low, but genetic differences among populations are often marked (McPhail and Baxter 1996). This, along with striking inter-population differences in nuptial colouration and sexual dimorphism, suggest the existence of distinct stocks. However, separate taxonomic units have not been identified. Phylogenetic work suggests that periodic contraction and local extinction followed by expansion and colonization from local refugia have been important across the species' range (Haas and McPhail 2001).

1.2 Distribution

Bull trout are endemic to western North America (Haas and McPhail 1991). Their current distribution extends from the southern Yukon and southwestern Northwest Territories south to northern California and Nevada, and from the Pacific coast east to western Alberta (AB) (Haas and McPhail 2001; Mochnacz 2002). The range of bull trout has declined in recent years due to population extinctions, particularly in the southern portion of their range (Goetz 1989; Brown 1992; McPhail and Baxter 1996; Baxter *et al*. 1999). Even in pristine habitats, bull trout have a patchy distribution (Rieman and McIntyre 1993). Within the Mackenzie River system, the bull trout has been found in the Hyland Highland, Sibbeston Lake Plain, Nahanni Plateau, Hay River Lowland, Peel River Plateau, Franklin Mountains, Mackenzie River Plain, and Norman Range ecoregions, where it is widely but sparsely distributed (Figure 1) (Marshall and Schut 1999; Sawatzky *et al*. 2007)

Bull trout often occur with mountain whitefish (*Prosopium williamsoni*) and upstream of barriers, an indication of early colonization (Meehan and Bjornn 1991). Like cutthroat trout (*Oncorhynchus clarki*), they tend to occur in stream reaches at higher elevations than brook trout (*S. fontinalis*) or rainbow trout (*O. mykiss*) (Paul and Post 2001). Ripley *et al*. (2005) found that the vast majority of bull trout in the Kakwa River basin of Alberta were present in third- and fourth-order streams located at elevations of 950 to 1,600 m above sea level. These reaches may provide refugia, wherein bull trout can prevent colonization by introduced species and are isolated from harvesting pressures (Paul and Post 2001). In Washington and Oregon the species' distribution follows a pattern of decreasing elevation with increasing latitude and longitude (Goetz 1994).

Bull trout distributions can be difficult to delineate, as the species is often found in low conductivity water in areas with cover and current. Electrofishing during the day may tend to underestimate juvenile bull trout populations, which may be more efficiently sampled or observed by divers at night, using nets or flashlights respectively (Bonneau 1994; Bonneau *et al*. 1995; Goetz 1994, 1997a). Snorkelling surveys in streams tend to generate higher bull trout counts at night than during the day, and these counts can be biased toward fish longer than 100 mm (Zurstadt 2000).

2.0 LIFE HISTORY TYPES

Bull trout exhibit both non-migratory and migratory life history types in response to the local environmental conditions (Table 1; Goetz 1989; Brenkman *et al*. 2001; Bahr and Shrimpton 2004; Mogen and Kaeding 2005). The non-migratory populations are stream residents that inhabit spawning tributaries year-round. The migratory populations also spawn and rear in tributary streams but, as older fish, winter in larger rivers (**fluvial**[1]) or in lakes (**adfluvial**), and sometimes feed at sea (**anadromous**). Most migrations take place from June through October, when fish move to and from the spawning tributaries.

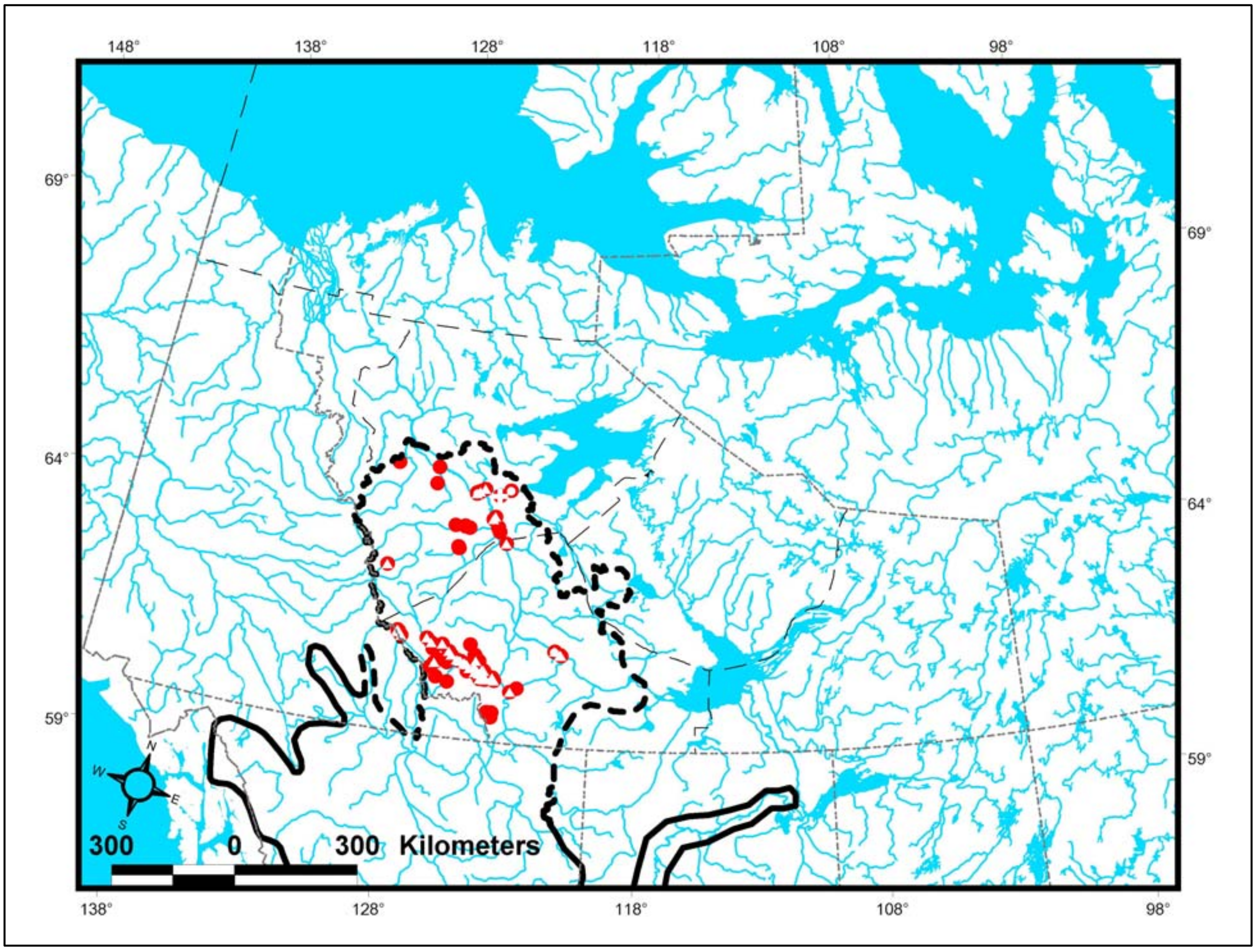

Figure 1. Bull trout distribution in the Northwest Territories (from Sawatzky *et al*. 2007). Solid red dots indicate recent specimens with confirmed identity; dots with symbols are older records that are now considered to be bull trout but cannot be verified. Those containing a white triangle were initially identified as Dolly Varden, a white "+" as Arctic charr, and a white dot as *Salvelinus* species complex.

Stream resident, fluvial, and adfluvial populations of bull trout have been reported from the Northwest Territories, but the life histories of these populations are not well known (Mochnacz 2002). Fish from stream resident populations are typically shorter and smaller bodied than those from fluvial and adfluvial populations (Rieman and McIntyre 1993; McPhail and Baxter 1996), and may mature earlier and at a smaller size than migratory forms (Cannings and Ptolemy 1998; Mochnacz 2002). Stream resident adults range from 150 to 300 mm in length, while migratory fish commonly exceed 600 mm

[1] Terms in bold type are defined in the Glossary.

Table 1. Habitat use by bull trout populations with different life history types.

HABITAT	POPULATION			
	STREAM-RESIDENT	FLUVIAL	ADFLUVIAL	ANADROMOUS
Small high-gradient tributary streams	• Year-round use by all life history stages for all activities.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.
Rivers		• Migration corridors and feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding habitat for juveniles and adults. • Overwintering habitat for some juveniles.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Lakes		• Migration corridors for some adults.	• Feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Brackish or marine coastal waters				• Migration corridors and feeding habitat for juveniles and adults.

(Rieman and McIntyre 1993). Adfluvial bull trout can grow to at least 1,025 mm and 14.5 kg (Goetz 1989).

Life history and habitat parameters are defined in Appendix 1. Stream and lake habitat requirements are summarized in Appendices 2 and 3, respectively.

2.1 Stream Resident

In the Northwest Territories, fish caught in summer at the Kotaneelee River system, Funeral Creek, the South Nahanni River (Mochnacz 2002), Little Smith Creek, a tributary of the Blackwater River (McCart *et al*. 1974), and Prairie Creek (Beak Consultants Ltd. 1981) may be stream resident (Figure 1).

Stream resident fish remain in the spawning tributary streams year-round, and often spawn and overwinter within a 2 km reach of river (Jakober *et al*. 1998; Chandler *et al*. 2001). In the West Castle River of southwestern Alberta, juvenile and adult bull trout overwinter in small, shallow (maximum depth 0.4 to 1.5 m) pools that are isolated from one another, have little cover, and receive flow from groundwater springs (Boag and Hvenegaard 1997). In the Bitterroot River drainage of Montana fish will move 1 to 2 km downstream in early October from spawning sites to overwintering sites; some move over 1 km further downstream later in the winter at temperatures of 1°C or lower (Jakober 1995; Jakober *et al*. 1998). The first movements coincide with decreasing water temperature, and may reflect a change in concealment behaviour; the second, about 6 weeks later, coincides with formation of anchor ice and exclusion of fish from habitat with preferred cover. Beaver ponds provide important overwintering habitat for some stream resident bull trout.

Reaches influenced by groundwater provide resident bull trout with cold-water refugia in summer, and warm-water refugia in winter (Baxter and Hauer 2000). These areas have relatively stable thermal regimes, with less winter ice cover and no anchor ice formation. Groundwater upwellings also prevent frazil ice formation (Bonneau and Scarnecchia 1998). While **redds** are associated with areas of groundwater upwelling, within these areas they can also be associated with localized downwelling (Baxter and Hauer 2000). Stream resident fish remain active on or above the substrate throughout the winter at night, even during extreme temperatures and ice conditions (Jakober 1995; Jakober *et al*. 2000). During the day, small (<200 mm) fish stay concealed in the interstices of large substrates and in accumulations of large woody debris.

2.2 Fluvial

Fluvial bull trout populations inhabit the Keele, Flat and South Nahanni rivers of the Northwest Territories (Figure 1; Mochnacz 2002). Like the stream resident populations, the fluvial populations spawn in high-gradient smaller rivers and tributary streams (Bahr and Shrimpton 2004). These streams also provide rearing habitat for periods of months or years. Older juveniles eventually move downstream into larger rivers where they feed, mature and overwinter. Adults remain in these rivers unless they are returning to the tributaries to spawn, or to escape overly warm water. Spawning in the mainstems of these larger rivers has not been documented.

Unlike stream-resident populations, adult bull trout from fluvial populations undertake extensive seasonal movements, typically upstream into tributary streams in May-August, and downstream to overwintering areas by late September or early October (Pattenden *et al*. 1991; McLeod and Clayton 1993, 1997; Fernet and O'Neil 1997; Swanberg 1997a; Burrows *et al*. 2001; Hemmingsen *et al*. 2001; Bahr and Shrimpton 2004; Pillipow and Williamson 2004). Upstream pre-spawning migrations are typically slower than the downstream post-spawning movements, when fish can move 30 km in a 6 to 7 h period (Pillipow and Williamson 2004). Downstream movements to spawning tributaries have been observed in the McLeod River of Alberta (Carson 2001). Migrations of up to 500 km demonstrate the large spatial scale and diversity of habitats required to sustain fluvial bull trout populations (Swanberg 1997a), and the importance of high-quality stream spawning habitat (Pillipow and Williamson 2004) and of stream connectivity (USFWS 2000; Muhlfeld and Marotz 2005).

Migration timing varies among systems. Fish that undertake longer migrations and gain more elevation, that enter systems where there is a greater seasonal decline in flow following the spring freshet (Thiesfeld *et al*. 1996), or that find themselves in unfavourable temperature conditions (Swanberg 1997a) may migrate earlier in the season. The temperature at which peak migrations are observed varies among rivers. McPhail and Murray (1979) found migrations to peak at 10 to 12°C. Fish migrating at the lower temperatures are typically preparing to spawn shortly.

In contrast, the annual migrations in the Blackfoot River of Montana are cued by an increase in the maximum daily water temperature and a decrease in discharge from peak runoff (Swanberg 1997a). In this southern system, the mean temperature at which fish began their migrations was 17.7°C. Larger fish began moving upstream at cooler temperatures and earlier in the season than smaller fish. The migrations were nocturnal and generally rapid (4.4 $\pm$ 2.2 km/d; see also McPhail and Murray 1979). Spawners ascended tributaries in late June to early July, 67 $\pm$ 10 d before spawning (Swanberg 1997a). Non-spawning fish entered the lower portions of these tributaries after the spawning fish, and remained there 28 $\pm$ 18 d before returning downriver in late August. The primary purpose of these migrations by non-spawners may be to avoid unfavourable temperature conditions, since prey densities were lower in the tributaries than in the Blackfoot River. Some bull trout, probably immature, did not migrate but they did use confluences with cold tributaries when temperature conditions became unfavourable.

Exclusive of spawning, adult bull trout in some fluvial populations appear to occupy small discrete home ranges with great fidelity (Carson 2001; Hvenegaard and Thera 2001). In some systems the fish show strong fidelity to the same spawning tributaries and overwintering areas (Bahr and Shrimpton 2004), but in others they shift spawning sites over time (McPhail and Murray 1979; Pratt 1992). In the Blackfoot River of Montana, most (86%) migrants returned downriver to within 20 km of sites occupied in the spring, and winter movements were very local, never exceeding 300 m (Swanberg 1997a). Likewise, only localized movements were detected among fish overwintering under the ice in the mainstem of the Athabasca River in Alberta (McLeod and Clayton 1997).

Bull trout in the Morice River system of British Columbia (BC) appear to use Morice Lake primarily as a corridor for moving between river systems; larger fish sometimes spend part of the winter in the lake but would still be classified as fluvial (Bahr and Shrimpton 2004).

2.3 Adfluvial

Drum Lake, Northwest Territories, supports an adfluvial bull trout population (Figure 1; Mochnacz 2002). Adfluvial bull trout follow a similar life-history pattern to that of the fluvial populations, spawning in high gradient small rivers and tributary streams (Fraley and Shepard 1989; Ratliff *et al*. 1996; Olmsted *et al*. 2001). Lake spawning has not been documented. Juveniles begin rearing in the spawning streams and eventually move downstream into large rivers or lakes to feed, mature, and overwinter. Larger adults are more likely to feed and winter in lakes (Connor *et al*. 1997). They remain in the lakes unless they are returning to the tributaries to spawn, or to escape overly warm water.

In Chester Morse Lake, Washington, adult bull trout were found in every habitat zone (Connor *et al*. 1997). They occurred in the highest densities in the deepest areas of the lake (**profundal**, 42 m), but were also locally abundant along the shore of the lake (littoral). Relatively few fish were observed in the pelagic regions of the lake. Peak activity was observed during the night and few fish were active during daylight or full moon, when they rested on the bottom.

The availability of suitable stream spawning habitat affects the distance and duration of spawning migrations by adfluvial populations. Some fish from Flathead Lake, Montana, for example, migrate 250 km upstream in the Flathead River to spawn in headwater streams (Fraley and Shepard 1989). They move upstream from May through July and spawn from late August through early October before returning downstream to overwinter. In contrast, fish in high, isolated, oligotrophic lakes, such as Pinto and Harrison lakes in Alberta, spawn a short distance upstream in the lake inlet, or downstream in the outlet (Herman 1997; Wilhelm *et al*. 1999). The spawning migrations of populations in these two lakes last only a few weeks and, because stream rearing habitat is close and limited, juveniles tend to enter the lakes at a younger age than those with access to more suitable river habitat (Hanzel 1985; Ratliff *et al*. 1996; Wilhelm *et al*. 1999; Brenkman *et al*. 2001).

2.4 Anadromous

In general, bull trout do not appear to undertake extensive ocean migrations, although some regularly enter the sea and even move between drainages (Haas and McPhail 1991, 2001). Anadromous bull trout have not been reported from the Northwest Territories. However, they have been reported from the Hoh River (Brenkman *et al*. 2007) and Puget Sound (Mongillo 1993) areas of Washington State and the lower reaches of the Fraser and Skeena rivers in British Columbia, and may be present in other coastal rivers such as the Nass (Haas and McPhail 1991, 2001). Fish from the Hoh River migrated to sea for the first time at age 3 to 6, and the smallest juvenile migrant observed was 243 mm TL (Brenkman *et al*. 2007). Adults moved at least 47 km along the coast from their river of origin (Brenkman and Corbett 2005).

3.0 LIFE HISTORY STAGES AND HABITAT USE

Bull trout have very specific habitat requirements, that are often summed by the “Four C’s” -- cold, clean, complex, and connected (USFWS 2000). Habitat selection by different age classes appears to be heavily influenced by intraspecific competition and avoidance of predation by younger animals (Goetz 1997b). Stream habitat use by bull trout has been studied in detail, but the specifics of habitat use and requirements in rivers, lakes, and coastal waters are poorly known. Key transitions in the bull trout life history are illustrated schematically in Figure 2 and discussed below.

These fish require a narrow range of cold temperature conditions to reproduce and survive (Table 2). In general, they are observed more frequently and appear more likely to occur at summer means of about 6 to 9°C, or with summer maxima less than about 13 to 14°C (Rieman and Chandler 1999; Gamett 2002). The upper optimal temperature threshold for bull trout has been estimated at a maximum daily maximum temperature (MDMT) of 12°C, which translates to a maximum weekly maximum temperature (MWMT) of 11°C (McCullough and Spalding 2002). Temperatures greater than 16°C are generally unsuitable for long-term survival of bull trout (McMahon *et al*. 2001).

Bull trout do, however, exhibit a high degree of behavioural thermoregulation and are able to forage for periods of time in areas where temperatures are higher than their preferred (USFWS 2000). While age 0, juvenile, and adult bull trout in Idaho streams will enter water that exceeds 20.0°C for several hours on hot, summer days, the average daily temperatures recorded at their distribution limits were between 2.0 and 12.0°C (Adams 1994). As water temperatures exceed a single daily maximum of 20°C, it becomes increasingly unlikely that juvenile bull trout will be found using a given habitat (Dunham and Chandler 2001).

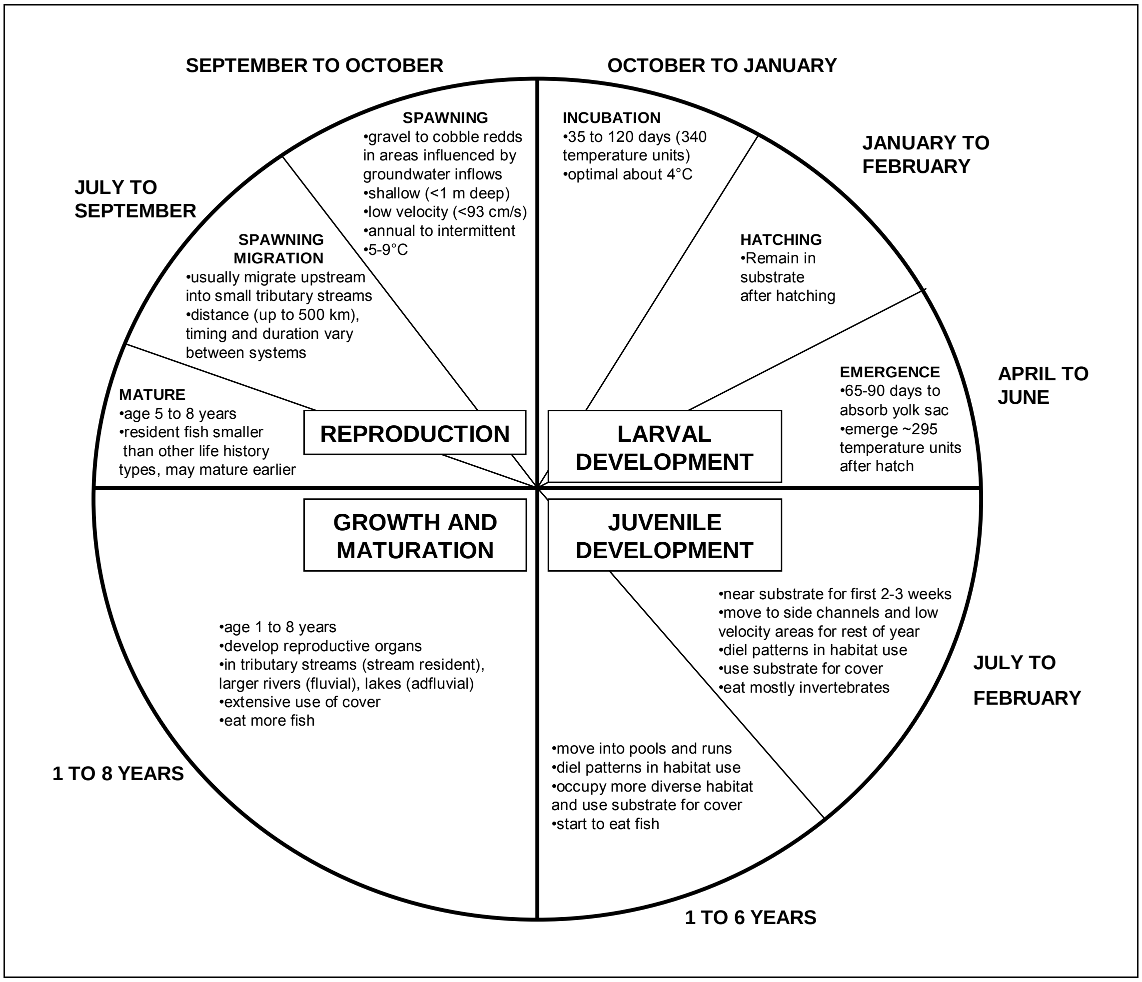

Figure 2. Generic life cycle of bull trout (modified from Mochnacz 2001).

General characteristics of stream habitats where bull trout have been captured in the summer in the Northwest Territories include: average water velocities in the range of 18 to 68 cm/s (range 0.0 – 172 cm/s), depths of 19 to 149 cm (range 3 – 282 cm), average temperature 3.6 to 12.7°C, average wetted width 1.70 to 16.4 m, with cobble as the dominant substrate and boulders as the dominant cover (Table 2) (Mochnacz *et al*. 2004).

Table 2. Observed stream habitat use by bull trout (data from Northwest Territories populations in bold type; numbers in brackets refer to sources cited below). Abbreviations are defined in Section 8.0 and habitat parameters are defined in Appendix 1.

HABITAT FEATURES		LIFE STAGE			
		Spawn/egg	**Young-of-the-year (YOY)**	**Juvenile**	**Adult**
Habitat type		Interstices of bottom substrate in small tributary streams. Redds often associated with groundwater discharges (4, 6,10, 16, 19)	Shallow shoreline pools and riffles in side channels of high gradient streams; interstices of bottom substrate; diel changes in microhabitat preferences (5b); will winter in the interstitial, sub-surface flow under a dry channel bed (8)	**High gradient habitats at or near the bottom, often in** shallow pools and riffles; interstices of bottom substrate; **pocket pools created by large cobble and boulders (1a,b);** sometimes winter in isolated pools maintained by groundwater inflows (7)	**High-gradient mountain streams (1c)**; pools, riffles, runs; sometimes winter in isolated pools maintained by groundwater inflows (7)
Stream gradient		High (4), Low, Meandering (12)	**High (1a)**	**High (1a,b)**	**High (1c)** 1.0 - 15.6% (21)
Depth range (m)		0.454 ± 0.022 (4a) 0.07 - 0.93 (4b)	**0.222 - 0.468 means (1a)** **0.07 - 0.90 overall range (1a)**	**0.222 - 0.468 means (1a,b)** **0.07 - 1.30 overall range (1a,b)**	**0.191 - 1.49 means (1c)** **0.03 - 2.82 overall range (1c)**
Substrate		Gravel (4a), sand to cobble (4b), sometimes with an appreciable amount of silt (8)	**Cobble (1a)** and boulder (5a)	**Cobble and boulder (1a,b)**	**Gravel, rubble, cobble (23) and boulder (1c)**
Cover		Overhead cover is not a prerequisite for spawning (7), will construct redds within 2.5 m of the banks (8)	**Boulder (1a)**	**Boulder (1a,b)**	**Undercut banks, deep pools, boulders (1c)**
Velocity range (cm/s)		58 ± 2 (4a) 2 - 93 (4b)	**22 - 30 means (1a)** **10 - 133 overall range (1a)** Microhabitat values may be lower	**22 - 55 means (1a,b)** **0 - 146 overall range (1a,b)** Microhabitat values may be lower, 0 - 10 (11,13)	**18 - 68 means (1c)** **0 - 172 overall range (1c)**
Turbidity (NTU)	Range	0.1 - 1.0 (14)			
	Limits				
Oxygen (mg/L)	Range	Intergravel: 8 - 12, mean 9 (16) Instream: 10 - 11.5, mean 10 (16)			**11 (23)**
	Limits				
Temperature (°C)	Range	Spawning: 5 - 9 (9,24) Incubation: 1.2 - 5.4 (9,18)	**Summer: 4.1 - 4.6 (1a)** Rearing: 2 - 12 (20)	**Summer: 4.1 - 12.7 (1a,b)**	**Summer: 1.5 (23), 3.6 - 7.9 (1c)**
	Limits		UUILT 20.9 (60 d) (3) UUILT 23.5 (7 d) (3)	UUILT slightly lower than for young-of-the-year (3)	MDMT 12°C (2), MWMT 11°C (2)

Prey items	Primary		Aquatic insects (17)	**Aquatic and terrestrial insects /larvae (1a)**	**Fish (Arctic grayling, bull trout, longnose sucker, slimy sculpin) (1c)**
	Secondary			**Fish (1a)**	**Aquatic and terrestrial insects /larvae (1c)**
Period		Spawning: 1 August - 31 September (15, 24) Incubation: 113 d (340 temperature units) (9) Fry emergence: 223 d (635 temperature units) (9)		**Female: 6 - 7 y (age range 1 - 8) (1c)** **Male: 6 - 8 y (age range 1 - 7) (1c)**	**Female: 8 - 9 y (age range 7 - 16) (1c)** **Male: 8 - 10 y (age range 9 - 18) (1c)**
Size/age range (Note: fish are considered to be age 0 until December 31 of the year they are hatched)		Egg diameter: 5.0 - 6.2 mm (15,18), 3.9 - 4.8 mm (16) Redds: 1m long by 0.5 m wide (16, 18)		**Female: 35-289 mm,** **1 - 235 g, age 1 - 8 (1c)** **Male: 75-323 mm,** **1.8 - 387 g, age 1 - 7 (1c)**	**Female: Maximum:** **661 mm, 3379 g, age 16 (1c)** **Male: Maximum:** **642 mm, 3144 g, age 18 (1c)** Stream resident: 140 - 410 mm FL; Fluvial: 410 - 730 mm FL; Adfluvial: 508 - 824 mm FL (22).

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT - 61°36'N 124°44'W; b) unnamed creek, Keele River - 64°14'N, 125°59'W; c) NT.
2 = McCullough and Spalding 2002 – laboratory study.
3 = Selong *et al*. 2001 – laboratory study.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC, b) various systems throughout the range from 49-56°N.
5 = Baxter and McPhail 1997 – a) Chowade River, Peace R. drainage, BC, b) laboratory study.
6 = Boag and Hvenegaard 1997 – West Castle River, AB.
7 = Shepard 1985 – Flathead River, Montana.
8 = Oliver 1985 – Wigwam River, BC.
9 = Fraley and Shepard 1989 – Flathead River, Montana.
10 = Baxter and Hauer 2000 – Swan River, Montana.
11 = Earle and McKenzie 2001 – Beaverdam Creek, Alberta.
12 = Pillipow and Williamson 2004 – Goat River, Fraser River drainage, BC.
13 = Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.
14 = Craig 1997 – Yakima River basin, Washington.
15 = Goetz 1989 – review.
16 = Fairless *et al*. 1994 – Clearwater River, AB.
17 = Shepard *et al*. 1984 – Flathead River, Montana.
18 = McPhail and Murray 1979 – Mackenzie Creek, BC.
19 = Cope *et al*. 2002 – Wigwam River, BC.
20 = Adams 1994 – Weiser River drainage, Idaho.
21 = Rich 1996 – streams in western Montana.
22 = Mochnacz 2002 – review.
23 = Beak Consultants Limited 1981 – Prairie Creek, NT.
24 = Herman 1997 – Pinto Lake, AB.

3.1 Eggs (Spawning and incubation habitat)

Bull trout spawn more than once, but not necessarily every year following maturity **(iteroparous**) (Fraley and Shepard 1989; Cannings and Ptolemy 1998; Bahr and Shrimpton 2004) (Table 3). Alternate year spawning is common and probably an adaptation to marginal productivity throughout the year (Clayton 2001; Hvenegaard and Thera 2001; Mochnacz 2002). Resting females and males have been found in the Northwest Territories from all life history types, and spawning there may occur at 2 to 3 year intervals (Mochnacz 2002). If a smaller proportion of the mature population spawns each year, northern populations may be slower to recover from adverse impacts.

Temperatures ≤ 9°C may trigger spawning (McPhail and Murray 1979; Weaver and White 1985; Fraley and Shepard 1989; Ratliff *et al*. 1996), while those ≤ 5°C cause it to be suspended (Allan 1987 cited in McPhail and Baxter 1996). Spawning activity in the Pine Creek watershed of Oregon was initiated in mid-September at mean daily stream temperatures between 9.3 and 11.5°C, which declined rapidly to between 4.9 and 6.9°C near the completion of spawning activity in early October (Chandler *et al*. 2001). Kitano *et al*. (1994) observed spawning in the upper Flathead River of Montana in mid-September at water temperatures of 5.3 to 8.9°C. Bull trout in the Chowade River of northeastern British Columbia (Baxter and McPhail 1999) and Castle River system in Alberta (Fernet and O'Neil 1997) also spawn in mid-September through early October.

The female chooses the spawning site and constructs the redd, while the male defends the area and remains nearby for an average of two weeks after spawning (Fraley and Shepard 1989). In some systems, higher densities of redds have been observed in areas with > 54% overhead cover (Craig 1997). Fertilized eggs are fanned by the female and then covered with gravel (James and Sexauer (1997). The demersal, non-adhesive eggs incubate under the gravel throughout the winter and the **fry** emerge in early to late spring (Baxter and McPhail 1999). Detailed descriptions of spawning behaviour and spawning site activities are provided by James and Sexauer (1997), Kitano *et al*. (1994), and McPhail and Murray (1979).

The fecundity of bull trout populations varies widely, with larger fish having greater fecundity. In the Flathead River system of Montana, fecundity averaged 5,482 eggs per female for a sample of 32 adults averaging 645 mm TL (Fraley and Shepard 1989), while bull trout in the Arrow Lakes of British Columbia were smaller and contained fewer than 2000 eggs (McPhail and Murray 1979). A 6.7 kg female in the Flathead River system contained 12,000 eggs (Fraley and Shepard 1989); while fish in Sun Creek, Oregon, can mature at 152 mm and carry as few as 74 eggs (Goetz 1994). Eggs typically range in diameter from 5.0 to 6.2 mm (Goetz 1989), but eggs ranging from 3.9 to 4.8 mm have been found in redds in the upper Clearwater River of Alberta (Fairless *et* *al*. 1994). The bottom area disturbed by redd construction varies from 0.50 to 3.72 m² (Goetz 1989).

Table 3. Habitat and life history parameters related to bull trout reproduction, with data from the NT in bold type. Numbers in brackets refer to data sources listed below.

PARAMETER	STREAM (data source)
Reproductive strategy:	Iteroparous
Age at maturity:	Female: **age 7 - 8 (1c ,** 8**),** 6 - 7 (9) Male: **age 8 - 9 (1c),** 7 - 8 (9)
Fecundity (eggs/female):	Mean 5482 (mean TL 645 mm) (5); Range <2000 (6) to 12000 (5)
Spawning:	May not occur annually following maturity (5; 10)
Habitat type	Redds often associated with groundwater upwellings (2a, 3); Stream gradient 1.5% (5)
Builds nest	Yes. Gravel redd (2a)
Temperature (°C)	5 - 9°C (5a, 6, 8)
Depth (m)	0.454 $\pm$ 0.022 (4a) 0.07 - 0.93 (4b)
Substrate	Gravel (2a), sand to cobble (2b, 5), sometimes with an appreciable amount of silt – 22 - 30% (3, 7)
Current velocity (cm/s)	2 - 93 (2b)
Maximum age: (Note: fish are considered to be age 0 until December 31 of the year they are hatched)	Female: **age 16** (1b) Male: **age 18** (1b)
Age at senescence:	Unknown.

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT, b) Drum Lake outlet, NU, c) NT.
2 = Baxter and McPhail 1999 – a) Chowade River, Peace River drainage, BC; b) systems through range from 49-56°N.
3 = Oliver 1985 – Wigwam River, BC.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC; b) various systems throughout the range from 49-56°N.
5 = Fraley and Shepard 1989 – Flathead River, Montana.
6 = McPhail and Murray 1979 – Mackenzie Creek, BC.
7 = Ratliff *et al*. 1996 – Metolius River basin, Oregon.
8 = Herman 1997 – Pinto Lake, AB.
9 = Mushens and Post 2000 – Kananaskis Lake, AB.
10 = Bustard and Schell 2002 – Morice River, BC.

Water velocities at redd sites range from 2 to 92 cm/s, and depths from 0.07 to 0.93 m (Fernet and Bjornson 1997; James and Sexauer 1997; Baxter and McPhail 1999). In the Cedar River watershed of Washington State, the majority of bull trout redds were found in water depths ranging from 12 to 49 cm (mean 25 cm) and water velocities (mean column) ranging from 12 to 61 cm/s (mean 38 cm/s) (Reiser *et al*. 1997). Redd surveys were conducted during the day, but no spawning activity was observed, suggesting that spawning may take place primarily at night.

Water in the interstitial spaces of the gravel (8-12 mg/L) and above the redds (10-11.5 mg/L) is well oxygenated (Weaver and White 1985; Fairless *et al*. 1994).

Intergravel flow may be an important factor in spawning area selection by bull trout (Weaver and White 1985). In Washington's Yakima River basin, conductivity ranged from 193 to 222 mV, pH 7.5 to 7.8, and turbidity 0.1 to 1.0 NTU in most watersheds that contained redds (Craig 1997). An exception was the South Fork Tieton River, which receives turbid glacial runoff (3.3 NTU) during the summer, when eggs and larvae are not affected by siltation.

Bull trout redds in the shallow, high-gradient Chowade River of British Columbia were often associated with groundwater discharges that provided warmer, more stable temperatures for incubating eggs -- particularly during the coldest part of the winter (Baxter and McPhail 1999). These warmer temperatures provided a stable rearing environment and protection from freezing, and they reduced incubation time leading to an earlier date of emergence than for eggs reared at a lower temperature. The survival rate from eggs to **alevins** was significantly higher (88.6 vs. 76.1%) and less variable in areas selected by female bull trout, than in non-selected areas. There was no difference in alevin survival rates at different depths (10, 20, 30 cm).

The association of redds with groundwater discharge suggests that optimal habitats for bull trout reproduction may be limited, and that site selection by females may increase reproductive success (Baxter and McPhail 1999). The close association with groundwater inflows is a common feature of bull trout spawning habitat (Shephard 1985; Fraley and Shepard 1989; Fairless *et al*. 1994; Ratliff *et al*. 1996; Thiesfeld *et al*. 1996; Boag and Hvenegaard 1997; Craig 1997, 2001; James and Sexauer 1997; Bonneau and Scarnecchia 1998; Baxter and Hauer 2000; Gamett 2002). In the Swan River of Montana, zones of upwellings occurred consistently in bounded alluvial valley segments (Baxter and Hauer 2000). Spawning there was associated with low gradient reaches that had upwellings and stable, well sorted gravel and cobble. Floodplains in these segments allow overbank flow, which moderates sediment scour associated with flooding. In southwestern Alberta bull trout spawning is typically associated with bedrock that may intercept subsurface flow and direct it toward the surface (D. Evans, DFO Calgary, pers. comm.). These areas also provide suitable pool cover habitat and appropriately sorted substrates.

Bull trout eggs from an interior population showed an increase in survival as the temperature decreased from 10°C and a slight decrease in survival if the temperature dropped below 4°C (McPhail and Murray 1979). Lower temperatures slowed embryonic development, but led to the production of larger fry. Incubation time is temperature dependant (Weaver and White 1985), and can take from 35 to 120 days (McPhail and Murray 1979). In Coal Creek, a tributary of the Flathead River, Montana, bull trout eggs required 113 days (340 **temperature units**) to 50 percent hatch; the fry emerged from the gravel 233 days (635 temperature units) after egg deposition. Intergravel temperatures during the incubation period (October-March) ranged from 1.2 to 5.4°C, and survival to emergence averaged 53 percent.

Chronic exposure to oxygen concentrations ranging from 3 to 13.5 mg/L did not cause significant mortality or increase physical deformities in developing bull trout eggs, but low oxygen levels did retard embryonic development (Giles and Van der Zweep 1996).

Bull trout in the Flathead River, Montana, rework the substrate but do not alter its composition when constructing redds (Shephard and Graham 1982). The average percentages of fine substrates (sand, clay/silt; <2 mm sieved) ranged from 8 to 20%; gravel (2 to <6.5 mm) ranged from 16 to 19%; and larger substrates (e.g., rubble and cobble, ≥6.5 mm) ranged from 62 to 76%. Higher levels of fine substrates may impact egg survival. Redds in Smith-Dorrien Creek, Alberta, were composed largely of gravel to cobble sized substrate (Fernet and Bjornson 1997).

Hatching success is inversely related to the percent of fine material (<6.35 mm) in gravels (Weaver and White 1985; Weaver and Fraley 1991). In experimental studies, survival to emergence ranged from 49 to 69% in substrates that contained 10% fines to 0 to 4% in substrates that contained 50% fines. Kitano *et al*. (1994) observed that redds on the upper Flathead River of Montana were constructed at the downstream ends of pools, where fine gravels were prevalent. Levels of fine sediment in spawning areas of Oregon's Metolius River tributaries, which have high densities of juvenile bull trout, ranged from 22 to 30% (Ratliff *et al*. 1996). Entombment by sediment and crushing by gravel movement may be significant sources of egg mortality (Weaver and White 1985).

3.2 Alevins and fry (Rearing habitat)

Yolk absorption after hatching takes 65 to 90 days (Shepard *et al*. 1984), and fry do not attain neutral buoyancy for another three weeks (McPhail and Murray 1979). Negative buoyancy makes feeding after emergence awkward, but enables them to maintain their position in the stream. After emergence in late spring, young-of-the-year are typically found in shallow, low velocity areas near the edges of small tributary streams with an abundance of cover (McPhail and Murray 1979; Fraley and Shepard 1989; Baxter 1997a,b; Cope *et al*. 2002), although some out migration to lakes occurs shortly after fry emergence in some systems (Reiser *et al*. 1997). In the Northwest Territories, young-of-the-year are about 35 to 38 mm fork length and weigh less than 1 g in mid-September (Mochnacz *et al*. 2004).

Fry show diel movement patterns, with peak numbers out of cover from late morning to early evening, and all individuals under cover about two hours before dusk (Goetz 1997a). In the upper Chowade River of British Columbia, during summer days, fry (33-62 mm FL; 3.94-14.04 g) used slightly shallower, slower areas of side channels than juveniles (71-112 mm FL; 0.2.8-2.3 g) (Baxter 1997b). They used depths between 2 and 50 cm, but preferred depths between 10 and 30 cm. They used focal points with bottom velocities between 0 and 25 cm/s, but strongly preferred areas with bottom velocities between 5 and 18 cm/s. Fry used primarily instream overhead cover in the form of boulder, cobble and small wood. However, when habitat availability is considered, fry preferred cover in the form of small rootwads, followed by boulder, small wood, and cobble. They were found primarily over substrates consisting of silt, pebble, and cobble, but preferred areas with boulder and cobble substrate.

In Idaho streams, during summer nights, age 0 bull trout (<75 mm TL) were found primarily (88%) in the channel margins of runs and riffles, while the older juveniles (≥ age 1; 75-270 mm TL) were found primarily (92%) in the main channels, where they selected deeper, slower pool areas (Saffel and Scarnecchia 1995). The density of juvenile bull trout in reaches increased with the number of pocket pools. Reaches with high densities (3.9 to 11.2 fish/100 m^2) of bull trout had maximum summer temperatures ranging from 7.8 to 13.9°C. During summer nights, fry (<66 mm TL) in the South Fork Clearwater River basin of Idaho were associated with shallow stream margins over coarse substrates (Spangler and Scarnecchia 2001). They moved to significantly deeper (mean 0.19 m), lower velocity water and closer to cover in the fall, but maintained their association with coarse substrates.

Young-of-the-year bull trout in the West Castle River drainage of Alberta overwinter in interstitial, sub-surface flow under a dry channel bed, within and upstream of the spawning area (Boag and Hvenegaard 1997).

3.3 Juveniles (Rearing habitat)

Juvenile bull trout rear in second and third order streams, and move to rivers primarily during ages 3 to 4 (14-36 cm TL) (Fraley and Shepard 1989), although in Alberta they may remain in rearing areas for up to 6 years (Allan 1980). Sexual maturation typically occurs during ages 5 to 7 at total lengths of 30 to 50 cm (Fraley and Shepard 1989; Pratt 1992). Juveniles become less associated with the streambed as they grow larger than 100 mm TL, but remain near cover (Fraley and Shepard 1989).

During summer days, juveniles (71-112 mm FL; 0.2.8-2.3 g) in the upper Chowade River of British Columbia used slightly deeper, faster areas of side channels than the fry (33-62 mm FL; 3.94-14.04 g) (Baxter 1997b). Both groups used depths between 2 and 50 cm, but the larger fish preferred slightly deeper areas (30-40 cm), used a slightly broader range of bottom velocities (0 to 40 cm/s), and preferred slightly faster water (28 cm/s). During summer nights, juvenile bull trout (66-130 mm TL) in the South Fork Clearwater River basin of Idaho occupied significantly deeper water on average (0.30 m) than the fry (0.05 m) (Spangler and Scarnecchia 2001). In the fall, like the fry, they too moved to deeper, lower velocity water and closer to cover.

In both summer and winter juvenile bull trout (70-170 mm TL) in Idaho's Trestle Creek selected pools over riffles and used a wide range of depths at night but were absent from shallow water (<15 cm) during the day (Bonneau and Scarnecchia 1998). They occupied higher velocity water on average during summer days (21 cm/s) than nights (7 cm/s) and during summer days than winter days (0 cm/s -- assuming water velocities were at or near zero below the substrate). During summer days they were, on average, 7 cm above the substrate, while on winter days they were found within or resting upon the cobble substrate. They were more closely associated with cover during the day, and made greatest use of cover during winter days (Bonneau and Scarnecchia 1998). However, even at night juveniles usually stay within 72 cm of cover (Sexauer 1994; Sexauer and James 1997).

Cover use appears to be dictated by latitude and elevation, since the diversity of cover types (e.g., woody debris) tends to decrease with increasing latitude and/or elevation (Mochnacz *et al*. 2004). In summer, in Funeral Creek, Northwest Territories (61°36'N, 124°48'W), juvenile bull trout were found most frequently in high velocity habitats, at or near the bottom, in pocket pools created by large cobble and boulders (Mochnacz *et al*. 2004). Unembedded cobbles and boulders are particularly important cover for juvenile bull trout, followed by overhanging vegetation (Sexauer 1994; Baxter 1997b; Sexauer and James 1997; Bonneau and Scarnecchia 1998; Earle and McKenzie 2001). However, where rootwads are available they may be preferred over other forms of cover (Baxter 1997b). The water velocity in microhabitats selected by juvenile bull trout is significantly lower than that across stream transects, indicating that the fish are selecting low velocity habitats (Sexauer 1994; Sexauer and James 1997; Earle and McKenzie 2001).

Further south, in Oregon, juvenile rearing habitat is characterized by high levels of shade, undercut banks, the presence of large woody debris, gravel in riffles, low levels of fine sediment in riffles, and little bank erosion (Dambacher and Jones 1997). The presence of pools was not an important descriptor of juvenile bull trout presence, since the typical rearing streams have gradients of 5.0%, and are dominated by riffles and rapids.

With the onset of winter, at water temperatures of 1.1 to 1.3°C, juvenile bull trout remain concealed beneath "home stones" during the day and emerge at night to feed and rest on the bottom, primarily in pool and run habitats (Thurow 1997; Jakober *et al*. 2000). Once ice cover forms, use of submerged cover declines (Jakober 1995; Jakober *et al*. 1998). They avoid areas where frazil or bottom ice forms and will move downstream or into adjacent riffles and runs in mid-winter to avoid these unfavourable ice conditions (Jakober 1995; Jakober *et al*. 1998; D. Evans, DFO Calgary, pers. comm.).

In laboratory studies, juvenile age 1 bull trout (62.4 mm mean FL; 2.23 g mean round weight), showed diel microhabitat preferences (Baxter and McPhail 1997). Substrate preference during the day was primarily cobble and boulder, and at night primarily silts and gravel. Significantly shallower water and lower water velocity were associated with the habitats preferred during the day, than those at night. A similar pattern has been observed in the wild (Goetz 1997a).

The preference of juvenile bull trout for coarser substrate than is used by spawning adults (Goetz 1994), means that it is important to ensure that adequate amounts of large substrates are maintained in bull trout streams to provide rearing habitat (Baxter and McPhail 1997). The high fidelity of juvenile bull trout to cover during the day makes it difficult to accurately assess their populations and habitat use using daytime observations (Jakober *et al*. 2000).

Given a natural thermal gradient (8-15°C) juvenile bull trout chose the coldest water available (Bonneau and Scarnecchia 1996). In the Flathead River system they were seldom observed in streams with summer water temperatures over 15°C (Fraley and Shepard 1989). They were present in many reaches that were not used by adults, and apparently swam upstream to these sections to grow.

Age 0 bull trout began to show evidence of heat shock response at 14°C (Weber *et al*. 2001). In laboratory studies, food consumption by age 0 bull trout declined significantly at temperatures over 16°C, and fish held at temperatures ≥22°C did not feed (Selong *et al*. 2001). Age 0 and 1 bull trout did survive temperatures up to 20°C for up to 60 d, but survival decreased rapidly with exposure to even small increases in temperature above this level. None of the fish held at 22°C survived a 60 day trial. In Idaho streams, bull trout have been observed in temperatures of 20.5°C (Adams and Bjornn 1997).

Radiotelemetry studies found that some subadult bull trout (247-399 mm TL) in Montana's upper Flathead River are migratory, while others are not (32 cf. 35 fish; Muhlfield and Marotz 2005). Most migrating subadults made rapid or incremental downstream movements (mean distance 33 km; range 6-129 km) within the river system or to Flathead Lake during high spring flows and as temperatures declined in the fall and winter. During the day, subadults used complex habitats throughout the upper river system, including deep runs that contained unembedded boulder and cobble substrates, pools with large woody debris, and deep lake-influenced areas of the lower river system.

Juvenile bull trout are benthic foragers that roam slack water areas and pick prey items off the bottom during both day and night (Nakano *et al*. 1992; Bonneau and Scarnecchia 1998; Stewart *et al*. 2007). They use different foraging strategies and occupy different microhabitats than sympatric cutthroat trout (Nakano *et al*. 1992). In summer, juvenile bull trout in the Mackenzie River watershed eat aquatic and terrestrial insects (e.g., grasshopper) and insect larvae (Mochnacz *et al*. 2004). In August, baetid mayflies are an important dietary item for juvenile bull trout in the upper Flathead River of Montana (Nakano *et al*. 1992).

3.4 Adults

In summer, adult bull trout in the Mackenzie River drainage are typically captured in deep pools of small, high gradient mountain streams with cobble to boulder-type substrates (Mochnacz *et al*. 2004). During the day they are often associated with some type of large cover, such as undercut banks, deep pools, or boulders.

The maximum size of adult bull trout, and their weight at length relationship, varies among systems (Pillipow and Williamson 2004). Precocious males, aged 3 and averaging 215 mm in length, have been observed actively spawning with larger females (500 to 600 mm) (Shepard and Graham 1983a cited in Goetz 1989). Small "sneaker" males (mean 412 mm TL) have also been observed avoiding larger dominant males (mean 735 mm TL) to spawn with larger females (mean 651 mm TL) (Baxter 1997a), as have small resident males with fluvial females (Brown 1994).

Within its range the occurrence of bull trout is strongly correlated with maximum daily water temperatures <14 to 16°C (Dunham *et al*. 2003). Temperature may affect the ability of bull trout to compete with other species. In sympatry, bull trout were numerically dominant to rainbow trout at temperatures <13°C and vice versa (Haas 2001). In warmer water, bull trout are in **allopatry**, rather than **sympatry**, with westslope cutthroat trout, suggesting that the distribution of bull trout with respect to temperature may be partially dependant on the presence or absence of cutthroat trout (Pratt 1984). Shephard *et al*. (1984) suggested that increasing temperatures might shift species distribution in the Flathead River, Montana to favour cutthroat trout over bull trout.

Brook trout seem to be segregated from bull trout by temperature (Parkinson and Haas 1996). In the North Thompson River of British Columbia, bull trout are absent from warmer streams and brook trout from colder streams, with an overlap in temperature range of <2°C. In the laboratory, bull trout growth was 25% higher in allopatry than when they were held in sympatry with brook trout, while the presence of bull trout had a significant positive effect on brook trout, especially at temperatures >12°C (McMahon *et al*. 1999). In the laboratory, brook trout had a 2.5-times greater growth rate advantage over bull trout when together at 17°C (McMahon *et al*. 2001). Bull trout may inhabit warmer waters in the absence of other *Salvelinus* species (Adams 1994).

Adult bull trout eat a wide variety of invertebrates and fishes (Boag 1987; Connor *et al*. 1997; Wilhelm *et al*. 1999; Mochnacz *et al*. 2004; Stewart *et al*. 2007). In the Mackenzie River watershed they eat aquatic and terrestrial insects (e.g., grasshoppers, ants, wasps) and insect larvae; fish (e.g., slimy sculpin *Cottus cognatus*, longnose sucker *Catostomus catostomus*, Arctic grayling *Thymallus arcticus*, and bull trout); and small worms (Mochnacz *et al*. 2004). In the upper reaches of the Muskeg River system of Alberta they eat primarily insects, while in the lower reaches they also feed on rainbow trout (Boag 1987). After ice-out in July, both small (≤250 mm FL) and large (≥250 mm FL) bull trout in a small alpine lake fed on seasonally abundant prey species, in particular chironomid pupae, *Daphnia pulex* var. and the amphipod *Gammarus lacustris*, which are cropped after they reproduce (Wilhelm *et al*. 1999). Mink (*Mustela vison*), bears (*Ursus* spp.), osprey (*Pandion haliaetus*), and river otter (*Lontra canadensis*) prey on adult bull trout (Stelfox 1997; Jakober *et al*. 1998; Chandler *et al*. 2001).

4.0 HABITAT IMPACTS ON FISH BIOLOGY

Bull trout populations in tributary streams of the Mackenzie River drainage appear to be small, but are wide ranging and use a variety of habitat types over a large geographical area (Mochnacz *et al*. 2004). Many of these streams likely provide critical spawning and rearing habitat for bull trout and other species, so care must be taken to ensure that industrial development does not disrupt these habitats, especially at times critical to the species' life history. Understanding of local bull trout ecology and microhabitat use is necessary to prevent or mitigate adverse effects from development (Earle and McKenzie 2001).

Habitat degradation and fragmentation are leading causes of the decline and extirpation of migratory bull trout populations throughout their range (Fraley and Shephard 1989; Goetz 1994; Rieman and McIntyre 1995; Rieman *et al*. 1997; Baxter *et al*. 1999; Ripley *et al*. 2005) (Table 4). Harvesting pressure and species introductions are also important factors affecting the survival of bull trout populations. The bull trout's specific requirements for spawning and rearing habitat, and the general sensitivity of each life stage, make it an excellent indicator of environmental disturbance (Fraley and Shepard 1989; Mochnacz 2002). Shepard and Graham (1983b) provide a detailed description of the program and techniques used to monitor bull trout populations in the Upper Flathead River of Montana.

Table 4. Some activities with the potential to affect key aspects of bull trout habitat and their potential effects on the species.

Activity	Potential impact		
	Habitat	Species	Directly affected life stage(s)
• water removal • drainage alterations • seismic testing	• reduced groundwater flow • altered baseflow 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 • bank alteration	• 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 instream 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 • alteration of bedload movement and bottom substrate composition	• interruption of spawning migrations • restricted access to coldwater summer refugia in headwater tributaries • inundation or dewatering of spawning areas • population extirpation • creation of new overwintering areas • alteration of bottom substrate suitability for spawning, rearing, and invertebrate production	• all life stages with greatest effects on adult spawners
• road and right-of way construction • population growth	• improved access to bull trout 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 hydrological 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 • changes in the frequency of extreme weather events that lead to flooding or drying and alter recruitment	• all

4.1 Habitat degradation

The reliance of bull trout on groundwater inflows to provide suitable stream spawning habitats and maintain shallow isolated pools for overwintering, makes them very vulnerable to activities that disturb or reduce these inflows (Boag and Hvenegaard 1997; Craig 2001). High road densities may degrade bull trout habitat by reducing **baseflow** discharges (Craig 2001) and increasing sediment inputs (Rieman and McIntyre 1993; Ripley *et al*. 2005). Blasting and water withdrawals are examples of other activities that might affect inflows from these aquifers; global or local climate change might also alter baseflow. Logging may increase warm surface runoff, moderating the cooling influence of groundwater-dominated stream flow (Ripley *et al*. 2005). It may also result in nutrient pulses that alter food web structure.

Logging, right-of-way construction for roads, transmission lines and pipelines, often remove riparian vegetation, reducing instream woody debris that provides important bull trout habitat and increasing overland runoff and sedimentation (McPhail and Baxter 1996; Knotek *et al*. 1997; de Graff 1999; USFWS 2001; Post and Johnston 2002; Ripley *et al*. 2005). Mathematical projections suggest that forest harvesting over the next 20 years might result in the local extirpation of bull trout from 24 to 43% of stream reaches that currently support them in the Kakwa River basin of Alberta (Ripley *et al*. 2005). Attempts have been made to restore reaches of tributaries in the upper Flathead River basin that have been adversely affected by high sediment inputs (Knotek *et al*. 1997). Sediment can also be introduced by small-scale suction dredging for gold (USFWS 2001). Washington State has imposed timing restrictions on this form of mining to decrease its impact on bull trout eggs and fry.

Unrestricted grazing by livestock can harm bull trout by mobilizing sediment, damaging riparian vegetation and trampling redds, but is readily mitigated by fencing (USFWS 2001).

Land management activities that reduce pool habitat, instream cover, and streambed stability may be especially detrimental to juvenile bull trout in winter (Bonneau and Scarnecchia 1998). The presence of stable, unembedded cobbles is important to juvenile bull trout, particularly as overwintering habitat. Sediment inputs that embed these cobbles may limit the carrying capacity of stream habitats for juvenile salmonids. In contrast, destabilization of cobble habitats may also result in low survival rates of eggs and fry, washouts of fish from sections of streams (Pearsons *et al*. 1992), and direct crushing of fish (Erman *et al*. 1988).

In the Swan River of Montana, changes in bull trout redds were positively correlated with the extent of alluvial valley segments bounded by knickpoints (abrupt changes in the longitudinal profile of the stream valley as a result of bedrock structure) and negatively correlated with the density of logging roads in spawning tributary catchments (Baxter *et al*. 1999). The alluvial valley segments may contain significant areas of groundwater discharge (Baxter and Hauer 2000), while the logging roads and logging may cause changes in the morphology and stream-channel features that provide habitat for aquatic biota and facilitate access by harvesters (Baxter *et al*. 1999). Logging the riparian zone of bull trout streams can alter the delivery, storage, and transport of large woody debris, and thereby alter natural stream morphology and habitat features (Cross and Everest 1995; Hauer *et al*. 1999). Upland logging can alter water flow regimes and sediment delivery, and may have cumulative effects on the balance of large woody debris in the streams. However, further work is needed to clarify the underlying mechanisms by which forest harvesting and road networks adversely affect the occurrence and abundance of bull trout (Ripley *et al*. 2005).

The relocation of spawners from areas affected by development does not appear to compensate for habitat losses. Development of a tailings dam for the Kerness Mine, in the Thutade watershed of northwestern British Columbia, removed 4.1 km of stream habitat used by bull trout in S. Kerness Creek (Paul and Bustard 2004). The total number of spawners in the creek decreased significantly following mine construction, as did the density of juveniles in the remaining 2 km section. While some spawners may have relocated to nearby tributaries the densities of age 0 and 1 bull trout in these tributaries did not increase. This suggests that relocation of spawners may not compensate for habitat losses, and that habitat quantity must be maintained. The effectiveness of mitigation measures to address the habitat losses, including removal of migration barriers and the construction of artificial spawning beds below the tailings dam, are being tested.

4.2 Habitat fragmentation

Complex river habitats with abundant cover, and natural connections of suitable spawning and rearing habitat, must be maintained over a large scale to conserve bull trout populations (Muhlfeld and Marotz 2005). Late-summer dewatering of stream habitats fragments populations, and can cause significant mortality among spawning bull trout in shallow tributaries (Wissmar and Craig 1997).

Barriers such as hydroelectric dams and beaver dams can fragment bull trout habitat and prevent fish from accessing optimal spawning habitat (Goetz 1994; Baxter and McPhail 1996; Fernet and O’Neil 1997; Swanberg 1997b; USFWS 2001; Post and Johnston 2002). Programs to transport adult bull trout upstream of hydroelectric dams can mitigate this damage, particularly in areas with small populations (Swanberg 1997b). BC Hydro has used discharge tunnels successfully to provide bull trout with upstream passage through the Duncan Dam (Olmsted *et al*. 2001). Entrainment of bull trout in irrigation channels caused significant (15%) mortality among bull trout spawning in the Belly River of Alberta and Montana until screening was installed at the canal headgate (Clayton 2001). In Oregon, the construction of water storage structures led to the extirpation of eight populations above these dams within 15 years (Goetz 1994).

Improperly designed, installed, or maintained culverts and weirs can also create smaller, often seasonal, physical barriers to bull trout movements (Goetz 1994). In some instances, impoundments can provide overwintering habitat and, in the case of the Williston Reservoir on the Peace River, may have led to the development of an adfluvial population (Bruce and Starr 1985; McPhail and Baxter 1996).

4.3 Species introductions

The introduction of lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), or their hybrids (splake) can displace bull trout, and may prevent them from becoming established in certain low-elevation lakes (Donald and Alger 1993; Donald and Stelfox 1997). In Bow Lake, Alberta, for example, the introduction of lake trout in 1964 decimated the bull trout population by 1992. Competitive interactions with brook trout may be an important factor in the mechanism responsible for the regulation of bull trout densities in tributary streams, at least on a local scale (Nakano *et al*. 1998). Stocking bull trout streams with hatchery reared steelhead trout (*O. mykiss*) and chinook salmon (*O. tshawytscha*) may slow bull trout growth (Underwood *et al*. 1995). Removal or suppression of introduced species to promote bull trout recovery is difficult (Montana Bull Trout Scientific Group 1995).

Bull trout will hybridize with Dolly Varden (Haas and McPhail 1991; Baxter *et al*. 1997; Hagen and Taylor 2001) and brook trout (Markle 1992; Adams 1994; Kitano *et al*. 1994; Saffel and Scarnecchia 1995). However, hybrids do not appear to be common in the wild (Baxter *et al*. 1997; Leary and Allendorf 1997). Sympatric populations of Dolly Varden and bull trout maintain their genetic integrity in spite of gene flow (Baxter *et al*. 1997; Hagen and Taylor 2001).

4.4 Improved access

Bull trout are sensitive to exploitation because their populations are small and individuals are slow-growing, late to mature, and spawn in non-consecutive years (Carl *et al*. 1989; Clayton 2001; Bustard and Schell 2002; Post and Johnston 2002). They are voracious **piscivores** and highly susceptible to exploitation by angling before they reach maturity (Goetz 1989; Brown 1992; Stelfox and Egan 1995; McPhail and Baxter 1996; Mushens and Post 2000; Olmsted *et al*. 2001). Because of their migratory habit and range, bull trout populations can be very vulnerable to activities that interrupt migration routes, and to angling pressure along the migration route (McLeod and Clayton 1997;

Stelfox 1997; Pillipow and Williamson 2004). However, overharvested populations can recover quickly when sport angling is reduced or eliminated (Stelfox 1997). Adfluvial populations in lakes that do not have restricted access, and that have been stocked with other *Salvelinus* species are particularly vulnerable to extirpation (Donald and Stelfox 1997).

Unfortunately, opportunities for population enhancement are limited, and the major hope for restoring bull trout numbers lies with regulation (e.g., closures, gear restrictions, minimum size limits, harvest limits) (McPhail and Baxter 1996). In the Northwest Territories sport harvesters are allowed to catch 2 bull trout per day, and can only have 3 in their possession at any one time (G. Low, DFO Hay River, pers. comm. 2005).

4.5 Climate change

Elevated temperature is considered a major factor in the decline of southern bull trout populations (Rieman *et al*. 1997), some of which already migrate into headwater streams early in the season to avoid unfavourably warm temperatures (Swanberg 1997a). Climatic warming could change the availability of suitable thermal habitat to bull trout. In the south this might significantly restrict the species' range over its current distribution (Rieman and McIntyre 1993). In the north, it might facilitate northward colonization by bull trout and subsequent sympatry and hybridization with Dolly Varden (Reist 1994; Mochnacz 2002). In both areas, it could increase competition or predation by other species that colonize cold bull trout habitat as it warms. Whether bull trout distributions would expand to the north and to higher elevations in the event of significant warming is unknown.

Winter flooding caused by heavy precipitation or glacial floods can damage bull trout habitat and extirpate populations (Goetz 1994). Under normal circumstances populations should recover over time, but those that are already depleted or limited by migratory barriers or other factors may not recover.

5.0 SUMMARY

Bull trout require cold, clean water. They have complex life histories and, in some cases, very large home ranges. Their populations can be resident or migratory, and the latter can follow fluvial, adfluvial or anadromous life histories. Spawning occurs in shallow, fast-flowing tributary streams, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. Spawning streams have stable channels with suitable substrate (gravel-boulder) for redd construction and rearing, and abundant cover. The migratory populations require uninterrupted migratory corridors that connect suitable spawning and overwintering habitats that may be hundreds of kilometers apart. The species' relatively specific habitat requirements, particularly for spawning and rearing, make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators bull trout are also vulnerable to overharvesting. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Based on the limited data available, habitats used by bull trout for spawning and rearing in the Northwest Territories appear to be similar to those used elsewhere. However, they may make less use of large woody debris for cover, as it is less abundant in the region.

Efforts to understand and conserve key processes likely to influence the persistence of populations may be more likely to conserve bull trout populations than efforts to design minimal habitat reserves (Rieman and Dunham 2000). Land management for bull trout protection should be site-specific (Watson and Hillman 1997), due to the species' patchy seasonal habitat use, extensive migratory movements, and narrow spawning and rearing requirements.

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8.0 ABBREVIATIONS

FL = fork length—distance from the tip of the fish’s snout to the notch in its tail.

MDMT = Maximum daily maximum temperature is the warmest daily maximum temperature recorded during a given year or survey period.

MWMT = Maximum weekly maximum temperature is the mean of daily maximum temperatures measured over the warmest consecutive seven-day period (typically during a given year).

NTU = Nephelometric turbidity units or NTU are a measure of light scattered by suspended particles in water. High NTU measurements indicate low water clarity (i.e. high turbidity).

SL = standard length—distance from the tip of the snout to the base of the caudal fin rays.

TL = total length—distance from the tip of the fish's snout to the tip of its tail.

UUILT = ultimate upper incipient lethal temperature.

YOY = young-of-the-year.

9.0 GLOSSARY

Adfluvial fish populations move between lake and river or stream environments.

Alevins are newly hatched, incompletely developed fishes (usually salmonids) still in the nest or inactive on the bottom and living off stored yolk.

Allopatric species occur in geographical isolation from one another.

Anadromous fish populations move downstream into marine waters to feed, and return upstream into fresh water to spawn and/or overwinter.

Baseflow is stream flow derived from groundwater.

Fluvial fish populations remain in rivers and streams throughout their lives.

Fry are young fish, newly hatched, after yolk has been used up and active feeding has commenced.

Iteroparous fish spawn more than once in their lives.

Piscivores eat fish.

Profundal species occupy deep water habits near the lake bottom, below the effective depth of light penetration.

Larval fishes (plural larvae) are young fish, newly hatched, before the yolk has been used up (see also **Alevins**).

Redds are gravel nests constructed by salmonid fishes.

Sympatric species occur in the same or overlapping areas.

Temperature units are Centigrade degree days above 0°C.

Appendix 1. Life history and habitat parameters

The emphasis of this work is on observations from within the Mackenzie Valley region. Terms such as “dominant”, “preferred” and “optimum”, which have been used in other summaries (e.g., Ford *et al*. 1995; Roberge *et al*. 2002), are avoided unless they are supported by directed research studies. This is because sampling observations may not accurately reflect a species’ preferences unless the spatial and temporal biases related to sampling design and gear are carefully controlled. The following sections define what is meant by the various life history and habitat use parameters used in the text and tables and in the appendices that follow. Some parameters described here may not be used in this report because this description applies to all of the habitat use reports in the series.

TABLES 2 and 3

Habitat use and requirements

These tables summarize habitat associations during the life history stages of the species. Separate tables may be included for stream, river, and lake environments. Observations from areas within the Mackenzie River watershed are in bold type. The following parameters are included, with the units of measurement typically used:

- **Habitat type** – habitat type most commonly associated with observations of the life history stage (e.g., streams–pools, runs, riffles; lakes–littoral, pelagic, benthic);
- **Stream gradient** – percent (%) slope;
- **Depth range (m)** – range of depths from which the species has been reported;
- **Substrate** – substrate type(s) most commonly associated with observations of the species;
- **Cover** – cover type(s) most commonly associated with observations of the species:
- **Habit** – typical distribution within the habitat type (e.g., surface, midwater, benthic, above or below thermocline, inshore or offshore);
- **Velocity range** – water velocities (cm/s) wherein the species is most commonly observed;
- **Turbidity (NTU):**
    - **range** – turbidity range wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Oxygen (mg/L):**
    - **range** – dissolved oxygen levels wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Temperature (°C):**
    - **range** – water temperatures wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Prey:**
    - **Primary** – taxa or taxon typically comprising the majority (by weight/volume/food value) of the food found in the stomachs of fishes sampled, or that were seen to be eaten during *in situ* behavioural studies;
    - **Secondary** – taxa or taxon comprising the minority (by weight/volume/food value) of food found in the stomach of fish sampled, or that were seen to be eaten during *in situ* behavioural studies. [Note: Differences in prey selection (i.e. primary/secondary) may reflect changes in the seasonal availability rather than the relative importance of food items.];
- **Duration** – number of seasons, months, or years in which each specific life stage exists or occurs;
- **Size/Age range** – average and/or maximum size range (mm) of the life history stage; or maximum size range (mm); FL = fork length, SL = standard length, TL = total length. A fish is age 0 until December 31 of the year it was hatched unless otherwise indicated.

Reproduction

This table summarizes habitat and life history parameters related to the species' reproduction. Observations from areas outside the Mackenzie River watershed are italicized. The following parameters are included:

- **Reproductive strategy** – *oviparous* species produce eggs that hatch outside the body of the mother; *iteroparous* species produce their young in annual or seasonal batches (most fishes); *semeloparous* species (e.g., salmon) produce all of their offspring at one time and then usually die; *annual* spawners reproduce each year following maturity until they die or reach reproductive senescence; under marginal conditions a portion of the reproductive population may rest for a year or more between spawning events (*% resting*);
- **Age at maturity** – range of ages at which males (M) and females (F) become sexually mature, with any estimate of the most common age at maturity provided in brackets;
- **Fecundity** – range in the number of eggs produced by females;
- **Spawning habitat** – habitat types wherein spawning has been observed, ripe and running fish have been caught, ripe and spent fish have been caught together, or eggs or sac larvae have been found. The presence of mobile young-of-the-year was used to identify nursery areas, and sometimes "suspected" spawning areas;
- **Spawning habit** – some species *build a nest* by altering the bottom substrates to meet their requirements before spawning; others *use existing nests* constructed by other species; *broadcast spawners* spread their eggs over suitable areas of unaltered bottom substrates; some species *care for the eggs* or *care for the young*;
- **Spawning temperature** – temperature range at which spawning has been observed;
- **Spawning depth** – depth range at which spawning has been observed;
- **Spawning substrate** – substrate type(s) observed at spawning locations;
- **Spawning current velocity** – current velocity observed at spawning locations;
- **Maximum age** – life expectancy of the species;
- **Reproductive senescence** – age at which the species stops reproducing.

APPENDICES 2 and 3

The seasonal habitat requirements for each life history stage are presented below in separate appendices for stream and lake environments. Within these appendices, observations from the Mackenzie River watershed are in bold type.

Life history stage

Observations on habitat use are summarized by life history stage. Four stages are recognized:

- **Spawning/eggs** – includes habitats on the spawning grounds where adults spawn and eggs mature and hatch;
- **Young-of-the-year (YOY)** – larvae and fry less than age 1 (age 0 until December 31 of the year they are hatched);
- **Juveniles** – sexually immature fish older than age 1;
- **Adults** – include fish that have attained sexual maturity.

Seasons

Habitat use was divided into four seasons, which correspond to the environmental conditions rather than to the calendar seasons. Calendar months are also provided if possible, but the correspondence between environmental variables and calendar months varies from south to north and from year to year. In the north of the Mackenzie watershed (Inuvik; S. Stephenson, DFO, pers. comm.), the seasons used are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, typically late April to mid June;
- **Summer (Su)** – the period of open water, typically mid-June to late September;

- **Fall (Fa)** – the period of ice formation, typically late September to late November;
- **Winter (Wi)** – the period of ice cover, typically late November to late April.

In the south (Hay River; G. Low, DFO, pers. comm.) they are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, mid-April to early June;
- **Summer (Su)** – the period of open water, typically early June to late-September;
- **Fall (Fa)** – the period of ice formation, typically late-September to mid-November;
- **Winter (Wi)** – the period of ice cover, typically mid-November to mid-April.

These date ranges are averages, since the timing of breakup varies from river to river and lake to lake depending upon factors such as stream gradient, exposure to sunlight, and lake size.

Water depth

Five water depth categories area used for stream environments: 0–0.2, >0.2–0.6, >0.6–1, >1–2, and >2 m. Depth represents the distance from the surface of the water downwards. The depth association of a fish found in the upper metre of the water column, for example, would be reported as 0–0.2, >0.2–0.6 and >0.6–1.0. Depth is reported as stated in the reference, but if "shallow" water was the only descriptor, a depth of 0–20 cm was used to represent "shallow" water. A broader range of depths is used to describe lake environments: 0–1, >1–2, >2–5, >5–10, and >10 m.

Substrate type

Substrate type was reported as stated in the reference. However, if particle size was provided, substrate type was classified as follows:

- **bedrock** = uniform continuous substrate;
- **boulder** = >25 cm;
- **cobble** = 17–<25 cm;
- **rubble** = 6.4–<17 cm;
- **gravel** = 0.2–<6.4 cm;
- **sand** = <0.2 cm;
- **silt/clay** = finer than sand with fine organic content;
- **muck (detritus)** = mud with coarse organic content;
- **hard-pan clay** = clay; and
- **pelagic** = open water.

Cover type

Cover features that may provide protection, or a refuge, from predators, competitors, and adverse environmental conditions include:

- **None** – no cover;
- **Submergent vegetation** – aquatic plants that grow entirely below the surface and are attached to the bottom by roots or rhizomes;
- **Emergent vegetation** – aquatic plants with foliage that is partly or entirely borne above the water surface (e.g., cattail *Typha* spp.) or float on the surface of the water (e.g., milfoil);
- **Algae** – aquatic algae present on the bottom or within the water column;
- **Wood** – large (LWD) or smaller woody debris (SWD) on the bottom or within the water;
- ***In situ*** – submerged cavities and/or crevices, undercut banks;
- **Substrate** – interstitial spaces between any size of substrate (boulder-sand);
- **Overhead** – cover originating outside the riparian zone that overhangs the stream and/or banks, which includes overhanging banks or riparian vegetation, woody debris outside the channel, or anything above the surface that provides shade.

Habitat

In flowing water, habitat refers to the type of channel unit, and typical water velocity within the unit that the species inhabits, including:

- **Pool** – velocity range <0.25 $m \cdot s^{-1}$;
- **Run** – velocity range 0.25–0.50 $m \cdot s^{-1}$;
- **Riffle** – velocity range 0.50–1.00 $m \cdot s^{-1}$;
- **Rapid** – velocity range >1.00 $m \cdot s^{-1}$;
- **River margin** – habitat along the banks of the mainstem channel, often low velocity;
- **Off-channel** – any habitat that is outside the mainstem flow including side channels, backwaters, and off channel habitats, often low or no velocity.

Water velocity differences are not used to differentiate lake habitats; rather they are differentiated on the basis of their proximity to flowing water or shorelines, as follows:

- **Lake inlet** – near or within stream or river plumes entering the lake;
- **Lake outlet** – near or within the channel that drains the lake;
- **Inshore** – typically associated with littoral habitat along the edges, rather than the middle of the lake;
- **Offshore** – typically associated with the middle, rather than the edges of the lake. Where possible their typical position in the water column is described (e.g., surface, midwater, benthic, above or below thermocline).

Appendix 2. Stream habitat requirements for bull trout. Data from the Northwest Territories are in bold type.

Stream habitat features:	**LIFE STAGES** [Season of use (reference)]				**LEGEND/COMMENTS/REFERENCES**
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**Season of use:**
Depth (m)					Sp = spring
0-0.2	Fa, Wi (2a,b)	**Su** (**1**,6), Fa (6)	**Su** (**1**,6), Fa (6)	**Su (1)**	Su = summer
>0.2-0.6	Fa, Wi (2a,b)	**Su (1)**, Fa (6)	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Fa = fall
>0.6-1	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Wi = winter
>1-2			**Su (1)**, Fa (6), Wi (5)	**Su (1)**, Wi (5)	
>2				**Su (1)**	
Substrate					
Bedrock					
Boulder		Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	*In areas without surface flow, YOY may winter in the interstices of the substrate where there is sub-surface flow (5)
Cobble	Fa, Wi (2b)	**Su (1)**, Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	
Rubble	Fa, Wi (2b)		Su (8)	**Su (3)**	
Gravel	Fa, Wi (2a,b, 4, 5)		Su (8)	**Su (3)**	
Sand	Fa, Wi (2b)		Su (8)		
Silt/Clay	Fa, Wi (4)				Some spawning sites have appreciable amounts of silt (4)
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					Use of submerged cover decreases after formation of surface ice (7)
None					
Submergents					
Emergents					
Algae					
Wood			Su (8)		
In situ					
Substrate		**Su (1)**	**Su** (**1**,8)	**Su (1)**	Boulder, cobble
Undercut bank/overhang	Fa, Wi (4)			**Su (1)**	Shallow redds excavated within 2.5 m of the banks of the Wigwam R. (4)
Overhead					
Other				**Su (1)**	Depth, turbulence
Velocity/Habitat					
Pool	Fa, Wi (2b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Run	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Riffle	Fa, Wi (2b)		**Su** (**1**,8)	**Su (1)**	
Rapid					
River Margin					
Off-channel					

1 = Mochnacz *et al*. 2004 – Northwest Territories.

2 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, British Columbia, b) various systems throughout the range 49-56°N.
3 = Beak Consultants Inc. 1981 – Prairie Creek, Northwest Territories.
4 = Oliver 1985 – Wigwam River, British Columbia.
5 = Boag and Hvenegaard 1997 – West Castle River, a tributary of the Oldman River, Alberta.
6 = Spangler and Scarnecchia 2001 – South fork Clearwater River, Idaho.
7 = Jakober *et al*. 1998 – Bitterroot River drainage, Montana.
8 = Sexauer 1994, Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.

Appendix 3. Lake habitat requirements for bull trout.

Lake habitat features:	**LIFE STAGE** [Season of use (reference number)]				**LEGEND/COMMENTS/REFERENCES**
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**LEGEND**
Depth (m)					**Season of use:**
0-1				All (1)	Sp = spring
>1-2				All (1)	Su = summer
>2-5				All (1)	Fa = fall
>5-10				All (1)	Wi = winter
>10				All (1)	All = year-round
Substrate					
Bedrock					
Boulder					
Cobble					
Rubble					
Gravel					
Sand					
Silt/Clay					
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					
None					
Submergents					
Emergents					
Algae					
Wood					
In situ					
Substrate					
Undercut bank/overhang					
Overhead					
Other					
Habitat					
Lake inlet					
Lake outlet					
Inshore (littoral)				All (1,2)	
Offshore-surface					
Offshore-midwater					
Offshore-benthic				All (1,2)	

1 = Connor *et al*. 1997 – Chester Morse Lake, Washington.
2 = Hanzel 1985 – Flathead Lake, Montana.