A future outlook on the effects of climate change on Chinook salmon (*Oncorhynchus tshawytscha*) 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 Chinook 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 Chinook salmon habitats across the Cariboo-Chilcotin (Nelitz et al. 2009). Other papers provide similar summaries for coho salmon (Nelitz and Porter 2009) 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 Chinook 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 Chinook populations of the Cariboo-Chilcotin in the future.

Life history

Chinook salmon have a diverse life history with variations in age of seaward migration, variations in the duration of estuarine and ocean residence, migration patterns in the ocean, and timing of spawning migrations and spawning (Healey 1991). Much of this variation is associated with the length of time juveniles spend in freshwater before smolting (Holtby and Ciruna 2007). "Stream-type" Chinook spend a larger proportion of their life in freshwater, both before migration to the ocean (one to three years) and during migration to spawning grounds (several months). "Ocean-type" Chinook salmon spend less than a year in freshwater and will enter freshwater only days or weeks before spawning (Healey 1991; Roberge et al. 2002). Stream-type adults return to freshwater during the spring and summer, while ocean-types return in the fall, shortly before spawning. Many river systems have more than one stock of Chinook, some rivers having spring, fall and winter runs. Stream and ocean types do not appear to be genetically distinct within B.C. though there is no evidence that facultative switching is occurring between the two forms (Healey 2001; Holtby and Ciruna 2007). A relationship has been shown to exist, however, between mean summer rearing temperatures and Chinook life-history type in the Columbia Basin.

Chinook experiencing water temperatures below 11^{o}C tend to be stream-type while those populations experiencing water temperatures in excess of 12^{o}C are more likely to be ocean-type (Brannon et al. 2004). Most of the Chinook in the Cariboo-Chilcotin display stream-type behaviour (Candy et al. 2002) and overwinter in their natal stream before migrating to the ocean as smolts in their second year, where they spend three to five years before returning to their spawning grounds (Cariboo Chilcotin Conservation Society 2008).

Time of spawning varies greatly among different Chinook stocks within the region with mid-river stocks from Quesnel and Chilcotin Rivers spawning from early September to early October. Some upper river stocks, such as West Road and Bowron Rivers, spawn from mid-July to late August (Cariboo Chilcotin Conservation Society 2008).

Population status

Most Fraser River Chinook spawn in the middle and upper regions of the basin. Populations are traditionally divided into four major geographical stock complexes and three timing groups. Chinook in the Cariboo-Chilcotin are par of the Middle Fraser geographic stock strata (downstream of Prince George, excluding the Thompson) and demonstrate two run timing groups (DFO 2009a): “spring” (migrates through lower Fraser before July 15), and “summer” (migrates through lower Fraser between July 15 and September 1). A different breakdown of migration timing for Fraser River Chinook (Parken et al. 2008) suggests 3 spring-run and 11 summer-run Chinook populations in the Cariboo-Chilcotin. Of the summer-run populations, five have early summer migrations (June), four are mid-summer (July) and two are late-summer (August).

As part of Strategy 1 of the Wild Salmon Policy (DFO 2005), Fisheries and Oceans Canada has divided BC into 68 Conservation Units (CUs) for Chinook salmon, three of which are within the Cariboo-Chilcotin (Figure 1): (1) Middle Fraser River – spring timing, (2) Middle Fraser River – summer timing, and (3) Middle Fraser River – Portage (Holtby and Ciruna 2007; DFO 2009b). 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). A primary concern in identifying CUs is the protection of genetic diversity; an element that was not specifically considered in the stock groupings used previously for Fraser River Chinook (Candy et al. 2002). These units will form the geographic basis for managing stocks in the future under the Wild Salmon Policy (DFO 2009b).

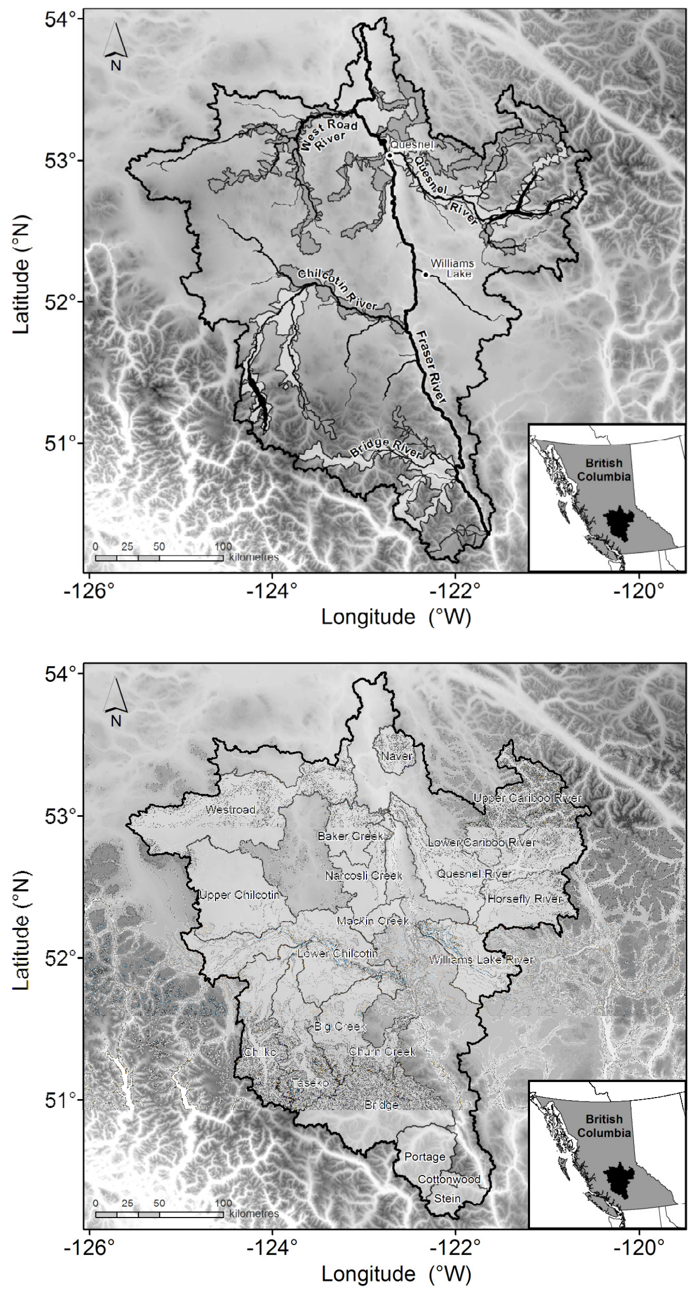

Figure 1. Cariboo-Chilcotin study area and Conservation Units for Chinook salmon (top panel includes Middle Fraser, spring timing CU in dark shading, Middle Fraser, summer timing in light shading from Holtby and Ciruna 2007). Draft Chinook salmon stock units in bottom panel (C. Parken, DFO, pers. comm.).

Fraser River Chinook salmon spawn in more than 100 streams, primarily within the middle and upper parts of the basin (DFO 1999; Candy et al. 2002).

Escapement is estimated through a variety of means: visual surveys, fences/weirs, and mark-recapture studies (Cariboo Chilcotin Conservation Society 2008). Escapement numbers indicate that spring Chinook runs in the region have experienced significant declines recently while summer Chinook have been increasing (FBC 2009; DFO 2009c, see Figure 2). Within the Cariboo-Chilcotin spring-run Chinook populations from upper Chilcotin, Chilako and Cottonwood Rivers have been assessed as *stocks of concern* as escapements have dropped to less than 100 fish (DFO 2009c) and returns are expected to continue well below the long term average (escapements in 2008 averaging approximately 35% of brood year escapements in 2003 (DFO 2009d)). Returns for summer-run Chinook have been strong in recent years (see Figure 2) but returns in 2008 were poor across populations, with escapements averaging only 36% of brood year escapements in 2003 (DFO 2009d). Very poor marine survival is considered an ongoing factor (DFO 2009d).

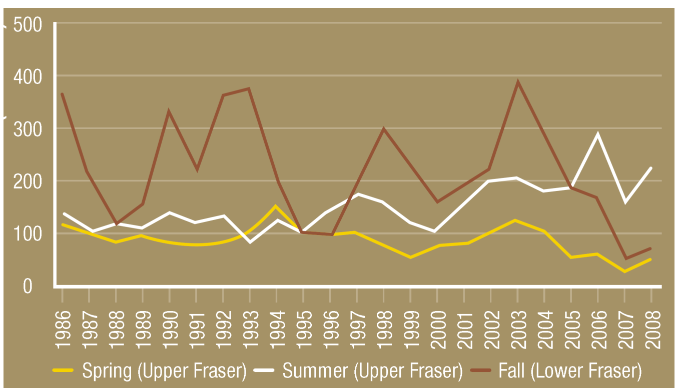

Figure 2. Returns of Fraser River Chinook salmon from 1986 to 2008 (extracted from FBC 2009).

Harvest

Fraser River Chinook salmon contribute to First Nation, recreational and commercial fisheries. Managing harvest is complex due to the variation in abundance and biological status among populations, and the overlap in migration timings through the lower Fraser River (Parken et al. 2008). Under the 1985 Pacific Salmon Treaty, Canadian and the U.S. committed to halting the decline of Chinook salmon escapements. Catch ceilings were established for all major BC Chinook fisheries, as well as varied time and area closures (DFO 1999). Since 1994 additional fishery management actions have included increased minimum size limits and reduced bag limits for the recreational fishery. In 1997-98 a significant reduction of ocean fisheries to protect coho also lowered catches of all Fraser Chinook (DFO 1999). It is believed that spring-run and, more markedly, summer-run middle and upper Fraser Chinook stocks benefited from these reductions in harvest (DFO 1999; Bailey et al. 2002; FBC 2006; 2009) with returns for spring Chinook reaching a peak in 2003 (see Figure 2). Recent declines in middle and upper Fraser spring-run Chinook have elicited further restrictions to First Nations, recreational, and commercial in-river fisheries (DFO 2009c).

Habitat

Chinook spawn in large rivers and are found as fry in many small tributaries within the Cariboo-Chilcotin. Spawning habitat range from small streams such as McKinley Creek to larger rivers such as the Chilko, where a combination of gravel and cobble located within a riffle or run is preferred. Juvenile Chinook are typically found in association with cobble and boulder substrates in shallow areas of cool, fast flowing streams and rivers. In the interior the principal characteristics influencing quality of salmon habitat include riparian vegetation, channel morphology, streamflow, deposited sediment, and winter snow and ice accumulation (Brown 2002). Habitat is not thought to limit Chinook populations in the Fraser River basin (Parken et al. 2002). Juveniles appear to disperse through the large quantities of accessible rearing habitats within natal streams, non-natal tributaries to the Fraser River, and the Fraser River mainstem. It is hypothesized that the more critical freshwater bottleneck is the availability of spawning habitat (Parken et al. 2002). Adults appear to be displaced from higher to lower quality spawning habitats during high escapements when spawning areas are saturated (Parken et al. 2002).

Key threats

Insights into the condition of habitats in the Cariboo-Chilcotin are inferred from a qualitative assessment of streams for Interior Fraser coho (Appendix 4, IFCRT 2006). Though site-specific impacts vary, across the entire study area the effects of forestry, agriculture, and water withdrawal are considered more extensive with 44%, 35% and 31% of 124 assessed streams within the area as 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. The effect of hydropower, linear development, and urbanization is generally low. Such activities can affect fundamental processes such as the supply of sediment, wood, and nutrients to channels, the flow regime, connections to floodplains, and riparian vegetative cover and composition that are necessary for maintenance of salmon habitats (Larsen et al. 2004). Mountain pine beetle has also lead to dramatic and extensive changes to the forested landscape of the Cariboo-Chilcotin, which can adversely affect hydrology (Uunila et al. 2006). Across the province 7.1 million hectares were affected between 1999 and 2005 (Aukema et al. 2006).

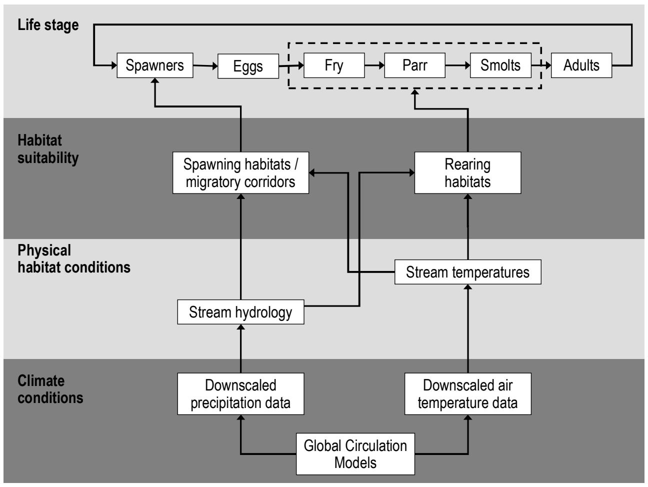

Figure 3. Simplified conceptual model illustrating the linkages among climate, physical habitat conditions, habitat suitability, and Pacific salmon life stages.

Study approach

The vulnerability of Chinook habitats was assessed by linking results from a series of mathematical and GIS models (see Figure 3). 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 Chinook salmon in GIS. Lastly, predictions from the stream flow and temperature models were compared against biologically-based habitat criteria for Chinook 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).

Study findings

The modeled distribution of Chinook salmon is shown in Figure 4. Chinook are widespread using most accessible low to moderate gradient streams in the region. The bulk of their distribution falls within what would be classified as cool water or cool-warmwater transition areas (see overlap with Figure 5).

The extent of cooler habitats is predicted to decrease throughout the region as demonstrated in Figure 6 and Figure 7, which show a progressive shift to warmer stream temperatures in most parts of the region, particularly in the northeast part of the study area (Quesnel and Williams Lake drainages). Conversely, accessible habitats for Chinook in the southern parts of the region (Bridge River drainage) may shift from cold water to the cooler water temperatures. The general pattern across Chinook CUs shows an increase in warm water streams considered sub-optimal by Chinook and a decrease in cold water and cold-cool water transition habitats. In some areas analyses suggest no significant net loss in the overall quantity of cool water stream habitats within Chinook CUs. This result might reflect a coincidental switching of many coldwater habitats to coolwater classifications in the southern section of the region, a pattern that essentially counters the loss of habitats in northern areas where coolwater streams are expected to warm considerably.

For three key Chinook stocks the linear extent of accessible habitat classified as warm water is predicted to increase, whereas cold water and cold-coolwater transition habitats will decrease (Figure 8 through Figure 10). In one (the Lower Chilcotin) there is a significant decrease in the extent of cool water habitats by 2080s. Within the other two stock units there is no predicted change in the amount of cool water-classified streams available.

Late summer / early fall flows necessary to maintain rearing juveniles and allow return of spawning spring and summer Chinook are also predicted to decrease more markedly in the north of the region than in the south. In some northern streams summer / fall flows are predicted to decline to such an extent that minimum thresholds required for successful spawning and rearing may not be reached consistently in the future. Figure 11 and Figure 12 indicate that Euchiniko River, Baker Creek, and Moffat Creek are streams that may have particular problems in achieving future minimum flow needs for both rearing and spawning Chinook 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 (see Nelitz et al. 2009). For instances, these models are not able to consider interactions with mitigating or exacerbating effects of human activities. The general patterns of this analysis suggest that regional climate change impacts on Chinook salmon may be mixed. In some locations there may be benefits of habitat changes, while in other locations there may be constraints on production. For instance, stream habitats with temperatures optimal for Chinook rearing are predicted to decrease in northern areas on the study area and increase in southern areas. Late summer / early flows necessary to maintain rearing juveniles and allow return of spawning spring and summer Chinook are also predicted to decrease more markedly in the north than in the south. In some of the more northern streams summer / fall flows are predicted to decline to such an extent that minimum flows to support successful spawning and rearing may not be reached consistently in the future. Further exploration of these data and field validation of the modeled interpretations would be fruitful.

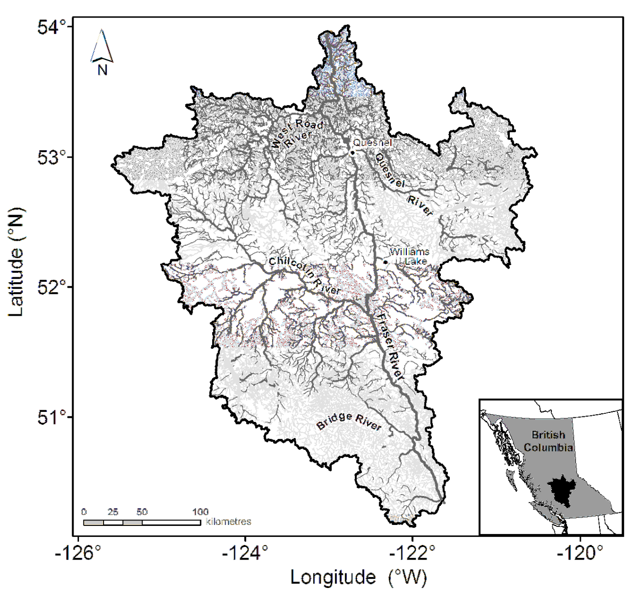

Figure 4. Baseline distribution of Chinook salmon in the Cariboo-Chilcotin. Suitable reaches for Chinook salmon habitats are dark grey, those not suitable are light grey.

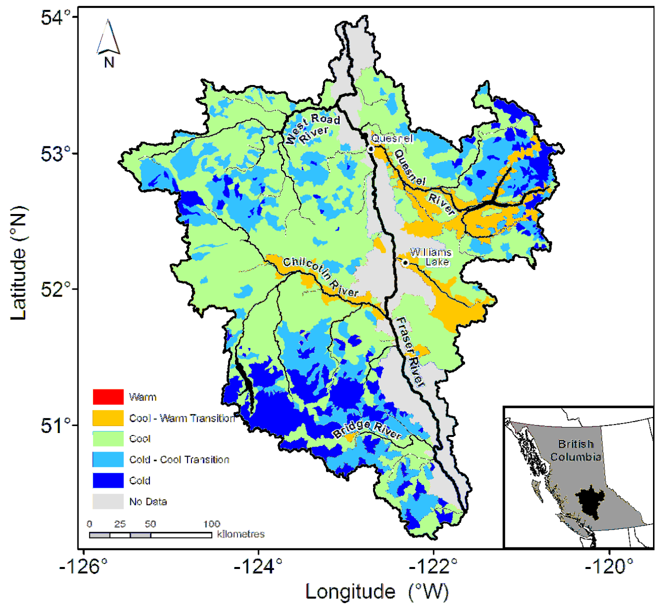

Figure 5. Classification of watersheds by thermal class for a historic reference period (1961-1990). Thermal classes preferable to Chinook salmon are represented by cool and cool-warmwater transition areas.

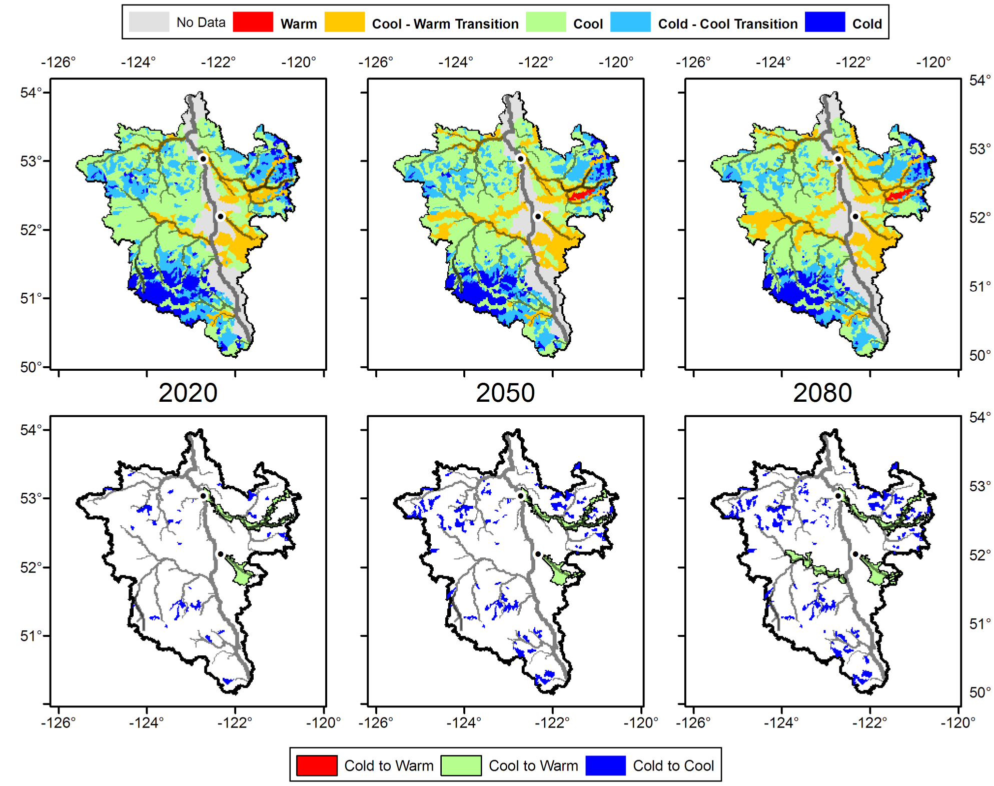

Figure 6. "Best" case outcome (i.e., least change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 5.

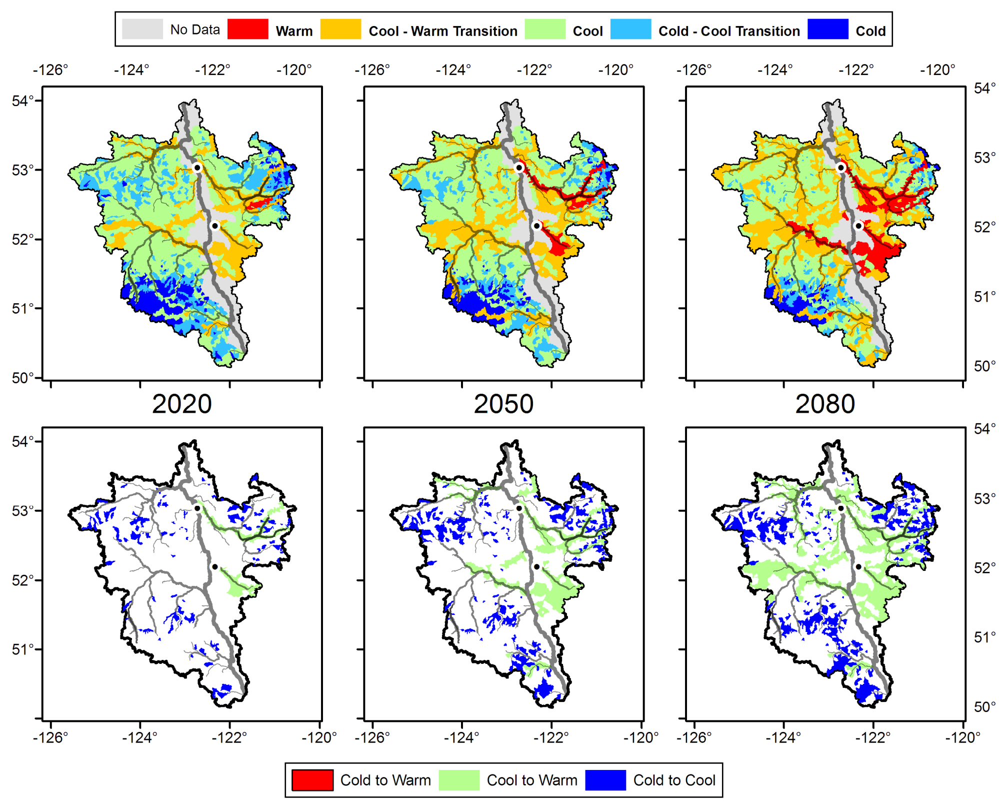

Figure 7. "Worst" case outcome (i.e., most change in thermal classes) out of six climate change scenarios. Top panel represents predicted thermal classes over three time periods (2020s, 2050s, 2080s), while the bottom panel represents shifts in thermal classes (as noted by legend) from baseline predictions in Figure 5.

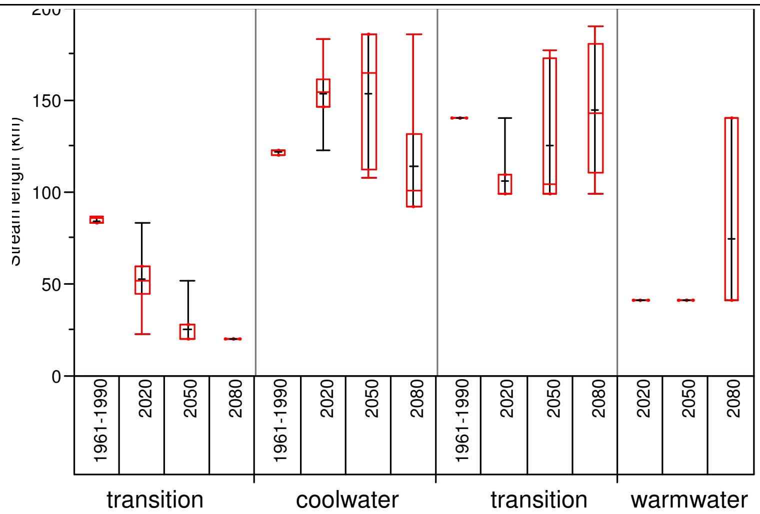

Figure 8. Linear extent (km) of thermal habitats across **Horsefly River stock unit** in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

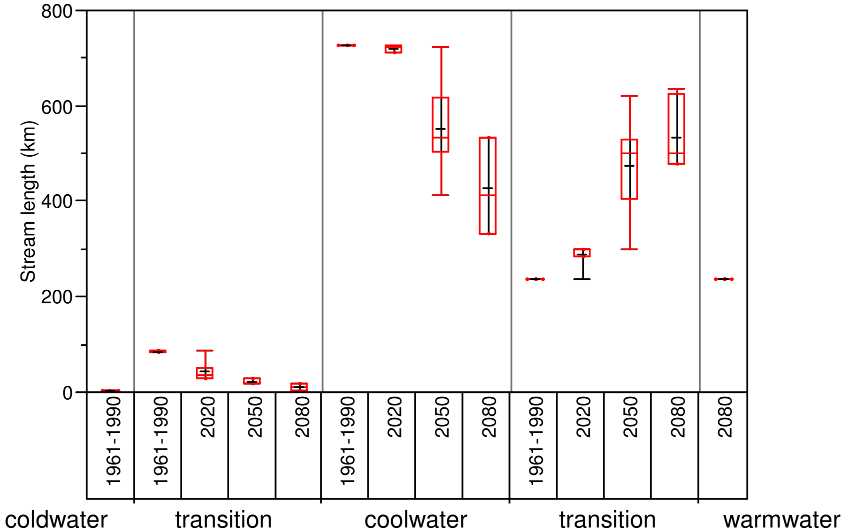

Figure 9. Linear extent (km) of thermal habitats across **Lower Chilcotin River stock unit** in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

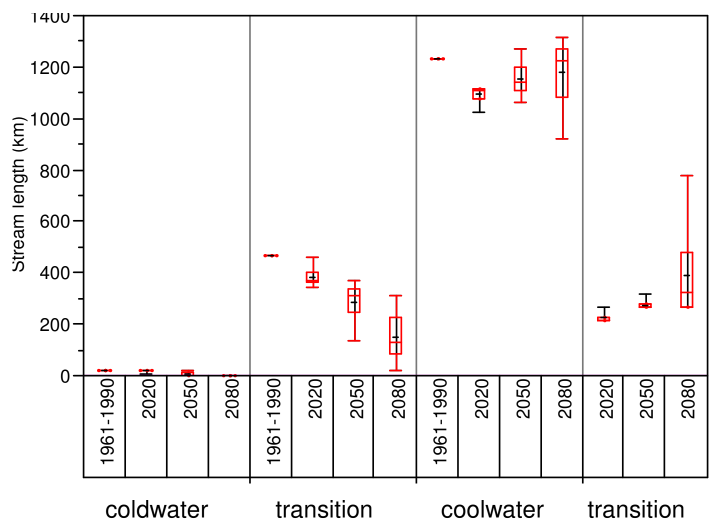

Figure 10. Linear extent (km) of thermal habitats across **West Road River stock unit** in a historic (1961-1990) and three future time periods (2020s, 2050s, and 2080s) under a range of climate change scenarios (box plots).

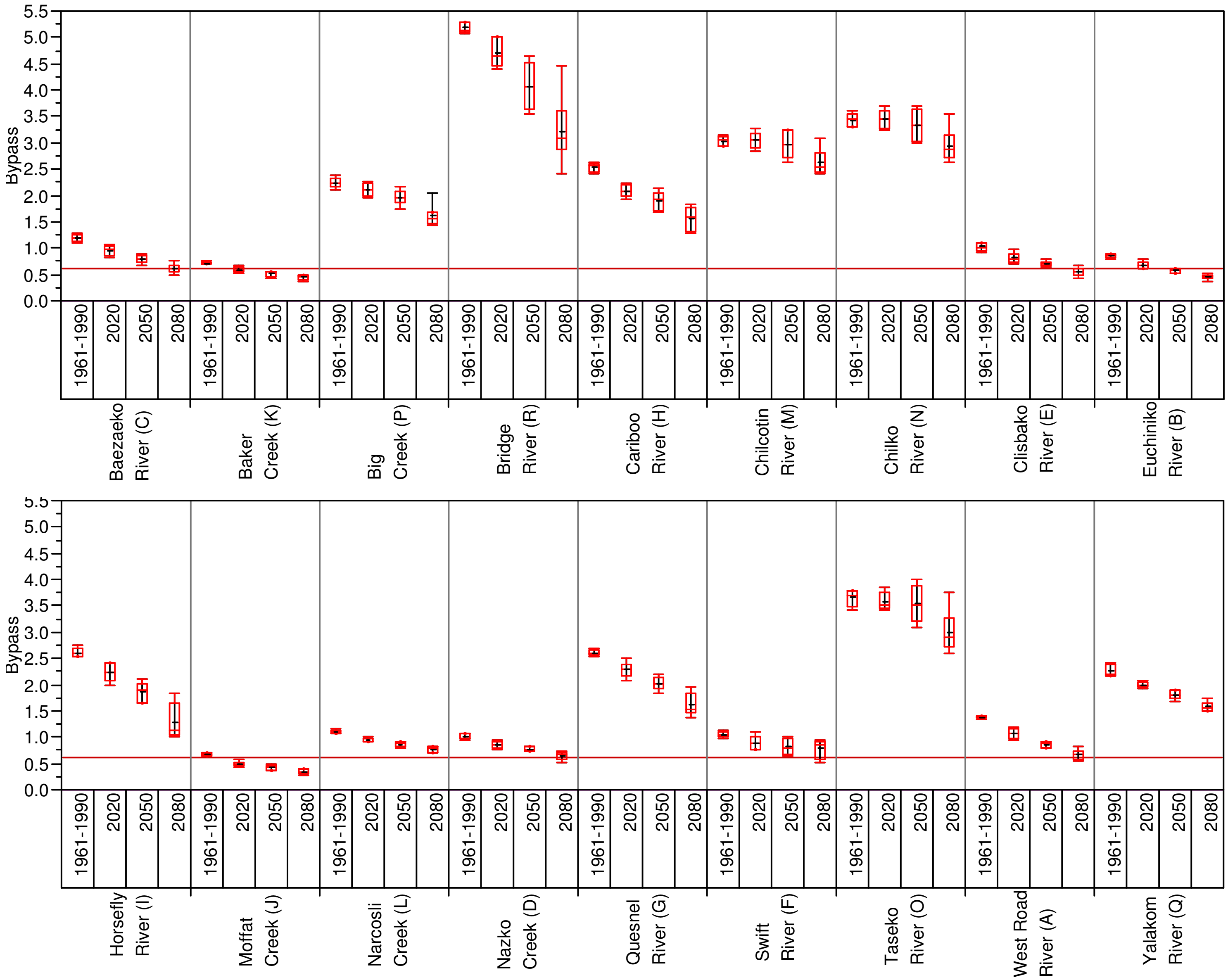

Figure 11. Maximum flow of a 7-day rolling average between July 15 and October 15 as a percentage of Mean Annual Discharge for historic and future time periods.

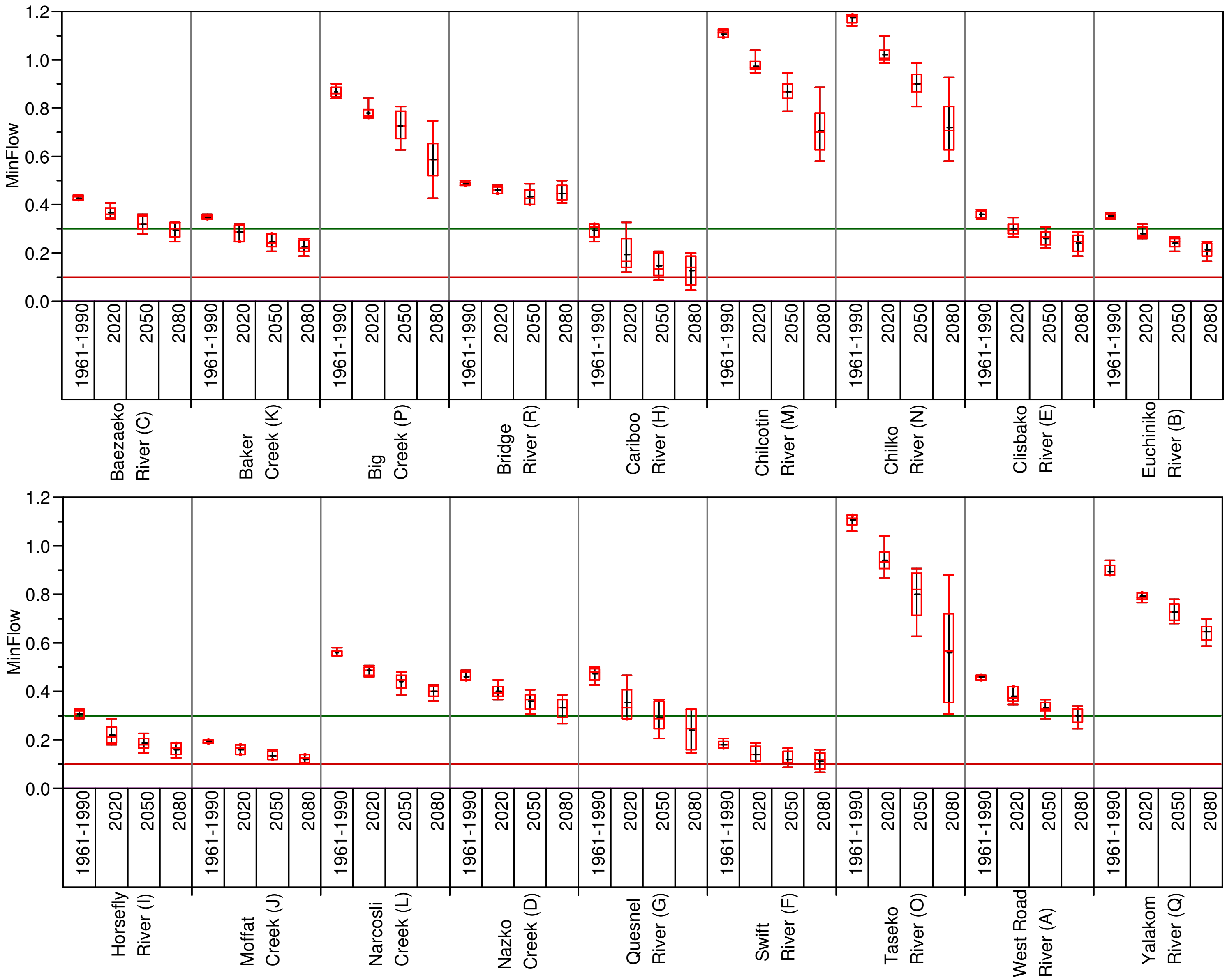

Figure 12. Minimum flow of a 7-day rolling average between July 1 and October 1 as a percentage of Mean Annual Discharge for historic and future time periods.

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