A future outlook on the effects of climate change on bull trout (*Salvelinus confluentus*) habitats in the Cariboo-Chilcotin

Study background

Due to climate change by the 2050s average annual air temperatures and average annual precipitation in the Cariboo-Chilcotin are predicted to increase from 2.0-2.5 °C and 5-20% respectively, although in some locations summer precipitation is expected to decrease by as much as 5% (Dawson et al. 2008). Such changes in air temperatures and precipitation are expected to lead to significant changes in hydrology and water temperatures (Tyedmers and Ward 2001; Pike et al. 2008a).

Snowmelt-dominated watersheds of the Cariboo-Chilcotin tend to have peak flows in the spring, low flows in the late summer and fall – due to low precipitation and dwindling snowpack – and low flows through the winter due to cold conditions that lead to precipitation accumulating as snowpack (Eaton and Moore 2007). In the future, these types of watersheds are expected to see shifts in runoff where periods of snow accumulation are reduced and peak flows start earlier in the spring (Pike et al. 2008b). Given the known relationship between air and water temperatures (Moore 2006; Nelitz et al. 2007b; 2008) increasing thermal regimes can also be expected in tributary and headwater systems. The biological implications of such climate-induced changes are significant given their fundamental linkages to behavioural and physiological responses of life stages of freshwater dependent fish species, such as bull trout (e.g., Dunham et al. 2001; 2003).

The effects of human activities on freshwater habitats are overlaid on top of these underlying biophysical changes. Stressors can magnify adverse effects by reducing water availability in stressed freshwater habitats, removing riparian buffers from thermally sensitive habitats, or imposing unsustainable harvest rates on vulnerable populations. Restoration actions can help mitigate the effects of climate change by reducing water withdrawals to improve summer flows during adult migration and spawning or by adjusting harvest rates to account for poor ocean productivity or in-river conditions. Given our general understanding of the adverse effects of climate change and role of human actions in both positive and negative ways, it is critical we develop strategies to help fish species cope (see strategies in Nelitz et al. 2007a). Developing intelligent strategies, however, requires making decisions today using more detailed information so we know what to do, where and when so as to avoid wasting precious resources. Evaluating the vulnerability of freshwater habitats to climate change is a critical first step to providing decision makers with such information.

This paper summarizes key results from a study to assess the vulnerability of bull trout habitats across the Cariboo-Chilcotin (Nelitz et al. 2009). Other papers provide similar summaries for coho salmon (Nelitz and Porter 2009) and Chinook salmon (Porter and Nelitz 2009). This study is the first of its kind for the Cariboo-Chilcotin (study area boundary in Figure 1). This paper starts by setting the context for understanding vulnerability by briefly summarizing existing information on bull trout populations, and then presenting results from the assessment. The hope is that regional decision makers can use these results to make choices today that will benefit human communities, freshwater habitats, and bull trout populations of the Cariboo-Chilcotin in the future.

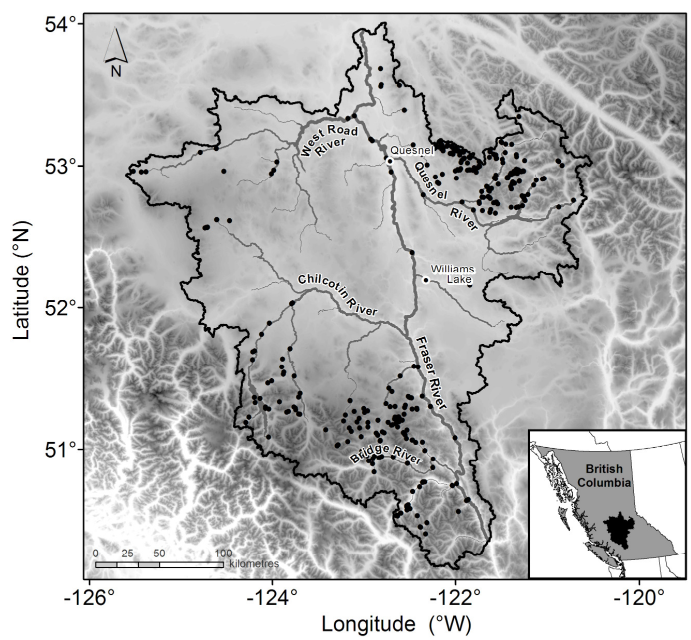

Figure 1. Cariboo-Chilcotin study area and location of bull trout observations (as extracted from B.C. LRDW, March 2009).

Life history

Bull trout in the Cariboo-Chilcotin display a variety of life-history patterns encompassing both resident and migratory strategies (Cannings and Ptolemy 1998;

Hammond 2004). Resident forms complete their entire life cycle in small headwater or tributary streams in which they spawn and rear. Other bull trout are migratory and live in tributary streams for several years before migrating downstream into a larger river (fluvial form) or lake (adfluvial form). Migratory forms spend several years in large rivers or lakes before returning to tributary streams to spawn (Rieman and McIntyre 1993). Body size of mature bull trout varies according to their life history strategy with stream residents being much smaller, relative to river or lake migratory forms. Resident and migratory forms can, however, be found together and it is believed that both forms can produce offspring that show either resident or migratory behaviour (Hammond 2004). Bull trout may spawn every year or in alternate years, and the proportion of adult fish that do not spawn in any given year can be significant (Cannings and Ptolemy 1998). Migratory forms begin their spawning migration to tributary streams in late summer. Spawning for both resident and migratory forms occurs during September and October in running water (Cannings and Ptolemy 1998). The distance covered for spawning varies by life history strategy, with resident forms generally traveling short distances to spawning grounds, while migratory populations may travel up to or over 250 km (McCleod and Clayton 1997).

Population status

In British Columbia bull trout are found in every major drainage (Cannings and Ptolemy 1998; Hammond 2004) and within the Cariboo-Chilcotin they are in all major tributary basins of the Fraser. Although no formal stock delineations exist, localized differences in life-history traits, nuptial colouring and spawning morphology suggest genetic differences among bull trout populations in B.C. (McPhail and Baxter 1996), which has been confirmed by genetics studies that have shown a substantial degree of genetic divergence among bull trout populations from different areas of the province. (Taylor et al. 1999; Taylor et al. 2001; Taylor and Costello 2006). These studies also indicated limited genetic divergence within bull trout populations. This type of genetic structuring suggests either past population “bottlenecks” or strong local selection with limited gene flow between drainages. Either case provides strong evidence for the existence of local stocks in B.C. (McPhail and Baxter 1996; Hammond 2004).

In recent decades both the distribution and abundance of bull trout have declined, particularly in the southern and eastern parts of its North American distribution. While bull trout are still considered fairly widespread in British Columbia (it is considered the last remaining jurisdiction with a large presence and wide distribution of the species), major declines have been identified within the Columbia and lower Fraser systems, among others (Cannings and Ptolemy 1998). Bull trout are generally considered stable or diminishing (Pollard and Down 2001) and is currently blue-listed, a species of special concern in British Columbia, primarily as a result of declines noted throughout its global range. Detailed knowledge of bull trout distribution and status is considered inadequate for most areas of the province (Cannings and Ptolemy 1998). Improved monitoring is required to assess trends in productivity and population size in different regions. An expert-based assessment of conservation status concluded that of 198 watershed groups within the province, 40% were presumed healthy (data available, viable for at least 20 years, no significant threats), 5% had a known conservation risk (data available, population in decline, threats identified), and 30% had a presumed conservation risk (unknown population status, identified threats) (BC MWLAP 2002). For the remaining 25% of watersheds the conservation risk to bull trout was unknown (bull trout present, but no data on either population status or threats). For the 27 watershed groups from the Cariboo-Chilcotin, populations in 1 watershed was ‘presumed healthy’, at ‘conservation risk’ in 1 watershed, with a ‘presumed conservation risk’ in 8 watersheds, with ‘conservation risk unknown’ in 12 watersheds, and had ‘no historical presence’ in 5 watersheds.

The majority of monitoring work for bull trout in the Cariboo-Chilcotin has focused on populations inhabiting Chilko Lake. Monitoring over the past decade has detected declines in the lake’s bull trout populations which have recently led to significant alterations in sport fishery harvesting strategies (R. Dolighan, BC MOE, pers. comm.). Conversely, populations of bull trout inhabiting select watersheds (such as Quesnel Lake) in the Cariboo mountains seem to have recovered from past overexploitation in the sports fishery and now appear to be increasing in numbers (R. Dolighan, BC MOE, pers. comm.).

Angling

Bull trout are a desirable trophy for wilderness fishing in the Cariboo-Chilcotin (Angling BC 2006). Given their long lives (up to 10 years, with sexual maturity often not obtained until their 6th year or later) bull trout are vulnerable to overfishing (Haas 1998; Hammond 2004; Cariboo Chilcotin Conservation Society 2009). Successful recruitment for a population depends to some degree on the number of available spawners present, and adult bull trout are considered relatively easy to catch making it difficult to sustain recreational fisheries that target adult bull trout (McPhail and Baxter 1996). Overharvest from angling has been cited as one of the major factors responsible for the overall decline in bull trout abundance across its range (Post and Johnston 2002).

Bull trout numbers in key sport fishing lakes in the Cariboo-Chilcotin have experienced declines in recent decades (to a point that they were virtually 'non-detectable' in Quesnel Lake, for example). No harvest policies invoked in Cariboo mountain lakes has led to restored numbers for many of these lakes, while new harvest strategies for Chilko Lake that set minimum size limits based on life history traits is aimed at ensuring all age classes of mature bull trout will be allowed to spawn prior to being harvested in the fishery (R. Dolighan, BC MOE, pers. comm.). Logging roads and power lines that allow increased angler access to watersheds, particularly to upper stream reaches, will remain a major concern for bull trout populations (Hammond 2004). Pre-spawning bull trout are large, conspicuously coloured, good to eat and will take almost any lure (McPhail and Baxter 1996). Illegal poaching of bull trout (either intentionally or unintentionally through misidentification) is a common problem whenever access to tributary streams is increased (McPhail and Baxter 1996).

Habitat

Bull trout live primarily in colder lakes, streams and rivers that drain high mountainous areas, especially where snowfields and glaciers are present. They may be found in high gradient areas (up to 30%) where other game fish would not be expected to occur (Cannings and Ptolemy 1998). All bull trout populations in British Columbia use streams and rivers at some point for rearing and spawning, and maintenance of high quality stream habitat is particularly critical for their survival (Baxter and McPhail 1996). Similar to other salmonids water temperature, channel and hydraulic stability, substrates, cover and the presence of migration corridors have been identified as habitat features that consistently influence bull trout presence and abundance (Cannings and Ptolemy 1998). Bull trout, however, are considered to have more specific habitat preferences than other salmonids (Rieman and McIntyre 1993). They require clean, well-oxygenated water within a narrow range of cold temperature conditions, between 5 and 9 ^{o}C for spawning and summer temperatures less than 15 ^{o}C for successful rearing (McPhail and Baxter 1996; Selong et al. 2001).

Bull trout spawning and initial rearing areas are constrained by temperature and these are thought to define the spatial structuring of local bull trout populations or habitat "patches" across larger river basins (Rieman and McIntyre 1995). In the Cariboo-Chilcotin temperatures have been found to be strongly associated with distribution of bull trout in Chilko Lake tributaries and determines which streams provide reproductive habitat (R. Dolighan, BC MOE, pers. comm.). Given the broad distribution of bull trout in British Columbia no studies have attempted to quantify overall trends in bull trout habitat within different regions of the province (Hammond 2004). Road density has been suggested as a surrogate for describing general habitat conditions for bull trout, based on a link between impacts to habitat attributes for bull trout and road construction (Cross and Everett 1997). A summary of environmental statistics for the province (BC MWLAP 2002) found that road length increase by 45% between 1988 and 1999, suggesting a general decline in the quality of bull trout habitats in British Columbia over that time period (Hammond 2004).

Key threats

Bull trout are considered extremely sensitive to warm water temperatures, instream disturbances, and siltation. They have been likened to "canaries in a coal mine" as an early warning system for disruptive habitat changes (Cariboo Chilcotin Conservation Society 2008). Human activities (e.g., road construction, forest harvesting, etc.) can lead to changes in temperature, substrate composition, or channel / hydraulic stability which increase the risk of extirpation (Cannings and Ptolemy 1998; Haas 1998). Any process that leads to increased siltation or the removal of riparian vegetation, especially in small spawning streams, can represent a major concern for bull trout (McPhail and Baxter 1996). Survival of bull trout eggs is a function of the proportion of fine sediment in the incubation gravel (incubation mortality increasing sharply above 30% fines) (Shepard et al. 1984), whereas loss of riparian shade in the summer can increase water temperatures above suitable ranges. Removal of vegetation can also result in lower flows in summer and fall, greater scouring flash floods in spring, and substrate freezing in winter (McPhail and Baxter 1996).

A broader threat to bull trout in BC relates to the potential fragmentation of populations through the disruption of migration patterns, including movement among populations (Hammond 2004). Connection of populations is necessary to ensure genetic exchange and allow recolonization of streams following catastrophic events (Dunham and Rieman 1999, Hammond 2004). Persistence of local bull trout populations will decrease if local populations become isolated from each other through the creation of barriers to migration (Rieman and McIntyre 1996). Barriers to bull trout movement can be fairly obvious (e.g. perched culvert outlets) or more subtle, such as sections of degraded habitat (e.g., unstable stream channels, elevated water temperatures, etc.) (Hammond 2004). Isolation of bull trout populations is anticipated to become a growing threat as climate change impacts that are predicted to increase water temperatures may restrict bull trout distributions to smaller fragments of habitat suitable for this cold water specialist (Hammond 2004; Rieman et al. 2007). Because bull trout are distributed across a broad range of environments and landforms of varied relief, the effects of climate change on bull trout populations will be more pronounced in some regions than in others (Rieman et al. 2007). In the Cariboo-Chilcotin the direct effects of climate change are likely to be exacerbated by current and continuing loss of stream cover and stream channel degradation associated with mountain pine beetle infestations, particularly in the dry "south Chilcotin" area (R. Dolighan, BC MOE, pers. comm.). Much anticipated work in terms of habitat work for bull trout in the region is focused on clearing decadent fallen pine from stream channels and rehabilitating damaged stream banks. Without intervention in the form of clearance of Chilko Lake tributaries, for example, it is anticipated that most of the lake's key spawning streams will become inaccessible to adult bull trout (R. Dolighan, BC MOE, pers. comm.).

Study approach

The vulnerability of bull trout habitats was assessed by linking results from a series of mathematical and GIS models (see Figure 2). A first step was to calculate downscaled climate projections from six unique Global Climate Model (GCM) and emissions scenario combinations. These six scenarios provided a range of predictions about future air temperatures and precipitation across the Cariboo-Chilcotin. Predictions of future air temperatures and precipitation were then used as inputs for a physically-based, macro-scale hydrological model that generated daily flow measurements at focal "nodes" across the study area. Downscaled air temperatures were also used in an empirical model to predict the annual maximum of a seven-day running average of the daily mean water temperature across a different set of "nodes". Next, fish observations, known barriers, and channel characteristics were used to develop a reach-scale distribution layer for bull trout salmon in GIS. Lastly, predictions from the stream flow and temperature models were compared against biologically-based habitat criteria for bull trout and combined with the species distribution layer to determine the spatial extent and suitability of habitats for a historic reference (1961-1990) and future time periods (2020s, 2050s, and 2080s). A more detailed description of methods is available in Nelitz et al. (2009).

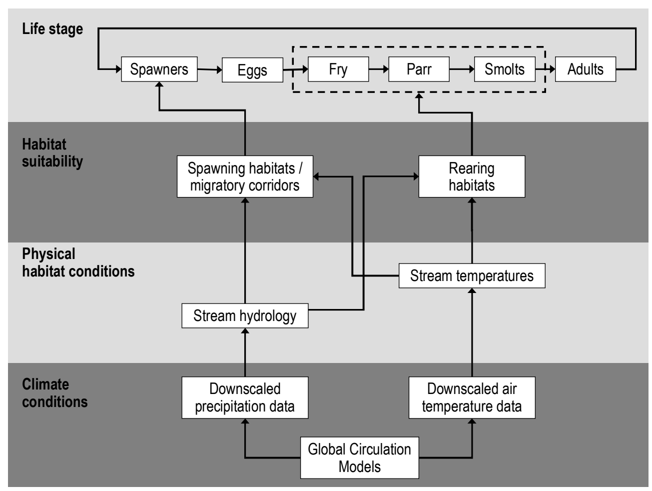

Figure 2. Simplified conceptual model illustrating the linkages among climate, physical habitat conditions, habitat suitability, and Pacific salmon life stages.

Study findings

The baseline distribution layer developed for bull trout is shown in Figure 3. This distribution overlaps markedly with three watersheds (the Quesnel, Bridge and West Road River drainages) characterized by predictions of the coldest habitats in the study area (Figure 4) and observations of bull trout (Figure 1). This observation is consistent with the cold water preferences for this species. The extent of colder water in each of these areas is predicted to become markedly reduced over time in both "best" case and "worst" case scenarios (Figure 5 and Figure 6). The time series depicted in these figures shows a progressive overall restriction in available cold water habitats and a progressive fragmentation of habitat patches. In the worst case scenario cold water habitats are predicted to almost completely disappear from the West Road and Quesnel River drainages by 2080s, with the exception of extremely small and widely scattered refuges. Only the Bridge River drainage is predicted to maintain relatively extensive and connected colder water habitats under climate-change.

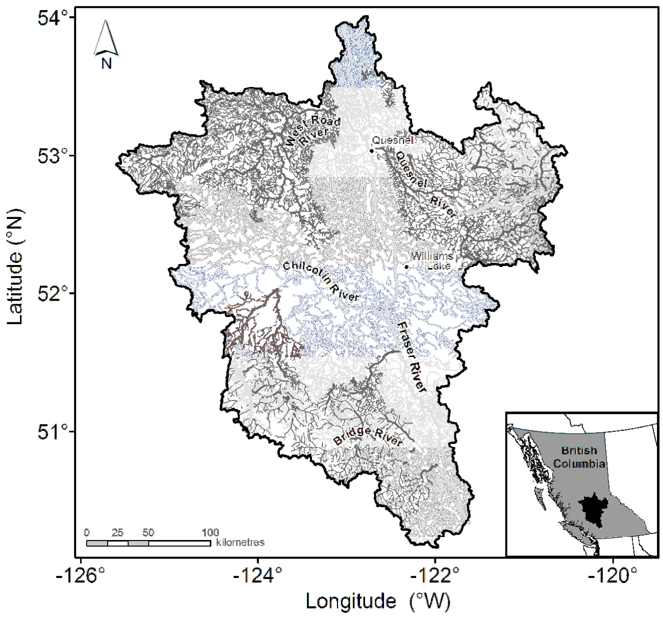

Figure 3. Modeled baseline distribution of bull trout. Suitable reaches for bull trout habitats are dark grey, those not suitable are light grey.

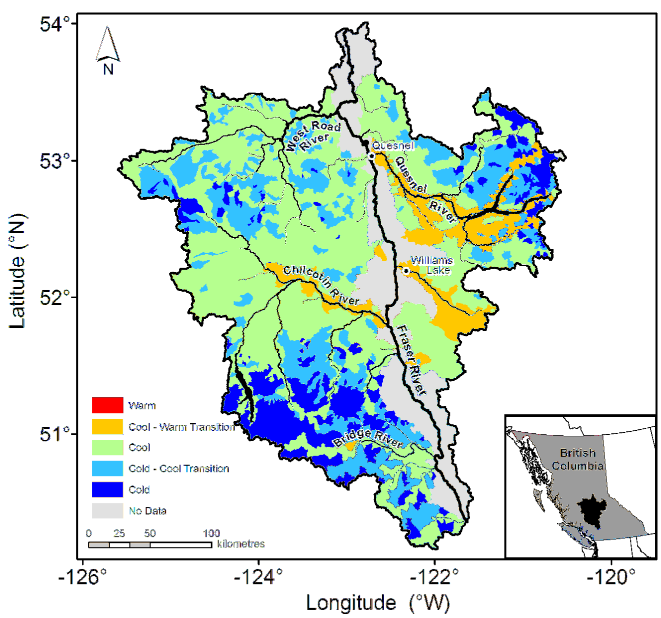

Figure 4. Classification of watersheds by thermal class. Thermal classes preferable to bull trout are represented by cold and cold-cool transition areas.

Our analyses suggest that for all regional watersheds with resident bull trout the extent of preferred coldwater habitats will decrease considerably under the varied climate change scenarios and that the extent of habitats considered thermally sub-optimal or potentially unusable by bull trout will increase. Figure 7 through Figure 9 illustrate the expected changes in total amount of bull trout habitat classified within each of five stream temperature categories for the Bridge, Quesnel, and West Road River watersheds. In all watersheds, useable stream length within the most optimal cold and cold-cool transition categories decreases sharply over time, with coldwater habitats disappearing almost entirely from the Quesnel and West Road River drainages by the 2080s. Concurrently, the extent of current bull trout habitat that is predicted to transition to warmer water temperatures (likely unusable by bull trout) is expected to increase in all watersheds and become particularly noticeable by the 2080s.

Implications

These predictive analyses are based on modeled inputs and as such there are a range of assumptions and caveats that should be considered when interpreting results. These are outlined in detail in Nelitz et al. (2009). In projecting future temperature changes to streams it must be noted that the model cannot account for future local changes in land use that could ameliorate broader temperature impacts to some extent, nor does it account for the role of localized groundwater in regulating stream temperatures. The general patterns of this analysis do not, however, seem promising for bull trout. Bull trout are already considered a sensitive species within BC with very specific cold water habitat requirements, so further impacts to their remaining core habitats is likely a cause for concern. The long term patterns suggest both an expected decrease in the total amount of cold water stream habitat and fragmentation of these colder areas into disconnected “patches” of suitable habitat. Maintaining viable sized patches of cold water habitats for bull trout and ensuring unimpeded connectivity between them may become an important future issue for maintaining genetic exchange between increasingly isolated regional bull trout populations.

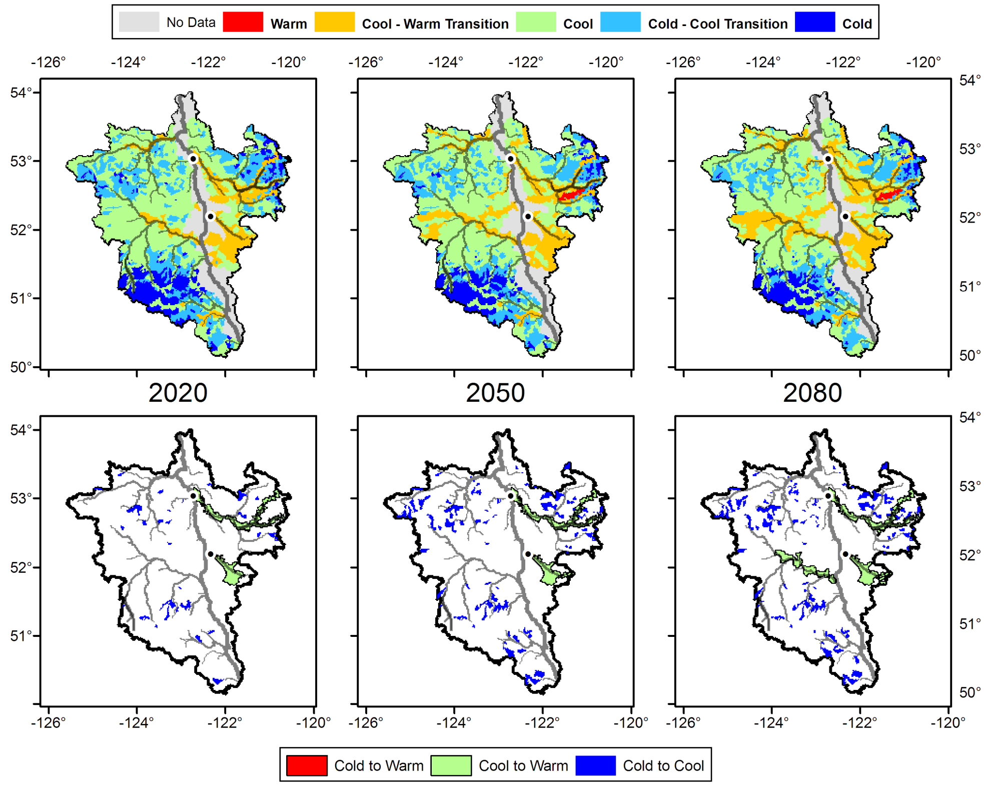

Figure 5. "Best" case outcome (i.e., least change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 4.

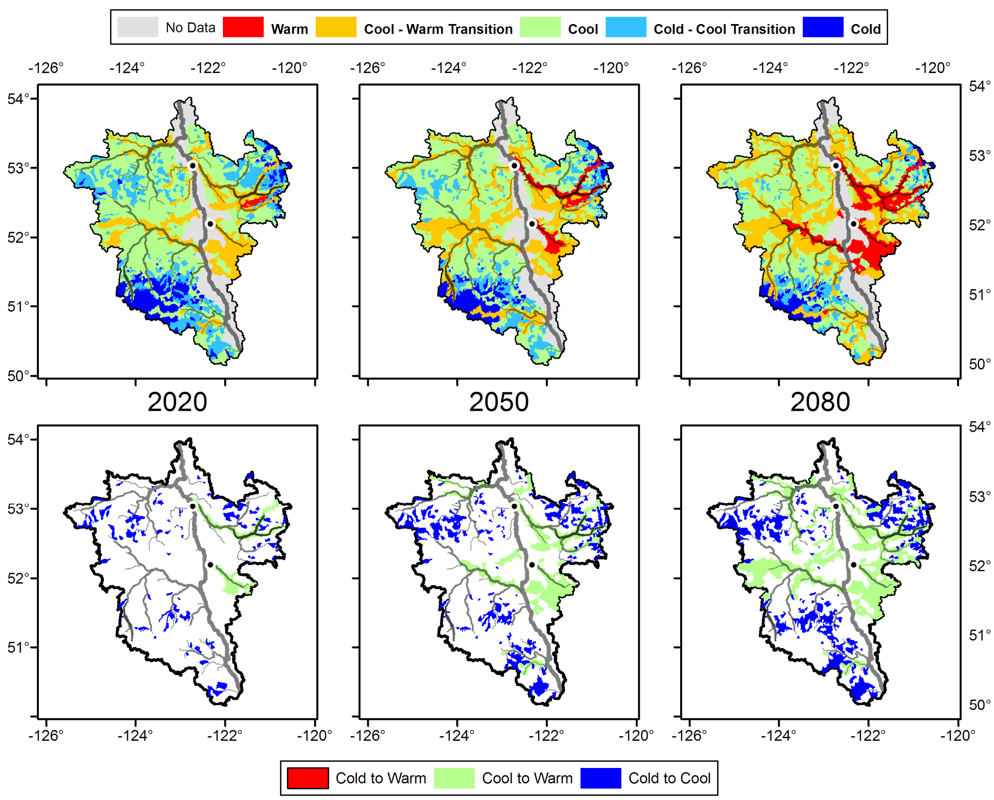

Figure 6. "Worst" case outcome (i.e., most change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 4.

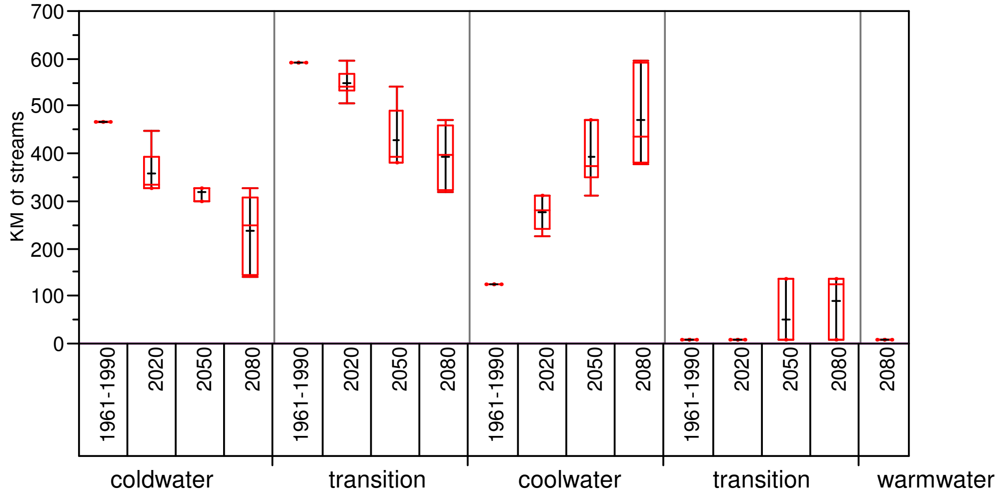

Figure 7. Linear extent (km) of thermal habitat classes across **Bridge River** watershed in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

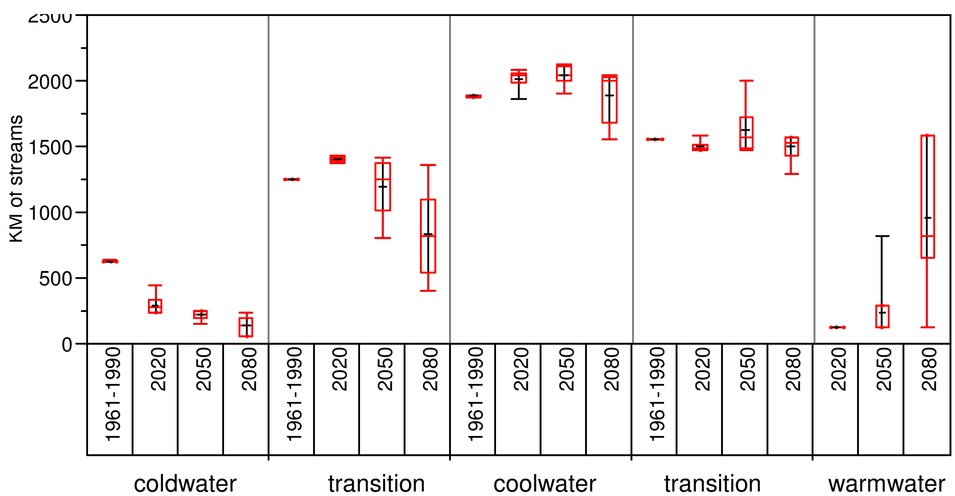

Figure 8. Linear extent (km) of thermal habitats across **Quesnel River** watershed in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

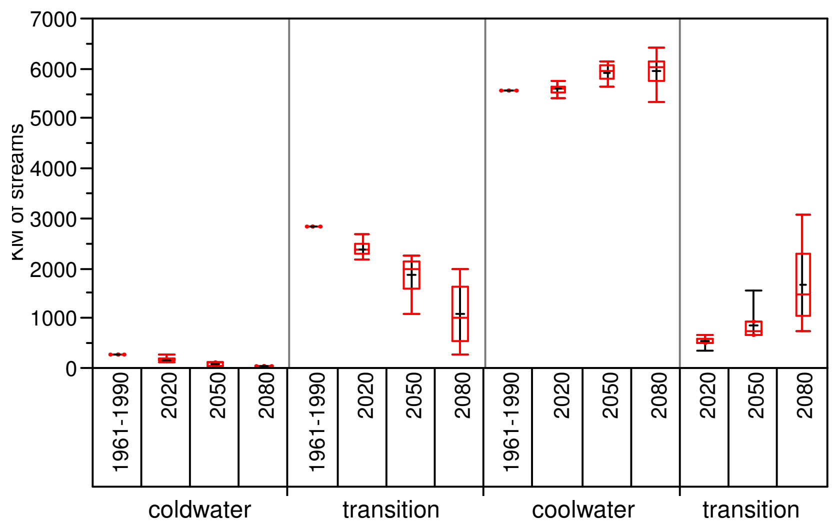

Figure 9. Linear extent (km) of thermal habitats across **West Road River** watershed in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

Acknowledgements

Foremost we are grateful to the Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and the Pacific Fisheries Resource Conservation Council who collaboratively funded this project.

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This study could not have been completed with the same level of rigour without the Pacific Climate Impacts Consortium (PCIC). Katrina Bennett and Arelia Werner of PCIC provided data and expertise with the climate change and hydrology modeling. Their work was supported by Eric Salathé of the University of Washington, Climate Impacts Group, and Makus Schnorbus of the BC Ministry of Environment, River Forecast Centre.

A technical working group guided our study with their wisdom and experience. This group included Richard Bailey, Carrie Holt, Erland MacIsaac, and Chuck Parken of Fisheries and Oceans Canada, Eric Parkinson of the Ministry of Environment, Sara Howard of Nature Conservancy Canada, and Mary-Sue Atkinson of the Pacific Fisheries Resource Conservation Council. Mike Ramsay and Rob Dolighan of the BC Ministry of Environment (Williams Lake) provided helpful guidance in preparing this outlook paper.

Suggested citation

Porter, M. and M. Nelitz. 2009. A future outlook on the effects of climate change on bull trout (*Salvelinus confluentus*) habitats in the Cariboo-Chilcotin. Prepared by ESSA Technologies Ltd. for Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Resource Conservation Council.

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