Evaluating the vulnerability of freshwater fish habitats to climate change and identifying regional adaptation strategies in the Cariboo-Chilcotin

Prepared for:

Fraser Salmon and Watersheds Program
Suite 300, 1682 West 7th Avenue
Vancouver, BC V6J 4S6

Prepared by:

Marc Nelitz, Katherine Wieckowski, Marc Porter,
Katy Bryan, Frank Poulsen, and David Carr
ESSA Technologies Ltd.
Suite 300, 1765 West 8th Avenue
Vancouver, BC V6J 5C6

March 31, 2010

Citation: Nelitz, M., K. Wieckowski, M. Porter, K. Bryan, F. Poulsen, and D. Carr. 2010. Evaluating the vulnerability of freshwater fish habitats to climate change and identifying regional adaptation strategies in the Cariboo-Chilcotin. Report prepared for Fraser Salmon and Watersheds Program by ESSA Technologies Ltd.

Acknowledgements

Foremost we are grateful to the Fraser Salmon and Watersheds Program who provided core funding for this work over the past two years. For their continued support, we are grateful to the Pacific Climate Impacts Consortium (PCIC) especially Katrina Bennett who provided updated climate projections and hydrology predictions for the study area. To guide our efforts we engaged a technical working group who offered their time, support, and interest in the work. This group included Richard Bailey and Don Lawrence with Fisheries and Oceans Canada, Robin Hoffos and Rick Dawson with the Integrated Land Management Bureau, Rob Dolighan, John Youds, and Art Tautz (emeritus scientist) with the Ministry of Environment, Dave Levy, Gord Sterritt with the Upper Fraser Fisheries Conservation Alliance, Rick Holmes with Cariboo Envirotech Ltd., and Richard Case with the Cariboo-Chilcotin Beetle Action Coalition. Lastly, the work presented herein is based on a foundation of effort that extends well beyond this project. We have integrated and built upon the efforts of many field technicians, researchers, and project funders from many different organizations across British Columbia. Without their effort and support in building the technical foundation, this project would not have been possible.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Context for vulnerability

The fourth assessment report from the Intergovernmental Panel on Climate Change (Parry et al. 2007) defines vulnerability as:

> *"the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and the variation to which a system is exposed, its sensitivity and its adaptive capacity."*

Across British Columbia the projected effects of climate change are towards increasing air temperatures with the largest increases in the north and during the winter, and variable changes in precipitation especially drier conditions during the summer and in the south with wetter conditions in the north (Rodenhuis et al. 2007; Pike et al. 2008). By the 2050s average annual air temperatures and precipitation in the Cariboo-Chilcotin are predicted to increase from 2.0-2.5 °C and 5-20% respectively, while in some locations summer precipitation is expected to decrease by as much as 5% (Figure 1). This overview of the vulnerability of the province and region is consistent with those projections from other global or regional studies.

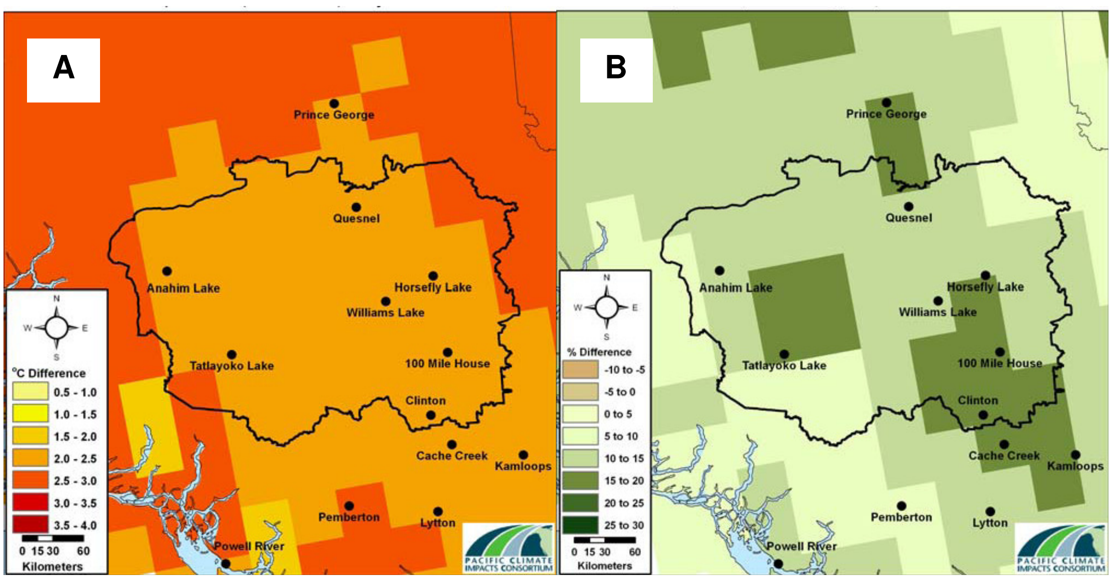


Figure 1. Panel A illustrates annual mean air temperatures (2041-2070) as a °C difference from a historic baseline (1961-1990). Panel B illustrates annual precipitation (2041-2070) as a % difference from a historic baseline (1961-1990). Source: Dawson et al. 2008.

However, to understand the implications of these changes at a regional scale, we need to make the connection to the ecosystem goods and services that human communities value and upon which they rely. In British Columbia both historic evidence and future projections demonstrate that these kinds of climate effects will translate to alterations in other physical conditions, including changes in forest cover (Hamann and Wang 2006; Aukema et al. 2006), snowpack (Leung and Qian 2003; MOE 2007), glaciers (Schiefer et al. 2007), stream flows (Leith and Whitfield 1998; Whitfield and Cannon 2000;

Zhang et al. 2001; Whitfield et al. 2003; Merritt et al. 2006), and water temperatures (Foreman et al. 2001; Morrison et al. 2002; Farrell et al. 2008).

Ultimately, changes in these conditions affect the vulnerability of freshwater fish habitats as climate change will alter the capacity of watersheds to store and release water and buffer against stream heating. As the timing of spring freshet becomes earlier, the summer low flow period will likely be extended and constrain the availability and amount of rearing habitats for juvenile salmonids. Given the inverse relationship between stream flow and water temperature, further declines in summer low flows will increase the vulnerability of streams to increases in air temperatures, thereby altering the thermal suitability of rearing habitats and creating thermal barriers to migration. Similar reductions in flow during the late summer and fall will further constrain the accessibility of spawning habitats in both space and time.

1.2 Context for adaptation

The fourth assessment report from the Intergovernmental Panel on Climate Change (Parry et al. 2007) defines adaptation as:

> *"the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."*

while Lemmen et al. (2008) refers to adaptation as:

> *"any activity that reduces the negative impacts of climate change and/or positions us to take advantage of new opportunities that may be presented."*

Overlaid on top of the above climate-related vulnerabilities are the additional stressors (due to land and water use) and restoration actions associated with human activities. Riparian harvesting on a stream that is already thermally sensitive will impair its ability to buffer against the impacts on fish communities due to climate heating, while restoring a previously disturbed riparian forest can increase stream shading and help maintain cooler stream temperatures. Alternatively, consumptive water uses in a watershed with scarce water supplies may exacerbate summer low flows and enhance conflicts between people and fish for water in the future, while restrictions in water use in vulnerable areas can mitigate the adverse effects of climate change. Although regional managers have no control over the drivers of climate change, they do have control over these kinds of land and water use decisions today that can be implemented as adaptation strategies to help mitigate the effects of climate change in the future.

The rationale for developing an understanding of vulnerability and identifying adaptation opportunities is clear. As acknowledged by the Intergovernmental Panel on Climate Change (Parry et al. 2007) adaptation will be necessary *"to address impacts resulting from the warming which is already unavoidable due to past emissions"* and that a "*portfolio of adaptation and mitigation measures can diminish the risks associated with climate change*". Yet despite this recognized need many struggle with knowing how, where, and when to adapt. For this reason, decision makers need to have the best available information and tools that translate climatic changes into other physical and ecological responses before large scale investments in adaptation can occur.

In light of this rationale, decision makers must also acknowledge the potential barriers to implementation. Foremost, we do not have perfect information. Uncertainties affect our understanding of both vulnerabilities and adaptation. From a vulnerability perspective, there are a range of Global Circulation Models and downscaling approaches each of which is associated with different predictions about the future climate. As well, we can not know the future development pathway, its carbon footprint, and the related severity of climate change. Establishing the link between future climate drivers and ecosystem responses requires many assumptions along this cause-effect pathway. From an adaptation perspective, we can not know the effectiveness of adaptation strategies in mitigating the effects of future climate change. Similarly, we can not be clear about the socio-economic tradeoffs of adaptation given that the costs today are certain and the benefits uncertain in the future.

Furthermore, there are a range of other considerations that will affect the feasibility of implementation (Lemmen et al. 2008). Tangible (up-front, maintenance, and operating costs) and intangible costs (opportunity cost to current and future generations) may block implementation. The institutional capacity (human resources and time) of communities and government agencies may be limited. The existing regulatory, legal, and policy frameworks that affect management of land, water, and freshwater fish habitats may constrain adaptation. A strategy may be associated with behavioural resistance at the individual, community, institutional, or political level. Finally, there may be limits in the availability or effectiveness of technologies to mitigate impacts on freshwater habitats.

Despite these challenges, governments and communities in Canada have demonstrated their commitment to climate change adaptation by investing in efforts to better understand vulnerability and identify adaptation opportunities. Some efforts have focused on developing high level indicators of vulnerability (WLAP 2002; Government of B.C. 2008; Eddington et al. 2009), while others have been focused on establishing the link between impacts and adaptation at a high-level (Taylor and Taylor 1997; Lemmen et al. 2008). In response to the devastation from the mountain pine beetle, the Cariboo-Chilcotin Beetle Action Coalition recently developed a terrestrial focused conservation strategy to identify adaptation priorities that could help the region mitigate the effects of climate change (Case and Coupe 2007). More recently governments are moving towards more on-the-ground adaptation by funding initiatives including the B.C. Ministry of Forests and Range Future Forest Ecosystems Initiative (FFEI)[1] and Natural Resources Canada's Regional Adaptation Collaboratives (RAC)[2].

Given the above context, the overall purpose of this project was to increase the specificity of information available to describe the vulnerability of freshwater fish habitats to climate change (as mediated by changes in stream flow and temperature), and identify opportunities for adaptation (given existing human pressures and management activities) in the Cariboo-Chilcotin (Figure 2). The intent was to develop a pilot approach for providing this information in a way that can best inform decision making in the near-term that will benefit people and freshwater ecosystems in the long-term. This work builds on previous efforts that identified potential adaptation strategies for Pacific salmon (Nelitz et al. 2007) and developed the technical foundation for assessing vulnerability of freshwater fish habitats (Porter and Nelitz 2009a; 2009b; Nelitz and Porter 2009; Nelitz et al. 2009a; 2009b). Though this work was not designed to gain a commitment towards implementing any specific adaptation strategies, there is a hope that the results will be used to help regional decision makers understand potential vulnerabilities and pursue technology or management oriented actions today that will benefit human communities, freshwater habitats, and fish populations of the Cariboo-Chilcotin in the future.

[1] Future Forest Ecosystems Initiative. http://www.for.gov.bc.ca/hts/Future_Forests/
[2] Regional Adaptation Collaboratives. About the Program. http://adaptation.nrcan.gc.ca/collab/abosuj_e.php

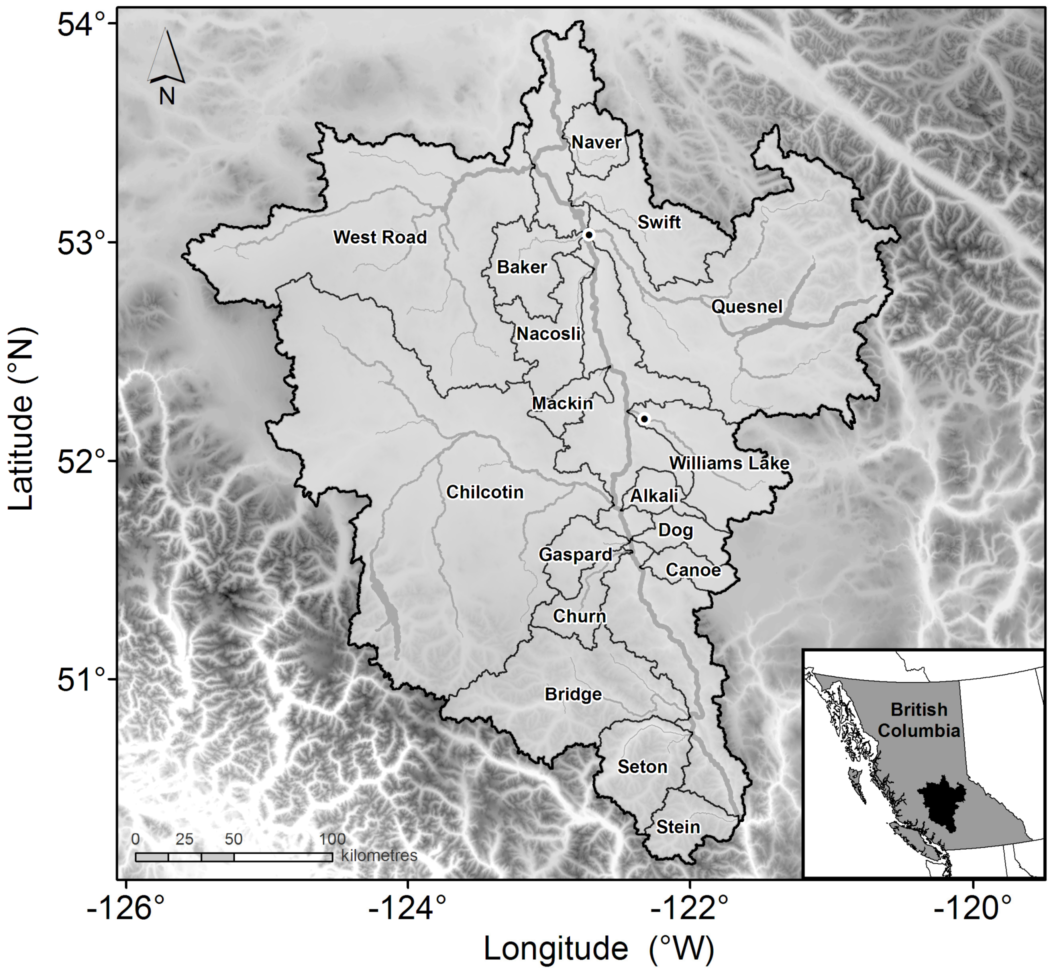


Figure 2. Cariboo-Chilcotin study area and fourth order (or higher) watersheds.

2.0 Methods

This year's project builds on previous efforts that focused on assessing vulnerability of freshwater fish habitats (Nelitz et al. 2009a). The emphasis, however, was to (1) use experts to guide the assessment of vulnerability and analysis of adaptation so it could best be tailored for decision making (see *Section 2.1*), (2) update information sources and methods for assessing vulnerability (see *Section 2.2*), and (3) analyze existing data layers to identify adaptation opportunities (see *Section 2.3*).

2.1 Expert input

A group of 11 technical experts were brought together to guide our efforts and ensure that our approach to modelling vulnerability and identifying adaptation opportunities would best inform decision making and regional planning. These experts were asked to be involved based on their local knowledge of the Cariboo-Chilcotin, expertise in fisheries, forestry, regional planning, hydrology, and/or water management, and familiarity with the regional planning agencies that would be involved in implementing climate change adaptation. Originally the plan was to engage experts through a series of face-to-face meetings, iteratively developing and presenting results from our work. However, scheduling challenges across the group meant we could not use this approach over the course of the project. Instead, we deployed a survey (see Appendix A) to get initial feedback on our proposed approaches. The survey sought feedback on four topics: (1) prioritizing adaptation strategies; (2) identifying indicators of adaptation potential; (3) identifying metrics of freshwater vulnerability; and (4) identifying appropriate administrative units for summarizing adaptation information. We then followed up with phone conversations to clarify responses and get further guidance for our work. Finally, we hosted a face-to-face technical meeting in Williams Lake to present the results of the vulnerability modelling and analysis of adaptation (see Appendices B and C). During the meeting, experts validated the flow and temperature vulnerabilities given their familiarity with the Cariboo-Chilcotin, and provided advice on how the vulnerability information could be presented in a way that would be most meaningful for decision making and regional planning.

2.2 Assessing vulnerability

Our approach to assessing vulnerability of freshwater fish habitats was identical to last year's work (Nelitz et al. 2009a) with the exception of the updates and changes described below. This approach required linking a series of readily available quantitative models to translate predicted changes in air temperature and precipitation into impacts on fish habitats (Figure 3). The first step in the modeling converted climate projections from four Global Circulation Models (GCM) and three emissions scenarios into higher resolution data that is more appropriate for use at a regional scale. Next, these data were used as inputs in a physically-based macro-scale hydrologic model which predicted flow at 58 stream locations across the study area (concentrated in the Chilcotin, West Road, and Quesnel River watersheds). Air temperature predictions were also used in an empirical stream temperature model to predict a measure of the annual maximum water temperature at the most downstream point of interest for 1,611 watersheds. Fish observations, barriers, and channel characteristics were then used to identify the extent of accessible streams for bull trout (*Salvelinus confluentus*), Chinook salmon (*Oncorhynchus tshawytscha*), and coho salmon (*Oncorhynchus kisutch*). Finally, predictions from stream flow and temperature models were compared against biologically-based fish habitat criteria to determine the accessibility and suitability of freshwater habitats for a historic reference (1961-1990) and three future time periods (2020s, 2050s, and 2080s).

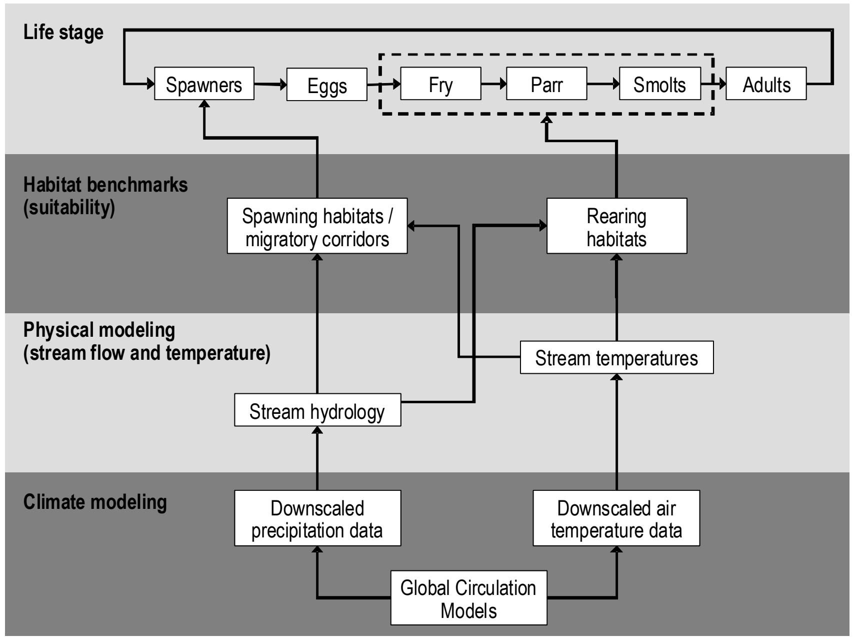


Figure 3. Simplified conceptual model illustrating the linkages among climate modelling, physical modelling of stream flow and temperature, habitat suitability, and life stages for Pacific salmon.

2.2.1 Modelling climate change

Relative to last year, the Global Circulation Models, emissions scenarios, downscaling techniques and time periods were identical. However, the climate data were different due to a need to include additional historic climate stations and fix other bugs in the model which generated erroneous air temperature values. Updates in these data affected the process for generating stream flow and stream temperature predictions as described below.

2.2.2 Predicting stream flow conditions

The methods and locations for generating hydrology predictions were identical to last year. However, the hydrology data differed for two reasons. Updates in the climate information (as described above) and vegetation layers affected these flow predictions. The updated vegetation layer corrected a known error in last year's model, which included unrealistically high evapo-transpiration rates across the Fraser basin.

2.2.3 Predicting stream temperature conditions

The empirical model for predicting stream temperature was identical to last year. However, the locations at which temperature predictions were generated, underlying climate data (see above), and method for interpolating air temperatures from the climate grid differed from last year. Last year we predicted stream temperatures at 1,071 watershed locations that were delineated by the 1:50,000 Watershed Atlas polygons. This year we generated predictions across 1,611 stream locations using the watershed assessment units from the 1:20,000 Freshwater Atlas. Last year we used the nearest neighbour and elevation difference to interpolate air temperatures from the provincial climate grid. This year we used a bilinear interpolation to estimate the air temperature at a given watershed location. To do so, this approach considered data from the four points on the climate grid that bounded a watershed's downstream point of interest.

2.2.4 Assessing suitability of habitats

Relative to last year's methods, there were no changes in the analytical rules (gradient, stream order, barriers, fish observations, etc) for delineating the spatial distribution of Chinook salmon, coho salmon, and bull trout and no change in the habitat benchmarks for assessing the suitability of thermal and flow conditions for these species. The main difference was related to how changes in the suitability of habitats due to climate change were represented. The previous modelling represented the accessibility of habitats across the study area using the 1:50,000 hydrology and summarized impacts according to the linear length of stream in the Watershed Atlas polygons. To allow for a better assessment of change, the 1:50,000 distribution linework was transposed to the 1:20,000 assessment watershed polygons from the Freshwater Atlas. This step then allowed for the classification of the assessment watersheds according to whether they were both accessible and thermally suitable, recognizing that bull trout prefer cold or cold-cool transition habitats and salmon prefer cool or cool-warm transition habitats (see *Section 3.1*).

Despite some concerns with this modeling approach, we feel confident in the methods because it is becoming increasingly feasible to predict species distribution using GIS technology and statistical models based on key landscape features that drive fish species distribution. Such models can often make efficient use of site-scale data that have already been collected (Creque et al. 2005), and represents the approach we adopted for this pilot study. In deploying this model we linked historic field observations to GIS derived habitat data at the landscape scale. The resulting GIS maps provide an opportunity for biologists and managers to visually compare their own internal mental models of fish species occurrence and habitat capacity with those developed mathematically (McCleary and Hassan 2008). These representations can then facilitate continuing dialogue on how to improve modeling approaches and advance our understanding of factors affecting fish distribution at broad scales, particularly as needed for understanding vulnerability of freshwater habitats due to climate change.

2.3 Identifying adaptation opportunities

As described in Section 2.1, priority adaptation strategies were identified on the basis of expert responses to an individual survey. Priorities were identified on the basis of those actions with the potential to mitigate adverse changes in stream flow and temperature (drawn from Nelitz et al. (2007)) and where their feasibility of being implemented was believed to be highest. Based on responses to this prioritization, we identified three adaptation strategies that ranked high and were diverse: restore riparian ecosystems, adjust water licensing and allocations, and improve fish passage. These strategies formed the basis of our analysis moving forward. However, as became clearer through our work, the "improve fish passage" strategy could not be completed because the base data layer (i.e., model to predict probability of blockage due to road crossings, such as a culvert) is still experimental and not yet available for broader distribution and use. Other guidance on adaptation was drawn from the survey. Reponses helped guide our selection of GIS layers to describe human pressures and management activities, choice of indicators of vulnerability, and the administrative units that are most appropriate for summarizing information for decision making and regional planning. Table 1 summarizes the design of our analyses for identifying adaptation opportunities. The results were then overlaid with information on vulnerability to identify priorities for adaptation.

Table 1. List of adaptation strategies, related metrics, and available data sources to identify adaptation opportunities.

Adaptation strategy	Adaptation metrics	Data source	Description	Reference
Restore riparian ecosystems	- Linear extent of riparian disturbance	Forestry cutblocks	Provincial cutblock layer. Included cutblocks harvested later than 1995 within 50 metres of a stream.	Forest Tenure Cut Block Polygons https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=50580
	- Linear extent of 1:20K streams	Freshwater Atlas	Stream linework and assessment polygons at the 1:20,000 scale.	Freshwater Atlas Stream Network https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50648&recordSet=ISO19115 Freshwater Atlas Assessment Watersheds http://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=57079&recordSet=ISO19115
	- Count of historic riparian restoration actions	Fisheries project registry	Summary of fish projects including stock assessment, stewardship, resource planning, restoration and enhancement.	DFO Oceans, Habitat and Enhancement Branch http://www.canbcdw.pac.dfo-mpo.gc.ca/FPR/Qf_frames.asp
Adjust water allocations and licensing	- Volume of consumptive allocations - Count of consumptive water licenses	Surface water licenses	Province-wide spatial layer displaying water license points of diversion with license allocations and purpose. Queries for active or pending consumptive licenses (stockwatering, irrigation, and domestic)	BC Points of Diversion with Water Licence Information https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47674&recordSet=ISO19115
	- Count of water restrictions	Water restrictions	Province-wide layer showing streams having a water allocation restriction.	Water Allocation Restrictions https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=34251&recordSet=ISO19115
	- Upstream influence from a dam or reservoir	Storage dams / weirs	Province-wide spatial view displaying dam locations and associated attributes. Used regulated dams with height > 4 metres	BC Dams https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49718&recordSet=ISO19115
Improve fish passage	- Count of obstructions	Obstructions	Obstacles to fish passage from all provincial corporate fish datasets. Layer reports obstacles to fish that are known. These features are obstacles to fish passage (i.e., rapids, falls, etc), not barriers.	Freshwater Atlas Obstructions https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50645&recordSet=ISO19115
	- Linear extent of opened and thermally useable habitat by species	Fish distribution layer	Fish distribution layers at the 1:50,000 scale for bull trout, coho, and Chinook salmon with information on thermal suitability of habitats.	
	- Count of historic obstruction removal	Fisheries project registry	Summary of fish projects including stock assessment, stewardship, resource planning, restoration and enhancement.	DFO Oceans, Habitat and Enhancement Branch http://www.canbcdw.pac.dfo-mpo.gc.ca/FPR/Qf_frames.asp

3.0 Results

3.1 Vulnerability and adaptation

Figure 4 illustrates the projected changes in fish community thermal classes across three time periods. At the cold end of the spectrum, by the 2080s the models predict a gradual elimination of coldwater and transition I habitats in the headwaters of the West Road and Quesnel watersheds. Though dramatically reduced in size, a stronghold of cold water habitats remains in the headwaters of the Chilcotin and Bridge likely due to the presence of glaciers in these watersheds. At the warm end of the spectrum, by the 2080s the models predict an overall expansion of transition II habitats across the study area and the introduction of several warm water areas, including Dragon Creek, multiple reaches of Quesnel River, Williams Lake and San Jose Rivers, the lower reaches of the Little Horsefly River, and the lower reach of the Chilcotin River.

From the perspective of our three salmonid species, Figure 5, Figure 6, and Figure 7 identify watersheds that are both accessible and thermally suitable. For bull trout by the 2080s the models predict a fragmentation and near elimination of habitats in the Quesnel and West Road River watersheds (Figure 5). The remaining stronghold of habitats lies within the headwaters of the Chilcotin and Bridge River watersheds. For Chinook salmon by the 2080s many more watersheds are gained than lost in terms of their thermally suitability (Figure 6). This change may not have much of an impact on the amount of thermally suitable rearing habitats. However, the models predict warming in the lower reaches of important migration corridors, mainly the Horsefly, Quesnel, and Chilcotin Rivers, which might lead to concerns about thermal barriers. Similarly, for coho salmon by the 2080s many more watersheds are gained than lost and potential warming is concentrated in the lower reaches of important migration corridors (Figure 7). Given the later timing of coho migration, this warming may have a noticeable effect on adult spawners.

Figure 8 and Figure 9 illustrate vulnerability from a flow perspective. Across all nodes there is a predicted reduction in summer rearing and spawning access flows by the 2080s. Locations with the greatest concerns for summer rearing include the Swift, Quesnel, and Horsefly Rivers (Figure 8), while the greatest concerns for spawning access include Swift River, Moffat and Baker Creeks (Figure 9).

Figure 10 and Figure 11 illustrate results from the GIS analyses for identifying adaptation opportunities. Figure 10 illustrates locations where there may be opportunities for adaptation around riparian restoration. Though there are a large number of watersheds with a high proportion of streams affected by harvesting, opportunities are generally concentrated in the Nazko, Quesnel, and Horsefly River watersheds. Figure 11 illustrate locations where there may be opportunities for adaptation around water licensing. Areas where water allocations are high relative to the upstream drainage area include many tributaries watersheds to the Fraser River and some of the lower portions of the Chilcotin River watershed (Figure 11A). There are fewer areas where the number of restrictions relative to the number of water licenses is high (Figure 11B). Potential areas for adaptation include some tributary watersheds to the Fraser River and small portions of the Quesnel and Chilcotin River watersheds.

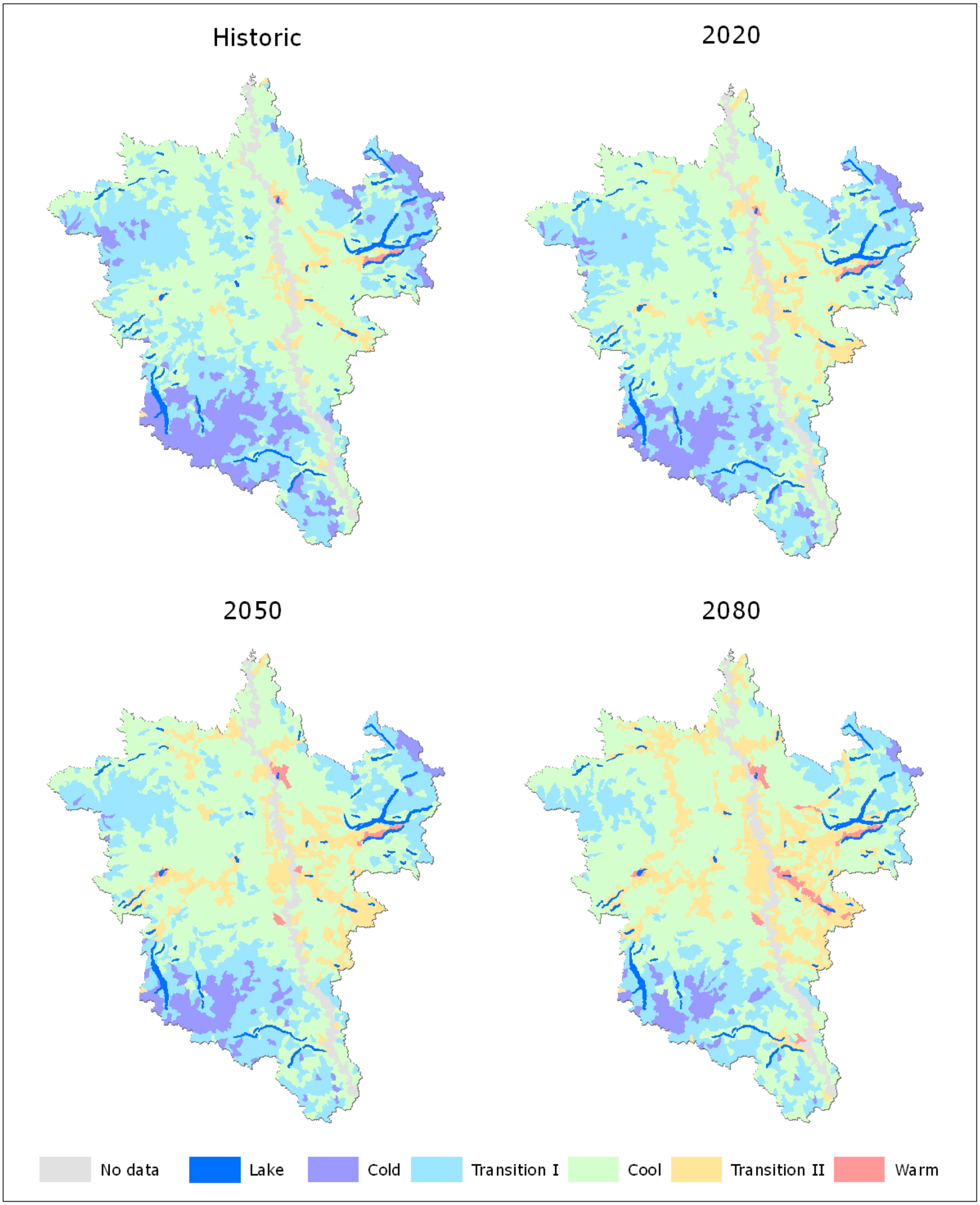


Figure 4. Representation of the stream temperatures across study area based on the thermal suitability of 1:20,000 Freshwater Atlas polygons classified according to different fish community classes (i.e., cold, cool, or warm water fish communities). Predictions of thermal classes are based on a model ensemble (i.e., average across 6 GCM-scenarios combinations).

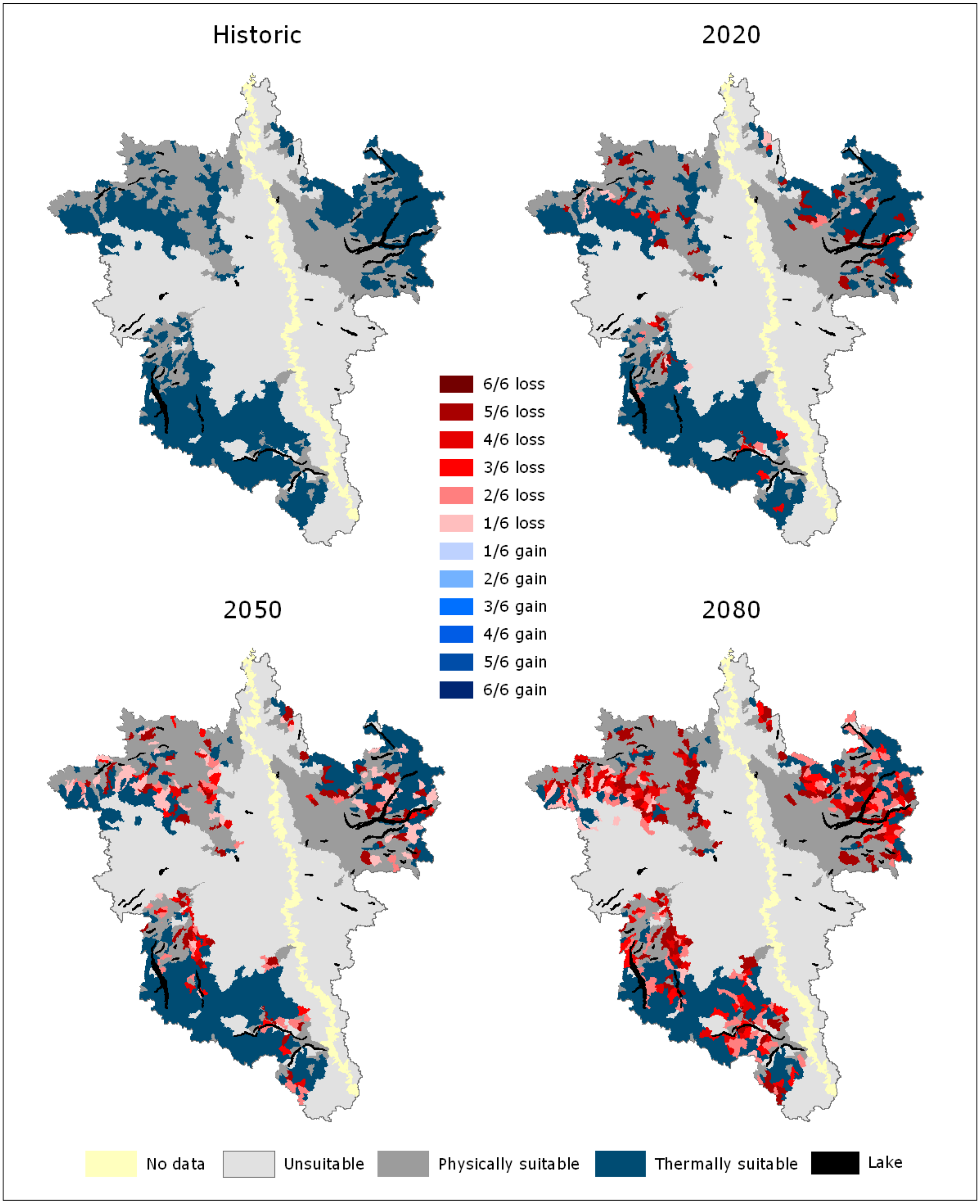


Figure 5. Representation of the accessible and thermally suitable polygons for bull trout across the study area. Polygons with increasingly deeper shades of red denote the number out of 6 GCM models-scenarios that predict the loss of this area as thermally suitable.

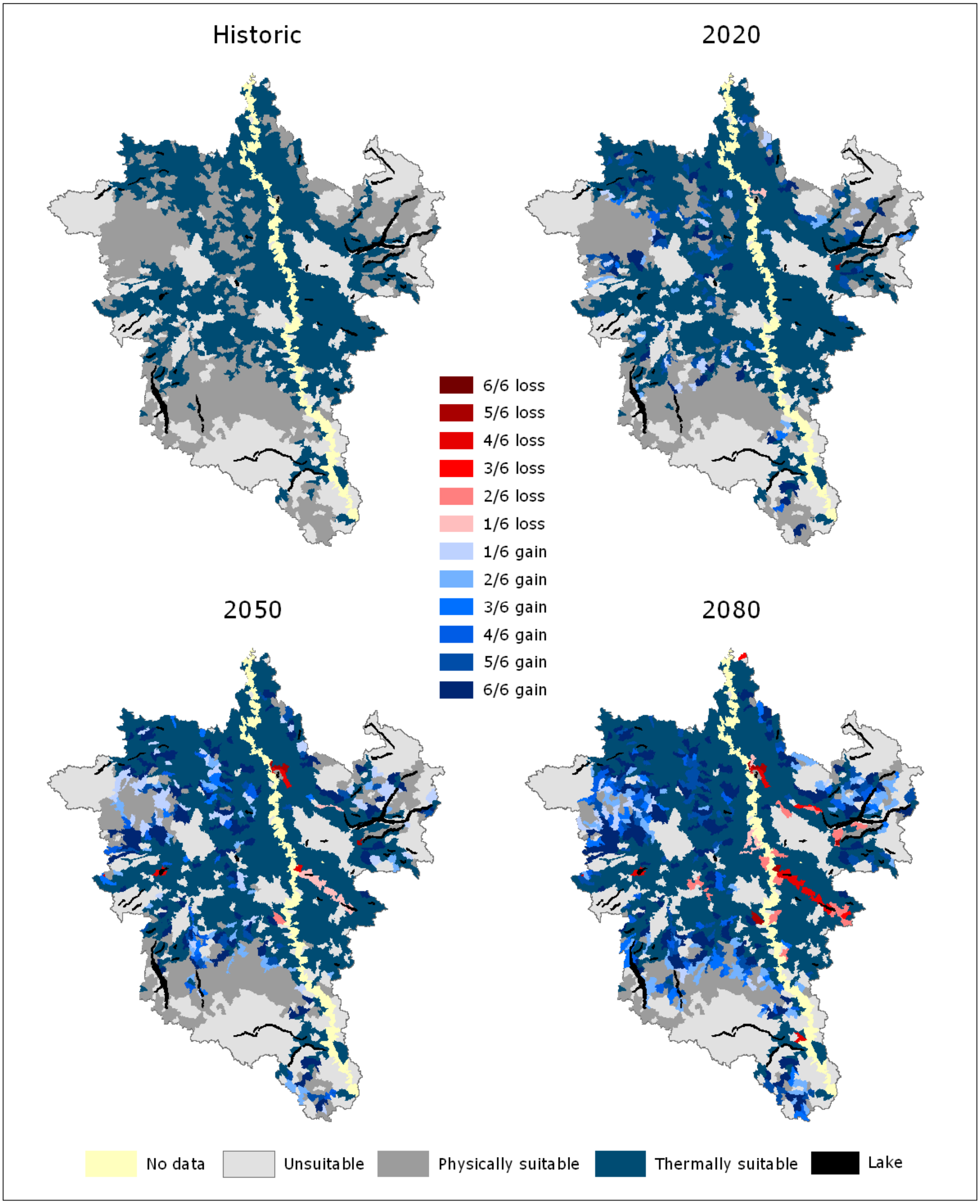


Figure 6. Representation of the accessible and thermally suitable polygons for Chinook salmon across the study area. Polygons with increasingly deeper shades of red (or blue) denote the number out of 6 GCM models-scenarios that predict the loss (or gain) of this area as thermally suitable.

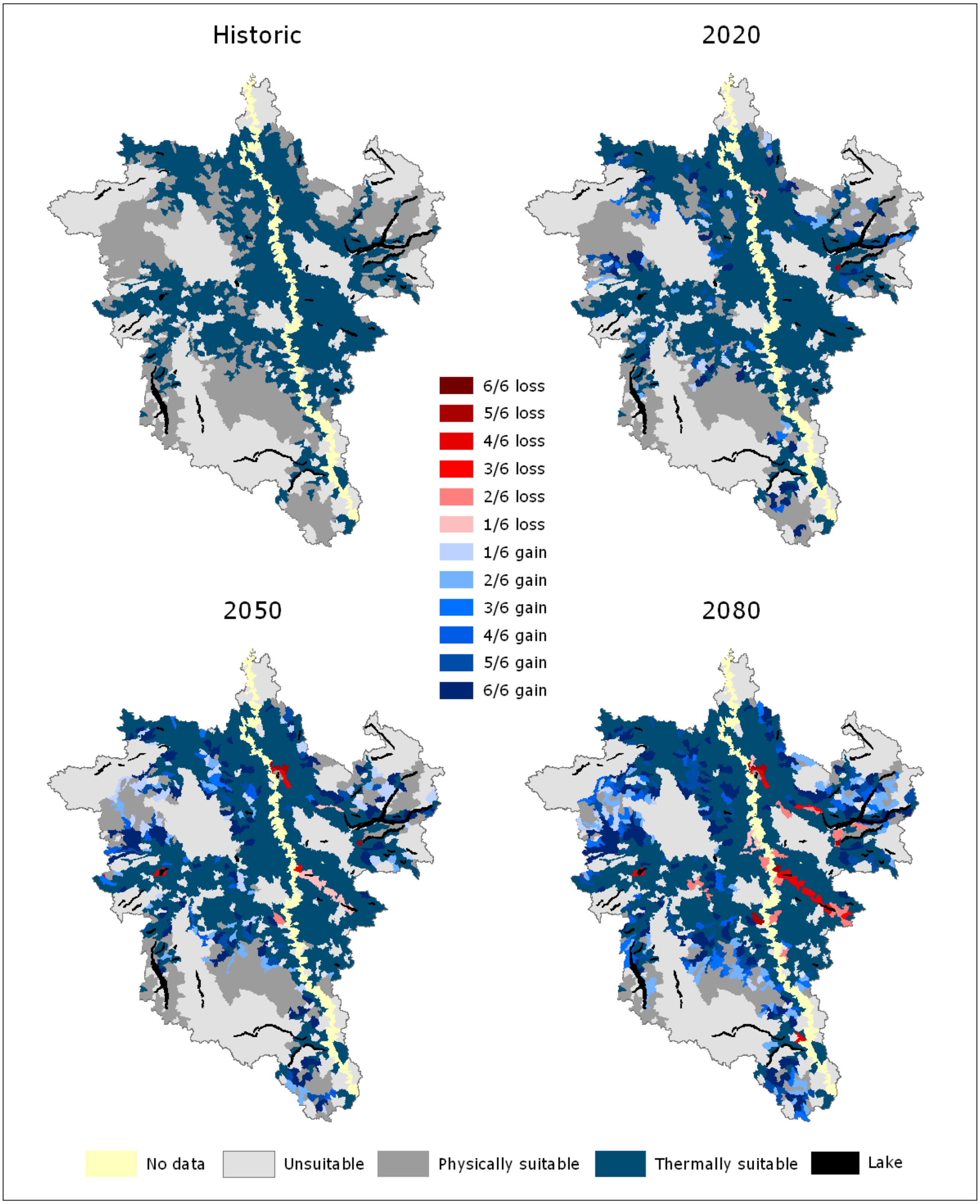


Figure 7. Representation of the accessible and thermally suitable polygons for coho salmon across the study area. Polygons with increasingly deeper shades of red (or blue) denote the number out of 6 GCM models-scenarios that predict the loss (or gain) of this area as thermally suitable.

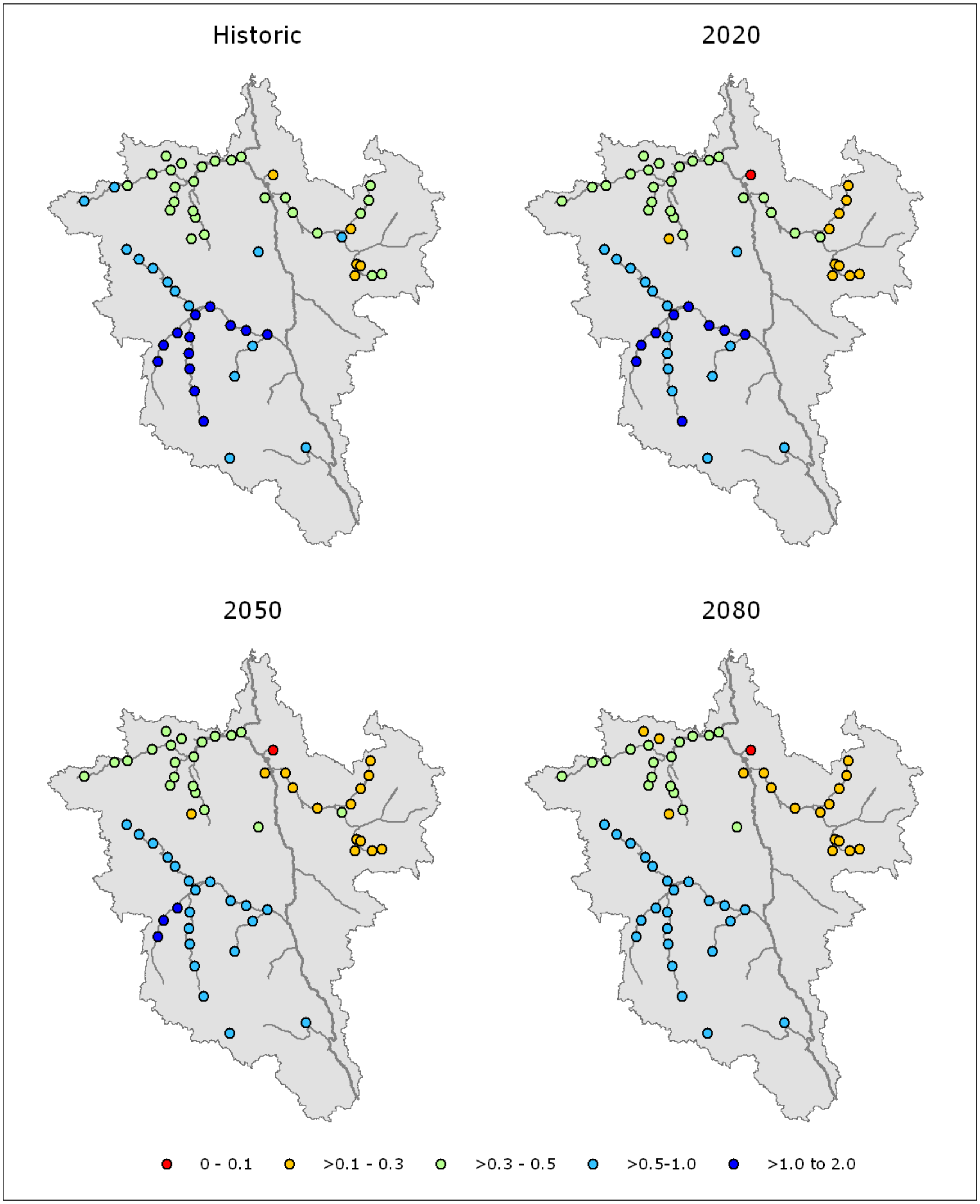


Figure 8. Representation of the summer rearing low flows at 58 nodes across the study area based on the percentage of mean annual discharge during the late summer. Flow predictions are based on a model ensemble (i.e., average across 6 GCM-scenarios combinations).

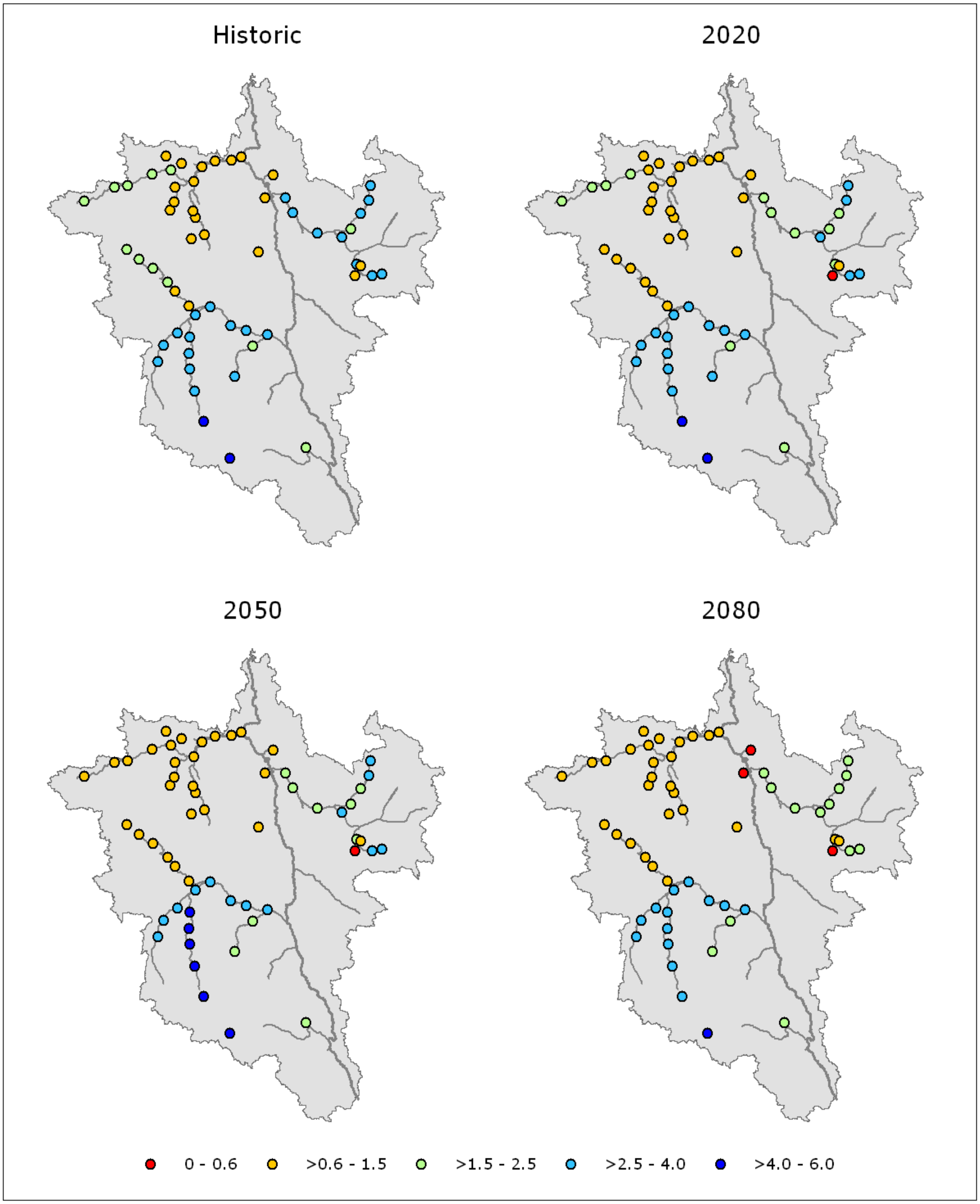


Figure 9. Representation of the spawning access flows at 58 nodes across the study area based on the percentage of mean annual discharge during the late summer / early fall. Flow predictions are based on a model ensemble (i.e., average across 6 GCM-scenarios combinations).

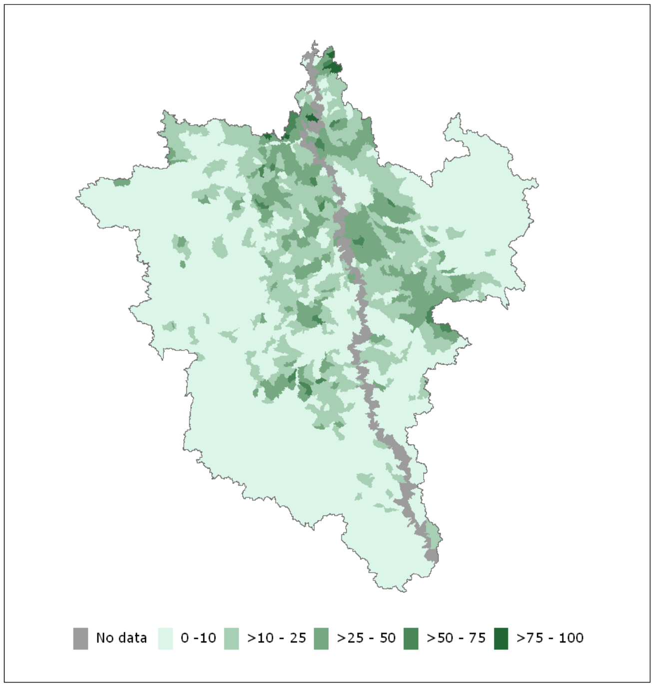


Figure 10. Percentage of streams in the upstream Freshwater Atlas polygon with riparian harvesting.

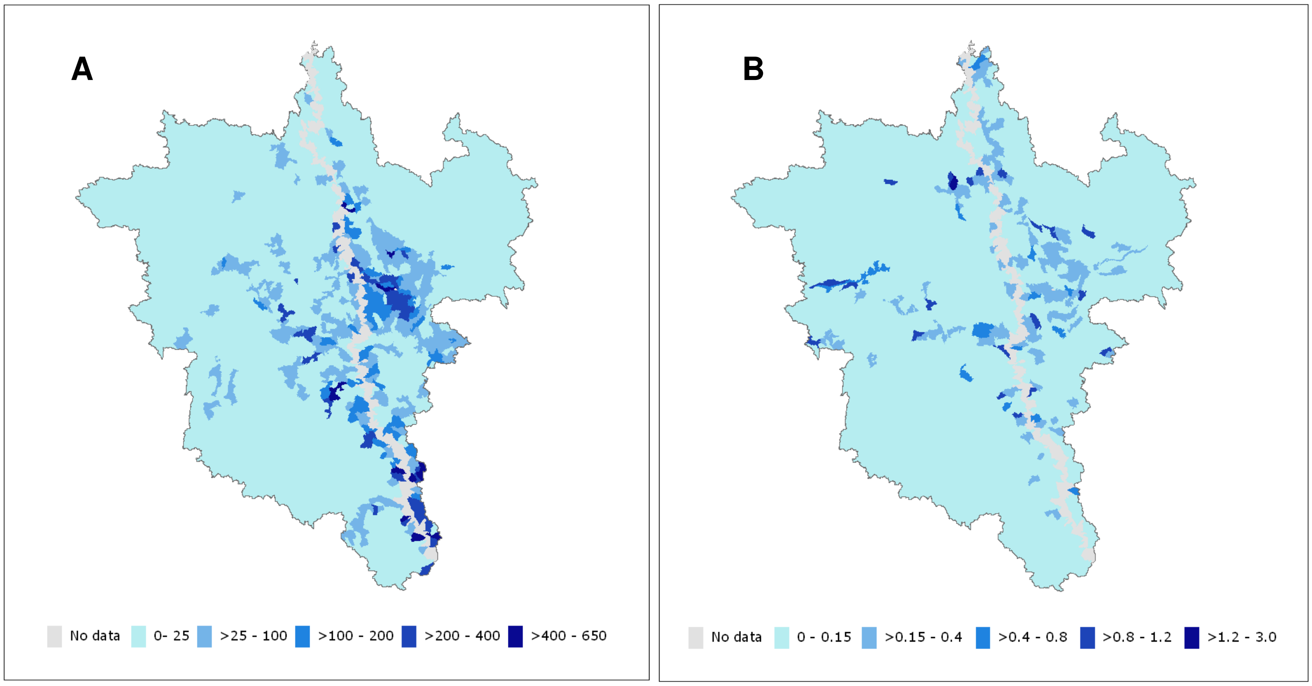


Figure 11. Panel A: Sum of consumptive water license allocations (m^3/year) divided by the drainage area (hectares) of the upstream Freshwater Atlas polygon. Panel B: Number of water license restrictions divided by the total number of consumptive water licenses for the upstream Freshwater Atlas polygon. Polygons with increasingly darker blue denote areas where water allocations are increasingly large relative to the upstream drainage area, or there are an increasing number of restrictions relative to the total number of licenses in a watershed.

3.2 Feedback from experts

The above results were presented to technical experts at a face-to-face meeting in Williams Lake. Overall, experts expressed that the baseline predictions of stream temperature and flow conditions across the study area were consistent with local knowledge. There was more disagreement with fish distribution predictions, largely because our analysis did not include some major barriers. A number of other more specific comments and recommendations were provided, a subset of which is included in Table 2.

Table 2. Summary of feedback and recommendations from technical experts following a presentation and discussion of results.

Modelling theme	Feedback and recommendations
Hydrology	Currently, the bypass period only captures 80% of the Chinook stocks in the region. The other 20% that migrate in late spring / early summer are not captured by this metric. These stocks are likely the most vulnerable because they need complex and cold habitats while they hold for 4 months before spawning. These stocks will be affected if the timing or magnitude of spring freshet changes too much. As well, if flows decrease during the four month holding period these stocks could be subject to warmer waters that decrease spawning viability. The recommendation is to expand temporal period for bypass flow and refine thresholds for fish dependent on freshet to access spawning habitat. Key holding areas for these unique stocks can be identified and used to define the nodes for our flow modelling.
	For coho the limiting factor is not access to spawning grounds but access to rearing habitats with good groundwater inflow.
Fish distribution and barriers	The recommendation was to check our barrier information. Some major barriers are not represented in our distribution modeling (e.g., barriers on McKinley and Big Creeks).
	It is useful to distinguish between man-made barriers and natural barriers to inform adaptation actions. Furthermore, barriers differ by species and time of year.
Species considerations	If model is expanded to include sockeye, consider early-summer runs as they are the most vulnerable.
	The recommendation was to use run timing or stock as another filter in our modelling, rather than the broad species representations we have employed (e.g., spring Chinook are more in need of adaptation strategies than summer Chinook which use lakes to buffer against warm waters).
Communication of results	Our results either aggregated variability across models into an average or presented them separately. It is also important to represent the frequency of extreme events (e.g., annual variability) because one extreme event (e.g., high temperature or low flows) can have substantial effects a population.
	The recommendation was to communicate both flow and thermal vulnerabilities in an integrated way at the same time as managers don't think about them separately.

4.0 Next steps

> *"In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed."*
>
> *"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."* – Charles Darwin –

Given an expectation that extensive warming due to past emissions is unavoidable, the rationale for pursuing adaptation remains sound. However, as evidenced through this work decision makers need to base adaptation decisions on a solid foundation of information. Though progress has been made in terms of advancing the vulnerability modeling and analyzing available information to identify adaptation opportunities, more is needed before regional planners are working deliberately towards climate change adaptation. To move in this direction, the next steps require effort in three core areas.

<u>Communicate findings from vulnerability modeling to a wider audience.</u> Our observation is that there is a strong appetite for credible climate change information to improve current management decisions and enhance the consideration of aquatic resources in planning across the region. However, further communication is needed for establishing the level of collaboration necessary for moving towards adaptation. The main goal in communicating with other audiences would be to facilitate further development and uptake of the work. These audiences include:

- Cariboo-Chilcotin management committee (i.e., heads of environmental agenices in region)
- First Nations leaders in the region
- BC government agency staff in Victoria
- DFO staff in Kamloops
- DFO staff responsible for implementing Strategy 3 of the Wild Salmon Policy

Some of these audiences have already expressed an interest in hearing more about this work.

<u>Refine modeling and analyses based on expert guidance.</u> As described in *Section 3.2*, there are a variety of improvements to the vulnerability modeling that can enhance the technical foundation of this work. These priority enhancements include:

- improving the biological relevance of flow metrics (i.e., make them stock specific);
- identifying more biologically relevant nodes where we can extract hydrology data; and
- adjusting the species distribution models to ensure key barriers are represented.

To complete these tasks, we believe it would be most efficient to work closely with agency biologists who are knowledgeable about the species requirements and habitat conditions across the study area.

<u>Overlay vulnerability and adaptation information to iteratively develop adaptation strategies.</u> Once a stronger a collaborative and technical foundation is available, the next step would be to use the available information with the appropriate audiences (e.g., the public, industry, First Nations, government staff) to work iteratively towards adaptation. The intent would be to identify priority areas and strategies to employ in those areas. Given that adaptation decisions will affect many different resource users and other stakeholders, we expect these discussions to be consistent with the level of dialogue and effort involved in previous planning exercises (e.g., Cariboo-Chilcotin Land Use Plan).

5.0 References

Aukema, B. H., A.L. Carroll, J. Zhu, K.F. Raffa, T.A. Sickley and S.W. Taylor. 2006. Landscape level analysis of mountain pine beetle in British Columbia, Canada: spatiotemporal developments and spatial synchrony within the present outbreak. Ecography. 29: 427-441.

Case, R.L. and B.J. Coupe. 2007. A Conservation Strategy: Maintaining ecological systems and communities in the face of change. Prepared for The Cariboo-Chilcotin Beetle Action Coalition. Available from: http://www.ccconserv.org/CCBAC%20Conservation%20Strategy%20-_final%20November%202007.pdf

Creque, S.M. and E.S. Rutherford. 2005. Use of GIS-derived landscape-scale habitat features to explain spatial patterns of fish density in Michigan Rivers. North American Journal of Fisheries Management 25: 1411-1425.

Dawson, R., A.T. Werner, and T.Q. Murdock. 2008. Preliminary analysis of climate change in the Cariboo-Chilcotin area of British Columbia. Pacific Climate Impacts Consortium. University of Victoria, Victoria, B.C. 49 pp. Available from: http://pacificclimate.org/docs/publications/CaribooChilcotinClimate.08Sept08.pdf

Eddington, M.M., J.L. Innes, A.E. McHugh, and A.C. Smith. 2009. Monitoring Forest and Rangeland Species and Ecological Processes to Anticipate and Respond to Climate Change in British Columbia. Forest and Range Evaluation Program (FREP) Report #20.

Farrell, A.P., S.G. Hinch, S.J. Cooke, D.A. Patterson, G.T. Crossin, M. Lapointe, and M.T. Mathes. 2008. Pacific salmon in hot water: Applying aerobic scope models and biotelemetry to predict the success of spawning migrations. Physiological and Biochemical Zoology. 81(6): 697–708

Foreman, M.G.G., D.K. Lee, J. Morrison, S. Macdonald, D. Barnes, and I.V. Williams. 2001. Simulations and retrospective analyses of Fraser Watershed Flows and Temperatures. Atmosphere-Ocean 39(2): 89–105.

Government of British Columbia. 2008. Environmental Trends in British Columbia: 2007. Available from: http://www.env.gov.bc.ca/soe/et07/EnvironmentalTrendsBC_2007.pdf

Hamann, A., and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology. 87 (11): 2773-2786.

Leith, R.M. and P. Whitfield. 1998. Evidence of climate change effects on the hydrology of streams in southcentral B.C. Canadian Water Resources Journal 23(3):219–230.

Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush (editors). 2008. From Impacts to Adaptation: Canada in a Changing Climate 2007; Government of Canada, Ottawa, ON. 448 p. Available from: http://adaptation.nrcan.gc.ca/assess/2007/index_e.php

Leung, L.R. and Y. Qian. 2003. Changes in seasonal and extreme hydrologic conditions of the Georgia Basin/Puget Sound in an ensemble regional climate simulation for the mid-century. Canadian Water Resources Journal 28 (4): 605–631.

McCleary, R.J. and M.A. Hassan. 2008. Predictive modeling and spatial mapping of fish distributions in small streams of the Canadian Rocky Mountain foothills. Canadian Journal of Fisheries and Aquatic Sciences 65: 319-333.

Merritt, W.S., Y. Alila, M. Barton, B. Taylor, S. Cohen, D. Neilsen. 2006. Hydrologic response to scenarios of climate change in subwatersheds of the Okanagan basin, British Columbia. Journal of Hydrology 326: 79–108.

Ministry of Environment (MOE) 2007. Environmental Trends in British Columbia: 2007. State of Environment Reporting. Victoria, B.C. Available from: http://www.env.gov.bc.ca/soe/et07/EnvironmentalTrendsBC_2007.pdf

Ministry of Water, Land and Air Protection. 2002. Climate Change Indicators of Change for British Columbia 2002. Available from: http://www.env.gov.bc.ca/epd/climate/pdfs/indcc.pdf

Morrison, J., M.C. Quick, and M.C.G. Foreman. 2002. Climate change in the Fraser River watershed: Flow and temperature projections. Journal of Hydrology 263: 230–244.

Nelitz, M. and M. Porter. 2009. A future outlook on the effects of climate change on coho salmon (Oncorhynchus kisutch) 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. Available from: http://www.thinksalmon.com/reports/CohoHabitatOutlook_090314.pdf

Nelitz, M., K. Wieckowski, D. Pickard, K. Pawley, and D.R. Marmorek. 2007. Helping Pacific salmon survive the impacts of climate change on freshwater habitats: Pursuing proactive and reactive adaptation strategies. Final report prepared by ESSA Technologies Ltd., Vancouver, B.C. for the Pacific Fisheries Resource Conservation Council, Vancouver, B.C. Available from: http://fish.bc.ca/files/PFRCC-ClimateChange-Adaptation.pdf

Nelitz, M., M. Porter, K. Bennett, A. Werner, K. Bryan, F. Poulsen, and D. Carr. 2009a. Evaluating the vulnerability of freshwater fish habitats to the effects of climate change in the Cariboo-Chilcotin: Part I – Summary of technical methods. Report prepared by ESSA Technologies Ltd. and Pacific Climate Impacts Consortium for Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Resource Conservation Council. Available from: Available from: http://www.thinksalmon.com/reports/PartI-MethodsReport_090314.pdf

Nelitz, M., M. Porter, K. Bennett, A. Werner, K. Bryan, F. Poulsen, and D. Carr. 2009b. Evaluating the vulnerability of freshwater fish habitats to the effects of climate change in the Cariboo-Chilcotin: Part II – Summary of results. Report prepared by ESSA Technologies Ltd. and Pacific Climate Impacts Consortium for Fraser Salmon and Watersheds Program, B.C. Ministry of Environment, and Pacific Fisheries Resource Conservation Council. Available from: http://www.thinksalmon.com/reports/PartII-ResultsReport_090314.pdf

Parry, M.L., O.F. Canziani, J.P. Palutikof, and co-authors. 2007. Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78. Available from: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Pike, R.G., D.L. Spittlehouse, K.E. Bennett, V.N. Egginton, P.J. Tschaplinski, T.Q. Murdock, and A.T. Werner. 2008. Climate change and watershed hydrology Part I – Recent and projected changes in British Columbia. Streamline Watershed Management Bulletin. Vol. 11. No 2.

Porter, M. and M. Nelitz. 2009a. 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. Available from: http://www.thinksalmon.com/reports/BullTroutHabitatOutlook_090314.pdf

Porter, M. and M. Nelitz. 2009b. A future outlook on the effects of climate change on Chinook salmon (Oncorhynchus tshawytscha) 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. Available from: http://www.thinksalmon.com/reports/ChinookHabitatOutlook_090314.pdf

Rodenhuis, D., K.E. Bennett, A. Werner, T.Q. Murdock, and D. Bronaugh. 2007. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium. Available at: http://www.pacificclimate.org/publications/PCIC.ClimateOverview.pdf

Schiefer, E., B. Menounos, and R. Wheate. 2007. Recent volume loss of British Columbian glaciers, Canada. Geophysical Research Letters 34 L16503, doi:10.1029/2007GL030780

Taylor, E. and B. Taylor (editors). 1997. Responding to Global Climate Change in British Columbia and Yukon, Volume 1 Canada Country Study: Climate Impacts and Adaptation. British Columbia Ministry of Environment, Lands and Parks and Environment Canada, Vancouver, British Columbia.

Whitfield, P.H. and A.J. Cannon. 2000. Recent variations in climate and hydrology in Canada. Canadian Water Resources Journal 25:19–65.

Whitfield, P.H. Wang, J.Y., and Cannon, A.J. 2003. Modelling future streamflow extremes—Floods and low flows in Georgia Basin, British Columbia. Canadian Water Resources Journal. 28(4): 633–656.

Zhang, X., K.D. Harvey, W.D. Hogg, and T.R. Yuzyk. 2001. Trends in Canadian streamflow. Water Resources Research 37(4):987–998.

Appendix A: Survey

Evaluating the vulnerability of freshwater fish habitats to climate change and identifying regional adaptation strategies in the Cariboo-Chilcotin
– Survey preamble –

Across British Columbia, climate change will undeniably alter freshwater ecosystems. The biological implications of physical habitat changes on Pacific salmon and other freshwater fish species are significant as changes in timing / magnitude of flow and thermal regimes are linked to behavioural and physiological responses at different life stages (see Figure 1). Human activities can affect these biophysical changes in both negative and positive ways by imposing additional stressors (e.g., exaggerating hydrologic impacts) or restoration actions (e.g., changing water use to mitigate against low summer flows) in vulnerable habitats.

Given such relationships, the goal of this work is to develop and demonstrate a pilot approach for providing decision makers in the Cariboo-Chilcotin (see Figure 2) with information to make choices in the near-term that will benefit people and freshwater ecosystems in the long-term. The hope is to improve decision making by summarizing information in a way that: (1) describes vulnerability of freshwater ecosystems to climate change (i.e., *which locations are vulnerable to what kinds of changes?*), and (2) identifies opportunities for adaptation (i.e., *which strategies could be applied in which locations?*). The intent is not to gain a commitment towards implementing any adaptation strategies identified through this work. This effort builds on previous research which developed the foundation models and datasets for assessing vulnerability of freshwater ecosystems across the Cariboo-Chilcotin[3].

To achieve these goals, our efforts are focused on updating existing vulnerability models and summarizing existing information that describes human pressures and management activities at a broad spatial scale. Vulnerability modelling is only focused on estimating changes in water flow and temperature at select locations across the region. Given this emphasis, our exploration of adaptation strategies is focused on those that could help mitigate climate change impacts on water flow and temperature. Moreover, this exercise focuses on identifying technology or management oriented strategies. Other strategies targeting behavioural (e.g., education and awareness campaigns) or policy changes (e.g., alterations to existing permitting processes) are beyond the scope of this work.

With this focus in mind, the survey that follows has been designed to guide specific components of our modeling and analysis. There are four parts to this survey each of which begins by discussing the purpose of the exercise, presenting background information about the analytical problem, and then asking for your guidance in a structured way. These parts include the following:

Part 1 is focused on identifying which adaptation strategies are worth exploring in our analysis after considering the types of barriers that affect implementation. This list of strategies has been developed after a thorough review of the literature and interviews with scientists and managers.

Part 2 is focused on mapping these adaptation strategies to the data that describe the extent of existing management actions and stressors across the study area. The intent is to use these data to identify opportunities where a particular adaptation strategy is most feasible given existing actions and stressors.

Part 3 is focused on identifying ways of summarizing the information from our vulnerability models in a way that is most informative for decision making.

Part 4 is focused on identifying the most appropriate administrative or management units for summarizing information about each adaptation strategy. The intent is that these units would allow for appropriate comparisons of vulnerability and adaptation potential across the region.

---

[3] "*Evaluating the vulnerability of freshwater fish habitats to climate change in the Cariboo-Chilcotin*". Project Summary at: http://www.thinksalmon.com/fswp_project/item/evaluating_the_vulnerability_of_pacific_salmon_to_effects_of_climate_change/

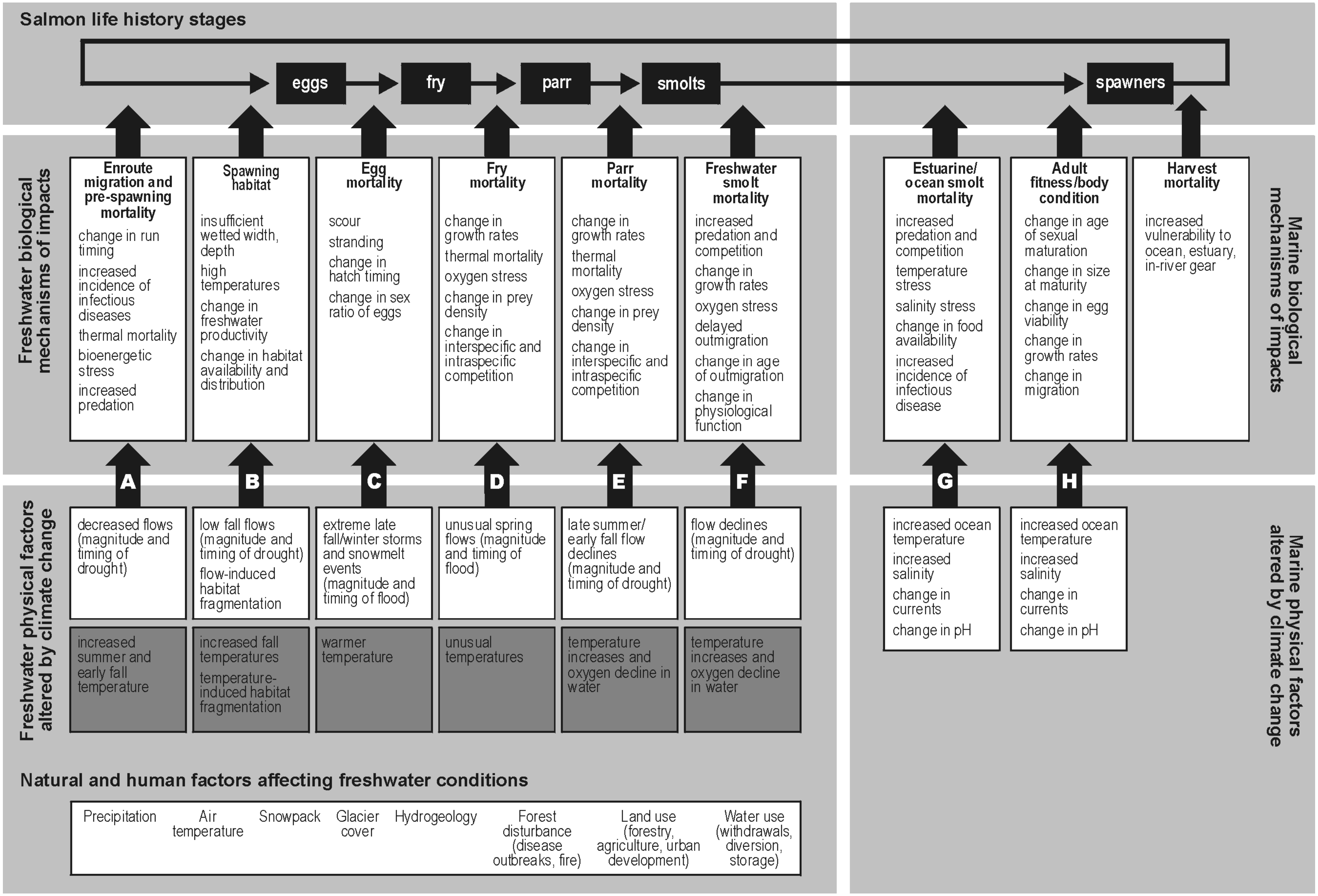


Figure 1. Conceptual diagram illustrating links among freshwater habitat features altered by climate change (e.g., water flows and temperatures) and the mechanisms affecting survival by life stage for Pacific salmon (extracted from Nelitz et al. 2007).

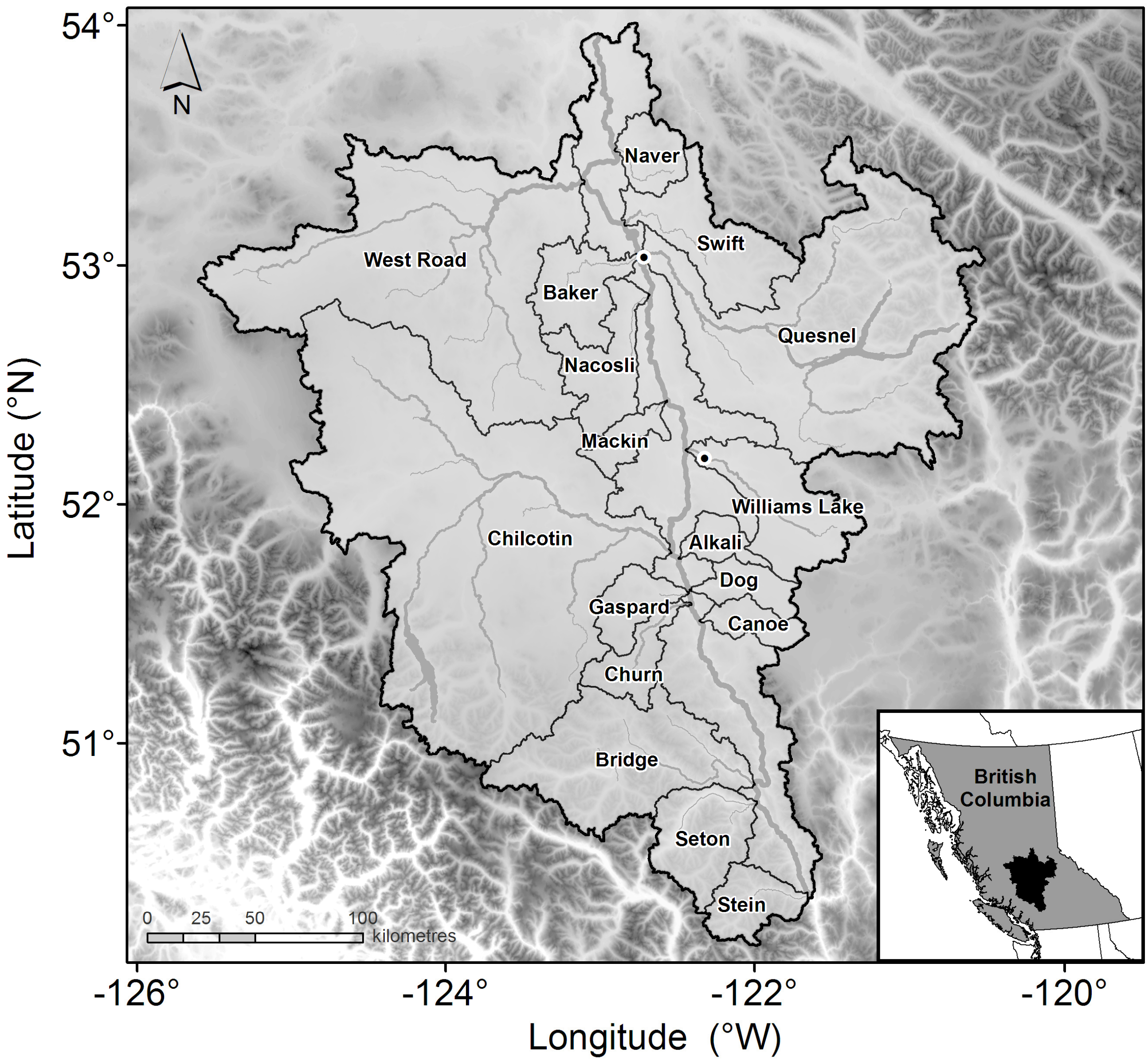


Figure 2. Delineation of the Cariboo-Chilcotin project study area and fourth order (or higher) watersheds.

Part 1: Prioritizing adaptation strategies

This section is designed to help frame our vulnerability modeling and analysis of adaptation opportunities by focusing our efforts on those adaptation strategies with the highest perceived priority (as determined by those which are most feasible to implement). The list of strategies is largely limited to those that can benefit freshwater ecosystems by mitigating impacts on water flow and temperature. They have a technology or management focus and are mostly relevant to rural environments.

In evaluating the feasibility of each strategy in questions A1-A20, we ask you to consider how six potential barriers might hinder implementation (see Table 1) and then rate how these barriers affect feasibility (high, moderate, low, or unknown feasibility). Recognizing that institutional and policy barriers will likely change the most over time and pose some of the greatest constraints, we ask you to consider the feasibility of implementation with and without these considerations. For instance, you could rate the feasibility associated with "restore riparian ecosystems" as high across all barriers and thus associate an overall high rating of feasibility (10), both with and without institutional / policy barriers. Adaptation strategies are listed in Table 2.

Table 1. Potential barriers and levels of feasibility in affecting implementation of adaptation strategies.

Type of barrier	Description	Level of feasibility
Economic	Barrier related to tangible costs (up-front, maintenance, and operating costs) and intangible costs (will lead to foregone investments or cost to future generations) of implementation.	**High:** Small tangible or intangible costs. **Moderate:** Moderate tangible or intangible costs. **Low:** Large tangible or intangible costs associated with implementation of the strategy.
Institutional	Barriers related to the institutional capacity (human resources and time) to implement a strategy. Consider institutions as including community organizations and government agencies.	**High:** Strong capacity currently available to implement strategy. **Moderate:** Limited capacity to implement strategy. **Low:** No capacity to implement strategy.
Policy	Barriers related to the existing regulatory, legal, or policy frameworks that affect management of freshwater ecosystems and reliant fish species. Federal, provincial, municipal, and First Nations levels of government should be considered.	**High:** Existing policies support or enable implementation of strategy. **Moderate:** Existing policies neither hinder nor support implementation of strategy. **Low:** Existing policies inhibit or hinder implementation of a particular adaptation strategy.
Scientific	Barriers related to our ability to understand the current status of freshwater ecosystems or predict future impacts due to climate change (i.e., related to information gaps or a lack of understanding about key cause-effect relationships between climate change, human adaptation, and ecosystem responses).	**High:** Analysis and interpretation of available information can reasonably support decisions about implementing adaptation strategies. **Moderate:** Analysis and interpretation of available information can partially support decisions about implementing adaptation strategies. Data are likely incomplete spatially or temporally. **Low:** Limited data available to support decisions about implementing adaptation strategies.
Social	Barriers related to the behaviour of those involved in implementing or supporting a particular adaptation strategy. This type of barrier can be described by resistance at the individual, community, institutional, or political level. These barriers can also include lack of alignment with First Nations values and principles.	**High:** Little opposition to implementation. **Moderate:** Some opposition to implementation. **Low:** Likely strong opposition to implementation of the strategy at the individual, community, institutional or political level.
Technology	Barriers related to the level of technological innovation required for implementing a particular strategy as related to the effectiveness of the strategy in mitigating impacts on freshwater habitats.	**High:** Strategy is standard practice with known effectiveness. **Moderate:** Some experience in applying the strategy with some known level of effectiveness. **Low:** An untested strategy with unknown effectiveness.

Table 2. List of adaptation strategies with the potential to mitigate impacts of climate change on water flow and temperature.

Grouping	Adaptation strategy	Description of strategy
Manipulation of fish populations and fish habitats	Restore riparian ecosystems	Restore riparian zones to help maintain shading in support of cool stream temperatures.
	Create deep pools	Dig deep pools for adult holding or juvenile rearing to provide cool thermal refuges, especially if associated with groundwater upwelling and streamside shading.
	Enhance production with hatcheries	Use hatcheries to aid conservation of depressed salmon stocks or enhance catch for fisheries adversely affected by alterations in water temperature and flow. Population enhancements can help offset mortalities due to habitat changes resulting from climate change.
	Transport fish manually	In locations where low flows constrain movement, manually capture and move spawners / juveniles to facilitate upstream / downstream access to critical habitats (e.g., spawning or rearing areas).
	Improve fish passage	Remove barriers or use passage devices to expand extent of habitats, enhance access to cool water habitats, and/or improve survival at different life stages (e.g., adults migrating upstream to spawning areas or juveniles moving to rearing habitats).
	Implement low impact grazing practices	Use grazing practices that minimize impacts on rivers and riparian zones (i.e., adjust timing of grazing, managing riparian vegetation, limit access to streams). Maintenance and protection of riparian zones can help maintain cool stream temperatures.
Adjustments to water use and management	Restrict water use across space and/or time	Restrict licensed water use in years of drought or locations with limited water supply.
	Adjust water allocations and licensing	Adjust existing water licenses to specify best management practices, adjust rates of water use, or establish minimum conservation flows in vulnerable locations.
	Implement low impact irrigation practices	Implement irrigation practices to improve water use efficiency and decrease impacts on fish due to entrainment.
	Build additional storage capacity	Build additional storage capacity to provide a greater ability to manipulate instream flows in watersheds where the hydrology and temperatures are adversely affected by climate change.
	Divert water from other locations	Divert water across or within basins to enhance water flows and decrease water temperatures at a recipient location. Note this action could be associated with decreased water flows and possible increases in temperature at the donor location.
	Manage water storage	Alter the timing and volume of water releases from existing storage facilities to compensate for adverse changes in hydrology due to climate change (i.e., managing flows to meet requirements of freshwater ecosystems).
	Release cold water	Use cold water releases from lakes or reservoirs to reduce water temperatures.
	Manipulate surface water / groundwater interactions	Manually recharge groundwater sources by injecting surface water into groundwater aquifers to enhance cooling in warmer streams and/or moderate surface flows.

Grouping	Adaptation strategy	Description of strategy
Adjustments to land use and management	Use existing land designations to promote special management	Designate locations requiring special management (e.g., Fisheries Sensitive Watersheds, Temperature Sensitive Streams, Wildlife Habitat Areas, SARA critical habitats). Special management could include application of best management practices or adherence to specific conditions to mitigate impacts on water flow and temperature.
	Enhance forest retention at the landscape level	Alter distribution of mountain pine beetle salvage in space and/or time to enhance riparian retention and minimize impacts on watershed hydrology.
	Adjust patterns of forest harvesting	Adjust patterns of forest harvesting in space and time to minimize hydrological impacts in sensitive watersheds, or enhance recovery of previously disturbed watersheds (i.e., high equivalent clearcut area).
	Adjust management of forest roads	Adjust management of forest roads to minimize impacts on forest hydrology (e.g., decommission roads, alter culvert placement, size and design)
	Enhance conservation of pristine habitats	Expand conservation of habitats that currently support or could support high value fish communities (e.g., extensive roadless areas). Strategy would fit within other multi-species conservation planning exercises (e.g., eco-regional assessment by Nature Conservancy Canada).

For each adaptation strategy below, indicate the level of feasibility associated with each barrier (high, moderate, low, or unknown feasibility from Table 2), then rate overall feasibility of implementation on a scale from 1 (lowest feasibility) to 10 (highest feasibility). Please rate feasibility twice – once with barriers 1-6 and once without barriers 2 & 3.

Q#	Adaptation strategy	– #1 – Economic	– #2 – Institut-ional	– #3 – Policy	– #4 – Scientific	– #5 – Social	– #6 – Techn-ology	Feasibility (1-10) with barriers 1-6	Feasibility (1-10) with barriers 1, 4-6
A1	Restore riparian ecosystems								
A2	Create deep pools								
A3	Enhance production with hatcheries								
A4	Transport fish manually								
A5	Improve fish passage								
A6	Implement low impact grazing practices								
A7	Zone water availability in space and/or time								
A8	Adjust water allocations and licensing								
A9	Implement low impact irrigation practices								
A10	Build additional storage capacity								
A11	Divert water from other locations								
A12	Manage water storage								
A13	Release cold water								
A14	Manipulate surface water / groundwater interactions								
A15	Use existing land designations to promote special management								
A16	Enhance forest retention at the landscape level								
A17	Adjust patterns of forest harvesting								
A18	Adjust management of forest roads								
A19	Enhance conservation of pristine habitats								

Part B: Identifying indicators of adaptation potential

This section is designed to help us identify indicators that could be used to identify areas with the greatest extent of stressors and/or management activities (i.e., indicators of adaptation potential). The intent is that these indicators of adaptation potential would be overlaid with information about vulnerability to identify opportunities for implementing adaptation strategies (i.e., areas that are both vulnerable and have the potential for adaptation). A description of the data sources for you to consider is provided in Table 3.

For each adaptation strategy in questions B1-B19 we ask that you align the adaptation strategy to the data source in Table 3 which would provide the best information for understanding the existing extent of stressors and management activities. For example, with the strategy, "restore riparian ecosystems" you might consider that existing land cover, vegetation resource inventory, and mountain pine beetle salvage / affected areas would be the best data sources to identify locations with the potential for riparian restoration.

Table 3. List of data sources that could be used to describe existing management activities and stressors to help identify opportunities to implement specific adaptation strategies.

ID	Data source	Description	Reference
A	Obstructions	All known obstacles to fish passage, which combines data from all provincial corporate fish datasets that have obstacle information. Layer reports obstacles to fish that are known. These features are obstacles to fish passage (i.e., rapids, falls, etc), not barriers.	FISS Provincial Obstacles to Fish Passage https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50219&recordSet=ISO19115 and Freshwater Atlas Obstructions https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50645&recordSet=ISO19115
B	Fish habitat	Critical Fish Analysis for SRMP planning - land area buffer zones protecting critical habitat areas for fish.	Fish Critical Habitat for the Cariboo Region https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=35734&recordSet=ISO19115
C	Fisheries project registry	Map-enabled database that tracks minimum information about the existence, general nature, and location for specific fisheries-related projects. Projects include: inventory and biophysical surveys, stock assessment, stewardship, resource planning, restoration and enhancement.	DFO Oceans, Habitat and Enhancement Branch http://www.canbcdw.pac.dfo-mpo.gc.ca/FPR/Qf_frames.asp
D	Restoration activities	Point locations of DFO's community habitat enhancements in BC	Enhancements http://www-heb.pac.dfo-mpo.gc.ca/maps/themesdata_e.htm
E	Hatchery enhancement	Point locations of DFO and Community fish hatcheries. Locations link to releases database, which contains information for each hatchery (species, stock, run, brood year etc.).	DFO and Community Operated Salmon Hatchery and Habitat Enhancement Locations http://www-heb.pac.dfo-mpo.gc.ca/maps/themesdata_e.htm
F	Surface water licenses	Province-wide spatial layer displaying water license points of diversion joined with license information (e.g., purpose for diversion)	BC Points of Diversion with Water Licence Information https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47674&recordSet=ISO19115
G	Storage dams / weirs	Province-wide spatial view displaying dam locations and associated attributes (e.g., dam type, height, length, etc.)	BC Dams https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49718&recordSet=ISO19115
H	Reservoirs	All manmade waterbodies, including reservoirs and canals, for the province (area ha)	Freshwater Atlas Manmade Waterbodies https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50642&recordSet=ISO19115
I	Water reserves	Province-wide layer showing streams having a Water Reserve or a Water Allocation Restriction.	Water Reserves and Water Allocation Restrictions https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=34251&recordSet=ISO19115
J	Groundwater	Locations of ground water wells in BC.	Ground Water Wells

ID	Data source	Description	Reference
	wells	Artesian wells are flowing wells at the time of drilling.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49998&recordSet=ISO19115
K	Groundwater aquifers	Multi-part polygon features representing developed ground water aquifers in BC, linked to attributes e.g., area, vulnerability, etc.). Many of the aquifers boundaries presented are "administrative" boundaries based on limited data available.	Ground Water Aquifers https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3841&recordSet=ISO19115
L	Classified land use (LRMPs)	Resource Development zones from the Cariboo Chilcotin Higher Level Land-Use Plan	Land Use Plan for the Cariboo Region https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=35772&recordSet=ISO19115
M	Existing land cover	Land Cover information from classified Landsat 5 and Landsat 7 ortho-images, for agricultural and forest areas of Canada	Land Cover http://www.geobase.ca/geobase/en/find.do;jsessionid=1B2CC441DFDA98E8ADA9990C4A22902E?produit=csc2000v&language=en
N	Projects undergoing environmental assessment	Projects that are currently, or have been, subject to environmental assessment review. Layer includes (1) status of a given EA review process and (2) sector of project under review.	Electronic Project Information Centre Points – Environmental Assessment Office) https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3695&recordSet=ISO19115
O	Pine beetle salvage areas	Delineated Mountain Pine Beetle Salvage area	Mountain Pine Beetle Salvage Area https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49938&recordSet=ISO19115
P	Estimates of future forest disturbance due to pine beetle	Maps of % forest killed by pine beetle 1999-2006. Maps of forecast % forest killed by pine pine beetle (2011, 2019)	http://www.hectaresbc.org/app/habc/HaBC.html
Q	Seral stage	Seral stage assessment for various districts in the Cariboo-Chilcotin Region (100 Mile House, Chilcotin, Horsefly, Quesnel, Williams Lake)	Seral Stage Assessment https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=35760&recordSet=ISO19115 and ftp://ftpwml.env.gov.bc.ca/dist/forest/seral/seral_2008/maps/
R	Old Growth Management Zones	Legally established and spatially defined areas of old growth forest identified during landscape unit planning or operational planning processes. Forest licensees are required to maintain legally established OGMAs.	Old Growth Management Areas https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=51680&recordSet=ISO19115
S	VRI	Maps of vegetation cover across the entire study area.	http://www.hectaresbc.org/app/habc/HaBC.html
T	Protected areas	Boundaries for all provincial protected areas.	Parks and Protected Areas https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3997&recordSet=ISO19115
U	Wildlife Habitat Area (WHA) or Fisheries Sensitive Watersheds (FSW)	Location of approved wildlife habitat areas and specified areas. Approved legal boundaries for fisheries sensitive watersheds. A FSW is an area with specific management objectives intended to guide development activities which may adversely impact fish values.	Wildlife Habitat Areas https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=36172&recordSet=ISO19115 Fisheries Sensitive Watersheds https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49678&recordSet=ISO19115

For each adaptation strategy below, indicate the data source(s) in Table 3 (using the ID letter) that would best describe the adaptation potential (i.e., extent of existing stressors or management activities) across the Cariboo-Chilcotin. If none of these data sources are appropriate, please indicate an alternative source for providing this information across the study area. In some cases we acknowledge that expert opinions may represent the best available information source.

Q#	Adaptation strategy	Recommended data source(s) (ID letter from Error! Reference source not found.)	Other alternatives not listed in Table 3 (include references)
B1	Restore riparian ecosystems		
B2	Create deep pools		
B3	Enhance production with hatcheries		
B4	Transport fish manually		
B5	Improve fish passage		
B6	Implement low impact grazing practices		
B7	Zone water availability in space and/or time		
B8	Adjust water allocations and licensing		
B9	Implement low impact irrigation practices		
B10	Build additional storage capacity		
B11	Divert water from other locations		
B12	Manage water storage		
B13	Release cold water		
B14	Manipulate surface water / groundwater interactions		
B15	Use existing land designations to promote special management		
B16	Enhance forest retention at the landscape level		
B17	Adjust patterns of forest harvesting		
B18	Adjust management of forest roads		
B19	Enhance conservation of pristine habitats		

Part C: Identifying metrics of freshwater vulnerability

This section is designed to help us identify the best metrics for summarizing results from the vulnerability modeling. A description of the metrics available from existing models and data sources is provided in Table 4. Note that our ability to predict changes in water flow and temperature is limited to a fixed set of index locations across the study area. Flow predictions are available as monthly estimates of discharge from 2007 to 2099. Water temperature can only be estimated as a maximum weekly average temperature (i.e., no finer temporal resolution is available) at four time periods (baseline, 2020s, 2050s, and 2080s).

For each adaptation strategy in questions C1-C19 we ask that you align the strategy with the vulnerability metrics in Table 4 which would best provide an indication of vulnerability related to that adaptation strategy. For example, with the strategy, "restore riparian ecosystems" you might consider the metric "thermal class by linear extent" as the best metric for identifying locations that are both vulnerable to temperature increases and where riparian restoration could be implemented (if given additional information on adaptation potential).

Table 4. List of metrics available to describe vulnerability of climate change on water flow, temperature, and fish habitats in the Cariboo-Chilcotin.

ID	Vulnerability metric	Description
A	Mean annual discharge (MAD)	Average discharge (in m^3/s) across all days and years of reference at an index location.
B	Spring peak flow	Average spring peak flow across all days and years of record at an index location.
C	Timing of spring peak flow	Average date of spring peak flow across all years of record at an index location.
D	Bypass flow	Percent of mean annual discharge during the adult salmon spawning period (July 15 to October 15) relative to a bypass flow threshold (60% of MAD) at an index location.
E	Summer rearing flow	Percent of mean annual discharge during summer juvenile rearing (July 1 to October 1) relative to low flow thresholds (30% and 10% of MAD) at an index location.
F	Optimal flow	Stream flows that maximize the limiting or critical habitat for a specific fish species/life stage according to hydraulic suitability criteria using depth, velocity and substrate in a weighted useable area or weighted useable width analysis (WUA or WUW).
G	Maximum weekly average temperature (MWAT) by watershed	Maximum water temperature of a 7-day rolling average (°C) at an index location.
H	Thermal class by watershed	Translation of MWAT values (°C) into fish community thermal classes (cold, cool, or warm water) for a single watershed.
I	Thermal class by linear extent	Translation of MWAT values (°C) into fish community thermal classes (cold, cool, or warm water) summarized by linear extent of fish habitat (km) within a watershed.
J	Growing degree days	The sum of the daily growing degrees for each day over the growing season. A daily growing degree day is the daily mean air temperature minus a selected base temperature.
K	Baseline fish distribution	Predicted baseline distribution of accessible fish habitats (bull trout, Chinook salmon, and coho salmon) within a watershed by linear extent (km).
L	Critical fish habitats	Linear extent (km) of critical fish habitats as identified through the Cariboo-Chilcotin Land Use Plan.
M	Salmon escapement	Number of adult spawners returning to a natal stream (i.e., DFO's salmon escapment data).
N	Fisheries values	Fisheries value scores / ranking by watershed from the BC Ministry of Environment's Watershed Evaluation Tool.

For each adaptation strategy below, indicate the vulnerability metric from Table 4 (using the ID letter) that is most appropriate for summarizing information describing vulnerability. If none of these metrics are appropriate, please indicate an alternative form of summarizing water flow, temperature, or habitat data or an alternative data source to derive relevant metrics that would be helpful for identifying vulnerable freshwater habitats across the Cariboo-Chilcotin.

Q#	Adaptation strategy	Recommended vulnerability metric(s) (ID letter from Error! Reference source not found.)	Other alternatives not listed in Table 4
C1	Restore riparian ecosystems		
C2	Create deep pools		
C3	Enhance production with hatcheries		
C4	Transport fish manually		
C5	Improve fish passage		
C6	Implement low impact grazing practices		
C7	Zone water availability in space and/or time		
C8	Adjust water allocations and licensing		
C9	Implement low impact irrigation practices		
C10	Build additional storage capacity		
C11	Divert water from other locations		
C12	Manage water storage		
C13	Release cold water		
C14	Manipulate surface water / groundwater interactions		
C15	Use existing land designations to promote special management		
C16	Enhance forest retention at the landscape level		
C17	Adjust patterns of forest harvesting		
C18	Adjust management of forest roads		
C19	Enhance conservation of pristine habitats		

Part D: Identifying administrative units

This section is designed to help us frame the comparison of results from the vulnerability modeling and analysis of adaptation opportunities to assist in prioritizing implementation of adaptation strategies across the study area. A description of the potentially relevant administrative / management units is provided in Table 5.

For each adaptation strategy in questions D1-D19 we ask that you align the strategy to the administrative unit in Table 5 which would form the best basis for comparing vulnerabilities and adaptation potential. For example, with the strategy, "restore riparian ecosystems" you might consider that "watershed boundaries" are the best units to compare vulnerability of freshwater environments to thermal changes and summarize information about adaptation opportunities.

Table 5. List of administrative units available for comparing vulnerability and adaptation potential across the Cariboo-Chilcotin.

ID	Administrative unit	Description	Reference
A	Watershed boundaries	Delineation of the landscape on the basis of natural watersheds boundaries – with stream order of 4 or higher – as delineated by BC's Freshwater Atlas (e.g., Bridge River, Horsefly River).	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50648&recordSet=ISO19115 See watershed units used in http://www.thinksalmon.com/reports/PartII-ResultsReport_090314.pdf
B	Ecological Aquatic Units of BC (EAUBC)	EAU BC is a hierarchical classification of BC's freshwater ecosystems hosted by GeoBC.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=54019&recordSet=ISO19115
C	Freshwater Ecoregions	Freshwater Ecoregions are defined based on zoogeographic patterns in fish recolonization following the last glacial recession.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=51698&recordSet=ISO19115 http://science.natureconservancy.ca/resources/docs/Maps_1-6_EAU_BC_Nov2007.pdf
D	Ecological Drainage Units	Ecological Drainage Units (EDU) are nested within Freshwater Ecoregions and take into account zoogeographic, climatic, and physiographic patterns that define freshwater systems. EDUs incorporate the known distribution of native freshwater fishes in BC.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=52281&recordSet=ISO19115
E	Conservation units (CU) for the Wild Salmon Policy	Chinook 'Middle Fraser River – spring' CU covers 8,500 km^2, roughly 90% is within the study area. Chinook 'Middle Fraser River – summer' CU is 10,400 km^2 and 60% is within the study area. Coho 'Middle Fraser' CU covers the entire project study area and beyond. Total area is 128,000 km^2.	http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/wsp-pss/index-eng.htm
F	Salmon stock units from State of the salmon	25 stock units for Chinook salmon across the study area with an average size of 3,294 km^2.. 21 stock units for coho salmon across the study area with an average size of 3,058 km^2.	http://www.stateofthesalmon.org/resources/sosdb.asp
G	Sustainable Resource Management Plan (SRMP) areas for the CCLUP	SRMPs are a spatial application of the Cariboo Chilcotin Land Use Plan (CCLUP) direction at the sub regional planning level, i.e., take the numerical targets of the CCLUP and map them to see where you are meeting them and where you should improve. Seven sustainable resource management plan areas across the project study area.	http://www.ilmb.gov.bc.ca/slrp/lrmp/williamslake/cariboo_chilcotin/srmp.html

ID	Administrative unit	Description	Reference
H	CCLUP Resource Management Zones	Four resource management zones: (1) Enhanced Resource Development Zone (ERDZ); (2) integrated Resource Management Zone (IRMZ); (3) Special Resource Development Zone (SRDZ); (4) New Protected Area Zone (NPAZ). Each zone is broken into subunits.	http://ilmbwww.gov.bc.ca/slrp/lrmp/williamslake/cariboo_chilcotin/docs/cclup_zones.pdf
I	CCLUP Landscape units	Landscape units were drawn for the Cariboo Forest Region using the size range recommended by the Forest Practices Code and topographical features, primarily watershed boundaries. A total of 161 landscape units are available for the region.	http://www.ilmb.gov.bc.ca/slrp/lrmp/williamslake/cariboo_chilcotin/plan/biodiv/lusize.pdf
J	Landscape units for BC (RMP)	Landscape Units are spatially identified areas of land and/or water used for long-term planning of resource management activities.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=51078&recordSet=ISO19115
K	ILMB regional and subregional boundaries	Regional units for BC.	http://www.hectaresbc.org/app/habc/HaBC.html
L	Ministry of Forests and Range Forest districts	Four forest districts across the project study area: Quesnel Forest district (1.83 million hectares); 100 Mile house; Chilcotin Forest District (2.19 million hectares); Central Cariboo Forest district.	http://www.for.gov.bc.ca/mof/REGDIS.HTM
M	Timber supply areas	Three timber supply areas in the study area (100 Mile House TSA (1.22 million hectares), Williams Lake TSA (4.87 million hectares), and Quesnel TSA (1.6 million hectares)).	http://www.hectaresbc.org/app/habc/HaBC.html

For each adaptation strategy below, indicate the administrative unit in Table 5 (using the ID letter) that is most appropriate for summarizing information describing vulnerability and adaptation potential across the Cariboo-Chilcotin. If none of these units are appropriate, please indicate an alternative spatial unit(s) for comparing information across the study area.

Q#	Adaptation strategy	Recommended administrative unit(s) (ID letter from Error! Reference source not found.)	Other alternatives not listed in Table 5 (include references)
D1	Restore riparian ecosystems		
D2	Create deep pools		
D3	Enhance production with hatcheries		
D4	Transport fish manually		
D5	Improve fish passage		
D6	Implement low impact grazing practices		
D7	Zone water availability in space and/or time		
D8	Adjust water allocations and licensing		
D9	Implement low impact irrigation practices		
D10	Build additional storage capacity		
D11	Divert water from other locations		
D12	Manage water storage		
D13	Release cold water		
D14	Manipulate surface water / groundwater interactions		
D15	Use existing land designations to promote special management		
D16	Enhance forest retention at the landscape level		
D17	Adjust patterns of forest harvesting		
D18	Adjust management of forest roads		
D19	Enhance conservation of pristine habitats		

Appendix B: Meeting agenda

Climate change vulnerability and adaptation in the Cariboo-Chilcotin

Time / date: 10:00 – 16:00, Tuesday, March 23

Venue: Government Resource Building
Williams Lake Room (First Floor)
640 Borland Street
Williams Lake

Google map: http://tinyurl.com/yfjtfwk

MEETING OBJECTIVES

(1) Present the approach, methods, and results from analysis of vulnerability and adaptation.

(2) Gather feedback on the approach, methods, and results.

(3) Discuss key challenges to understanding vulnerability and adaptation.

AGENDA

9:45	**Arrival, coffee, and refreshments**	
10:00	**Approach, methods, and results to evaluating vulnerability and identifying adaptation opportunities**	Presentation, feedback, and discussion (1.5 hrs)
11:30	**Challenge 1:** Dealing with uncertainty in modelling climate change vulnerability	Group exercise and discussion (1 hr)
12:30-13:30	Lunch (not provided)	
13:30	**Challenge 2:** Prioritizing and identifying adaptation opportunities	Group exercise and discussion (1.25 hrs)
14:45	Break (snacks provided)	
15:00	**Challenge 3:** Validating vulnerability predictions and overcoming barriers to adaptation	Group exercise and discussion (1 hr)
16:00	Adjourn	

Modeling of vulnerability and analysis of adaptation
Have we selected the most relevant GIS layers for our analysis of adaptation opportunities? For example, we used the provincial cutblock layer for defining riparian disturbance. Would seral ages from the provinces VRI layers have provided more accurate and temporally relevant data?

Is there a regional database that summarizes current and ongoing restoration activities being undertaken in the Cariboo? Fisheries Project Registry is 2 years old and not being maintained.

Do the gradient criteria we've used for defining the limits of upstream distribution seem reasonable?

Do the MAD-based rearing and spawning flow metrics seem reasonable for broad comparison?

Challenge 1: Dealing with uncertainty in modeling climate change vulnerability
What are the key uncertainties that people are most concerned about?
– time periods, GCMs, factors not included in modeling (glacier, groundwater), defining benchmarks, effectiveness of actions to reduce vulnerability, socio-economic tradeoffs

What are the options for communicating / addressing uncertainties?
– ignore, sensitivity analysis, present uncertain outcomes explicitly (probability or ranges relative to some baseline or management threshold), consider in analysis then present without uncertainty

Challenge 2: Prioritizing and identifying adaptation opportunities
What process should be used to prioritize adaptation?
– independent analysis to inform priorities, public discussion, agency discussion for public approval

Who should be included in deciding on adaptation priorities?
– public, agencies, both, etc.

Which factors should be used to determine feasibility of adaptation priorities?
– cost, regulatory support, capacity to implement, etc

Are available data appropriate for decision making?
– spatial / temporal scales, sufficient quality, etc.

At what spatial scale do we summarize information into comparable units (administrative units)?

Challenge 3: Validating vulnerability predictions and overcoming barriers to adaptation
What is the level of evidence / burden necessary to justify pursuing an adaptation strategy?

How do we validate vulnerability predictions?
– field monitoring, other models, expert-based verification

What are the barriers to implementing adaptation and which are the most important / significant?

What strategies are available to reduce these barriers?

Appendix C: Meeting presentation

Climate change vulnerability and adaptation in freshwater ecosystems of the Cariboo-Chilcotin

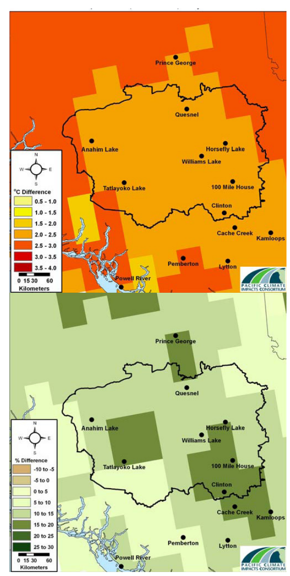
Marc Nelitz[1], Marc Porter[1], Katherine Wieckowski[1], Katrina Bennett[2], Katy Bryan[1], Frank Poulsen[1], and David Carr[1]

[1]ESSA Technologies Ltd.
[2]Pacific Climate Impacts Consortium

March 23, 2010

Context

- Expect warmer temperatures and changes in precipitation in Cariboo-Chilcotin which will translate into other physical and ecological changes (e.g., forests, flows, glaciers, fish communities)
- Few resources and a lack tools to translate these climatic changes into other physical and ecological pathways of effects ➔ needed to implement adaptation
- Uncertainties affect our understanding of climate change effects:
  - which development scenario?
  - which GCM and downscaling method?
  - which pathways of effects and models?
  - what are the socio-economic tradeoffs?



From Dawson et al. 2008

Project purpose

- Use best available models / data to:
  - describe vulnerability of freshwater ecosystems to climate change (stream flow and temperature)
  - identify opportunities for adaptation (human pressures and management activities)

- Develop a pilot approach for providing this information in a way that can best inform decision making

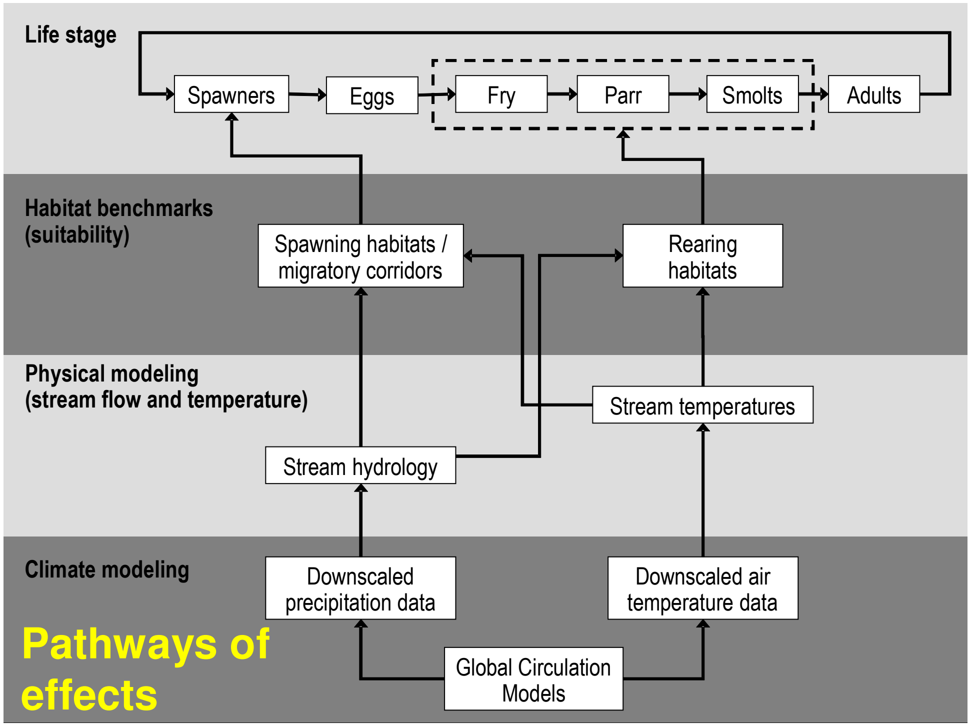
- Not developing a plan for implementing adaptation strategies

- Focused on technology or management oriented adaptation, not behavioural or policy adaptation

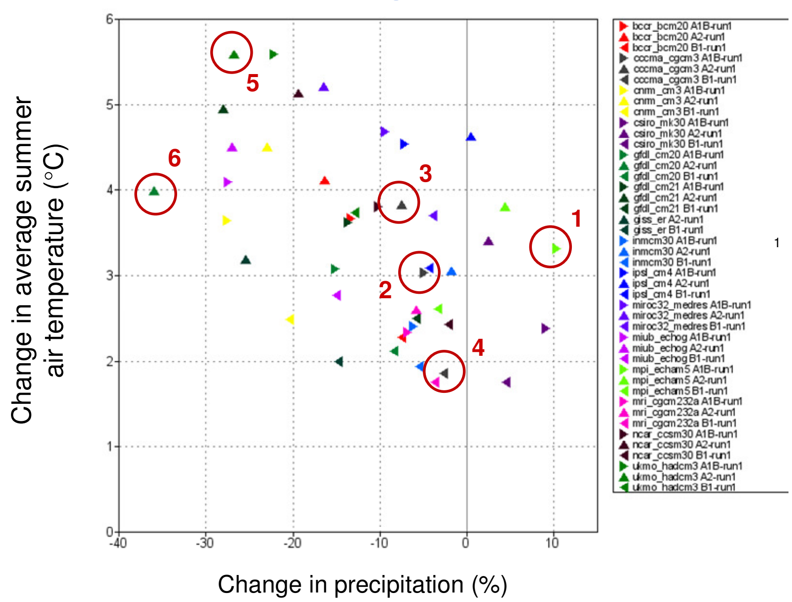
3

Vulnerability modeling

4



Climate modeling

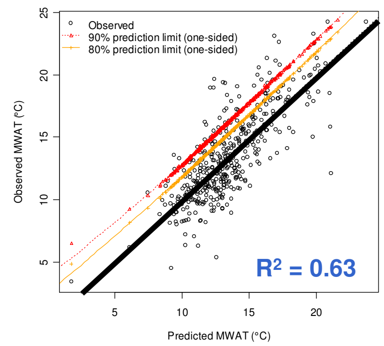


6

Stream temperature modeling

$$MWAT = 7.911 + (0.4835 * T_a) + (1.177 * Log(A)) - (0.003059 * Z_m)$$
$$-(0.9433 * \sqrt{f_g}) + (1.748 * \sqrt{f_l}) - (0.05292 * Slope) - (0.7194 * K_2)$$

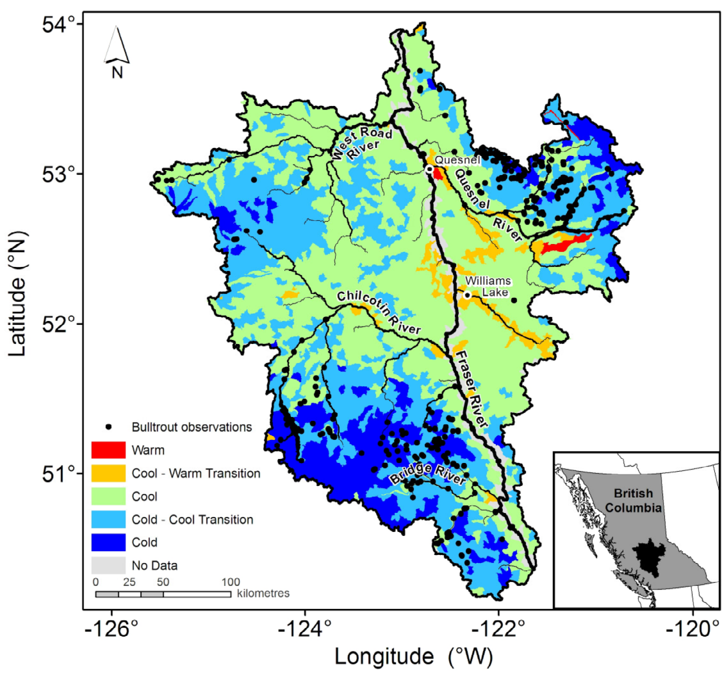
- Watershed area (+)
- Proportional lake coverage (+)
- Spatial climate variation (+)
- Year-to-year climate variation (+)
- Watershed elevation (-)
- Proportional glacier coverage (-)
- Stream gradient (-)
- 2 year flood index (-)



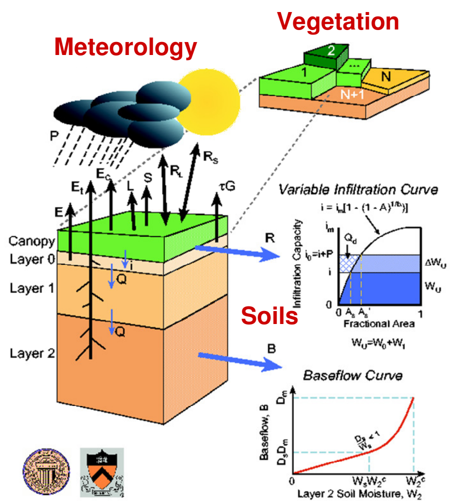
Calculates average MWAT across reference period (1990-2003) for all Freshwater Atlas polygons

From Nelitz et al. 2008.

7

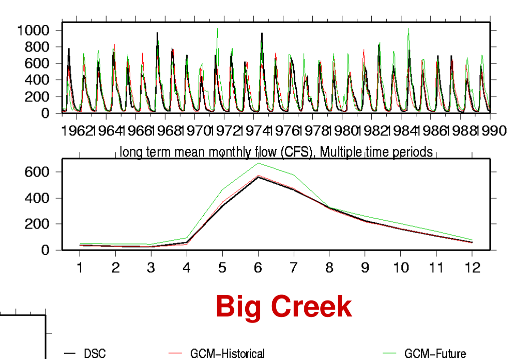


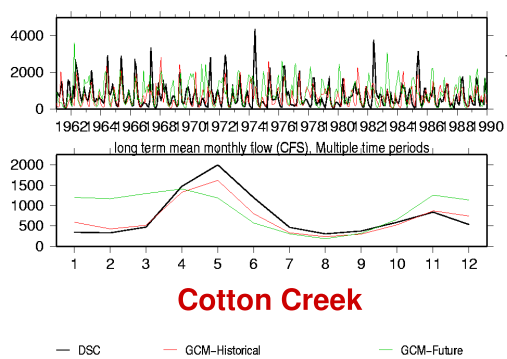
Stream flow modeling



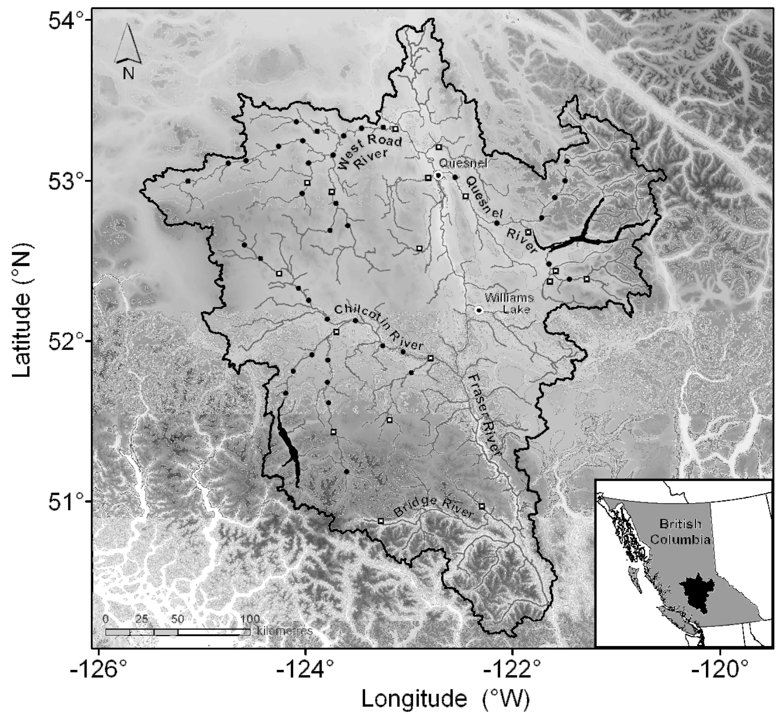
- Variable Infiltration Capacity (VIC) macro-scale hydrologic model
- Input data: meteorology, vegetation, and soils
- Developed by UoW, applied by PCIC / River Forecast Centre, as part of NRCAN MPB Project
- Model calculates fluxes within a cell at a daily time step
- Routing of flow across cells is a separate model

9



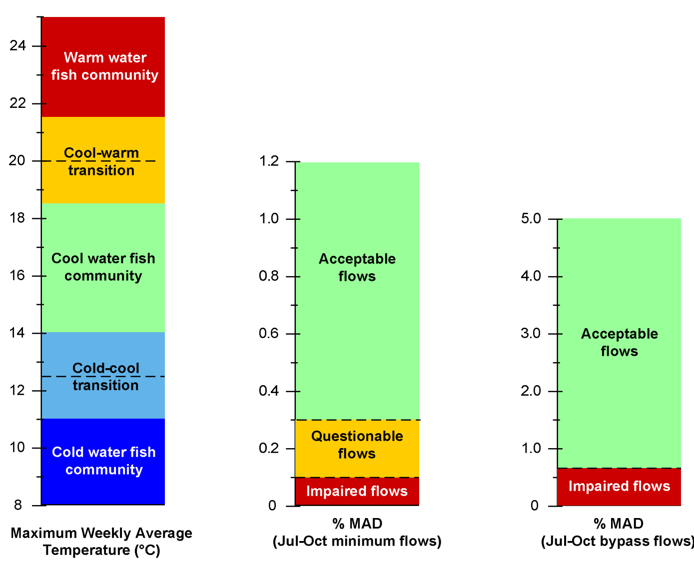


10



11

Habitat benchmarks



12

Fish distribution modeling

- Targeted Chinook salmon, coho salmon, and bull trout
- Applied decision rules to provincially available GIS layers to delineate fish distribution:
  - 1:50,000 intelligent stream linework
  - Fish observations (defines baseline extent)
  - Impassable barriers (natural and human)
  - Reach gradient (5%, 8%, and 12%)
  - Stream order (excl 1^{st} order)
- Approach consistent with spatial scale, methods, and decision rules applied by others (e.g., BC MOE, WDFW, USFW)

13

Analysis of vulnerability and adaptation

15

General approach

1) Identify **adaptation strategies** for analysis
   - focus on strategies to mitigate adverse change in stream flow and temperature
   - focus on most feasible (affected by economic, institutional, policy, scientific, social, and technological barriers)

2) Identify **indicators of adaptation** potential
   - use provincial GIS layers that describe human pressures and management activities

3) Identify **indicators and metrics of vulnerability**
   - use best and readily available models to predict changes in stream flow and temperature

4) Identify **administrative units** for decision making
   - allows for comparisons and prioritizing across region (location vs. area specific planning)

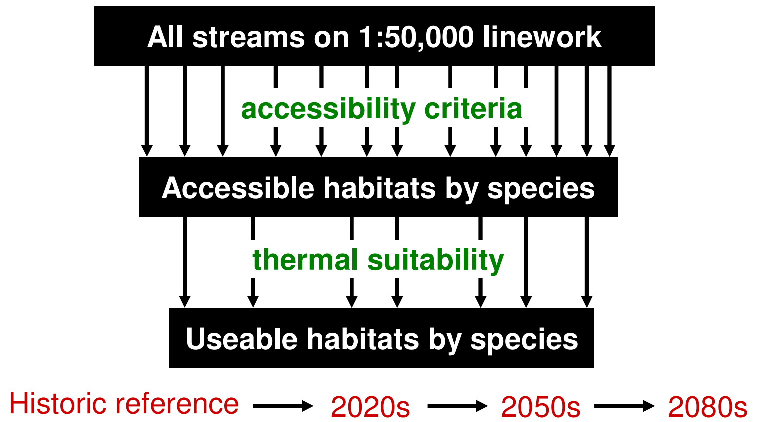
16

Adaptation strategies

- **Restore riparian ecosystems**
- Create deep pools
- Enhance production with hatcheries
- Transport fish manually
- **Improve fish passage**
- Implement low impact grazing practices
- Zone water availability in space and/or time
- **Adjust water allocations and licensing**
- Implement low impact irrigation practices
- Build additional storage capacity
- Divert water from other locations
- Manage water storage
- Release cold water
- Manipulate surface water / groundwater interactions
- Use existing land designations to promote special management
- Enhance forest retention at the landscape level
- Adjust patterns of forest harvesting
- Adjust management of forest roads
- Enhance conservation of pristine habitats

From Nelitz et al. 2007

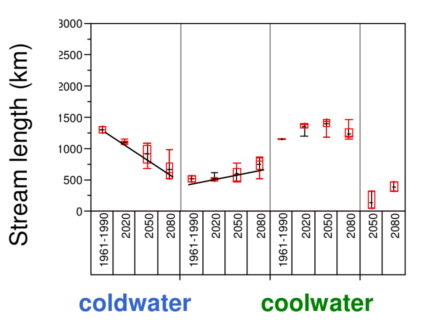
Thermal vulnerability



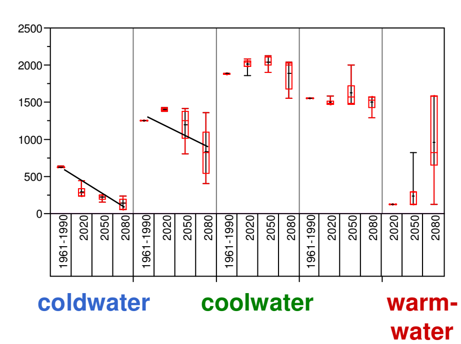
- linear extent of useable habitats by species, time period, and GCM
- % change in linear extent from historic reference by species, time period, and GCM

18

Linear extent of bull trout habitats



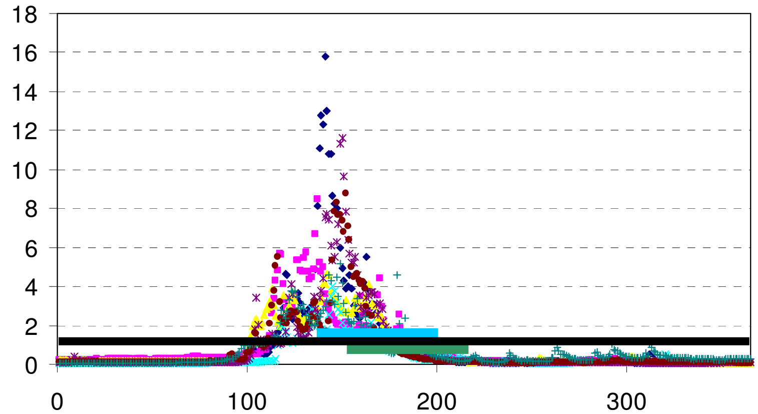
Chilcotin River



Quesnel River

19

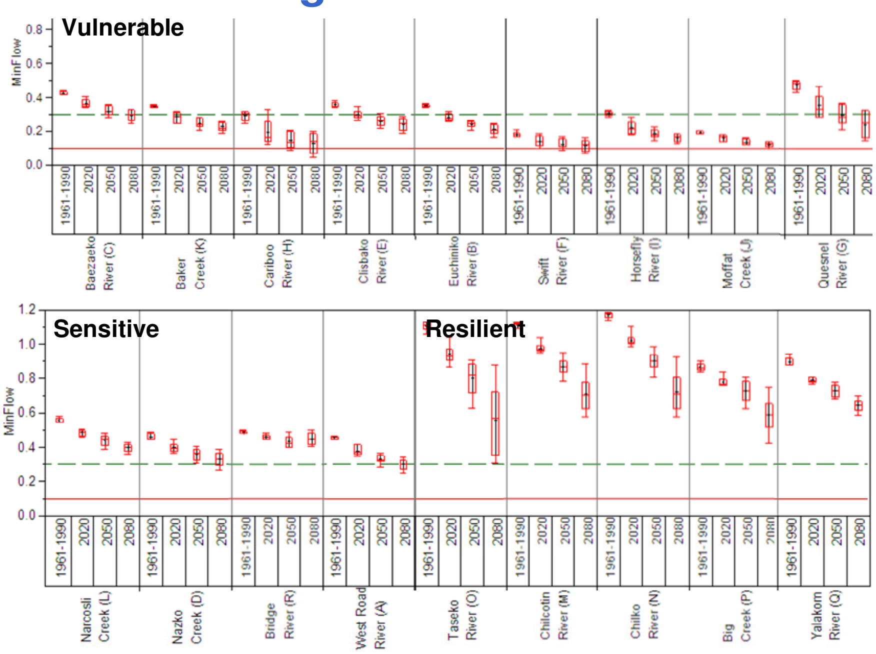
Flow vulnerability



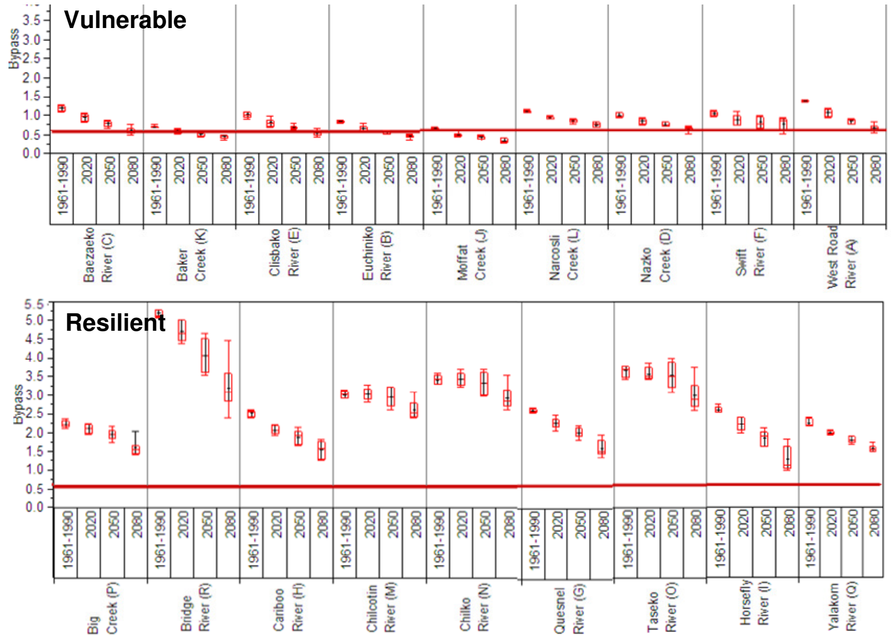
- mean annual discharge by time period and GCM
- summer rearing flow by time period and GCM (Jul 1 to Sep 30)
- spawning migration flow by time period and GCM (Jul 15 to Oct 15)

20

Summer rearing flow



Spawning migration flow



Adaptation metrics

Restore riparian ecosystems

- linear extent of riparian disturbance
  (intersect 1:20K stream buffer and cutblocks <15 years)
- count of historic riparian restoration
  (fisheries project registry)

Adjust water allocations and licensing

- sum of consumptive allocation (cubic metres)
- count of water restrictions / reservations
- count of active or pending water licenses
- upstream water management influence (regulated dams)

Improve fish passage

- linear extent of opened and useable habitat by species
  (with removal of barriers)
- count of obstructions (provincial barrier layer)
- count of historic obstruction removal
  (fisheries project registry)

23

Results

24

Next steps?

25

Acknowledgements

Project funding

- Fraser Salmon and Watersheds Program (FY08-09 & FY09-10)
- B.C. Ministry of Environment (FY08-09)
- Pacific Fisheries Resource Conservation Council (FY08-09)
- Various in-kind contributions of time

Technical support and guidance

- Pacific Climate Impacts Consortium
- Fisheries and Oceans Canada
- B.C. Ministry of Environment
- Climate Impacts Group, University of Washington
- University of British Columbia
- Nature Conservancy Canada
- Pacific Fisheries Resource Conservation Council

26

"In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed."

"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change."

-- Charles Darwin --

27