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Backgrounder:

WATERSHEDS OF CHANGE IN NORTHERN RIVERS

Prepared by

Jonathan Moore. Michael Price, and Emma Griggs

This document briefly overviews some of the emerging science of watershed change. This is not comprehensive, but rather aims to help set the stage for a conversation about the science and stewardship of rapidly-changing northern watersheds.

THE CHALLENGE

There is an urgent need to understand watershed change in northern river systems and consider forward-looking stewardship opportunities that foster climate resilience for salmon and people. Human-caused climate change is transforming watersheds of northern British Columbia and their capacity to support important species like salmon. In the coming decades, the degree to which humanity reduces greenhouse gas emissions will determine the magnitude and rate of climate change. Salmon watersheds are also facing pressures from industries such as forestry and mining. Local land-uses and their management could either exacerbate climate impacts or facilitate resilience.[1]

HOW ARE NORTHERN WATERSHEDS CHANGING FOR SALMON?

CLIMATE CHANGE WILL PRESENT CHALLENGES AND OPPORTUNITIES FOR SALMON

Climate warming may harm salmon in some areas, such as if waters get too low or too hot. It is also likely that in some local regions, the forthcoming decades of climate change may increase the suitability or productivity of freshwater habitats for salmon.

WARMING AIR AND WATER TEMPERATURES

One of the important ways that climate change is impacting northern rivers and lakes is via the rise in air and water temperatures. Most climate change scenarios predict warming of global air temperatures by ~2 to >4˚C by 2100.[2]

WARMER AIR TEMPERATURES RESULT IN WARMER WATER TEMPERATURES

Water temperature is critically important for sensitive fish such as salmon. Water temperatures that are too high (e.g., >20˚C) can stress and even kill adult and juvenile salmon. Water temperatures that are exceedingly cold (e.g., <4˚C) can halt the growth of juvenile salmon. The seasonal patterns of water temperatures also influence the timing of salmon runs, spawning, fry emergence, and emigration of juveniles to the ocean. Thus, salmon are strongly influenced by water temperatures and its warming.

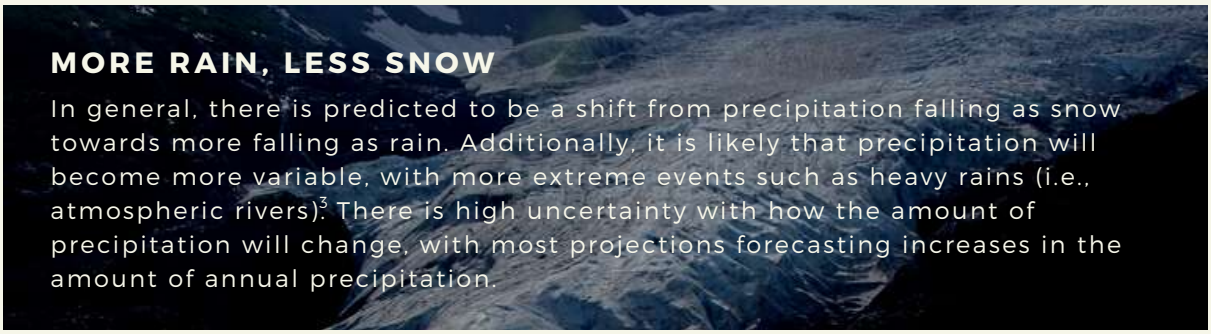
WARMING TEMPERATURES WILL HAVE VARIABLE IMPACTS ON THE FRESHWATER PRODUCTIVITY OF NORTHERN RIVER SYSTEMS FOR SALMON

The influence of climate warming on freshwater habitats will be unique at each location. In the Taku watershed for example, some rivers host summer water temperatures that already are potentially stressful for salmon (>19˚C), while other rivers influenced by glaciers may currently be too cold for most salmon to thrive (that is, until waters warm more). Thus, rising water temperatures

resulting from climate change could increase stress and harm in some already-warm rivers, or actually increase the suitability and productivity of rivers that currently are too cold for salmon.

WATER TEMPERATURES MAY NOT RESPOND EVENLY TO WARMING AIR TEMPERATURES

The coldest rivers may be the ones that warm most rapidly in the coming decades as they lose their glaciers and ice. There is also large variation in the "climate sensitivity" of freshwaters, the degree to which water temperatures respond daily to air temperatures. For example, even during hot days, rivers that are fed primarily by groundwater or glaciers may stay cold. Alternatively, rivers that drain shallow lakes may be particularly sensitive to warm air temperatures. These factors are an added challenge to our ability to predict change.

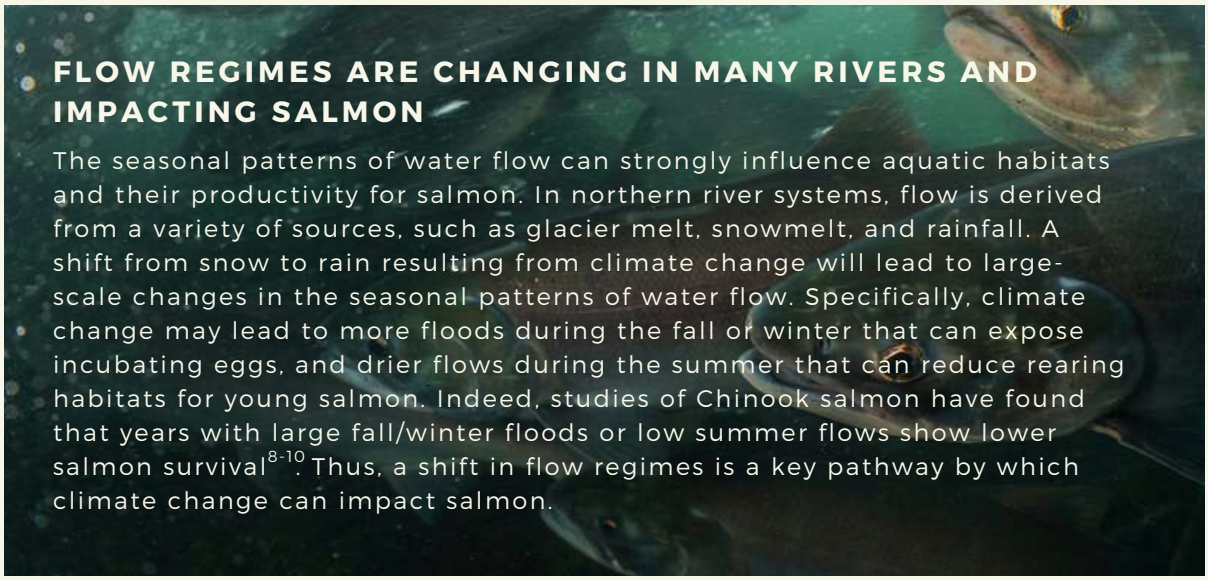


MORE RAIN, LESS SNOW

In general, there is predicted to be a shift from precipitation falling as snow towards more falling as rain. Additionally, it is likely that precipitation will become more variable, with more extreme events such as heavy rains (i.e., atmospheric rivers)[3]. There is high uncertainty with how the amount of precipitation will change, with most projections forecasting increases in the amount of annual precipitation.

DECREASES IN SNOW AND ICE

As air temperatures warm and precipitation begins to fall more as rain instead of snow, there will be decreases in the volume, areal coverage, and seasonal duration of snow and ice[5]. Rising temperatures also will accelerate the retreat of mountain glaciers. For example, depending on how much humanity reduces greenhouse gas emissions, western Canada is predicted to lose 60-100% of its glaciers by 2100[6,7].



FLOW REGIMES ARE CHANGING IN MANY RIVERS AND IMPACTING SALMON

The seasonal patterns of water flow can strongly influence aquatic habitats and their productivity for salmon. In northern river systems, flow is derived from a variety of sources, such as glacier melt, snowmelt, and rainfall. A shift from snow to rain resulting from climate change will lead to large-scale changes in the seasonal patterns of water flow. Specifically, climate change may lead to more floods during the fall or winter that can expose incubating eggs, and drier flows during the summer that can reduce rearing habitats for young salmon. Indeed, studies of Chinook salmon have found that years with large fall/winter floods or low summer flows show lower salmon survival[8-10]. Thus, a shift in flow regimes is a key pathway by which climate change can impact salmon.

GLACIER RETREAT WILL CREATE NEW HABITAT IN SOME LOCATIONS

In some locations with low-lying glaciers, glacier retreat will open new salmon habitat. Salmon can rapidly colonize newly formed rivers, and thus these glaciated regions offer potential as important future salmon habitats[11,12]. For example, anticipated glacier retreat across western North America due to climate change is predicted to create 6,146-9,296 km of new salmon rivers by 2100, with some predicted new habitats in the Taku, Stikine, and Nass[13]. If these emerging habitats are not degraded by human activities, they can provide local opportunities for salmon even as climate warming and other stressors threaten neighbouring regions.

AS SNOW AND ICE RETREATS, THERE WILL BE FAR-REACHING DOWNSTREAM IMPACTS

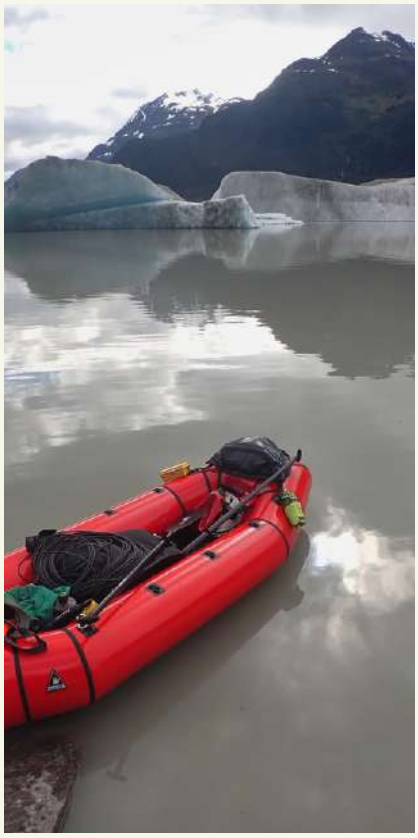
Glaciers and summer snowpack act as ice cubes on mountains, providing cool water during the hottest summer months. For example, in the Babine system of the Skeena, tributary streams with ~10% glacier coverage had summer water temperatures that were 5˚C cooler than non-glaciated catchments, and these tributary inputs measurably cooled the larger downstream Babine River[14].

THE LOSS OF GLACIERS OR SUMMER SNOWPACK, ESPECIALLY IN SMALLER CATCHMENTS, WILL MAKE DOWNSTREAM RIVERS LESS RESILIENT TO DROUGHTS AND HEAT WAVES

Watersheds with glaciers tend to provide more adequate flow and cooler water for salmon during times of intense heat and drought. For example, the drought and heat wave of 2019 lead to low oxygen and water flows, and high water temperatures, resulting in the premature death of thousands of spawning pink salmon in small coastal streams of Alaska[15]. However, watersheds with glaciers were unlikely to suffer these fish-kills as the meltwater from glaciers buffered such impacts.

AS GLACIERS RETREAT, DOWNSTREAM RIVERS WILL CHANGE IN THEIR PRODUCTIVITY FOR SALMON

It is often incorrectly assumed that rivers downstream of glaciers are too cold and turbid to support fish. In reality, while these habitats tend to have low productivity, the complexity of these rivers and their off-channel habitats can still support salmonids. Further climate warming in heavily glaciated river systems will likely lead to channel stabilization and increases in water clarity and temperature, which will, at least for the near future, increase their suitability and productivity for salmon[16].



MELTING GLACIERS AND CLIMATE CHANGE WILL ALTER THE TOTAL AMOUNT OF WATER FLOWING IN NORTHERN RIVERS

As glaciers melt, the total annual flow at first increases, and then decreases as the size of glaciers decline. Glacier melt in northern BC rivers like the Taku, Stikine, Nass, and Skeena now are past "peak water", and the amount of annual discharge from glacier melt will continue to decrease over time[17].

NATURAL HAZARDS WILL INCREASE

Climate change will also increase the probability of natural hazards such as major landslides[2]. Different components of climate change—alpine permafrost melt, glacier retreat, extreme storm events—can trigger landslides or other natural hazards. In most cases, such landslides won't pose a large problem for salmon, but they may introduce new barriers if they occur in constrained sections of the river. Forest fire frequency and intensity will also be influenced by climate change, with corresponding impacts on adjacent freshwater ecosystems.

OCEAN CHANGE IS UNDERWAY

There is much uncertainty in terms of how climate change will alter the ocean for salmon. Some species, like sockeye, appear quite sensitive to changes in ocean temperatures and associated food web. Competition on the high seas with hyper-abundant pink salmon, including those from production hatcheries, can further reduce ocean survival and growth, particularly in years with warmer ocean temperatures[18].

SALMON RESILIENCE AND VULNERABILITY

ENORMOUS VARIATION IN SALMON SYSTEMS

Salmon use diverse habitats, ranging from cold and turbid glacial rivers, to clear and flashy coastal rainforest streams, to high elevation lakes surrounded by spruce forests. Such disparate systems will respond quite differently to climate change, and these local differences represent different options for salmon in the unknown future. Thus, protecting diverse habitats will provide salmon with options, even if the precise impacts of climate change are not known. Salmon have persisted over millennia, through major climate shifts, and have repeatedly demonstrated their resilience when options exist.

SALMON ARE LOCALLY-ADAPTED TO THE TEMPERATURE AND FLOW REGIMES OF THEIR HOME RIVERS

Salmon populations have adapted to their local temperature regimes. Populations from warm rivers have genes, physiologies, and life-histories that help them cope with warm temperatures compared to salmon from cold rivers.[19] As their local rivers change, salmon populations will be challenged to keep pace with this change[20]. The timing of key life-history events, such as juvenile or adult migration, have already begun to shift in various places. The ability of salmon to adapt is a key component of their resilience. Ultimately, salmon need time and available options to successfully adapt and evolve.

CLIMATE CHANGE AND ITS INFLUENCE WILL BE UNPREDICTABLE AND VARIABLE

Climate change will not be a predictable and steady process, but rather one where there are unforeseen events that impact systems and result in locally-variable responses. Specific watershed attributes will modulate climate impacts. Smaller catchments will undergo greater local impacts than larger catchments that integrate across more climatic diversity[21]. Certain life-histories or populations of salmon will be more or less vulnerable to climate impacts. While our understanding of these specific factors is increasing, there will always be a major element of unpredictability when we look to the future.

INDUSTRY PRESSURES

THE EFFECTIVE GOVERNANCE OF WATERSHED ACTIVITIES WILL INFLUENCE THE RESILIENCE OF SALMON SYSTEMS TO CLIMATE CHANGE[1]

There are important industries in northern watersheds that can help support local economies, such as mining or forestry. However, mining has the potential to harm salmon and their habitats in multiple ways, such as via contamination and habitat degradation[22]. In addition, forestry can increase stream flashiness, decrease low summer flows, and increase summer water temperatures. For example, a study of 28 mid-sized streams in the Fraser watershed reported that maximum summer water temperatures were over 3.5˚C higher when adjacent forests were heavily logged (i.e., 35% of riparian area trees removed) versus if they had low forest removal (<5%)[23]. These forestry impacts are similar to those associated with climate, and can thus reduce the resilience of these habitats and fish populations to future changes in climate. This highlights the reality that local land-uses and their management could either exacerbate, or facilitate resilience to, climate impacts.

LITERATURE CITED

1. Moore, J. W. & Schindler, D. E. Getting ahead of climate change for ecological adaptation and resilience. *Science* **376**, 1421–1426 (2022).
2. IPCC (Intergovernmental Panel on Climate Change). *Climate change 2022: impacts, adaptation, and vulnerability. IPCC Sixth Assessment Report.* (2022).
3. Sharma, A. R. & Déry, S. J. Contribution of atmospheric rivers to annual, seasonal, and extreme precipitation across British Columbia and Southeastern Alaska. *J. Geophys. Res. Atmos.* **125**, (2020).
4. Harp, R. D. & Horton, D. E. Observed changes in daily precipitation intensity in the United States. *Geophysical Research Letters* **49**, (2022).
5. Huss, M. *et al*. Toward mountains without permanent snow and ice. *Earth's Future* **5**, 418–435 (2017).
6. Clarke, G. K. C., Jarosch, A. H., Anslow, F. S., Radić, V. & Menounos, B. Projected deglaciation of western Canada in the twenty-first century. *Nature Geosci* **8**, 372–377 (2015).
7. Rounce, D. R. *et al*. Global glacier change in the 21st century: Every increase in temperature matters. *Science* **379**, 78–83 (2023).
8. Warkentin, L., Parken, C. K., Bailey, R. & Moore, J. W. Low summer river flows associated with low productivity of Chinook salmon in a watershed with shifting hydrology. *Ecol Sol and Evidence* **3**, (2022).
9. Ward, E. J., Anderson, J. H., Beechie, T. J., Pess, G. R. & Ford, M. J. Increasing hydrologic variability threatens depleted anadromous fish populations. *Glob Change Biol* **21**, 2500–2509 (2015).
10. Jones, L. A. *et al*. Watershed-scale climate influences productivity of Chinook salmon populations across southcentral Alaska. *Global Change Biology* **26**, 4919–4936 (2020).
11. Pitman, K. J. *et al*. Glacier retreat and Pacific salmon. *BioScience* **70**, 220–236 (2020).
12. Milner, A. M. *et al*. Evolution of a stream ecosystem in recently deglaciated terrain. *Ecology* **92**, 1924–1935 (2011).
13. Pitman, K. J. *et al*. Glacier retreat creating new Pacific salmon habitat in western North America. *Nat Commun* **12**, 6816 (2021).
14. Pitman, K. J. & Moore, J. W. The role of large, glaciated tributaries in cooling an important Pacific salmon migration corridor: a study of the Babine River. *Environ Biol Fish* **104**, 1263–1277 (2021).
15. von Biela, V. R. *et al*. Premature mortality observations among Alaska's Pacific Salmon during record heat and drought in 2019. *Fisheries* **47**, 157–168 (2022).
16. Pitman, K. J. *et al*. Glacier Retreat and Pacific Salmon. *BioScience* **70**, 220–236 (2020).

LITERATURE CITED (CONTINUED)

17. Huss, M. & Hock, R. Global-scale hydrological response to future glacier mass loss. *Nature Clim Change* **8**, 135–140 (2018).
18. Connors, B. M. *et al*. Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. *Can. J. Fish. Aquat. Sci.* **77**, 943–949 (2020).
19. Eliason, E. J. *et al*. Differences in thermal tolerance among sockeye salmon populations. *Science* **332**, 109–112 (2011).
20. Reed, T. E. *et al*. Time to evolve? Potential evolutionary responses of Fraser River sockeye salmon to climate change and effects on persistence. *PLoS ONE* **6**, e20380 (2011).
21. Chezik, K. A., Anderson, Sean C. & Moore, J. W. River networks dampen long-term hydrological signals of climate change. *Geophysical Research Letters* **44**, 7256–7264.
22. Sergeant, C. J. *et al*. Risks of mining to salmonid-bearing watersheds. *Sci. Adv.* **8**, eabn0929 (2022).
23. Cunningham, D., Braun, D. C., Moore, J. W. & Martens, A. M. Forestry influences on juvenile coho salmon rearing habitat in the North Thompson River watershed, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* in press.