A future outlook on the effects of climate change on coho salmon (*Oncorhynchus kisutch*) 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 coho salmon (e.g., Nelitz et al. 2007a).

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 coho salmon habitats across the Cariboo-Chilcotin (Nelitz et al. 2009). Other papers provide similar summaries for Chinook salmon (Porter and Nelitz 2009a) and bull trout (Porter and Nelitz 2009b). 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 coho populations from the region, 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 coho populations of the Cariboo-Chilcotin in the future.

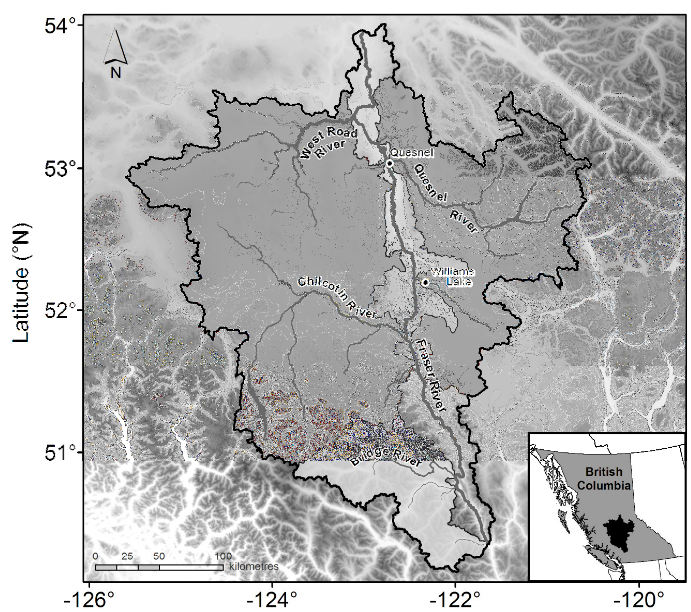

Figure 1. Upper Upper Fraser sub-population in dark shading and Middle Upper Fraser sub-population in light shading (from IFCRT 2006). Middle Fraser Conservation Unit includes both sub-populations (Holtby and Ciruna 2007).

Life history

Interior Fraser coho have a 3-year life cycle which is considered the least variable of Pacific salmon (Irvine et al. 1999; Irvine 2002; DFO 2002; IFCRT 2006; Holtby and Ciruna 2007). Adults return to natal watersheds of the Interior Fraser to spawn during the fall and early winter. Fry emerge the following spring during periods of high discharge and move to flooded and off-channel habitats. Most juvenile coho spend their first year in freshwater, outmigrating as smolts along the Fraser River the following spring during peak flows periods. Interior Fraser coho spend 18 months at sea rearing in the Strait of Georgia, Juan de Fuca Strait, the continental shelf off southwest Vancouver Island, and adjacent to the Washington and Oregon coasts. Individuals spending only one year (age 1.0, Jacks) or more than two years (age 1.2) at sea are generally rare.

Population status

Genetic studies confirm that Interior Fraser coho are genetically distinct from other populations in BC including those of the lower Fraser (Beacham et al. 2001; Irvine et al. 2000). Interior coho are comprised of five genetically distinct populations and eleven distinct sub-populations (IFCRT 2006). Of relevance to this study is the Upper Fraser population (Figure 1) which extends above the confluence of the Fraser and Thompson Rivers to northern extent of their range in the Fraser. Within this geographic area are two sub-populations – the Middle Upper Fraser (which includes Bridge, Seton, Portage, Gates, and Stein Rivers) and the Upper Upper Fraser (which includes Chilcotin, Quesnel, and Blackwater Rivers among others). As part of Strategy 1 of the Wild Salmon Policy (DFO 2005), Fisheries and Oceans Canada has divided BC into 43 Conservation Units (CUs) for coho. Each CU represents a "*groups of wild salmon living in an area sufficiently isolated from other groups that, if extirpated, are very unlikely to be recolonized within an acceptable time frame*" (Holtby and Ciruna 2007). These units will form the geographic basis for managing stocks in the future under the Wild Salmon Policy (DFO 2009b). The Middle Fraser CU includes the entire Cariboo-Chilcotin study area and overlaps exactly with the Upper Fraser population described above.

All Interior Fraser coho populations are currently recognized as stocks of concern (DFO 2009a). In 2002, Interior Fraser coho were designated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002) and put forward for consideration under the Species at Risk Act (SARA). In 2006 the federal government decided not to list Interior Fraser coho under SARA. The reason for conservation concerns is due to recent trends in abundance (Figure 2). Over the years of record, escapement for Interior Fraser coho showed peaks in the mid-1980s and sharp declines in the late 1990s mirroring declines in marine survival (Figure 3). Escapement since 2000 has been highly variable (FBC 2009). In 2001, 2002, 2004, and 2007 the number of spawners was the highest in recent decades. Interspersed among these years, however, were ones of low abundance including 2006 which was the lowest on record. Trends in total abundance (catch plus escapement) have shown a similar pattern with a peak in the late 1970s and 1980s followed by declines starting in the 1990s (Figure 2).

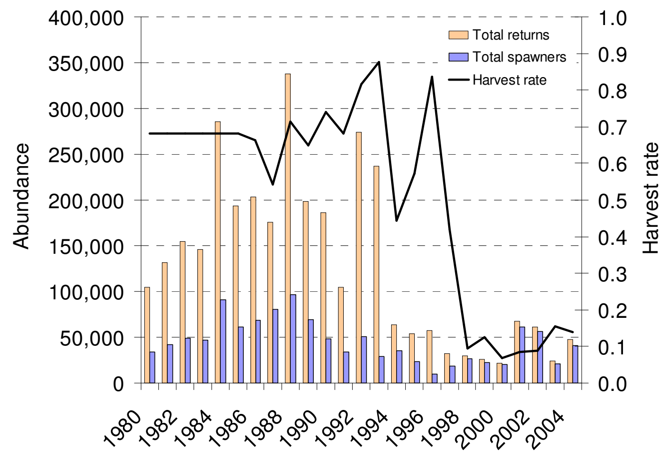

Figure 2. Total returns (catch plus spawners), total spawners, and harvest rate for Interior Fraser coho (data from Folkes et al. 2005).

Figure 3. Marine survival for two coho stocks from the Strait of Georgia (from Folkes et al. 2005).

Patterns in escapement for each population from the Interior Fraser are similar to the overall trend, though the relative contributions of each population are very different (Folkes et al. 2005; IFCRT 2006). The Upper Fraser population of the Cariboo-Chilcotin contributes one of the smallest proportions (Figure 4) and is also one where escapement estimates have the highest degree of uncertainty. Most escapement data in the Interior Fraser have been collected using visual observations of spawners and direct counts at fish fences. Prior to 1998, enumeration of Interior Fraser Coho spawners was sporadic and focused mostly in the North and South Thompson drainages. Historical escapement estimates to other systems, such as the Upper Fraser, have been extrapolated using proportions relative to North and South Thompson populations from 1998-2003 (Irvine 2002; IFCRT 2006).

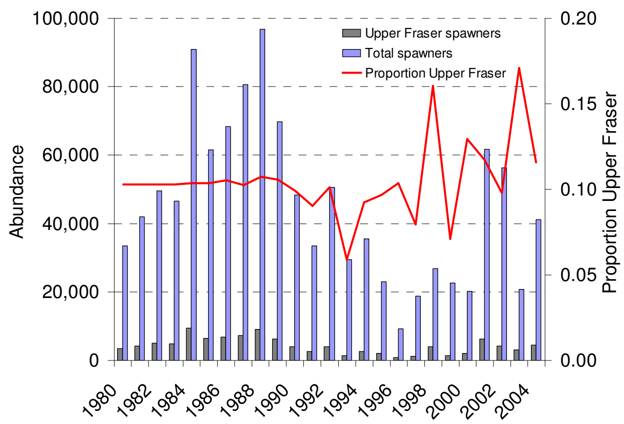

Figure 4. Total spawners across all Interior Fraser coho populations and the estimated abundance of spawners from the Upper Fraser; data also represented as a proportion (data from Folkes et al. 2005).

Current abundance is markedly lower than estimates from earlier in the 20th century. In the 1920s and 1930s, it has been estimated that the total abundance of Fraser River coho was 1.2 million, half of which were estimated as returning to the spawning grounds (Northcote and Burwash 1991). Of this total, one third (~200,000) was estimated as returning to spawn in Interior Fraser watersheds (Irvine 2002). Between 1913 (the year of the Hell's Gate rock slide) and 1966 (the year of completing the fishway), passage through Hells Gate to upstream spawning areas was limited and is believed to have contributed to large declines during this period (Northcote and Burwash 1991).

Harvest

Interior Fraser coho populations are most vulnerable to harvesting in the Juan de Fuca Strait from early April to mid-October. Historically, these populations were directly targeted by First Nations, commercial, and recreational fisheries in the Juan de Fuca and Johnstone straits, Strait of Georgia, along the coasts of Washington and Oregon, off the west coast of Vancouver Island, and in the Fraser River. More recently, actions have been taken to eliminate targeted coho fisheries, leading to remaining vulnerabilities from commercial and recreational fisheries targeting Fraser River sockeye and pink salmon. The Canadian target exploitation rate for coho from these fisheries is 3% or less (DFO 2008).

Since the early 1900's, Interior Fraser coho have been heavily harvested. In the early part of the 20th century, Northcote and Burwash (1991) estimated that Fraser River coho were subject to a 50% harvest rate. More recently, harvest rates have remained higher than 60% for all but two years between 1985 and 1996, reaching a peak of 88% in 1993. Strategies to reduce harvest were first implemented in 1995 after noticeable declines in abundance (Figure 2). In 1998 the coho fishery was closed due to their lack of effectiveness (IFCRT 2006). Since that time harvest rates on Interior Fraser coho from all sources have consistently been below 16% (FBC 2009).

Habitat

Although the distribution of the Upper Fraser population is poorly known, calculations have determined that 67 % of accessible streams (4,702 km) and 48% of suitable spawning habitats (1,754 km) within the Interior Fraser are located within this region (Figure 5). Despite the large extent of spawning habitats, there are relatively few streams with known spawning. For the Middle Fraser sub-population, spawning occurs in the Bridge, Yalakom, and Seton Rivers. Within the Upper Fraser population, coho are widely distributed throughout the Quesnel River watershed, though they have not extended beyond a fishway on the Cariboo River. In the Chilcotin basin, coho spawn on the Chilcotin and Chilko Rivers. Coho have also been observed in the West Road (Blackwater) River (IFCRT 2006).

While coho have a relatively simple life history, their use of freshwater habitats is highly varied. Spawning habitats are usually clumped within watersheds in areas upstream of riffles on small streams, in side-channels, or along mainstems. Juvenile coho are typically found in small and low elevation streams with low to moderate gradients (< 5-8%), preferring pools over riffles.

Given a general lack of knowledge about distribution and habitat utilization in the Cariboo-Chilcotin, it is extremely difficult to identify critical areas needed to support the Upper Fraser population. However, it does not appear that the quantity of either spawning or summer rearing habitats is limited (IFCRT 2006). Only 75 of 274 suitable streams across all Interior Fraser populations are used regularly for spawning. As well, there is an abundance of summer rearing habitats. Overwintering survival is recognized as a factor limiting smolt production in small streams, usually driven by the quantity of overwintering habitats (Nickelson and Lawson 1998; Nickelson et al. 1992) or the size of juveniles prior to the onset of winter (Holtby 1988; Quinn and Peterson 1996).

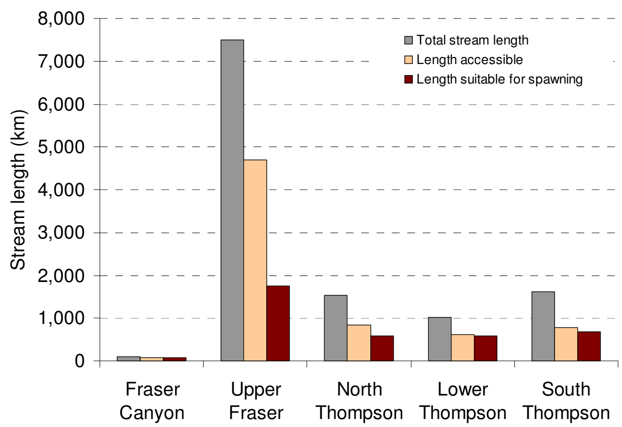

Figure 5. Total stream length, accessible stream length, and stream length suitable for spawning, grouped by Interior Fraser coho populations (data from IFCRT 2006).

Key threats

The conservation strategy for Interior Fraser coho focuses on reducing impacts from four key threats: overfishing, habitat alterations, hatchery production, and climate change (IFCRT 2006). It is generally recognized that overfishing was a primary contributor to declines in Interior Fraser coho (Irvine 2004; DFO 2002). Overfishing resulted when high harvest rates were maintained during a period of declining marine productivity.

Given the time spent in freshwater, juvenile coho are vulnerable to changes in habitat conditions. Although there is an abundance of coho habitats across the Upper Fraser, the level of human disturbance in watersheds has been recognized as having a contributing, though secondary, effect on declines in Interior Fraser coho (Bradford and Irvine 2000). Good quality habitats can help sustain salmon populations during periods with high harvest rates or poor marine conditions. Conversely, degraded habitats may exacerbate impacts or constrain recovery of populations with low abundance. Though site-specific impacts vary, across the entire study area the effects of forestry, agriculture, and water withdrawal are more extensive with 44%, 35% and 31% of 124 assessed streams within the Upper Fraser population having a moderate or high level of impact. Agricultural and water withdrawal concerns are concentrated in the Chilcotin River watershed, while forestry concerns are more prevalent in the Quesnel (Appendix 4, IFCRT 2006). The effect of hydropower, linear development, and urbanization is generally low. Mountain pine beetle has also lead to dramatic and extensive changes to the forested landscape of the Cariboo-Chilcotin, which can adversely affect watershed hydrology (Uunila et al. 2006). Across the province 7.1 million hectares were affected between 1999 and 2005 (Aukema et al. 2006).

Hatchery releases in the Interior Fraser have steadily increased through the period of declines in abundance (Figure 6). Accompanying artificial enhancement are concerns that hatchery fish can compete with wild fish in marine and freshwater environments, interbreed with wild fish and affect their genetic resilience, and encourage high harvest rates on wild populations (Orr et al. 2002; Nickelson 2003).

Lastly, the abundance and productivity of salmon population has been related to climate change. Such effects are expected to have an influence on marine (e.g., increased competition and predation, changes in ocean productivity, reviewed by Levy 1992; Beamish and Noakes 2002) and freshwater conditions (e.g., reduced peak and summer flows, earlier freshets, increased winter scouring, increased stream temperatures, reviewed by Levy 1992, Nelitz et al. 2007).

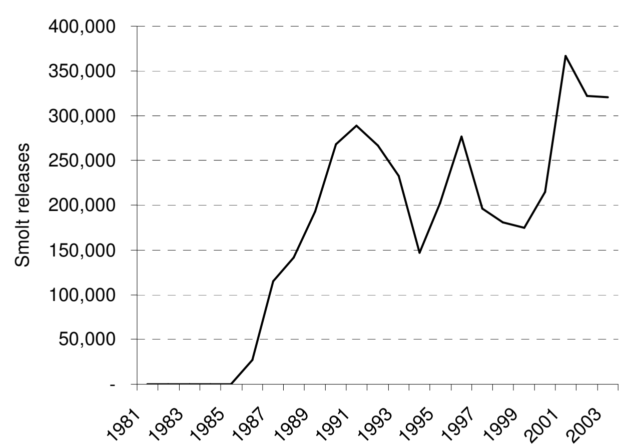

Figure 6. Total number of smolts released in the Interior Fraser from 1981 to 2003 (data from IFCRT 2006).

Study approach

The vulnerability of coho habitats was assessed by linking results from a series of mathematical and GIS models (see Figure 7). 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 coho. Lastly, predictions from the stream flow and temperature models were compared against biologically-based habitat criteria and combined with species distribution to determine the spatial extent and suitability of habitats for a historic (1961-1990) and future time periods (2020s, 2050s, and 2080s). A more detailed description of methods is available in Nelitz et al. (2009).

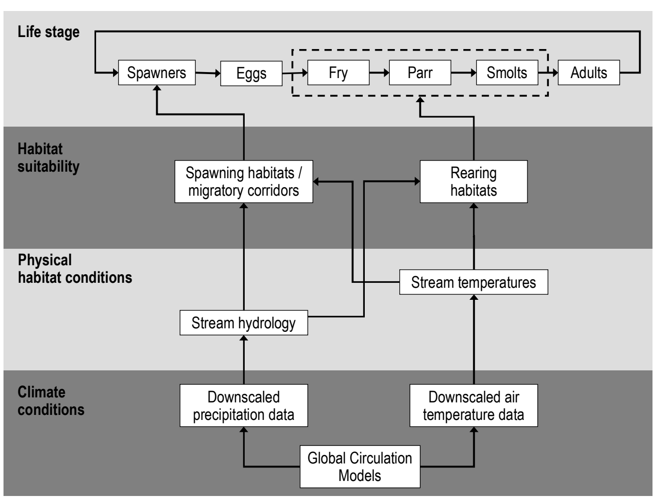

Figure 7. Simplified conceptual model illustrating the linkages among climate, physical habitat conditions, habitat suitability, and Pacific salmon life stages.

Study findings

The modeled distribution of coho salmon is shown in Figure 8. This distribution is widespread with habitats contained within the three largest watersheds – the Quesnel, Bridge, and West Road River. Results from modeling of stream temperatures and flows provide insights into potential future conditions for juvenile rearing during the summer.

From a thermal perspective, there appears to be a current abundance of suitable coolwater and cool-warm transition habitats within the downstream reaches of the Chilcotin, Quesnel, and West Road watersheds (Figure 9). Under a "best" case scenario of climate change (Figure 10), changes are predicted to be most significant in the Horsefly and Chilcotin drainages, with temperatures shifting towards those preferred by warmwater fish communities. Under a "worst" case scenario thermal shifts are even more significant and extensive in the Chilcotin and Quesnel (Figure 11). On average, the linear extent of coolwater habitats is predicted to decline in the Chilcotin by the 2080s, while cool-warm transition habitats are expected to increase (Figure 12). The pattern is the opposite in the Quesnel where coolwater habitats are expected to increase while cool-warm transition habitats are expected to decrease (Figure 13). These changes are accompanied by potentially large increase in the extent of warmwater habitats which could adversely affect coho. Although informative, it will be important to examine where these changes occur specifically to determine whether they might be a benefit (increasing extent of suitable thermal habitats, as in the Quesnel) or constraint (decreasing extent of preferable thermal habitats, as in the Chilcotin) on the productive capacity of coho habitats.

From a low flow perspective, four of seven streams of relevance to coho are predicted to maintain suitable low flow conditions into the future (Figure 14). Locations within the Quesnel River drainage, however, suggest that low flow conditions might constrain juvenile rearing. Model predictions show that summer low flows will generally decline in the Quesnel River, Horsefly River, and Moffat Creek by the 2080s.

Implications

When interpreting these results it is important to remember they are based on models applying a range of assumptions and caveats (see Nelitz et al. 2009). In general, these models do not consider the mitigating or exacerbating effects of human activities. However, these results are informative in that they suggest the potential changes of climate change might be mixed for coho – a potential benefit in some locations and a potential constraint in others. Further exploration of these data and field validations would be fruitful.

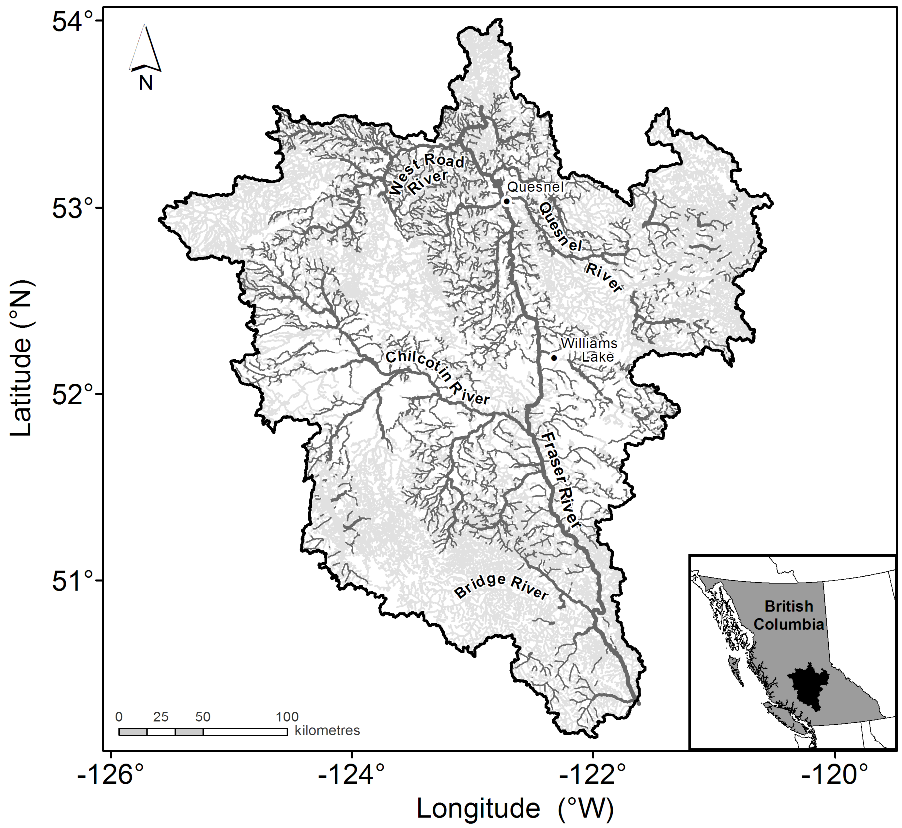

Figure 8. Modeled baseline distribution for coho salmon. Suitable reaches are dark grey, not suitable light grey.

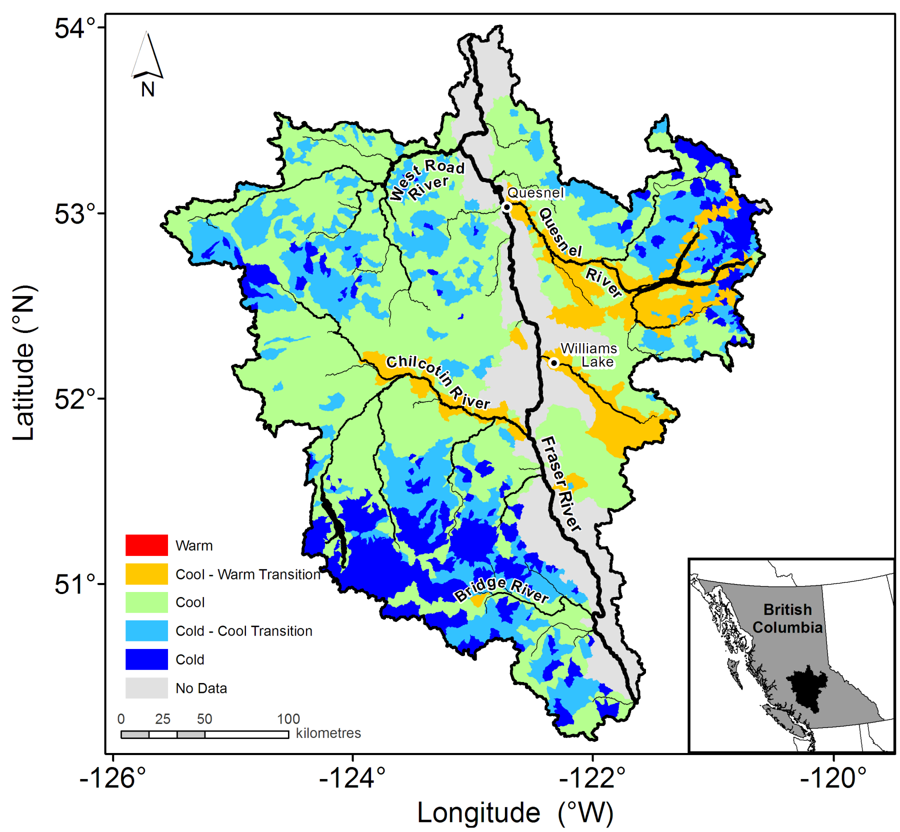

Figure 9. Classification of watersheds by thermal class. Thermal classes preferable to coho salmon are represented by cool and cool-warm transition areas.

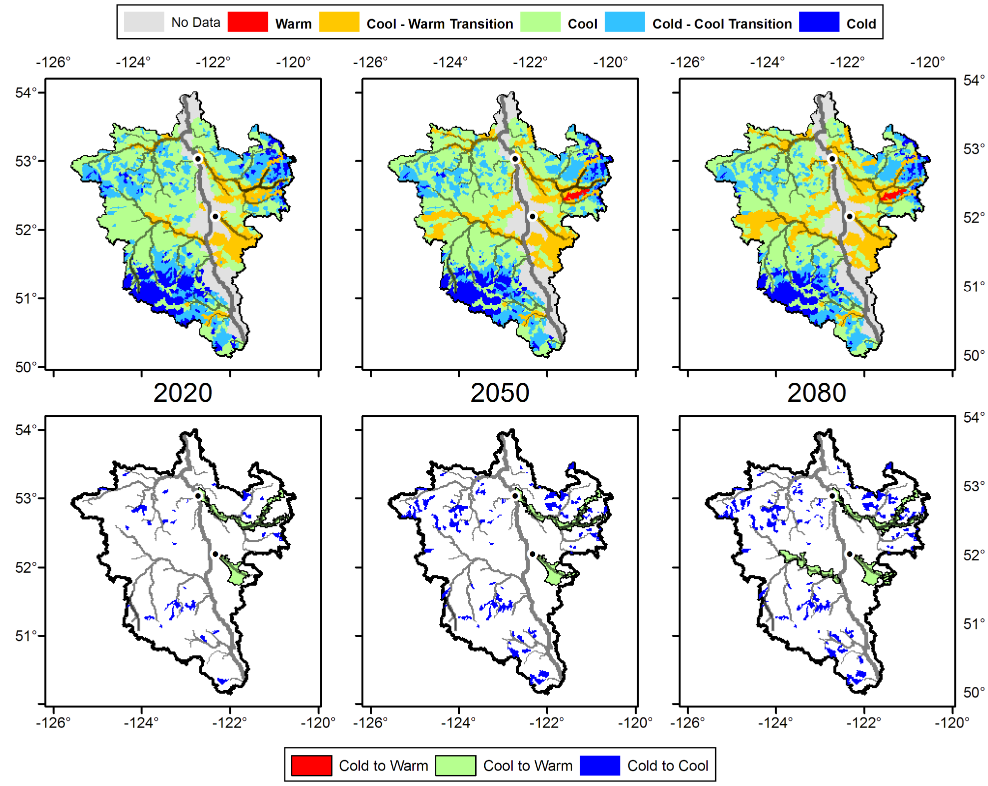

Figure 10. "Best" case outcome (i.e., least change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 9.

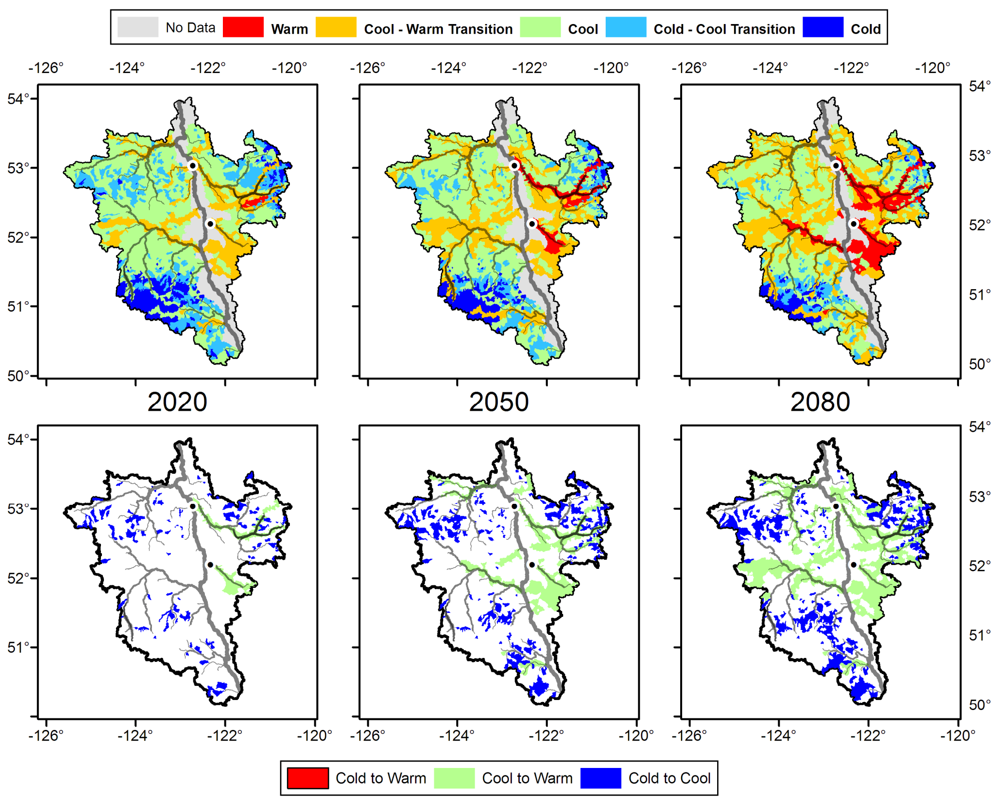

Figure 11. "Worst" case outcome (i.e., most change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 9.

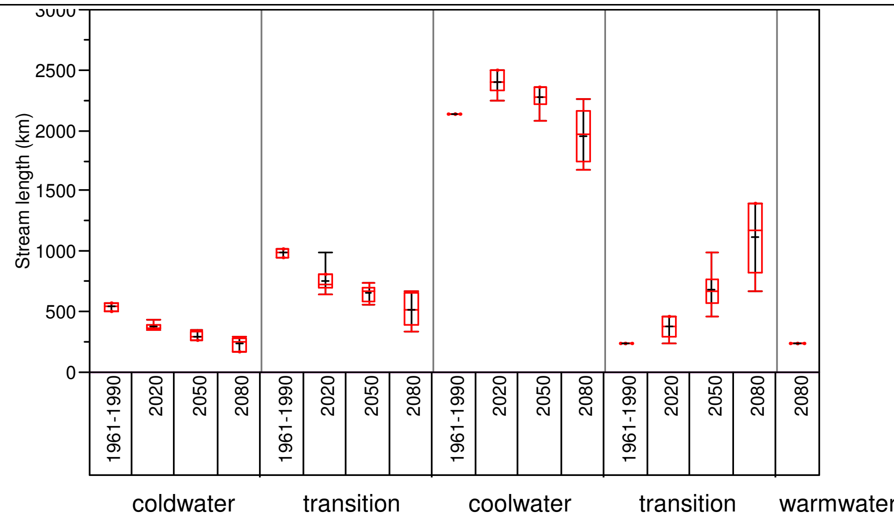

Figure 12. Linear extent (km) of thermal habitats for coho salmon across **Chilcotin River** watershed in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

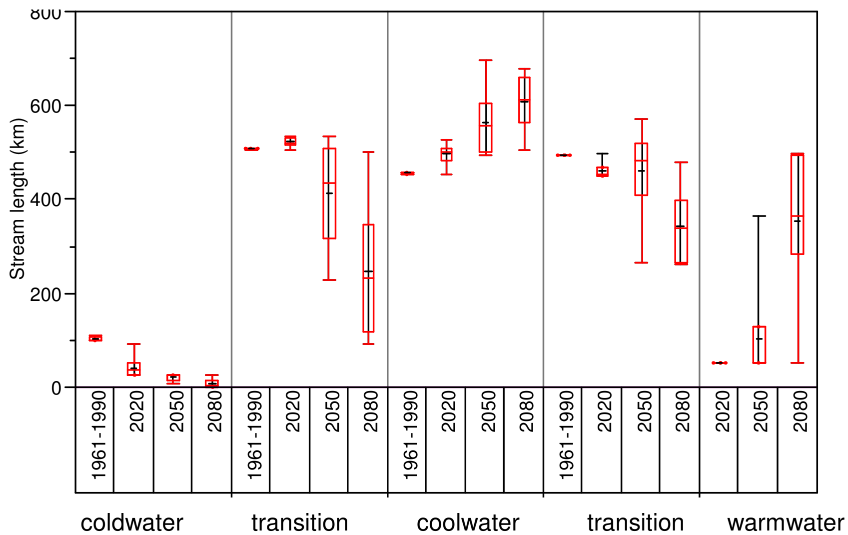

Figure 13. Linear extent (km) of thermal habitats for coho salmon across **Quesnel River** watershed in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

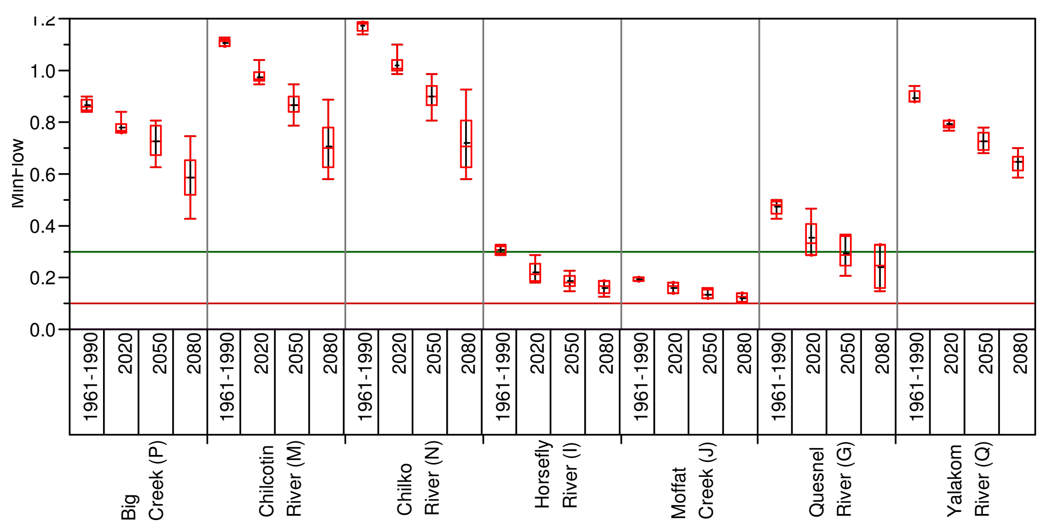

Figure 14. Minimum flow of a 7-day rolling average between July 1 and October 1 as a percentage of Mean Annual Discharge for historic and future time periods. Flows below lower horizontal threshold will likely impair juvenile rearing.

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Fraser Salmon & Watersheds Program

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