PROPOSAL:

Salmo River Bull Trout (Salvelinus confluentus) Conservation Status, Population Limitation, and Threats.

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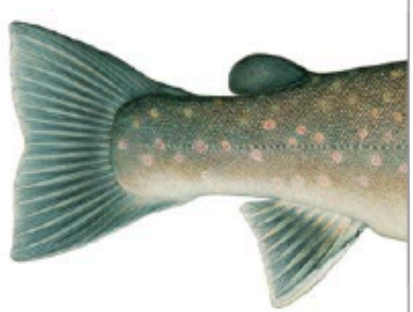
PREPARED FOR:
Salmo Watershed Streamkeepers Society
Box 718, Salmo, BC V0G 1Z0



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ABSTRACT

Bull Trout studies have been ongoing in the Salmo River watershed since the late 1990s. Because of low spawner abundance, concern about population viability began at this time as well. In 2008 and 2009, the Salmo Watershed Streamkeepers Society hosted Bull Trout conservation workshops focused on the Salmo Watershed. As one outcome of these meetings, a Bull Trout-specific information summary (this document) was identified as a necessary step in developing an action plan for Bull Trout conservation and management in the watershed. Salmo River Bull Trout behaviour, habitat use, and population data are available from several important studies targeting both juvenile and subadult/adult life stages. The Salmo River Bull Trout population exhibits both fluvial (migration to and from the mainstem Salmo River) and adfluvial (migration to and from Seven Mile Reservoir) life histories. With respect to adfluvial fish, significant uncertainty remains about how many Salmo River Bull Trout utilize Seven Mile Reservoir, and their survival there. Spawning and juvenile rearing habitats are located within the South Salmo River, Sheep Creek, Clearwater Creek, and upper Salmo River watersheds. With respect to life history and critical habitats, the most significant remaining data deficiencies may be: 1) uncertainty about the relative importance of adfluvial versus fluvial life histories for subadults/adults, and 2) juvenile rearing abundance and critical habitats outside of the Sheep Creek and South Salmo River watersheds. Salmo watershed Bull Trout population data suggests that the most important life stage limiting the population is probably not juvenile production in tributary environments, as observed juvenile densities are only marginally below those observed elsewhere in the upper Columbia Basin. Furthermore, current spawner densities do not appear to be high enough to seed the existing habitat space. The juvenile rearing environment may be limiting at higher spawner abundance, however, due to high water temperatures in lower reaches of these streams limiting the total amount of suitable space. It would be informative to increase knowledge of temperature variation in possible rearing areas. Instead, population limitation likely occurs in the subadult/adult rearing environments that are utilized following emigration from natal tributaries. Productivity within subadult/adult rearing habitats may be inadequate for a self-sustaining, migratory Bull Trout population, and could be limited by habitat degradation, increased water temperature, interrupted connectivity, and fish community changes. These limiting factors are associated with threats of moderate-to-high severity and scope. Conservation status and risk for Salmo River Bull Trout were estimated using a methodology that has been previously been applied to core areas (putative metapopulations) in the United States, Alberta, and British Columbia, and which estimates cumulative effects of distribution, abundance, trend, and threats on population viability. The resulting assessment was that Salmo River Bull Trout are threatened and at high risk of extirpation (‘C1-High Risk’). The next step in recovery planning is an Action Plan based on these assessments of conservation status and limiting factors, which will be delivered in a separate document.

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1.0 BACKGROUND

1.1 General trends

Bull Trout (*Salvelinus confluentus*) populations have declined in many areas of their native range, particularly in the U.S.A. and in southern parts of their Alberta and British Columbia distributions. Population declines appear to be due to the cumulative effects of habitat degradation, non-native species introductions, overharvest, and fragmentation of watersheds caused by dam construction (Rieman and McIntyre 1993; Rieman et al. 1997; Paul and Post 2001; Post and Johnston 2002; Hagen and Decker 2011). Loss of the migratory form (adfluvial, fluvial) in particular is evident in many populations, and many remaining populations in the U.S.A. presently persist as small-bodied residents isolated in headwater streams (Nelson et al. 2002).

Because of these population declines, along with small population sizes, limited or declining distributions, and elevated threats, the Bull Trout is considered a species of high conservation concern throughout its distribution in the contiguous United States, Alberta, and British Columbia. In the United States, listing of populations as "Threatened" under the Endangered Species Act commenced in June 1998, starting with the Columbia system, and all U.S. populations south of Canada had been listed by November 1999 (Lohr et al. 2000). In 1994, Alberta launched its Bull Trout management and recovery plan (Berry 1994), and the species is now considered "Sensitive" in the Province (Post and Johnston 2002).

In British Columbia, Bull Trout were blue-listed as a species of special concern by the BC Conservation Data Center in 1994 (Cannings and Ptolemy 1998), and have also been listed as an Identified Wildlife Species at Risk under British Columbia's Forest Practices Code (Haas and Porter 2001). To address the lack of a provincial review of Bull Trout population 'health,' a systematic information review and conservation status assessment for the province was conducted by the British Columbia Ministry of Environment (MOE) in 2011 (Hagen and Decker 2011). The exercise utilized conservation status and risk assessment protocol also employed in the U.S.A and Alberta (allowing comparisons among jurisdictions), and indicated a lower level of risk on average for the British Columbia Bull Trout conservation units. However, it was also apparent in the status review of Hagen and Decker (2011) that harvest restrictions alone have been insufficient to effect population recoveries, or even halt declines in several 'core areas[1]' (see section *3.1*) in British Columbia where Bull Trout habitat has been seriously degraded or connectivity between habitats has been lost due to hydroelectric development. Bull Trout populations utilizing the Salmo River and connected habitats in southeastern British Columbia (Figure 1), the subjects of this report, comprise one such core area ('Pend d'Oreille' core area; Hagen and Decker 2011).

[1] Group of populations interconnected or potentially interconnected through gene exchange (USFWS 2005; Hagen and Decker 2011)

1.2 Study area

Detailed physical descriptions of the Salmo watershed and its history are available in Sigma Engineering (1996), Baxter (1999), Westslope Fisheries (2003), Steeger (2003), and Green et al. (2006). Some physical properties of the watershed are of high relevance to Bull Trout conservation and management. First, the Salmo watershed is not a large system, with a watershed area of 1,230 km^2, mean annual discharge of 33 m^3/s, and mean monthly minimum discharge of 7.5 m^3/s (Baxter 1999). The Salmo River has its origin in the Selkirk Mountains near Nelson, B.C., and flows approximately 60 km to join the lower Pend d'Oreille system in Seven Mile Reservoir (Figure 1). Furthermore, the watershed has a generally south aspect and there are no glacial meltwater inputs, which buffer summer low flows and warm stream temperatures in many of the province's Bull Trout systems.

Information sources compiled in Sigma Engineering (1996) and Green et al. (2006) describe a relatively long history of development and human-induced aquatic habitat changes in the watershed, beginning in the late 1800s. Watershed developments with potentially important implications for Bull Trout conservation and management include:

- Extensive forest harvest resulting in almost-complete removal of old growth cedar/hemlock forests and other riparian vegetation along stream courses in the late 1800s and early 1900s.
- One of the greatest concentrations of mining development in the province, beginning in the late 1800s and continuing through until the 1970s, resulting in widespread removal of riparian vegetation, mass wasting along water courses, and widespread tailings deposits with no waste management.
- Linear developments including rail, highways, and extensive road and trail building associated with mining, resulting in significant loss of riparian vegetation, stream channel complexity, and connectivity with off-channel wetlands.
- Agricultural, rural residential, and urban/industrial development associated with the human community, resulting in elevated consumptive water demands, elevated angling pressure, and channelization of many kilometers of stream channel for flood protection (associated with loss of riparian vegetation, stream channel complexity, and connectivity with off-channel wetlands).

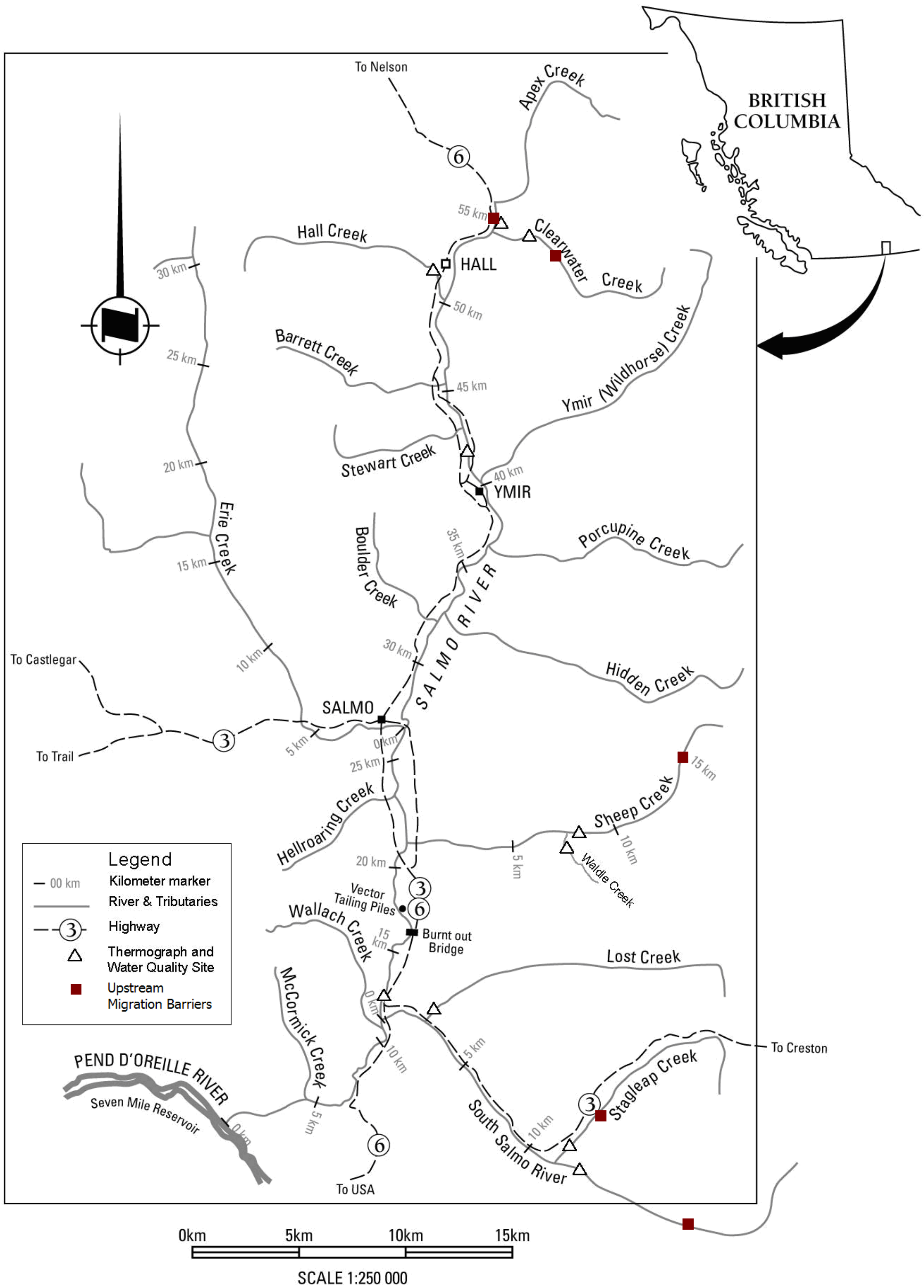

Figure 1. The Salmo River watershed study area.

While the construction of dams in the Columbia Basin did not result in extensive flooding of the Salmo River valley itself, these developments nonetheless comprise major habitat and fish community alterations that are also of direct relevance to Bull Trout conservation and management. The construction of Teck Cominco's Waneta Dam eliminated 7.5 km of fluvial habitats that were available to migratory subadult and adult Salmo River Bull Trout, and BC Hydro's Seven Mile dam eliminated a further 10 km (Hirst 1991). These dams permanently isolated the population from 68 km of suitable riverine habitats in the Canadian portion of the mainstem Columbia River (Hagen 2008). Major prey fish community shifts include the permanent loss of anadromous Pacific salmon juveniles (*Oncorhynchus spp*.; potentially also regional Mountain Whitefish *Prosopium williamsoni* stocks), and colonization of Seven Mile Reservoir by a warmer water fish assemblage with significant non-native components (Westslope Fisheries 2003).

Other, native salmonids inhabiting the Salmo River watershed above Seven Mile Reservoir include Rainbow Trout (*Oncorhynchus mykiss*), Westslope Cutthroat Trout (*O. clarki lewisi*), and Mountain Whitefish (*Prosopium williamsoni*). Brook Trout (*S. fontinalis*) are the only non-native salmonid present. Largescale Sucker (*Catostomus macrocheilus*), Longnose Dace (*Rhinichthys cataractae*), Slimy Sculpin (*Cottus cognatus*), Northern Pikeminnow (*Ptchocheilus oregonensis*), and Red Sided Shiner (*Richardsonius balteatus*) are also present (Westslope Fisheries 2003), and thought to be native to the watershed. Additional native and non-native fish species found in the Pend d'Oreille River, but not in the Salmo Watershed, include Brown Trout (*Salmo trutta*), Lake Whitefish (*Coregonus clupeaformis*), Pygmy Whitefish (*Prosopium coulteri*), Arctic Grayling (*Thymallus arcticus*), Black Crappie (*Pomoxis nigromaculatus*), Largemouth Bass (*Micropterus salmoides*), Pumpkinseed (*Lepomis gibbosus*), Yellow Perch (*Perca flavescens*), Walleye (*Stizostedion vitreum*), Peamouth Chubb (*Mylocheilus caurilus*), and Carp (*Cyprinus carpio*)(Westlope Fisheries 2003).

1.3 Salmo River Bull Trout studies

Following a Habitat Compensation Agreement between BC Hydro, the federal Department of Fisheries and Oceans (DFO), and the BC Ministry of Environment, Lands, and Parks (MELP), related to the proposed installation of a fourth turbine at the Seven Mile power plant, Bull Trout-focused studies were initiated in the Salmo River watershed in 1997 (Baxter 1999). Prior to that time, relatively little was known about the distribution, abundance, or life history of the population.[2] During 1997-1999 reconnaissance studies, Bull Trout spawning and rearing habitats were identified in the upper Salmo River above Ymir, and in the Clearwater Creek, Sheep Creek, and South Salmo River watersheds, while stream fertilization and spawning habitat enhancements were identified as potential compensation options (Baxter et al. 1998; Baxter 1999). Concern about the viability of Salmo River Bull Trout was expressed formally beginning

[2] Sigma Engineering had identified Bull Trout juveniles in the upper Salmo River mainstem and other tributaries during reconnaissance sampling in 1996, and adults were also identified in mainstem habitats in the lower watershed during reconnaissance snorkeling surveys (Sigma Engineering 1996).

at this time as well (Baxter 1999), based on the small number of spawners annually. Concern about small population size led the BC Ministry of Environment, Lands, and Parks to institute a basin-wide mandatory Bull Trout release regulation beginning in 1999 (Baxter and Nellestijn 2000). Redd counts have continued annually since 1998 in the upper Salmo, Clearwater, Sheep, and South Salmo watersheds (Nellestijn 2014 and references therein), making this important time series of spawner abundance data one of the longest in the province (see Hagen and Decker 2011).

Over the period 1999-2001, the Salmo Watershed Streamkeepers Society (SWSS) conducted a three-year radio telemetry study of adult, Salmo River Bull Trout in partnership with the Columbia-Kootenay Fisheries Renewal Partnership (CKFRP), Columbia Basin Trust, and BC Hydro (Baxter 2001). The study's objectives were to refine knowledge about life history, critical habitats, and potential use of Seven Mile Reservoir, and a significant finding was that no Bull Trout were tracked in the reservoir despite its proximity, suggesting at that time that the population was primarily of a fluvial life history (see Section *2.0*). A second telemetry study focused on subadult Bull Trout was conducted over the period 2007-2010, with the primary objective of reducing uncertainty related to the use of the Seven Mile Reservoir by Salmo River Bull Trout, and the potential for entrainment through the dam (Prince 2009). In contrast to the preceding telemetry study results, migration of subadult Bull Trout to the reservoir was documented for 45% of radio-tagged fish, confirming a significant adfluvial component to the population (Prince 2010).

Reconnaissance snorkeling surveys of the Salmo River mainstem were first conducted in 1996 (Sigma Engineering 1996), and systematic surveys of established index sections along the length of the mainstem were conducted over the period 2001-2009 (Hagen and Baxter 2010). While the primary objective of these latter surveys was to provide quantitative estimates of Rainbow Trout abundance, the abundance of other species including Bull Trout has also been recorded.

Starting in 2000, SWSS and CKFRP jointly undertook to develop a fisheries strategic plan for the Salmo River watershed, and by 2002 had adopted the Watershed Fish Sustainability Planning (WFSP) framework developed by the governments of British Columbia and Canada (Green et al. 2006). The 'Salmo River Watershed-based Fish Sustainability Plan Report' (Green et al. 2006), while not focused on Bull Trout, includes relevant background information within watershed (Westslope Fisheries 2003) and riparian (Steeger et al. 2003) profiles, and in the results of public meetings held to gather community input and direction (Betts and Maratta 2000)

Over the period 2003-2009, stream fertilization was evaluated experimentally by BC Hydro as a compensation option for Bull Trout (Decker 2010). Productivity of fish, benthic macroinvertebrates, and periphyton were monitored in fertilized (Sheep Creek) and control (South Salmo River) streams for three years pre-treatment (2001-2003) and four years post-treatment (2005-2007, 2009). Size and abundance of juvenile Bull Trout did indeed increase in the treatment stream (Decker 2010), and the study provided the additional benefit of providing quantitative estimates of juvenile abundance, growth, and survival within critical spawning and rearing habitats of the Salmo River watershed.

In the 2008 dam impacts study conducted by the Fish and Wildlife Compensation Program – Columbia Basin, the impacts of dam construction in the upper Columbia Basin on Bull Trout production, fisheries, and conservation status in the Salmo River watershed (along with other population units in the Canadian portion of the basin) were estimated (Hagen 2008). The construction of Teck Cominco's Waneta Dam eliminated 7.5 km of fluvial habitats that were available to subadult and adult Salmo River Bull Trout, and BC Hydro's Seven Mile dam eliminated a further 10 km. These dams permanently isolated the population from 68 km of suitable riverine habitats in the Canadian portion of the mainstem Columbia River (Hirst 1991; Hagen 2008), and in concert with other dams in the Columbia system have also affected the distribution and abundance of key prey fish species.

In 2011, the conservation status of Bull Trout was evaluated systematically across the entire province, for the first time, using status and risk assessment protocol developed by the United States Fish and Wildlife Service (USFWS 2005), which have also been applied to Bull Trout population units in the U.S. and Alberta. At that point in time, the Salmo population unit was assigned the most serious category of risk ('C4-High Risk'; Hagen and Decker 2011), on the basis of declining trend, low abundance and distribution, and elevated threats (see Section *4.0*).

1.4 Study objectives

In 2008 and 2009 the Salmo Watershed Streamkeepers Society (SWSS) hosted workshops focused on Bull Trout conservation in the Salmo River watershed, which were attended both by Bull Trout experts as well as representatives of agencies involved in fisheries management in the watershed – BC Hydro, BC Ministry of Environment (MOE), Fish and Wildlife Compensation Program – Columbia Basin (FWCP), and Columbia-Kootenay Fisheries Renewal Partnership (CKFRP), Department of Fisheries and Oceans (DFO). As one outcome of these meetings, a Bull Trout-specific information summary was identified as a necessary step in developing an action plan for Bull Trout conservation and management in the watershed. The following objectives are modified from original meeting minutes to eliminate redundancy, but include the same study components:

1. Review Bull Trout biology and life history information specific to the Salmo River watershed, and identify data gaps.

2. Assess the likelihood of potential limiting factors and threats, using the best information available.

3. Update the conservation status and risk assessment for the watershed, using the best information available.

4. Develop an Action Plan for conservation and enhancement of Bull Trout populations in the Salmo River watershed.

By mutual agreement between SWSS and consultant John Hagen and Associates, this report treats objectives #1-3, with objective #4 slated for a future report.

2.0 LIFE HISTORY

Relatively thorough life history reviews emphasizing Canadian Bull Trout populations are available in other documents (McPhail and Baxter 1996; Post and Johnston 2002; McPhail 2007; Hagen 2008). The following, abbreviated review of generalized life history characteristics is utilized below as a context for assessing the state of Bull Trout knowledge in the Salmo watershed.

In interior regions, the three general life history forms of Bull Trout are stream resident, fluvial (migrations to larger rivers), and adfluvial (migrations to lakes or reservoirs). Salmo River Bull Trout exhibit both fluvial and adfluvial life histories. Evidence is mixed for the relative importance of each. As mentioned previously, a three-year radio-telemetry study focusing on mature Bull Trout captured in the Salmo River watershed did not indicate any migration to the reservoir (Baxter 2002), while a subsequent telemetry study focusing on subadult Bull Trout found that 45% of tagged fish (potentially higher) on average utilized the reservoir, and that the period of reservoir utilization corresponded primarily to the winter months (Prince 2010).

Stream resident populations are typically separated from migratory populations by an obstacle or barrier to migration, either physical (e.g. waterfalls, dams; Latham 2002), physiological (e.g., unfavorably high temperatures; Rieman and McIntyre 1993; Rieman et al. 1997), or biological (e.g., presence of non-native competitor species; Paul and Post 2001; Nelson et al. 2002). Stream resident populations have not been identified within the Salmo River watershed, although it is possible that life history polymorphism exists (stream resident, precocious males present). Precocious males have been observed elsewhere in the upper Columbia Basin (McPhail and Murray 1979; Hagen 2008) and in tributaries of the Peace system (Baxter 1997), but have yet to be identified within the Salmo River watershed.

All Bull Trout populations require clean, cold stream reaches of small-to-moderate size for spawning and rearing. Bull Trout are clearly coldwater-adapted. Egg development and hatching are related to water temperature, with optimal development and survival for Bull Trout occurring at 2-4°C (McPhail and Murray 1979). Stream-rearing juvenile Bull Trout use shallow areas with low current velocities along channel margins, regardless of general habitat type (i.e., pool, riffle, etc.; Saffel and Scarnecchia 1995). Low velocity side channels are particularly valuable for young-of-the-year fry (McPhail and Murray 1979; Saffel and Scarnecchia 1995; Bustard 2004).

In the relatively confined tributaries of the Salmo watershed, the majority of the habitat area lies within riffles and cascades (80-90%: Decker 2010), and pool and side channel habitat area is limited. Large, unembedded substrate appears to be the most important cover component (Oliver 1979; Pratt 1992; Baxter and McPhail 1996), particularly in winter habitat when juveniles conceal themselves in the substrate during the daytime (Thurow 1997; Bonneau and Scarnecchia 1998), but instream wood cover is also important (Fraley and Graham 1981; Fraley and Shepard 1989; Baxter 1995; Jakober et al. 1998).

Within the Salmo watershed, paired juvenile Bull Trout abundance and habitat data exist for approximately 50 sites systematically distributed along the accessible lengths of Sheep Creek and the Canadian portion of the South Salmo River (Decker 2010, data on file). These data provide an opportunity in future analyses to evaluate habitat associations for juvenile Bull Trout within these spawning and rearing streams, and provide a baseline of habitat and fish abundance information for comparison with future conditions. Juvenile sampling in other systems known to be utilized by Salmo River Bull Trout, however, has been inadequate to properly delineate critical habitats, or to monitor abundance relative to expectations for healthy populations. This constitutes an important data gap that potentially limits prospective conservation and enhancement actions in the upper Salmo River and Clearwater Creek drainages. Water temperature and physical habitat assessments are also required.

While stream resident populations spend their entire life cycle within individual streams or stream reaches, fluvial and adfluvial Bull Trout rear in natal tributaries for 1-4 years before undergoing migrations downstream to larger rivers and lakes, respectively, with migration at age-2+ being the most common (McPhail and Murray 1979; Pratt 1992; Downs et al. 2006). Juvenile Bull Trout captured in Salmo River tributaries at the end of summer have ranged from 49 mm to 240 mm, and from 0+ to 4+ in age. Strong drop-offs in standing stock estimates following age-2+, however, suggest migration at age-2+ is most common in the Salmo watershed, as well (Decker 2010). Estimated mean lengths at the end of August were 52 mm, 105 mm, and 146 mm for ages 0+ to 2+, respectively. These cannot be compared directly to literature values which report length-at-age at the scale annuli (Goetz 1989), which is deposited at the end of the growing season at the onset of winter, but generally suggest slower or equivalent growth in the Salmo watershed relative to U.S. and other southern Canadian populations. For example, at the end of their first, second, and third years of life, juvenile Bull Trout in the non-glacial Flathead River Basin had mean sizes of 50-70 mm, 100-120mm, and 150-170 mm, respectively (Shepard et al. 1984). In the upper Columbia Basin, juvenile Bull Trout from the glacial Incomappleux and Illecillewaet systems were of comparable size near the end of their second and third growing seasons (October), averaging 118 and 156 mm, respectively (derived from Decker and Hagen 2007).

Following emigration from natal tributaries, in large riverine and lacustrine environments Bull Trout eat primarily fish, with individuals becoming progressively more piscivorous with increasing size. Bull Trout of all sizes are capable of eating prey of up to 50% of their own length (Beauchamp and Van Tassell 2001). Kokanee salmon and other salmonids appear to be the most important fraction of the diet in lacustrine environments, although cottids, cyprinids, and catostomids are also consumed (Shepard et al. 1984; Pratt 1992; Beauchamp and Van Tassell 2001). In rivers, Mountain Whitefish appear to be a highly important prey source for fluvial Bull Trout (Boag 1987; Swanberg 1997). In Lake Billy Chinook, Oregon, cannibalism on smaller Bull Trout (age-0+ and age-1+) was detected in the stomachs of Bull Trout of <450 mm, but not in larger fish (Beauchamp and Van Tassell 2001). Kokanee are seasonally available in large numbers to fluvial fish in the upper Kootenay, lower Duncan, and upper Columbia rivers in the upper Columbia Basin, and may have a strong effect on Bull Trout distribution and growth (Westover and Heidt 2004; Olmsted and den Biesen 1998). Within the Salmo River watershed, Mountain Whitefish are rare (Hagen and Baxter 2010), and the most abundant fish captured in past sampling have been Rainbow Trout (Sigma Engineering 1996; Baxter et al. 1998; Decker 2010). Relative to observations in other Bull Trout systems, therefore, the lack of an obvious association between Bull Trout and a salmonid prey fish base, such as Kokanee or whitefish, may be highly significant.

Outside of spawning migrations, fluvial adult and subadult Bull Trout in the Salmo River have a wide distribution ranging from the river's mouth to river km 42 (vicinity of Ymir Creek)(Baxter 2002; Prince 2010), with a significant proportion of the subadult Bull Trout population emigrating from the Salmo River to Seven Mile Reservoir (Prince 2010). Overwintering locations of radio-tagged, adult Bull Trout were distributed in the mainstem Salmo River primarily between river km 12 and km 36 (measured from the mouth), and individuals frequently utilized the overwintering location year-round outside of the spawning period (Baxter 2001). Overwintering habitat generally appear to be in deep pools associated with cover in the form of large woody debris or large substrate. With respect to adfluvial fish, significant uncertainty exists with respect to Bull Trout utilization of Seven Mile Reservoir and their survival there, which reflects limitations on tracking these fish in the reservoir environment and limitations imposed by transmitter lifespan (Prince 2010).

Pratt (1992) reported that adfluvial Bull Trout spawners in the interior regions of western North America were 4-9 years old, and Goetz (1989) reports a range in average spawner size among populations of 440-690 mm, with an absolute range of 300-875 mm. Adfluvial populations in B.C. frequently include larger and older individuals. Wigwam River spawners, which migrate from Lake Koocanusa Reservoir, are most commonly 7 years old, with observed ages from 5-13 years and sizes from 430-860 mm (mean = 670 mm; Westover and Conroy 1997). In Kootenay Lake, spawners measured at the Duncan Dam range from 320-970 mm (mean = 670 mm; BC Hydro data on file). Kokanee salmon are the prey fish base for both of these populations. Although fewer descriptions are available for comparative purposes, it appears that among fluvial populations there exists a greater range of adult body size. Means from several northwestern British Columbia populations range from 380-480 mm (McPhail and Baxter 1996; Bustard and Schell 2002), while fluvial fish utilizing the Peace River below Peace

Canyon dam and the upper Kootenay River above Lake Koocanusa can be as large as those belonging to adfluvial populations (up to 900 mm and 9.1 kg or more; McPhail and Baxter 1996; Westover and Heidt 2004). Inspection of captured Salmo River Bull Trout and radio telemetry observations suggest they mature at body sizes greater than 450 mm (Prince 2009). Mature Bull Trout captured within the watershed have ranged from 470-750 mm, averaging 570 mm (Sigma Engineering 1996; Baxter 2002; Prince 2009).[3] Observations of spawners made during redd surveys, however, have suggested that fish smaller than this are present in the spawning population, and furthermore that the mean size of spawners has declined in recent years (G. Nellestijn personal observation). Growth of subadult and adult Bull Trout, and age-at-maturity appear to be unknown. Missing estimates for these life history parameters may constitute a significant data gap, which could limit potential application of quantitative approaches (e.g. simulation models) to assessing population viability.

In B.C., peak migration towards spawning areas occurs between early June and August, and timing is likely related to the distance to be travelled and water temperatures (McPhail and Murray 1979; Swanberg 1997; Westover and Heidt 2004). Movements of radio-tagged Salmo River Bull Trout towards spawning areas began typically in the mid-July to early-August period depending on stream flow (and potentially water temperature – see Section *3.0*), on the declining hydrograph following freshet (Baxter 2001).

In coldwater streams found in northern B.C. and in southern B.C. watersheds with glacial influence, Bull Trout may preferentially select larger, lower gradient tributary reaches for spawning that have abundant gravel and cobble substrates. However, in non-glacial systems dominated by Rainbow Trout or Pacific salmon in their lower reaches, Bull Trout commonly spawn in the furthest upstream reaches they can access, which are often of higher gradient, and above obstructions that block the migration of other species (Bustard and Schell 2002; Westover and Heidt 2004; Decker and Hagen 2007; Hagen 2008 and references therein). This latter pattern appears to be typical within the Salmo River watershed, with spawning activity concentrated in the top half of tributaries and the upper section of the Salmo River mainstem (Baxter and Baxter 2003; Nellestijn 2014).

Knowledge of spawning areas within the Salmo watershed has been refined with 3 years of radio telemetry observations (Baxter 2001), along with 18 years of annual redd counts (which have included reconnaissance surveys outside of known spawning locations; Nellestijn 2014 and references therein). Salmo River Bull Trout are known to spawn presently within Apex Creek and Clearwater Creek within the Clearwater watershed, in the upper Salmo River above Barrett Creek, in Sheep Creek, and in Stagleap Creek and the South Salmo River (in the U.S. and Canada) within the South Salmo watershed (Baxter 2001; Baxter and Baxter 2003; Nellestijn 2014). The total accessible lengths of all known spawning streams within these systems is 5.1

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[3] Confirmed spawners have been captured for use in radio telemetry studies, and not likely to be a representative sample.

km, 12.1 km, 16.4 km, and 21.0 km for the Clearwater, upper Salmo, Sheep, and South Salmo systems, respectively. Estimates of the mean numbers of spawners annually since 1998, derived from redd counts using a methodology described in Nellestijn (2014), are 20, 26, 47, and 24 for these same respective systems. Anecdotal evidence suggests that the Wildhorse, Hidden, Erie, and Lost Creek systems have had spawning activity in the past, but recent surveys suggest no Bull Trout use of these systems currently (Nellestijn 2014).

Spawning sites (redds) are not always directly associated with cover, but cover in the form of pools, large wood debris, undercut banks, and overhead vegetation is nevertheless an important attribute of spawning streams, as adult Bull Trout often reside for a month or more in spawning reaches prior to spawning (McPhail and Murray 1979; Graham et al. 1981; Baxter 1995). Within spawning areas of the Salmo River watershed, Bull Trout redds themselves are often closely associated with cover and difficult to observe (Baxter and Baxter 2003).

Stream substrate at spawning sites averages 25 mm to 60 mm, and is probably related to substrate availability and the size of spawners (McPhail and Murray 1979; Hagen and Taylor 2001). Spawning site selection may be highly specific, and redd superimposition may occur. In larger streams spawning sites are often associated with aggrading areas and areas of groundwater infiltration (Oliver 1979; Graham et al. 1981; Fraley and Shepard 1989; Baxter 1995), while in some smaller streams all pockets of suitable looking substrate have been used (personal observation of the authors). Depths at redd locations average 24-58 cm, and appear to always be less than 90 cm, while velocities average 14-52 cm/s and are typically 65 cm/s or less (reviewed in Baxter and McPhail 1996). Physical habitat characteristics at spawning sites within the Salmo River watershed do not appear to have been described in previous studies, but this step is necessary prior to evaluating potential proposals for spawning habitat enhancements.

Spawning for fluvial and adfluvial stocks in B.C. appears to occur between mid-August and mid-October, with northern populations spawning earlier (McPhail and Murray 1979; Baxter 1997; Hagen and Taylor 2001; Westover and Heidt 2004). Spawning within the Salmo watershed likely peaks in the mid- to late-September period, and is largely concluded by the end of the first or week of October (Nellestijn 2014).

Adult Bull Trout in the Salmo River appear to have very high annual survival (>80%), based on observations of radio-tagged individuals over multiple years (Baxter 2001, 2003). While the Salmo-specific data are limited to relatively few observations, this compares favourably with literature values (usually >50% outside of angling mortality; Pratt 2003 and references therein). While both repetitive and non-repetitive (i.e. alternate-year) spawning strategies are known within studied Canadian populations (Baxter et al. 2000; Johnston et al. 2007), repetitive spawning following maturation appears to be the dominant (80-85%) reproductive strategy within the Salmo watershed (Baxter 2002).

3.0 POPULATION LIMITATION AND THREATS

For management and conservation actions to result in increased production of Salmo River Bull Trout, a production bottleneck that determines population size must be effectively targeted. Potential limits to production in both juvenile rearing stream (Section *3.1*) and subadult/adult habitats (Section *3.2*) must be considered, and their effects integrated over the whole life cycle in order to determine whether releasing that limit is likely to result in more Salmo River Bull Trout spawners. In this section, potential limiting factors are posed as hypotheses, and, where possible, weights of evidence for and against the proposed factor as a production bottleneck are compared.

3.1 Hypothesis #1: Productivity and carrying capacity in juvenile rearing habitats is limiting the population.

Because of the extended tributary residence of 1-4 years for juvenile Bull Trout, recruitment from tributaries has obvious potential to be a primary bottleneck regulating population size. Density-dependent survival, which occurs primarily in the period between egg deposition and age-1+ (Johnston et al. 2007; Hagen 2008), has been demonstrated to be an important factor regulating the Bull Trout population in Lower Kananaskis Lake, Alberta (Johnston et al. 2007). Density-dependent survival in this population, estimated over a twenty-fold range of spawner population size, occurred in the period between egg deposition and age-1+, with survival between age-1+ and the age of first spawning being density-independent. Hagen (2008, and references therein) suggested that within the most suitable reaches available for juvenile Bull Trout rearing, density-dependent survival appears to limit production of parr (all age classes) to mean densities of approximately 8 fish/100 m^2 or less. Pratt (2003) suggested a maximum probable density of 10 fish/100 m^2. However, Bull Trout distribution in a watershed is often limited such that core rearing habitats of maximum density represent a small fraction of the total amount of stream habitat available (McPhail and Baxter 1996; Bustard and Schell 2002; Decker and Hagen 2007).

Sampling data permit two approaches to evaluating support for hypothesis *1*. First, mean densities can be compared to established biostandards or systems where conservation status is considered secure. Bull Trout parr and spawner density estimates for the Arrow Lakes Reservoir (Decker and Hagen 2007) were utilized in the analysis of Hagen (2008) as biostandards for estimating production losses resulting from flooding of Bull Trout spawning and rearing streams, caused by dam construction in the upper Columbia Basin. The overall mean parr density estimate for the ALR was 316 juvenile Bull Trout (age-1+ and older)/km (range: 193-517), when integrated over the entire length of accessible habitats within spawning tributaries (not just high density, key rearing habitats). Pre-treatment parr (age-1+ and 2+ combined) densities from the Salmo River tributaries, averaged over the total stream length monitored during the fertilization experiment (Decker 2010), are indeed somewhat lower, ranging from 166-352 over the three year period 2001-2003 (mean = 280). The second and best approach is to derive a carrying capacity estimate directly from paired spawning stock-parr recruitment data. Unfortunately, such data are extremely limited for the Salmo watershed, and extend only over the period 2001-2009 (Decker 2010). This time series, although limited, nonetheless shows that parr abundance is positively related to brood spawner abundance for both age-1+ and 2+ Bull Trout (even when accounting for the effects of stream fertilization; Decker 2010), which is consistent with the notion that juvenile production may be limited by egg deposition because of low spawner abundance, rather than existing stream carrying capacity. In other words, there appears to be room for additional Bull Trout parr within existing rearing habitats, and increasing juvenile rearing space may not result in additional adult Bull Trout. If this is in fact true, it indicates the serious situation where the buffering capacity of density-dependent increases in juvenile survival at declining egg deposition may be nearly exhausted.

Against this evidence past and present threats to habitat productivity and carrying capacity must be weighed. Human activities can result in severe reductions in productivity that can threaten the long-term persistence of Bull Trout populations. In juvenile rearing habitats, stream temperature increases, habitat degradation, and introductions of non-native fish have all led to declines in Bull Trout populations (Rieman and McIntyre 1993; Post and Johnston 2002). These threats mechanisms are treated below as sub-hypotheses to hypothesis *1*, and are important to consider prior to planning conservation and enhancement actions.

Sub-hypothesis 1a: habitat degradation is limiting juvenile production. Degraded watersheds may have a reduced habitat capability for Bull Trout even if stream temperatures remain below threshold values, due to potential losses of riparian vegetation and stream habitat complexity, increases in sediment transport and associated channel destabilization, and channel widening with associated reduction of bed material size and stream depth (Saffel and Scarnecchia 1995; McPhail and Murray 1979; Pratt 1992; Fraley and Shepard 1989).

Monitoring data do not exist with which to quantify habitat degradation within Salmo watershed Bull Trout rearing tributaries. The approach of comparing estimated habitat conditions to ideals based on other species or other geographic areas is potentially not valid for Bull Trout rearing streams, given that in B.C. they are typically associated with mountainous areas and have elevated gradients, peak flows, and potential for bed material transport (Hagen 2008 and references therein). This association also limits the potential for success of instream structural habitat enhancements in rearing streams (Hagen 2008). Nonetheless, it can be stated without much doubt that rearing tributaries in the Salmo watershed have experienced severe habitat degradation from forestry, mining, road building, and residential development sources. Mechanisms have been forest removal affecting water quality and stream structural complexity, near-complete removal of riparian vegetation affecting water temperature and channel stability/complexity, extensive road and trail building affecting sedimentation, channel complexity, and connectivity with side channel and off-channel fish habitat, widespread unmanaged tailings deposits affecting water quality and sediment transport, and channelization of water courses affecting water temperature, stream channel complexity, and connectivity with side channel and off-channel fish habitat (Green et al. 2006 and references therein). If past habitat degradation was a strong enough mortality factor to drive Bull Trout populations to critical low levels, lingering effects may be inbreeding depression, loss of genetic diversity (and associated loss of adaptation potential), and losses of sub-populations, even if habitat has recovered since. Past habitat degradation in tributary streams should therefore be a considered a threat to the population's viability even for the future.

Current habitat conditions within tributary stream channels are known from physical habitat and biological measurements made prior to and during the fertilization experiment (Baxter 1999; Decker 2010) and are mostly focused on Sheep Creek and the South Salmo River. Data indicating current levels of water contamination, sedimentation (prevalence of fine substrates), and prevalence of unembedded large substrates as cover indicate a physical habitat structure that is capable of supporting rearing Bull Trout.[4] Support for sub-hypothesis *1a* is therefore limited except with respect to past impacts, and the severity of the threat should probably be considered of low severity, high scope, and low immediacy (see Appendix 1 for threats definitions).

As mentioned, the potential for instream physical habitat enhancements may be limited within rearing tributaries, and major works would certainly require the input of a fluvial geomorphologist or engineer. Within existing rearing space, however, it has been demonstrated that production of additional juvenile Bull Trout is possible through stream fertilization (Decker 2010). This enhancement activity has the potential to result in additional adult Bull Trout, and should therefore be considered an important potential mitigation strategy for past and current threats to the Salmo River population.

Sub-hypothesis 1b: high water temperature is limiting juvenile production. Water temperature, and temperature-mediated interspecific competition, have been suggested as the most important determinants of juvenile Bull Trout distribution and abundance. Haas (2001) studied Bull Trout abundance in tributaries of the upper Columbia Basin and found that Bull Trout were not present when summer maximum water temperatures were greater than 16°C. Bull Trout and Rainbow Trout parr abundance were also strongly negatively correlated in his study, with Bull Trout dominating numerically and showing relatively high growth rates and condition factor at sites with summer maximum water temperatures less than 13-14°C, and Rainbow Trout dominating at water temperatures greater than 14°C. Temperature thresholds for Bull Trout presence in watersheds in Montana and Idaho are consistent with the observations of Haas (2001). Fraley and Shepard (1989) found few Bull Trout juveniles in the upper Flathead system, Montana when maximum water temperatures were greater than 15°C, and Saffel and Scarnecchia (1995) found that reaches with high Bull Trout densities in Idaho streams had summer maximum water temperatures of 7.8 to 13.9°C. Dunham et al. (2003) found that at the southern limit of the distribution, temperature was the only biophysical variable that was strongly associated with Bull Trout presence, and that the probability of occurrence in a reach exceeded 50% when the maximum daily water temperature was less than 14-16°C. Pratt (2003) suggested

[4] Detailed riparian mapping has been proposed but is yet to occur (Steeger et al. 2003).

a maximum threshold for juvenile Bull Trout presence of 16°C, measured in terms of the average of weekly maximum temperatures. The notion that water temperature can limit Bull Trout distribution and abundance is consistent with laboratory trials demonstrating that Bull Trout have among the lowest upper thermal limits and growth optima of North American salmonids, and that physiological stress begins to occur at constant temperatures of 14-16°C (Selong et al. 2001).

From the above review, we suggest thresholds of 14°C and 16°C, estimated as the highest 7-day average of daily maximum temperatures, for expected Bull Trout dominance and Bull Trout presence, respectively. Temperature data were recorded in upper and lower sites of Sheep Creek and the South Salmo River, during the nutrient enrichment experiment, over the period 2005-2007 (Decker 2010; data on file). Temperature monitoring has also been resumed in Sheep Creek beginning in 2014 (SWSS data on file). The highest 7-day average of daily maximum temperatures, averaged over the 2005-2015 period, exceeded 14°C at all four locations, and exceeded 16°C in both lower river locations (Table 1). These data are reflected in the facts that juvenile salmonid abundance in the study area overall was dominated by Rainbow Trout, and that juvenile Bull Trout were nearly absent from the lower ends of both streams (Decker 2010; data on file). They offer strong support to sub-hypothesis *1b*, that stream temperature is a potential limit to juvenile Bull Trout production within the Salmo River watershed. Because current temperatures must be considered marginal for Bull Trout production, present and future stream temperatures, which are expected to increase as a result of climate change, should be considered a moderate threat of high scope and high immediacy within juvenile rearing habitats of the Salmo watershed.

Table 1. Highest seven-day average of daily maximum temperatures for two locations each in Sheep Creek and the South Salmo River, 2005-2015.

Location	2005	2006	2007	2014	2015	Average
Sheep Creek, lower	16.4	17.5	na	16.4	18.2	16.9
Sheep Creek, upper	13.2	15.4	15.1	13.3	14.4	14.3
South Salmo River, lower	17.5	17.6	18.8	na	na	18.0
South Salmo River, upper	13.3	na	15.4	na	na	14.3

Sub-hypothesis 1c: Non-native species are limiting juvenile production. Competition and hybridization with Brook Trout have also been identified as major threats to Bull Trout populations (Ratliff and Howell 1992; Rieman and McIntyre 1993; Paul and Post 2001; Rich et al. 2003). Bull Trout populations appear to have increased resistance to the invasion of Brook Trout when streams are cooler, have had less habitat degradation, and have high interconnectivity among neighbouring stream reaches permitting a migratory life history (Paul and Post 2001; Rich et al. 2003). Brook Trout are known to be abundant in the headwater of the Salmo mainstem above Clearwater Creek, and in Wildhorse Creek (Sigma Engineering 1996; Baxter et al. 1998; Westslope Fisheries 2003), and are observed at lower densities in lower Sheep Creek (Decker 2010; data on file) and throughout the Salmo River mainstem (Hagen and Baxter 2010). Brook Trout therefore constitute a threat to Bull Trout viability in the watershed, which will likely increase if the loss of the migratory life history form occurs within Bull Trout populations.[5] At the present, however, Bull Trout and Brook Trout distributions are largely segregated within the watershed. Relatively extensive molecular genetic analysis, utilizing tissue samples taken from all Bull Trout population sub-units within the Salmo watershed, has failed to detect Brook Trout × Bull Trout hybrids (Bettles et al. 2005). This finding, along with habitat segregation between the species, suggests that this threat is of low severity, scope, and immediacy at this point in time, and that sub-hypothesis *1c* is unlikely.

3.2 Hypothesis #2: Survival and growth in subadult/adult rearing habitats is limiting the population.

Given that parr production in the Salmo watershed is comparable if somewhat lower than the ALR-derived biostandard, comparison of estimates of Salmo watershed spawner densities (over total accessible lengths of spawning reaches) to the ALR spawner biostandard should give an indication of the relative productivities of adult rearing habitats in the two core areas. Mean estimated spawner densities across known spawning streams in the Salmo watershed have averaged 2.1 spawners/km over the 1998-2015 period. Significantly, the ALR estimate of 12.6 spawners /km is 5.9-fold greater, despite the fact of significant exploitation of the ALR Bull Trout population in the recreational fishery (Arndt and Schwarz 2011). The recently-derived spawner density estimate for Kootenay Lake tributaries is 15.8/km (Andrusak and Andrusak 2012), or 7.4-fold greater than the Salmo estimate. Although these comparisons are simplistic, they provide very strong support for hypothesis *2*. Given that harvest in the system has been regulated to zero, and annual survival of radio-tagged Bull Trout has been estimated in the past to be high (see Section *2.0*), a serious survival bottleneck prior to adulthood is indicated for Salmo River Bull Trout.

Among subadult/adult rearing habitats, anthropogenic (human-caused) factors that have led to declines in Bull Trout populations include habitat degradation, introductions of non-native fish, overharvest, and fragmentation of watersheds through dam construction (Rieman and McIntyre 1993; Post and Johnston 2002). Given the support for Hypothesis *2*, sub-hypotheses discussed below address the relative likelihood among potential mechanisms, which are important to consider prior to planning conservation and enhancement actions.

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[5] Body size differences at maturity probably result in significant pre-mating isolation between the species, which may break down if the Bull Trout population is reduced to a remnant population of smaller-sized residents (Hagen and Taylor 2001).

Sub-hypothesis 2a: habitat degradation is limiting subadult/adult production. Similar to the situation for juvenile rearing habitats in tributaries, monitoring data with which to quantify habitat degradation along the Salmo River mainstem, and the effects on fish populations, do not exist. It can also be stated without doubt that that the mainstem of the Salmo River has in the past experienced severe habitat degradation from forestry, mining, road building, agriculture, and residential development sources. Mechanisms have been the near-complete removal of the riparian old growth forest that dominated the valley prior to development, affecting water temperature and stream structural complexity, extensive road and trail building affecting sedimentation, channel complexity, and connectivity with side channel and off-channel fish habitat, widespread unmanaged tailings deposits affecting water quality and stream channel complexity, channelization of water courses affecting water temperature, stream channel complexity, and connectivity with side channel and off-channel fish habitat, and consumptive water use for agricultural and residential purposes (Sigma Engineering 1996; Slaney 2004; Green et al. 2006 and references therein). Assessments of current riparian and stream channel conditions have suggested that significant loss of important fish habitat structure has likely occurred, and that the most likely mechanisms are the removal of the mature riparian forest and widespread channelization (Steeger et al. 2003; Slaney 2004; Heinbuch and Nellestijn 2006).

During the late summer-to-spring low water period the Salmo River mainstem is a relatively small, clear stream. The number, distribution, or area of locations with suitable cover and feeding conditions for large-bodied fish are obvious potential limits to the size of the adult population. Evidence that supports this notion comes from radio telemetry observations of both Bull Trout and Rainbow Trout[6] behaviour in the watershed, which have indicated that during the low water period the distribution of radio-tagged fish is restricted to a relatively small number of locations. These locations are areas of deep water, primarily, but may also have cover in the form of large wood debris or boulder substrate (Baxter 2001; Hagen and Baxter 2004). Furthermore, over the 2002-2009 time series of mainstem Salmo River snorkeling counts, estimated adult Rainbow Trout abundance was positively related to minimum monthly average discharge of the previous year, supporting the notion that the population is limited by the availability of deep-water habitat during the low water period (Hagen and Baxter 2010). The number, area, and distribution of locations with these physical habitat characteristics are likely to have been significantly reduced as a result of the removal of the mature riparian forest and widespread channelization, and this loss of habitat structure is not expected to recover naturally over the next several decades (Slaney 2004). Therefore, habitat degradation within the Salmo River channel should probably be considered a threat to the Bull Trout population's viability of moderate-to-high severity and scope, and is a potential factor limiting the population. Support for sub-hypothesis *2a* exists, therefore, but quantitative evidence is lacking.

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[6] Rainbow Trout are also large-bodied within the Salmo River (radio-tagged individuals ranged from 40-60 cm; Hagen and Baxter 2004).

Consumptive water use may be exacerbating the effect of these reductions to physical habitat space. Maximum potential water withdrawal from the Salmo River, based on the capacity of existing water licenses, was estimated in 1996 to be 37% of stream flow estimated for the low water period (Sigma Engineering 1996). Additional licenses were under review which could have resulted in maximum potential water withdrawal of 81% of mean September discharge (Sigma Engineering 1996). This potentially serious situation for Salmo River fish habitat warrants further investigation.

Sub-hypothesis 2b: high water temperature is limiting subadult/adult production. In addition to known effects on juvenile distribution and abundance, as discussed above, water temperature also appears to be a factor affecting Bull Trout habitat use in larger rivers and lakes following emigration from natal stream reaches. Bull Trout tend to avoid areas where water temperatures exceed 15ºC for extended periods (Pratt 1992; McPhail and Baxter 1996). Water temperature influences the movements of fluvial Bull Trout as well, probably affecting the timing of migrations into tributaries, which may occur two months before spawning, and influencing movements by non-spawning fish into both spawning and non-spawning tributaries (Swanberg 1997; Westover and Heidt 2004).

Radio-tagged, Salmo River subadult Bull Trout have been tracked in Seven Mile Reservoir at higher temperatures than the 16 ºC assumed above (hypothesis *1b*) to cause physiological stress (Prince 2009). However, the fitness consequences (growth and survival) of these habitat choices could not be assessed. Lacking clear direction from the Bull Trout literature, we assumed that a threshold of 16°C (estimated as the highest 7-day average of daily maximum temperatures) could also be applied to adult rearing habitats as an index of their suitability.

Recent summer water temperature data has been recorded at three locations in the Salmo River mainstem (SWSS data on file). The highest 7-day average of daily maximum temperatures, averaged over the 2008-2015 period (Table 2) was within the 16ºC threshold only for the upper Salmo River location, suggesting that most of mainstem Salmo River's fish habitat may be poorly suited to Bull Trout production in summer[7]. Radio telemetry data from both adult and subadult populations support this notion. The seven-day average of daily maximum temperatures reaches 16ºC by mid-to-late July in the lower Salmo River, which corresponds with good agreement to the initiation of movements by radio-tagged Bull Trout adults towards spawning areas in tributaries and the upper Salmo River (Baxter 2001). Radio-tagged, subadult Bull Trout have also been tracked to locations at the top ends of spawning tributaries even though they were known to be sexually immature (Prince 2009), suggesting that spawning and rearing tributaries double as coldwater refuge habitats for Salmo River Bull Trout. Given that the thermal suitability of even these tributaries is threatened, under expectations of increased stream temperature due to climate change (see sub-hypothesis *1b*), high water temperature

[7] It is of concern that the 16ºC threshold has been surpassed even in the upper Salmo River location in each of the last two years of monitoring data (2014-2015; Table 2).

should probably be considered a moderate-to-severe threat of moderate-to-high scope and high immediacy for the population as a whole, and not just during the juvenile rearing life stage. Stream temperature should therefore be treated as an important potential limiting factor for the Salmo River Bull Trout population.

Table 2. Highest seven-day average of daily maximum temperatures for three locations on the Salmo River, 2008-2015.

Location	2015	2014	2013	2012	2010	2009	2008	Average
Lower Salmo	20.8	19.1	19.1	17.2	18.8	19.5	19.6	19.2
Middle Salmo	19.2	18.0	17.5	16.6	17.1	17.6	17.6	17.7
Upper Salmo	17.2	16.2	na	14.9	na	15.3	15.2	15.8

While Seven Mile Reservoir should presumably be thermally suited to Bull Trout production in winter, summer reservoir temperatures show little-to-negligible stratification and are significantly above 16ºC even at the bottom of the water column (Prince 2009), suggesting that the likelihood of significant use of the reservoir by Bull Trout at that time of year is low. Whether the reservoir is better utilized by Bull Trout during colder months requires additional study (Prince 2010).

Radio telemetry studies have necessarily targeted adult and subadult Bull Trout of larger sizes, given transmitter size limitations. These fish have the physical capacity to ascend steep tributaries with numerous cascades to attain cold water refuge, and also have exhibited reasonably high survival (Baxter 2001; Prince 2009). The serious survival bottleneck indicated for the post-juvenile life stage (see hypothesis *2*), therefore, presumably happens to smaller fish shortly following emigration from natal tributaries. The potential inability of these fish to efficiently undertake extensive migrations to escape high summer water temperatures in the lower Salmo River, or Seven Mile reservoir, is a potential mechanism for this survival bottleneck.

Sub-hypothesis 2c: Interrupted connectivity with suitable subadult/adult rearing habitats is limiting the population. Prior to dam construction in the upper Columbia Basin, Salmo River Bull Trout had potentially hundreds of kilometers of uninterrupted connectivity with large river habitats in the Pend d'Oreille, Columbia, and Kootenay river systems, which were known anecdotally to produce abundant, large Bull Trout (Hagen 2008 and references therein). Loss of connectivity with these habitats is perhaps the most likely mechanism for the critically low productivity of the Salmo River Bull Trout population. Population productivity is below replacement despite zero harvest and the likelihood that the intensity of intraspecific competition has declined in juvenile rearing habitats (see Hypothesis *2* above). This implies the unpleasant likelihood that neither of the potential subadult/adult rearing environments left to Salmo River

Bull Trout, Seven Mile Reservoir nor the Salmo River, are currently able to sustain the population. We therefore consider the interrupted connectivity to be a moderate-to-high severity, high scope (i.e. the entire population is affected) threat to the population. We also consider it reasonable to judge that this limiting factor sub-hypothesis has strong support.

Sub-hypothesis 2d: Fish community changes are limiting the population. A small amount of information from the upper Columbia Basin suggests that the composition of prey fish communities affects Bull Trout growth and survival. The introduction of Kokanee to lacustrine environments appears to enhance their capability for Bull Trout production. Bull Trout spawners captured in 1996 in the Wigwam River were more abundant and 140 mm longer on average than those captured in 1978, when introduced Kokanee were not yet established in Koocanusa Reservoir (Westover and Conroy 1997). Introductions of Kokanee by MOE into Kinbasket Reservoir also appear to have resulted in an abundant Bull Trout population with increased body size (Pole 1996, as cited in Hagen 2008). In fluvial habitats without Kokanee populations, strong positive associations have been made between Bull Trout presence (and migrations) and the presence of Mountain Whitefish (Boag 1987; Swanberg 1997). The lack of a juvenile salmon or Mountain Whitefish prey fish base in the mainstem Salmo River, or any abundant prey fish species at all, is likely to be a factor limiting productivity in this environment. It is unknown whether Mountain Whitefish were abundant in the Salmo River mainstem prior to the loss of connectivity with larger river systems downstream, but juvenile salmon were present, and whitefish populations in other habitats would have been accessible through migration.

Fish community changes also may limit the population through predation and competition. Cannibalism by older Bull Trout age classes has been identified as a potential factor limiting subadult Bull Trout at the critical life stage following emigration from natal tributaries (Beauchamp and Van Tassell 2001), and may be of particular importance in habitats lacking an alternative salmonid prey fish base, such as the Salmo River mainstem. The potential for predation to limit the Bull Trout population also exists in Seven Mile Reservoir, from Northern Pikeminnow and also from piscivorous, non-native species including Largemouth Bass and Walleye. Interspecific competition from these same species may also be a factor limiting the reservoir productivity for Bull Trout. It has been demonstrated that the introduction of Lake Trout (*Salvelinus namaycush*) can result in the competitive exclusion of Bull Trout in lacustrine environments (Donald and Alger 1993). Studies of the interactions between Bull Trout and other non-native species have yet to occur, but the potential for temperature-mediated competitive exclusion in the reservoir environment would appear to be high.

Fish community changes affecting growth and survival through alterations to the prey fish base, predation, and interspecific competition, when taken together, appear likely to have had a strong negative effect on the Salmo River Bull Trout population as discussed above. Therefore, this sub-hypothesis is supported by knowledge of pre-impoundment conditions, and should be considered to be a moderate-to-severe threat of high scope for the Salmo River Bull Trout population.

4.0 CONSERVATION STATUS AND RISK

Core area assessment methodology. The US Fish and Wildlife Service has adopted the 'core area' as the appropriate spatial scale for monitoring Bull Trout abundance and applying conservation status criteria (USFWS 2002, 2005, 2008). Core areas are coarse estimates of the potential meta-population structure (Rieman and McIntyre 1993), and can be defined as groups of local populations (and their critical habitats) over which demographic and genetic connections, or the potential for them, exist, and which function more or less independently from other core areas (USFWS 2005). The Pend d'Oreille system between Seven Mile and Boundary dams, including the Salmo River watershed, fits this definition and has previously been delineated as the 'Pend d'Oreille' core area (Hagen and Decker 2011). Additionally, the USFWS has developed a methodology for application to Bull Trout core areas that is designed to capture population and threat information available in a variety of formats (USFWS 2005 Appendix A). The methodology has been applied to all 121 core areas identified for the contiguous U.S., and has also been adopted and applied to 47 core areas in Alberta and 115 core areas in British Columbia (Hagen and Decker 2011). While this analysis included the Pend d'Oreille core area, the new analysis of population limitation and threats in this report warrants an update of the conservation status for Salmo River Bull Trout.

Specific details of the Bull Trout core area assessment methodology are presented in Appendix A of USFWS (2005). Briefly, the analysis involves entering codes corresponding to categorical estimates of distribution (stream km inclusive of all critical habitat elements; IUCN 2001 as cited in USFWS 2005), abundance of mature individuals (mean number of spawners annually), trends in abundance, and threats (Appendix 1). The 'threats' score is assigned based on estimated cumulative effects of all threats, in terms of severity, scope, and immediacy (urgency of the situation) for threats overall (Appendix 2).

As the final step in the core area assessment methodology, alphabetical scores corresponding to categorical estimates of abundance, distribution, trend, and threats are converted to numerical values with positive or negative signs (Appendix 3). The numerical values are summed across categories and added to a baseline value (USFWS 2005). The resulting total is then compared to the range of values corresponding to each of 4 conservation status ranks (C-ranks) in order to assign a rank to the core area. The C-ranks are C1-High Risk, C2-At Risk, C3-Potential Risk, and C4-Low Risk (see Appendix 3 for descriptions).[8]

Distribution. Species occurrences consisting of multiple, interconnected populations are generally thought to be more resilient than are single, isolated populations with restricted

[8] These correspond with NatureServe S-ranks utilized by the BC Conservation Data Center for assessing conservation status (although applied at a different spatial scale), with C1-High Risk=S1, C2-At Risk=S2, C3-Potential Risk=S3, and C4-Low Risk=S4 or S5.

distributions. This is because of the expectation that occurrences of the former category will possess greater diversity of habitats and genetic diversity, which should result in a greater chance of finding refuge from or adapting to environmental change. We estimated total distribution in the Salmo watershed to be approximately 110 km (category 'C'; Appendix 1), which was the sum of stream km utilized inclusive of all critical habitat elements (USFWS 2005), and excluding Seven-Mile Reservoir given uncertainy about its suitability for Bull Trout production.

Abundance and trend. Abundance and population growth rate (trend) are two key criteria for evaluating salmonid population viability (McElhany et al. 2000). Sustained, negative abundance trends obviously threaten a population's viability. If not checked, either by mitigating threats or boosting the population's productivity, extirpation may be inevitable. Aside from existing trend or threats, the extirpation risks posed by environmental and demographic stochasticity, and genetic processes (inbreeding depression and long-term genetic losses and genetic drift) are greatly magnified at population sizes (Simberloff 1988; Nunney and Campbell 1993). Guidelines in conservation biology suggest that effective population sizes (N_e) of less than about 50 are vulnerable to the immediate effects of inbreeding depression, and maintaining the genetic diversity required for adaptation to a changing environment probably requires an N_e of 500 or more (Franklin 1980, as cited in Nunney and Campbell 1993; Rieman and Allendorf 2001). Estimates of the ratio of N_e to adult population size N for Bull Trout populations in the U.S. ranged from approximately 0.5 to 1.0 (Rieman and Allendorf 2001), suggesting adult population sizes of approximately 50-100 and 500-1,000 would satisfy the above guidelines with respect to inbreeding depression and adaptation to environmental change, respectively. Empirical studies of extinction in mammals and birds have also generally suggested that an adult population size of $N < 50$ is clearly insufficient for a population's long-term persistence (Boyce 1992). Based on genetic criteria and empirical observations, therefore, we suggest that the Salmo watershed population's long-term viability would be critically imperiled if the mean expected number of spawners reached 50 or less over an extended period of time.

Bull Trout spawner abundance in the Salmo watershed, estimated using the protocol of Nellestijn (2014), exhibits a negative trend (t = -4.009; P = 0.001)[9] over the 1998-2015 time series (Figure 2), with a decline of 68% in evidence over that period (category 'B'; Appendix 1). If this rate of decline continues, the mean expected number of spawners annually will reach 50 or less (category 'A'; Appendix 1) by 2016.

The mean expected number of spawners in 2015, predicted using the exhibited abundance trend (Figure 2), is 56 (category 'B'; Appendix 1). Molecular genetic evidence of inbreeding and small effective population size within the Salmo River watershed suggests that population size in the watershed is already low enough to pose a risk to the population. Tissue samples collected from Clearwater Creek, upper Salmo River, Sheep Creek, South Salmo River, and lower Salmo River indicated that Salmo River populations were genetically unique within the

[9] Simple linear regression on untransformed abundance estimates.

Pend Oreille basin, and provided strong evidence for small effective population size within the Salmo watershed (Bettles et al. 2005). Importantly, the coefficient F_{IS} was significant for 4 of 5 populations, indicating these populations have already experienced some level of inbreeding, which would likely be the result of small effective population size N_e sustained over several generations. Additionally, upper Salmo and Clearwater populations appeared to be unique within the Salmo watershed, indicating restricted gene flow even at this scale. The expectation of reduced connectivity with the rest of the Pend Oreille basin and small N_e is that extinction of some existing populations and diminished founding of new populations are likely (Bettles et al. 2005).

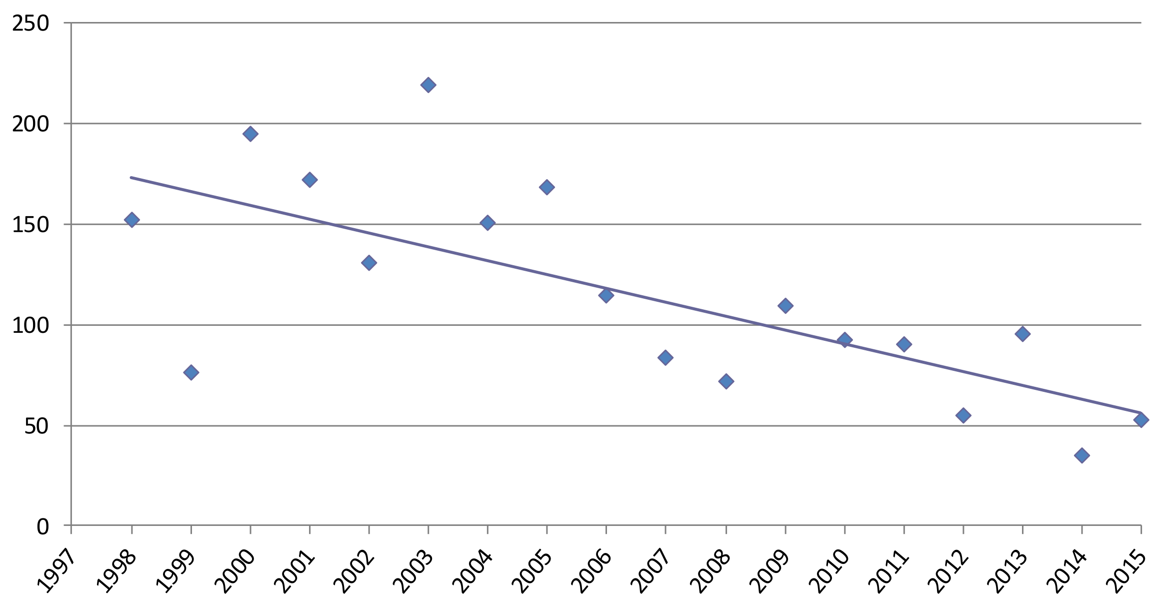

Figure 2. Estimated total Bull Trout spawner population within the Salmo River watershed, 1998-2015, estimated using the protocol of Nellestijn (2014).

Threats. Salmo River Bull Trout face a number of serious threats as discussed in the preceding section (Section *3.0*). Among conservation status indicators (distribution, abundance, trend, threats), these threats, when considered as a whole, paint the most serious picture with respect to the future viability of Bull Trout in the watershed. Moderate-to-high severity threats of moderate or high scope are indicated for habitat degradation, interrupted connectivity, and fish community changes within the subadult/adult rearing environment, and for stream temperature increases in both juvenile and subadult/adult rearing habitats. The cumulative effects of these threats is probably best indicated by the declining trend (Figure 2) in the adult population since 1998, despite the absence of legal angler harvest, and evidence (preliminary) of reduced intraspecific competition within tributary rearing habitats (see Section *3.1*). This trend suggests that the productivity of existing Salmo River Bull Trout habitat, integrated over the whole life cycle, is inadequate to support a self-sustaining, migratory Bull Trout population. Therefore, our assessment is that the cumulative effects of all threats warrants an overall threats score of moderate-to-high severity (major reduction or loss of population is likely; Appendix 1), high scope (>60% of total population or area is affected), and high immediacy (threat is happening now or imminent), corresponding to threats category 'A' (Moderate-to-severe, imminent threat for most of population, occurrences, or area; Appendix 2).

Conservation status rank. Input of categorical values for the four conservation status indicators distribution, abundance, trend, and threats into the conservation status and risk assessment methodology (Appendix 3) resulted in a rank of C1-High Risk, confirming the C-rank assigned previously by Hagen and Decker (2011). Our assessment, therefore, is that Bull Trout in the Salmo River watershed are highly vulnerable to extirpation.

5.0 CONCLUSIONS

Bull Trout of the Salmo River watershed have been under direct study since the late 1990s. Studies reviewed in this document have identified life history and critical habitats (Section *2.0*), permitted assessments of limiting factors and threats (Section *3.0*), and form the basis of the assessment of conservation status and risk (Section *4.0*). With respect to life history and critical habitats, the most significant data gap may be with respect to juvenile rearing abundance and critical habitats outside of the Sheep Creek and South Salmo River watersheds. This data deficiency limits the potential for effective enhancement and conservation actions in the upper Salmo River and Clearwater Creek watersheds, and, when paired with spawner abundance data, assessments of productivity and carrying capacity of these environments.

Salmo watershed Bull Trout population data suggested that the most important life stage limiting the population is probably not juvenile production in tributary environments, as observed juvenile densities are only marginally below those observed elsewhere in the upper Columbia Basin, and current spawner densities do not appear to be high enough to seed existing habitat space (Table 3). The juvenile rearing environment could possibly be limiting at higher spawner abundance, however, due to high water temperatures in lower reaches of these streams limiting the amount of suitable space. Instead, population limitation likely occurs in the subadult/adult rearing environments that are utilized following emigration from natal tributaries. Productivity within subadult/adult rearing habitats appears to be inadequate for a self-sustaining, migratory Bull Trout population, and is likely being limited by habitat degradation, increased water temperature, fish community changes and especially interrupted connectivity (Table 3).

Table 3. Summary of limiting factor hypotheses for the Salmo River Bull Trout population, derived from Section *3.0 Population limitation and threats*.

Hypothesized population limit	Level of support	Threat to population
#1: Productivity in juvenile life stage	**mixed**	**see sub-hypotheses**
#1a: Habitat degradation	low	low severity, high scope
#1b: High water temperature	high	moderate severity, high scope
#1c: Non-native species	low	low severity, low scope
#2: Productivity in subadult/adult life stage	**high**	**see sub-hypotheses**
#2a: Habitat degradation	moderate	moderate-to-high severity, scope
#2b: High water temperature	high	moderate-to-high severity, scope
#2c: Interrupted connectivity	high	moderate-to-high severity, scope
#2d: Fish community changes	high	moderate-to-high severity, high scope

The limiting factors habitat degradation, interrupted connectivity, and fish community changes within the subadult/adult rearing environment, and stream temperature increases in both juvenile and subadult/adult rearing habitats, correspond with moderate-to-high severity threats to population viability of moderate or high scope (Table 3).

Population data and threats information for Salmo River Bull Trout indicate that the population is threatened (C1-High Risk). The conservation status and risk assessment methodology we have employed has been applied previously for core areas across the province by the BC Ministry of Environment. While development of a management plan for Bull Trout in the province has not been finalized, it appears likely that the core area structure and assessment criteria will be integrated in to the management framework. What has yet to be developed is guidance for management and conservation actions in core areas where Bull Trout are deemed to be threatened, such as the Pend d'Oreille core area inhabited by Salmo River Bull Trout.

We suggest that the appropriate actions following a 'C1-High Risk' designation are: 1) determination of whether a recovery plan is warranted, and 2), if this is the case, development of the recovery/action plan. In this report, we feel we have confirmed the threatened status of Salmo River Bull Trout and identified likely factors limiting the population (step 1). The next step in recovery planning is an Action Plan based on this assessment. Specific tasks that need to be accomplished in the Action Plan are:

1. Identify potential recovery actions that address the likely limiting factors

2. Identify the feasibility of potential recovery actions identified in #1 above.

3. Prioritize among potential recovery actions, where this is possible.

4. Identify requirements for additional information with respect to assessing feasibility and/or priority of potential recovery actions.

5. Identify high-priority, feasible recovery actions that can be implemented right away, and delineate the steps required to implement these recovery actions.

6.0 ACKNOWLEDGEMENTS

First and foremost the Salmo Watershed Streamkeepers Society (SWSS) needs to thank their executive group for their continual support for Bull Trout in this watershed. It was the SWSS that supported this project when many others wouldn't.

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Appendix 1. *Instructions and categorical codes for inputting population data and threats assessments into the USFWS (2005) conservation status and risk assessment methodology (reprinted from Hagen and Decker 2011).*

1. EDU

- delineated based on zoogeographic patterns of fish re-colonization, climatic patterns, and existing physical geography.
- potential conservation units for assessing population 'health'

2. 'Core Area'

- population or groups of populations potentially interconnected by migration/straying, but acting approximately independently from other core areas
- intended to approximate meta-population structure
- examples: Squamish system, Lower Fraser, Morice system, Upper Kootenay, Upper Fraser, upper North Thompson, Upper Klinaklini
- approximate scale: watersheds within larger EDU's
- Fill in population size, distribution, and threats values for core area as a whole

3. 'Tributary'

- Tribs for which bull trout presence confirmed

4. 'Population size'

A 1-50 adults
B 50-250 adults
C 250-1,000 adults
D 1,000-2,500 adults
E 2,500-10,000 adults
F 10,000-100,000 adults; not relevant
U Unknown

5. 'Distribution' (area of occupancy within core area)

A <4 km
B 4-40 km
C 40-200 km
D 200-1,000 km
E 1,000-5,000 km
U Unknown

6. 'Trend' (within 25 years)

A Severely declining. Decline of >70% in population, distribution, or number of occurrences
B Very rapidly declining. Decline of 50-70% in " " "
C Rapidly declining. Decline of 30-50% in " " "
D Declining. Decline of 10-30% in " " "
E Stable. Population, distribution, or number of occurrences unchanged or remaining within +/- 10% fluctuation
F Increasing. Increase of >10% in population, distribution, or number of occurrences
U Unknown

7. Threats ('Severity', Scope,' and 'Immediacy')

- The degree to which bull trout in the core area are observed, inferred, or suspected to be directly or indirectly threatened
- Habitat threats include loss of connectivity due to migration barriers, loss of habitat complexity, human-induced water temperature increases (extensive forestry, etc.)
- Exploitation threats should consider high vulnerability of bull trout to angling, current regulations, and monitoring
- Competitors: Brook trout can displace bull trout or hybridize - their presence in a core area is a significant threat to long-term bull trout persistence. Introduced Lake Trout are likely to displace bull trout from lacustrine environments.
- For all threats (habitat, exploitation, and competitors) considered as a whole, estimate levels of severity, scope, and immediacy

Severity

High: Loss of population or destruction of species' habitat in area affected, with effects irreversible or requiring long-term recovery (>100 yrs)
Moderate: Major reduction of species population or long-term degradation or reduction of habitat in the core area, requiring 50-100 yrs for recovery
Low: Low but significant reduction of species population or reversible degradation or reduction of habitat in area affected, with recovery expected in 10-50 yrs
Insignificant: Essentially no reduction of population or degradation of habitat or ecological community due to threats, or recovery from minor temporary loss possible within 10 yrs
(Note that effects of locally sustainable levels of fishing are generally considered insignificant as defined here).

Scope

High: >60% of total population or area affected
Moderate: 20-60% of total population or area affected
Low: 5-20% of total population or area affected
Insignificant: <5% of total population or area affected

Immediacy

High: Threat is happening now or imminent
Moderate: Threat is likely to be operational within 2-5 yrs
Low: Threat is likely to be operational within 5-20 years
Insignificant: Threat is not likely to be operational within 20 yrs

8. Recovery potential

Low: Irreversible losses or requiring long-term recovery (>50 yrs)
Moderate: Significant losses but recovery possible within 10-50 yrs
High: minor temporary losses or recovery possible within 10 yrs

9. Comments

- Opportunity to qualify rankings, describe populations or information sources, etc.

Appendix 2. *Table used to calculate threats scores for individual Bull Trout core areas in British Columbia (Hagen and Decker 2011), based on categorical ratings of threat attributes (severity, scope, and immediacy, cumulative accross all threats)(derived from USFWS 2005; see Appendix 1 and Section 3.4 for details).*

SEVERITY	***SCOPE***	***IMMEDIACY***	***VALUE***	***DESCRIPTION***
High	High	High	A	Moderate to severe, imminent threat for most (>60%) of population, occurrences, or area
High	High	Moderate		
Moderate	High	High		
Moderate	High	Moderate		
High	Moderate	High	B	Moderate to severe imminent threat for a significant proportion (20-60%) of population, occurrences, or area
High	Moderate	Moderate		
Moderate	Moderate	High		
Moderate	Moderate	Moderate		
High	High	Low	C	Moderate to severe, nonimminent threat for significant proportion of population, occurrences, or area
Moderate	High	Low		
High	Moderate	Low	D	Moderate to severe, nonimminent threat for a significant proportion of population, occurrences, or area
Moderate	Moderate	Low		
High	Low	High	E	Moderate to severe threat for small proportion of population, occurrences, or area
High	Low	Moderate		
High	Low	Low		
Moderate	Low	High		
Moderate	Low	Moderate		
Moderate	Low	Low		
Low	High	High	F	Low severity threat for most or significant proportion of population, occurrences, or area
Low	High	Moderate		
Low	High	Low		
Low	Moderate	High		
Low	Moderate	Moderate		
Low	Moderate	Low		
Low	Low	High	G	Low severity threat for a small proportion of population, occurrences, or area
Low	Low	Moderate		
Low	Low	Low		
Two of three insignificant			H	Unthreatened. Threats are minimal or very localized
Two of three unknown or not assessed			U	Unknown. The available information is not sufficient to assign a degree of threat

Appendix 3. *Numeric scoring procedure for assigning core area conservation status ranks, and description of conservation status ranks (reprinted from Hagen and Decker 2011).*

Core Area Numeric Scoring (USFWS 2005, Appendix A)

(Starting value = 3.5)

Categorical value	Population Size	Distribution*	Trend	Threats
U	0	0	0	0
A	-1	-1	-1	-1
B	-0.75	-0.75	-0.75	-0.75
C	-0.5	-0.5	-0.5	-0.5
D	-0.25	-0.25	-0.25	-0.25
E	-0.25	0	0	0
F	0	-	+0.25	0
G	-	-	-	+0.75
H	-	-	-	+1.0

* lower score by one rank (i.e. reduce risk) if anadromous or adfluvial

Points (P)	C Rank	Description
P≤1.5	C1	**HIGH RISK** - Core area at high risk because of extremely limited and/or rapidly declining numbers, range, and/or habitat, making the bull trout in this core area highly vulnerable to extirpation
1.5<P≤2.5	C2	**AT RISK** - Core area at risk because of very limited and/or declining numbers, range, and/or habitat, making the bull trout in this core area vulnerable to extirpation
2.5<P≤3.5	C3	**POTENTIAL RISK** - Core area potentially at risk because of limited and/or declining numbers, range, and/or habitat even though bull trout may be locally abundant in some areas of the core area.
3.5<P≤4.5	C4	**LOW RISK** - Bull trout common or uncommon, but not rare, and usually widespread throughout the core area. Apparently not vulnerable at this time, but may be cause for long-term concern.
N/A	CU	**UNRANKED** - Core area currently unranked due to lack of information or due to substantially conflicting information about status and trends.
N/A	CX	**EXTIRPATED** - Core population extirpated; not a viable core area.