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Canadian Science Advisory Secretariat
Pacific Region | Science Advisory Report 2024/041

# GEOSPATIAL INDICATORS AND METRICS FOR THREATS TO FISH HABITAT IN THE FRASER RIVER BASIN WITH THOMPSON-NICOLA AS A CASE STUDY

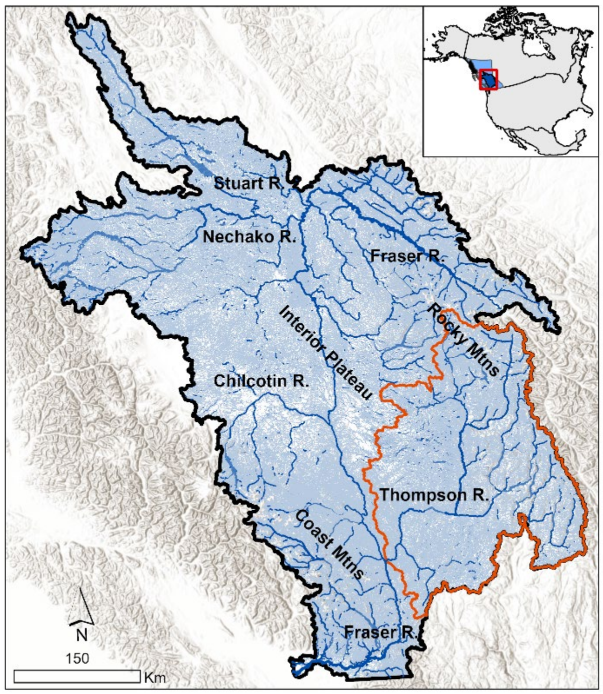


*Figure 1. Major rivers (blue lines) and full stream network (light blue lines) of the Fraser River Basin in British Columbia. The Thompson-Nicola Ecological Drainage Unit is outlined (orange).*

## Context:

*Human activities, landscape disturbances, and climate change are presenting numerous and cumulative threats to fish and fish habitat across freshwater British Columbia (BC). Modern tools and approaches for tracking and assessing these threats are needed to support responsive and integrated regulatory, planning, partnership, and monitoring activities to help safeguard fish and fish habitat.*

*The Fish and Fish Habitat Protection Program (FFHPP) has requested that Science Branch develop a geospatial approach for use in reporting on the state of fish habitat and to evaluate which elements can be assessed temporally. Outcomes of this assessment will be used to report on the status of threats to the state of fish habitat. FFHPP also requested a spatial analysis of intersecting climate change impacts to stream flow and temperature and human activity based threats on Pacific Salmon ecosystems in the Thompson-Nicola Ecological Drainage Unit (EDU).*

*This Science Advisory Report is from the February 27–29, 2024 regional peer review on Geospatial Indicators and Metrics for Threats to Fish Habitat in the Fraser River Basin with Thompson-Nicola as a Case Study. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.*

# SUMMARY


- The work presents an approach for compiling and quantifying a large amount of spatial information to estimate threats to fish and fish habitat in the Fraser River Basin (FRB), including nine anthropogenic threats, four climate-change related threats, and cumulative threat scores, using readily available data.
- For this document, threats are defined as the exposure of fish and fish habitat to anthropogenic activities and climate change. Additional information on the sensitivity of focal fish and fish habitats to the identified threats (such as stressor-response relationships) was beyond the scope of this analysis but would be needed to develop cumulative effects mapping.
- The approaches to estimating each of the indicators provide an initial broad-scale standardized framework that can be applied to characterize threats throughout the Pacific Region. Further, the approach presented incorporates many of the desirable features of geospatial mapping tools for fish and fish habitat identified in DFO (2022).
- Generally, Species At Risk (SAR) habitat with limited ranges (i.e., Coastrange Sculpin, Green Sturgeon, Nooksack Dace, and Salish Sucker) had higher median human activity cumulative threat scores relative to all streams in the FRB. Conversely, median human activity threat scores tended to be similar among Salmon Conservation Units (CUs) and relative to all streams, which is driven in part by the large extent of CUs that inherently capture a greater range of threat scores across streams.
- Re-assessing threats temporally was considered largely feasible based on updates to the included data, and by using the current threat assessment as a baseline.
- Example applications of the threat scores and associated inputs for informing management and prioritization decisions for Salmon habitat in the Thompson-Nicola Ecological Drainage Unit (EDU), particularly in the context of climate change were conducted:
    - The Deadman and Adams River watershed groups were identified as having high cumulative composite scores under current and future climate conditions across Salmon species in the EDU.
    - The riparian input composite score identified high scores including along the North Thompson River, Eagle River, and Shuswap River based on nonpoint source inputs, riparian disturbance, and modeled environmental favourability (probability of occurrence) for Salmon spawning.
    - The water resource composite score found the South Thompson River watershed had high scores across Salmon species based on co-occurrence of high water withdrawal allowances and low stream flows.
    - The anadromous fragmentation score identified high variation in this metric across the EDU, based on modeled environmental favourability above dams that are full barriers.
- Considerations for application:
    - The analytical approach would be strengthened by sensitivity analyses and validation with independent data. Currently, confidence in the relative characterization of threat scores (including cumulative threat scores) is uncertain. Recommendations for future analyses include developing and applying metrics for levels of confidence in threat scores, which could be based on expert review or formal criteria.

- A variety of improvements and alternatives to individual and cumulative threat scores are provided for consideration. It is recommended that uncertainty in outputs be considered prior to applying the approach to inform fish and fish habitat management decisions.
- This broad-scale tool can provide insight into within-watershed planning and prioritization. Local-scale application may be further informed by local expertise, Indigenous knowledge, salmon population data, and finer-scale tools.

# BACKGROUND

Where and how fish and fish habitat are impacted by human activities and climate change is critical information needed to focus resources on the most effective management actions to help preserve populations. However, the scale of landscape disturbance and climate change effects is intractable for addressing these questions with sole reliance on traditional field-based assessments. Advancements in spatial analysis programming, satellite data, and publicly accessible databases have enabled estimations of threats to fish and fish habitat across large spatial scales using geospatial tools. The development and improvement of methods for estimating individual and cumulative threats to freshwater ecosystems provides valuable information on where resources are most needed to better manage and conserve fish and fish habitat.

The Fish and Fish Habitat Protection Program (FFHPP) has requested that Science Branch develop a geospatial approach to report on the state of fish habitat and evaluate which elements can be assessed temporally. Outcomes of this assessment will be used to report on the status of threats to the state of fish habitat, including but not limited to those listed in the Fish and Fish Habitat Protection Policy Statement (DFO 2019). This stage of evaluation is an assessment of threats to fish and fish habitat, where threats are defined as the exposure of fish and fish habitat to anthropogenic activities and climate change. Future assessments will link exposure estimates to expected fish responses for evaluation of individual and cumulative effects. FFHPP also requested a spatial analysis of threats to Pacific Salmon ecosystems in the Thompson-Nicola Ecological Drainage Unit (EDU). The Thompson-Shuswap and Nicola River watersheds have been identified as pilot areas for collaborative planning processes intended to identify and prioritize actions that benefit Salmon ecosystems within these watersheds, while considering impacts from climate change and human uses. The results of the Thompson-Nicola spatial analysis will be used to inform these processes.

# ASSESSMENT

## Fraser River Basin

The base ecosystem component for this assessment was all stream reaches (mean length = 422 m, range = 0.1–9,208 m) delineated by the 1:20,000 scale BC Freshwater Atlas (FWA; GeoBC 2011) within the FRB. Results were further focused on fish habitat extents for the 8 species listed under the *Species at Risk Act* (SARA) within the FRB (Bull Trout, *Salvelinus confluentus*; Coastrange Sculpin, *Cottus aleuticus*; Green Sturgeon, *Acipenser medirostris*; Mountain Sucker, *Catostomus platyrhynchus*; Nooksack Dace, *Rhinichthys cataractae* ssp.; Salish Sucker, *Catostomus* sp. cf. *catastomus*; Westslope Cutthroat Trout, *O. clarkii lewisi*; White Sturgeon, *Acipenser transmontanus*) and CUs of the five Pacific Salmon (Chinook, *Oncorhynchus tshawytscha*; Chum, *O. keta*; Coho, *O. kisutch*; Pink, *O. gorbuscha*; Sockeye, *O. nerka*) distinguished by at risk status (i.e., ‘at risk’ identified as Special Concern, Threatened, or Endangered as reported by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) up to February, 2024).

The threats included for estimation were compiled from:

1. the FFHPP policy document (DFO 2019) and associated guide[1];
2. the original tool development in the Fraser Valley, BC (Boyd et al. 2022); and
3. a review of COSEWIC assessment and status reports for fish Species at Risk and at-risk Salmon CUs.

The nine evaluated human activity and disturbance-based threats were aquatic invasive species (AIS), flow alteration, in-stream habitat destruction, latitudinal fragmentation, longitudinal fragmentation (separately for anadromous and resident species), riparian disturbance, nutrients, pollution, and sedimentation (Fig. 1). Climate change related threats were treated separately in the cumulative threat scoring and included projected changes in flood risk, low stream flow, high stream flow, and high stream temperatures.

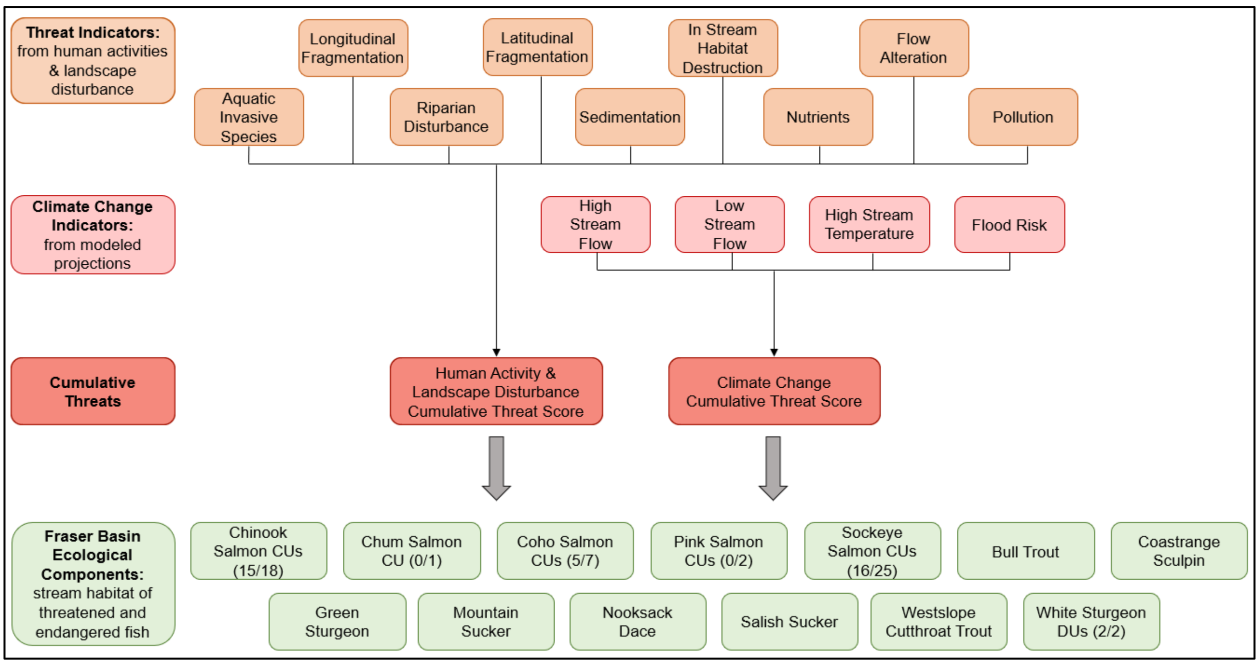


*Figure 2. Assessment framework for cumulative threats to fish and fish habitat in the Fraser River Basin, BC. Parentheses for focal species indicate the number of Designatable Units (DUs) identified for Species at Risk or Salmon Conservation Units (CUs) that are Special Concern, Threatened, or Endangered out of the total within the basin.*

Human activity and landscape disturbance-based threats were calculated from a series of spatial data selected based on:

1. other existing geospatial tools for BC (DFO 2022);
2. a literature search on human contributions to the threats (Boyd et al. 2022); and
3. data availability.

Pathways of effects diagrams were provided for each of these threats. Climate change-based threats were from modeled projections that represented climate averages (20-40 year averaged

[1] DFO. 2019. (Interim) risk management guide for the protection of fish and fish habitat. Fisheries and Oceans Canada – Fish and Fish Habitat Protection Program. Internal document.

periods), and results were presented for up to 2060 as a relevant timeframe for management. Requirements for data and model inclusion to estimate threats were:

1. spatial coverage for the entire FRB;
2. standardized information across the FRB;
3. resolution applicable to stream reaches; and
4. publicly accessible.

Extensive spatial coverage and standardized information were particularly important so that threat scores were not unevenly weighted across the FRB based on available information.

## Thompson-Nicola EDU

For the Thompson-Nicola EDU case study, examples were developed of how the individual and cumulative threat scores can be applied to help inform restoration priority setting and management actions for Salmon habitat. The overlap of focal threats were identified with two ways to distinguish areas important to Salmon to indicate where higher threats may be more detrimental. Specifically, scores were summarized by CUs or modeled probabilities of environmentally favourable Salmon spawning habitat were applied to identify where high or low threat scores coincided with high or low spawning favourability (Fig. 2). The modeled favourability predictions were from large scale Environmental Niche Models that focus on predicting shifts in habitat favourability from current to future climate conditions (Iacarella et al. 2023). Future iterations of geospatial analyses can apply other areas important to Salmon such as modeled juvenile rearing habitat suitability or known locations of rearing and spawning. The following composite scores were demonstrated for the EDU:

1. Cumulative threat composite score: This score identified where there was estimated co-occurrence of high human activity based cumulative threats and environmental spawning favourability under current and future climate conditions.
2. Riparian input composite score: This score identifies where riparian restoration may be most needed based on high estimated nonpoint source inputs (nutrients, pollution, sedimentation), low riparian filtering capacity, and high environmental spawning favourability. Point sources were not included in this score as it was assumed riparian filtering would not deter point source inputs.
3. Water resource composite score: This score identifies potentially detrimental water withdrawal based on licensed water withdrawal allowances from streams with projected low stream flows under historic and future conditions within Salmon CUs.
4. Anadromous fragmentation composite score: This score indicates which full dam barriers are potentially blocking the greatest extent of favourable spawning habitat under current and future conditions. It focuses on the portion of stream network from an initial dam to the next barrier upstream (dam or natural).

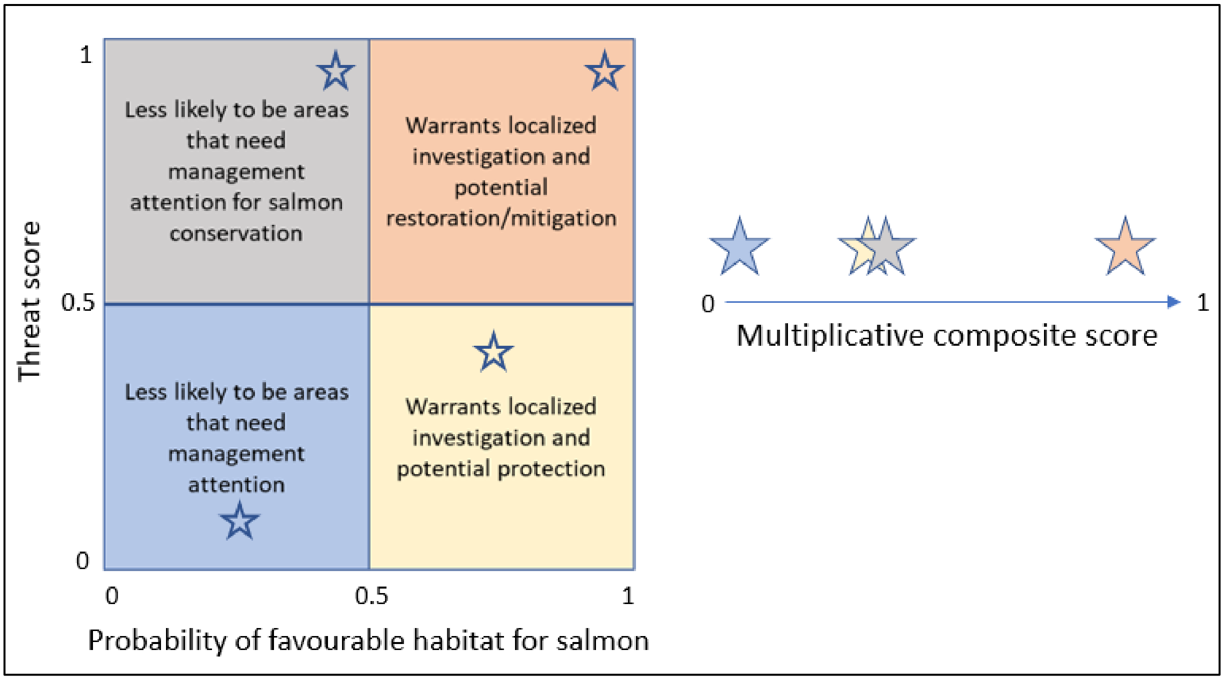


*Figure 3. Rubric of potential management implications indicated by multiplicatively combining threat scores with Salmon habitat values such as modeled probability of favourable habitat. Star symbols along the multiplicative composite score gradient approximate their relative distribution from 0-1 based on the colour-coded rubric and example locations within.*

## Results

The additive cumulative threat scores based on human activities and climate change showed high estimated threat levels across the lower Fraser River and interior plateau (Fig. 3). Watershed groups with the highest median cumulative threats were Nicola River, Guichon Creek, and San Jose River, from 1st to 3rd across watersheds (Fig. 4a). Within watershed groups across the FRB, the most prevalent activities or disturbances that contributed to threats based on identified occurrence as relevant for each individual threat score were roads, followed by dams and forest pest defoliation, and next by forest fires (Fig. 4b). The occurrence of an activity or disturbance as identified for each threat was based on its presence within a focal area for a stream reach for localized threats (e.g., flow alteration, riparian disturbance, in-stream habitat destruction), its presence upstream of a focal stream for flow accumulated threats (e.g., sedimentation, nutrients, pollution), or its presence downstream of a focal stream for longitudinal fragmentation for anadromous species.

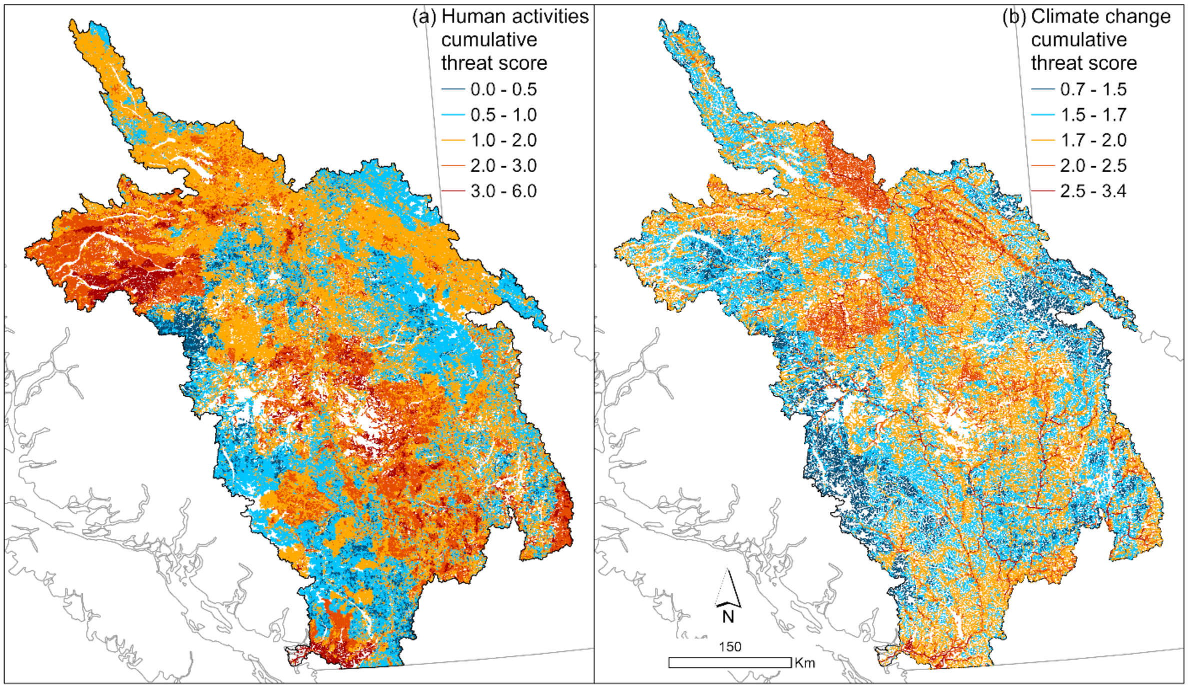


*Figure 4. Additive cumulative threat scores based on (a) human activity and landscape disturbance threats (AIS, longitudinal and latitudinal fragmentation, in-stream habitat destruction, flow alteration, riparian disturbance, and sediment, nutrient, and pollution loading from human-derived sources) and (b) climate change threats (flood risk, high and low stream flow, and high stream temperature up to 2060) to fish and fish habitat in the FRB.*

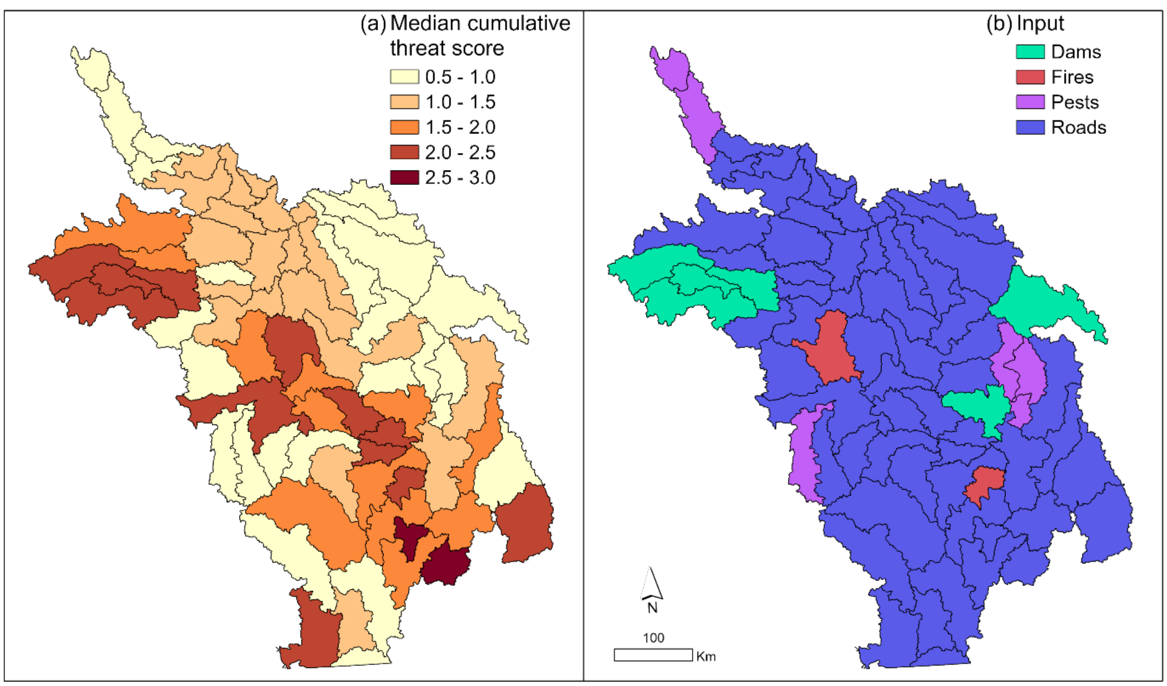


*Figure 5. Summary results for watersheds groups indicating (a) the median cumulative threat score for human activity and landscape disturbance based threats and (b) the most prevalent activity or disturbance contributing to threats across streams based on its occurrence upstream, downstream, or within a focal area of a stream reach as relevant for each individual threat score.*

Median cumulative threat scores for human activity and climate change based threats were generally similar across Salmon CUs grouped by at risk status (i.e., at risk versus not at risk) and in relation to all streams in the FRB. However, some individual CUs were associated with higher threat scores, particularly the Endangered Sockeye Cultus – Late Timing CU (SEL-03-02) and Momich Lakes – Early Summer Timing population (SEL-09-xx) for human activity cumulative threats (Fig. 5). Median scores for SAR extents were notably higher relative to all streams and other SAR for Coastrange Sculpin, Green Sturgeon, Nooksack Dace, and Salish Sucker for human activity cumulative threats, and Mountain Sucker, Green Sturgeon, and White Sturgeon for climate change cumulative threats (Fig. 6).

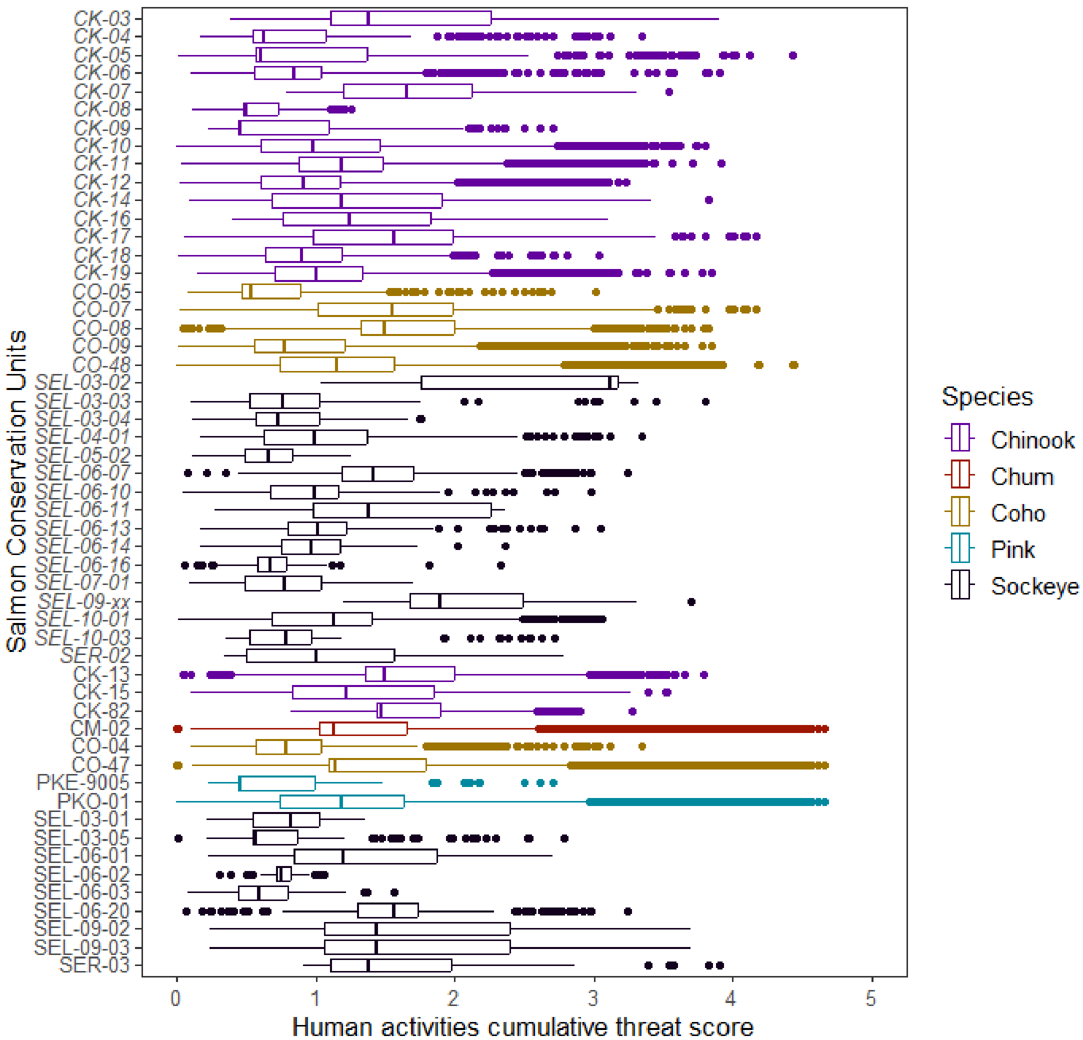


*Figure 6. Tukey's box-whiskers plots of the human activities cumulative threat score for each Salmon Conservation Unit (CU) in the Fraser River Basin (only including streams below natural barriers for Salmon). Those identified as Special Concern, Threatened, or Endangered ('at risk') by COSEWIC are in italics. CUs included Chinook (CK), Coho (CO), Pink – Even (PKE), Pink – Odd (PKO), Sockeye – Lake (SEL), and Sockeye – River (SER).*

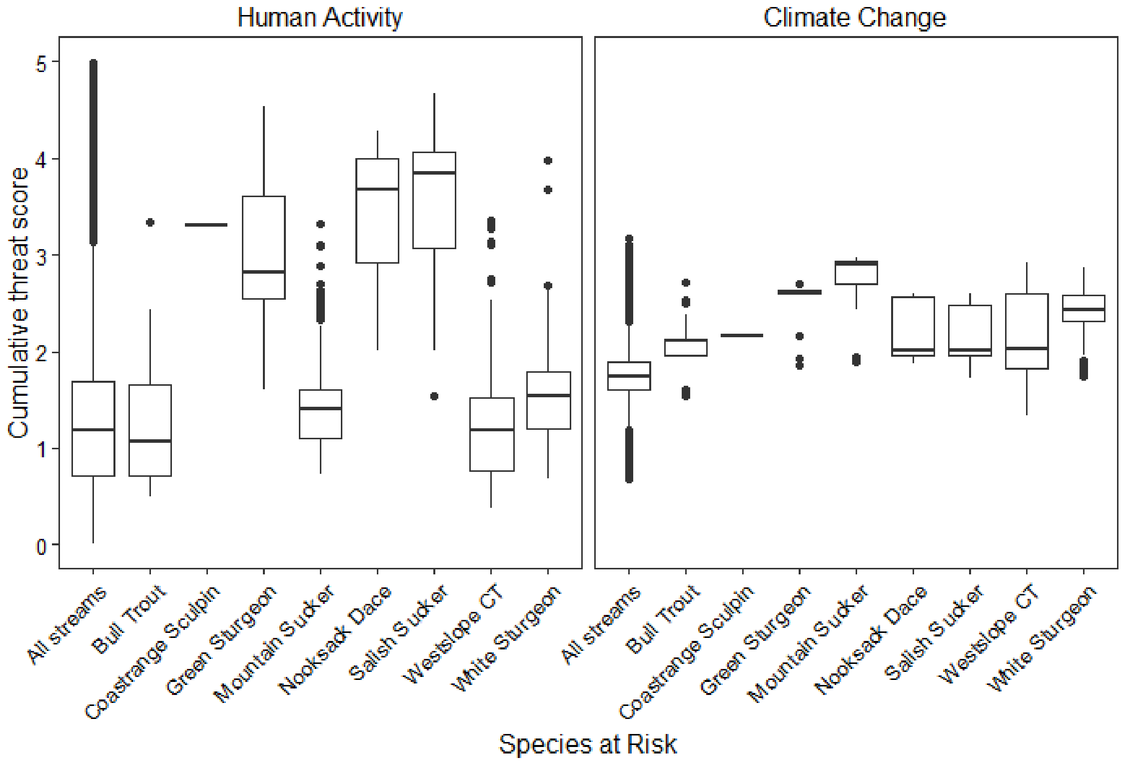


*Figure 7. Tukey's box-whiskers plots of the cumulative threat scores from human activity and landscape disturbance-based threats (left panel) and climate change based threats (right panel) for all streams in the FRB and delineated stream habitats of fish Species at Risk.*

Two of the four composite scores for the Thompson-Nicola EDU are highlighted here: the cumulative threat and riparian input composite scores. Median cumulative threat composite scores within watershed groups indicated overall higher scores for Sockeye based on modeled environmental favourability for spawning (Fig. 7). Higher probability of environmental favourability for spawning may or may not overlap current CU extents as these models match environmental conditions of stream reaches with conditions of where spawning has been observed, but do not include other limiting factors that may determine distributional constraints. In addition, model projections included currently inaccessible streams to help inform potential barrier remediation. Watershed groups with the highest median scores generally remained the highest between current and future conditions. Of the watersheds that are currently accessible, Adams River and Deadman River watershed groups had consistently high composite scores under both current and future conditions across Salmon species (including all streams) (Fig. 7).

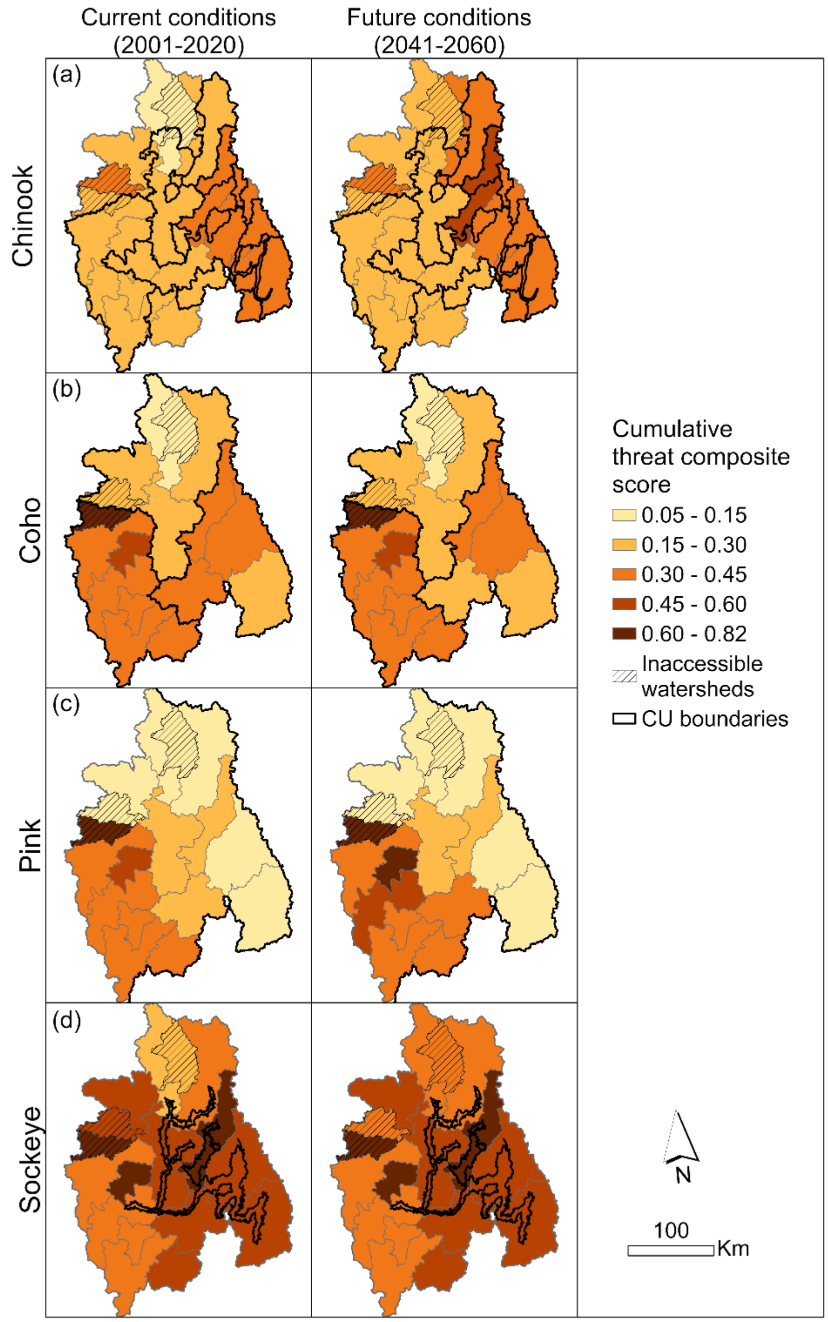


*Figure 8. Median cumulative threat composite scores for watershed groups in the Thompson-Nicola EDU based on the multiplicative value of human activity and landscape disturbance based cumulative threats and modeled environmental favourability for spawning (row a) Chinook, (b) Coho, (c) Pink, and (d) Sockeye Salmon. Modeled environmental favourability probabilities used in the composite score were based on projected (column a) current and (b) future conditions for all stream reaches (≥ 4th order) including inaccessible streams from dams and natural barriers. Watershed groups that are largely inaccessible are identified by hatched lines, and Salmon CU boundaries in black outlines.*

The riparian input composite score indicated where high estimated inputs of nonpoint sources based on land use and riparian disturbance corresponded with high predicted environmental spawning favourability for Salmon (Fig. 8). Nonpoint source inputs were estimated to be highest along the eastern edge of the Thompson-Nicola EDU (Fig. 8a). Riparian input composite scores were highest along the North Thompson River, Eagle River, and Shuswap River, particularly for Chinook, Coho, and Sockeye (Fig. 8b-e).

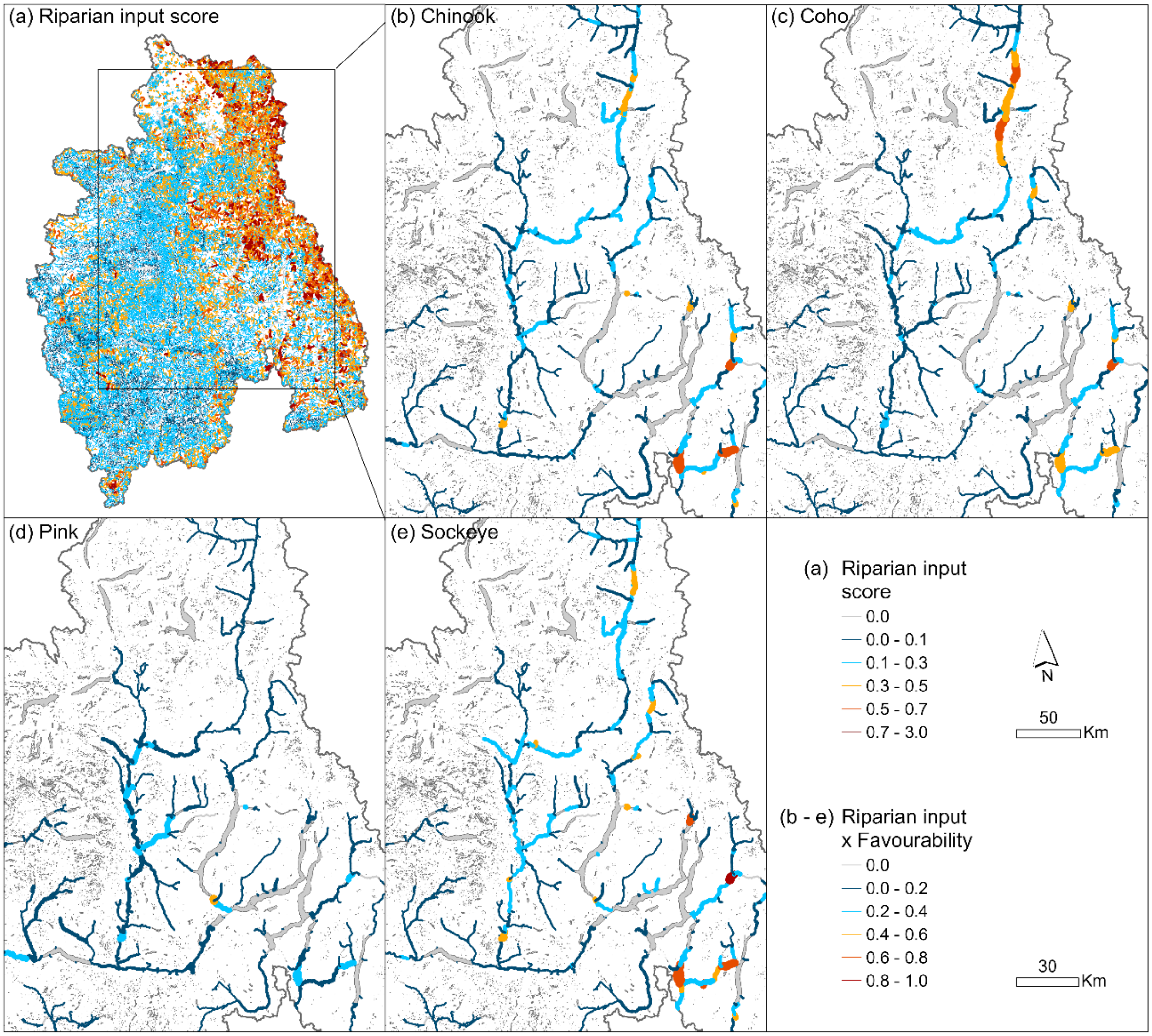


*Figure 9. Riparian input composite score (a) based on nonpoint source inputs and riparian disturbance scores. The riparian input score multiplied by modeled environmental favourability for Salmon spawning (baseline conditions 1981–2020) indicated accessible stream reaches where high riparian input values coincided with high environmental favourability for (b) Chinook, (c) Coho, (d) Pink, and (e) Sockeye Salmon. Stream lines are scaled to highlight those with higher scores.*

## Sources of Uncertainty

There are some common uncertainties associated with generating geospatial cumulative effect assessments. A few uncertainties associated with general approaches to assessing threats to a focal ecosystem component include whether the input layers should be treated as of equal importance; where focal assessment units are located within a grid cell of raster-based data (e.g., land use types); and how scores are transformed and normalized (Halpern and Fujita 2013). Data sources may also contain errors, for instance there are associated error rates in land use classification from satellite imagery depending on the applied algorithm. Another uncertainty associated with these geospatial analyses is that the derived scores are often based on proxies rather than direct measures (DFO 2022). This work sought to create more direct correspondence between the proxies and fish habitat to reduce some of this uncertainty, for instance by using input values for nutrients, pollution, and sedimentation collected by Environment and Climate Change Canada (ECCC 2022) and other known sources, rather than directly associating terrestrial human activity footprints with fish habitat. ECCC's pollutant data from Pollutants Affecting Whales and their Prey Inventory Tool (PAWPIT) are estimates based on available monitoring data and include extrapolations to fill gaps, and therefore also have uncertainties and are subject to change as more data become available. This work also incorporated some of the mechanisms involved in how human activities and landscape disturbances contribute to threats to fish habitat, though these were based on generalized approximations that likely better distinguish higher and lower values, whereas various sources of error may create more uncertainty for mid-range values. The approach used to combine individual threats into a cumulative threat score (e.g., addition, multiplication, etc.) is another uncertainty that can be evaluated in future work by modeling population responses to individual and cumulative threats. Much of the groundwork for large scale cumulative effect mapping has been on marine ecosystems (Halpern and Fujita 2013), which are not subject to the same kind of complexities present in stream networks, such as flow and transport downstream. There are many mechanisms and context-dependencies of how human activities and landscape disturbances influence streams and fish habitat that remain unresolved at large spatial scales.

Details are provided for each threat on the sources of uncertainty, limitations, ability to extend the analysis for the Pacific Region, and a rated level of confidence by the research document authors based on the identified uncertainties and limitations (Appendix A, Table A1). These uncertainties and limitations generally pertain to a lack of information on the importance of a human activity or landscape disturbance in contributing to a threat, generalized relationships between some activities or disturbances and associated threats, and modeled climate change projections. Confidence ratings were identified as low for five threats (data exist but are considered poor or conflicting), medium for four threats (data exist but there are some key gaps), and high for four threats (data exist and are considered sound) (Appendix A, Table A1).

## Future Considerations For Individual Threats and Species

Major considerations for future analyses are listed below, and more detailed considerations for each threat are in Appendix A (Table A1).

- Steelhead (O. mykiss irideus) is an additional species of socio-economic and cultural importance to assess; although populations have been assessed by COSEWIC as Endangered, it is not listed under the SARA, and it was not included as one of the five Pacific Salmon that were evaluated.
- The flow alteration threat could treat changes to water quantity versus changes to water velocity as separate scores. Weighting water withdrawal license amounts by stream flow and associating likely seasons of withdrawal with modeled seasonal flow levels would also help fine tune this score. In addition, forest disturbances can have important effects on stream flow that were not yet captured owing to a high degree of context-dependency.
- Dams that are partial barriers and culverts (that are full or partial barriers) may be included in future iterations of longitudinal fragmentation scoring depending on desired assumptions, outputs, and uses. Additional approaches for estimating fragmentation, such as evaluating series of dams, are being conducted in BC by the Canadian Wildlife Federation.
- Riparian disturbance threat scoring currently applies a 10-year window to forestry related data, with assumed recovery of filtering capacity within this time. Return of other riparian functions, such as contribution of woody debris, can take up to 100 years after forest

disturbance. A fully comprehensive assessment for riparian disturbance would include multiple timeframes for evaluation to capture other important functions (Quinn et al. 2020).

- Different substances have different toxicity and so pollutants vary in their degree of impact to fish and the concentrations at which they start to have an impact. Future iterations can separately estimate pollutant inputs by type to enable evaluation of pollutant impacts per substance through the application of toxicological assessments and environmental quality guidelines. Similarly, thresholds or stressor-response curves are needed for all threats to predict the effect of exposure on fish (see 'Next Steps' below).
- Stream flow threats would be improved with predictions of %MAD based on daily values instead of monthly, which can be achieved at the stream reach resolution upon completion of model development in BC by the Pacific Climate Impacts Consortium (Schnorbus 2020).
- The Thompson-Nicola EDU application and other future regionally specific applications would benefit from consideration of other Salmon habitat values (e.g., rearing habitat), as well as additional information from local data, modeling, and expert and Indigenous knowledge.

## Next Steps For Overarching Threat Assessment

- **Spatial expansion:** The threats that are currently most limited for extension to other basins in BC are those that require hydrological layers at a fundamental watershed resolution—nutrients, pollution, sedimentation, low stream flow, and high stream flow. The other threats rely on data that are readily available for the rest of BC, but the availability of these data for the Yukon has not been assessed here (Appendix A, Table A1). Methodological decisions will need to be re-evaluated for application to other basins with different characteristics.
- **Temporal re-analysis:** The ability to re-assess threats temporally is feasible moving forward using the threat scores provided here as a baseline. Threats can be re-assessed using updated data layers, with the caveat that new additions to datasets may also be from previously missing developments that are not new on the landscape. An exception is for point source inputs for nutrients and pollution which were taken directly from the Pollutants Affecting Whales and their Prey Inventory Tool (PAWPIT) (ECCC 2022); updated assessments would require updates to PAWPIT, or associating estimates with any changes in relevant human activities (Appendix A, Table A1).
- **Cumulative effects:** Linking the effect of threats on focal ecosystem components is a key next step for cumulative effect evaluation. Threat scores can be weighted based on expert opinion of how vulnerable the ecosystem component is to each threat (Halpern et al. 2008; Vörösmarty et al. 2010). A more fine-tuned approach would be to use stressor-response curves that delineate non-linear responses of focal ecosystem components across a range of threat levels (Rosenfeld et al. 2022; MacPherson et al. 2024).
- **Uncertainty quantification:** Further work to quantify confidence intervals for threat scores would be beneficial. Sensitivity analysis can be conducted to determine how assumptions or applied values influenced threat scores, for instance, when there is a range of reasonable expectations for an input into a threat or when there are multiple modeled inputs included in a single score. Examples of this could include weighting in Fstream habitat destruction activities differently based on expert elicitation versus treating them as equally destructive or testing a range of plausible coefficients for non-point source sediment loadings from land use. Such iterations of scoring would indicate the degree to which these decisions change the scores and is particularly pertinent if the relative comparisons across streams shift.

- **Field and biotic response validation:** Validation of threats using field verification and in situ data would be beneficial particularly for threats that involve applied relationships and estimations, such as the flow accumulated loadings (nutrients, pollution, sedimentation). Comparing individual and cumulative threat scores to focal ecosystem component responses would also be useful to explore relationships between estimated threats and biotic responses.

## CONCLUSION

The results of this cumulative threat assessment provide high resolution and large-scale estimates of spatial variation in threat levels across focal species extents and the FRB stream network to help inform management, restoration, and protection actions, as well as for reporting on the state of threats to fish and fish habitat. Example applications of this information for the Thompson-Nicola EDU indicate overlap of human activities and associated threats with important areas for Pacific Salmon for potential use in planning processes to improve Salmon habitat.

## LIST OF MEETING PARTICIPANTS

| Last Name | First Name | Affiliation |
|---|---|---|
| Appleby | Thomas | DFO Fish and Fish Habitat Program |
| Bailey | Richard | Nooaitch Band |
| Braun | Doug | DFO Science |
| Chartrand | Shawn | Simon Fraser University |
| Chu | Cindy | DFO Science |
| Davis | Ben | DFO Science |
| Dey | Cody | Environment and Climate Change Canada |
| Enders | Eva | National Institute for Scientific Research |
| Enslow | Chelsea | Province of British Columbia |
| Finney | Jessica | DFO Centre for Science Advice Pacific |
| Gravelle | Kristin | DFO Fish and Fish Habitat Program |
| Hilborn | Monica | Environment and Climate Change Canada |
| Hodgson | Emma | DFO Science |
| Iacarella | Josephine | DFO Science |
| Jumbo | Morgan | Nooaitch Band |
| Laubman | Robyn | Splatsin |
| Lemieux | Jeffrey | DFO Science |
| Little | Patrick | Province of British Columbia |
| Mazany-Wright | Nick | Canadian Wildlife Federation |
| Muirhead-Vert | Yvonne | DFO Centre for Science Advice Pacific |
| Naman | Sean | DFO Science |
| Nordin | Lisa | Province of British Columbia |
| Paterson | Keegan | DFO Science |
| Patterson | David | DFO Science |
| Porter | Marc | Pacific Salmon Foundation |

| Last Name | First Name | Affiliation |
|---|---|---|
| Semeniuk | David | DFO Fish and Fish Habitat Program |
| van Geloven | Chelton | Upper Fraser Fisheries Conservation Alliance |
| Weller | Daniel | DFO Science |

## SOURCES OF INFORMATION

This Science Advisory Report is from the February 27–29, 2024 regional peer review on Geospatial Indicators and Metrics for Threats to Fish Habitat in the Fraser River Basin with Thompson-Nicola as a Case Study. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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# APPENDIX

*Table A1.Uncertainties, limitations, ability to extend the methodology for the rest of the Pacific Region, and confidence ratings for each estimated threat. Confidence ratings include low (data exist but are considered poor or conflicting), medium (data exist but there are some key gaps), and high (data exist and are considered sound); major deciding factors for ratings are in parentheses.*

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| *Focal Ecosystem Components* | | | |
| • FWA stream reach delineations have inaccuracies<br>• Species at Risk habitat delineations may not fully encompass their habitat use | • Steelhead was not included based on initial scoping, but would be beneficial to include in future assessments as a species with populations designated by COSEWIC as Endangered | • Feasible for BC<br>• National Hydrographic Network could be used for Yukon with additional processing and preparation of fundamental watersheds | Medium (based on uncertainty in capturing full Species at Risk habitat extents) |
| *Aquatic Invasive Species* | | | |
| • Approximated polygon distributions of each species' range based on observations and 10 km search radius; the true distribution of each species is unknown<br>• Determination of Aquatic Invasive Species status versus non-native species (i.e., no recorded impact)<br>• Impact of each species on focal ecosystem components not fully known | • Only species observations from opportunistic surveys available<br>• Further delineation of each species' distribution (i.e., from species distribution models) would improve accuracy of this score<br>• Limited information on each non-native species and interactions with focal ecosystem components | • Feasible for BC<br>• Need equivalent data for Yukon | Medium (based on uncertainty in capturing full AIS distributions) |
| *Longitudinal Fragmentation* | | | |
| • Steep slopes may be a natural barrier for other species, but were only considered for Pacific Salmon<br>• Blocks to passage from culverts not known for all culverts in FRB, and was not included in the threat scoring | • Limited knowledge on slopes as barriers for resident fishes, and would require species-specific threat scores<br>• Limited assessment of culverts as barriers for the extent of the FRB | • Feasible for BC<br>• Need equivalent data for Yukon | Medium (based on conservative assessment using only dams as full barriers) |

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| • Possible passage over dams and natural barriers that were included as blocks to passage<br>• Partial barriers may fully block passage depending on the context, but were not included in the threat scoring | • Blocks to passage from culverts not included<br>• Lack of detailed information on dams identified as partial barriers | | |
| *Latitudinal Fragmentation* | | | |
| • Degree to which floodplain control infrastructure limits latitudinal movement from a given stream reach | • Simple presence/absence assessment of association of flood controls with stream reaches<br>• Amount of floodplain habitat connected to a given stream reach not yet delineated<br>• Did not yet consider other features that could limit latitudinal movement (e.g., roads, railways)<br>• Spatial data on channelization are not available and therefore not represented aside from those accounted for by the urban land cover and flood control infrastructure layers | • Feasible for BC<br>• Need equivalent data for Yukon<br>• Need to consider other transect lengths used to capture flood control infrastructure when applying to other basins | Medium (based on lack of association to lateral habitat) |
| *In-Stream Habitat Destruction* | | | |
| • Human activities were all treated equally with no current assessment of intensity<br>• Forestry and oil and gas roads data were based on tenures (i.e., roads may not have been built or may be decommissioned); roads may be present on the landscape that were not captured by this dataset | • No current delineation of which activities may be more harmful to in-stream habitat than others<br>• Activities on private land were not explicitly included, but were largely represented by the other included human activity and land cover layers based on visual inspection of layers | • Feasible for BC<br>• Need equivalent data for Yukon | High (based on robust and comprehensive data inputs for evaluating presence of disturbance) |

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| *Flow Alteration* | | | |
| • Human activities all treated equally, but likely have variable contributions<br>• Water withdrawal is based on licensed maximum allowances, actual amount withdrawn is unknown<br>• Withdrawals include both groundwater and surface water, which may have differing impacts on flow that were not considered<br>• Downstream and upstream effects of dams and water extraction not accounted for<br>• Other land uses, in particular forest disturbances, can have important effects on stream flow that were not included | • No current designation or consistent data on characteristics that make dams and culverts more impactful to flow regimes<br>• Data on amount of water withdrawn is not available<br>• Data on unlicensed domestic water withdrawal (e.g., fire prevention, private dwelling) in BC are not available<br>• Currently no general relationship to account for upstream/downstream effects of dams and water withdrawal on flow<br>• Ideally apply data on intensity of forest fires and harvest, and general relationships, to account for effect of forest disturbances on flow alteration | • Feasible for BC<br>• Need equivalent data for Yukon | Low (based on lack of information for water withdrawals, i.e., how much is withdrawn and association with seasonal flow levels) |
| *Riparian Disturbance* | | | |
| • Human activities were all treated equally with no current assessment of intensity<br>• Relevant fire and forestry timeline to include depends on riparian function of interest<br>• Forestry and oil & gas roads data were based on tenures (i.e., roads may not have been built or may be decommissioned); roads may be present on the landscape that were not captured by this dataset<br>• Riparian buffer based on standard of 30 m but other buffer distances | • Currently limited assessments of buffer widths necessary to maintain different riparian functions depending on the system<br>• Riparian zone based on static stream and river shorelines (does not account for any migration in river position over time)<br>• Activities on private land were not explicitly included, but were largely represented by the other included human activity and | • Feasible for BC<br>• Need equivalent data for Yukon<br>• Need to consider differences in riparian recovery times (e.g., from forest disturbance) for other basins/climates | High (based on robust and comprehensive data inputs for evaluating presence of disturbance and focused currently on the riparian function of filtering) |

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| can be important and is dependent on the system<br>• Level of forest pest defoliation that should be considered a disturbance depends on the riparian function of interest | land cover layers based on visual inspection of layers<br>• Not a full assessment of disturbance to all riparian functions; currently focused on filtering capacity | | |
| *Nutrients* | | | |
| • Land use inputs are likely context-dependent, but were applied as a single concentration coefficient (and accounting for runoff rates)<br>• Point source input effluent loads were estimated based on available environmental monitoring, and estimates were made based on correlations to fill data gaps (ECCC 2022)<br>• Non-point source coefficients were derived from limited literature including from the Western US (ECCC 2022)<br>• Concentration coefficients for nutrient inputs from forest related disturbances (cut blocks, fires, pest defoliation) were estimated based on relative effect compared to 'Other Non-Urban' classification<br>• Relevant fire and forestry timeline to consider can be variable<br>• Forestry and oil and gas roads data are based on tenures (i.e., roads may not have been built or may be decommissioned); roads may be present on the landscape that were not captured by this dataset | • Limited literature and data on land use inputs to derive contribution coefficients<br>• Dependent on extent of PAWPIT (ECCC 2022) data and high resolution hydrological layers | • Need high resolution hydrological layers for other basins (see 'stream flow' threat)<br>• Provided hydrological layers, feasible for the FRB, Vancouver Island, Haida Gwaii, and coastal watersheds based on PAWPIT (ECCC 2022) extent | Low (based on incomplete nonpoint source input information and generalized assumptions for downstream accumulation and riparian filtering) |

| **Uncertainties** | **Limitations** | **Extension** | **Confidence rating** |
|---|---|---|---|
| • More complex context-dependencies in riparian filtering capacity not accounted for<br>• More complex and localized settling dynamics not accounted for<br>• Uses runoff and stream flow from hydrological models that were downscaled with associated uncertainty | | | |
| *Pollution* | | | |
| • Land use inputs are likely context-dependent, but were applied as a single coefficient (and accounting for runoff rates)<br>• Point source input effluent loads were estimated based on available environmental monitoring, and estimates were made based on correlations to fill data gaps (ECCC 2022)<br>• Non-point source coefficients were derived from limited literature including from the Western US (ECCC 2022)<br>• Did not include air releases as deposition rates to a given stream reach were uncertain<br>• Contributions of pollutants from river sediments were not included (ECCC 2022)<br>• More complex context-dependencies in riparian filtering capacity not accounted for<br>• More complex and localized settling dynamics not accounted for | • Limited literature and data on land use inputs to derive contribution coefficients<br>• Dependent on extent of PAWPIT (ECCC 2022) data and high resolution hydrological layers | • Need high resolution hydrological layers for other basins (see 'stream flow' threat)<br>• Provided hydrological layers, feasible for the FRB, Vancouver Island, Haida Gwaii, and coastal watersheds based on PAWPIT (ECCC 2022) extent | Low (based on incomplete nonpoint source input information and generalized assumptions for downstream accumulation and riparian filtering) |

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| • All pollutants were treated as exposure only, but their impacts on fish and ecosystem health vary | | | |
| *Sedimentation* | | | |
| • Land use inputs are likely context-dependent, but were applied as a single coefficient (and accounting for runoff rates)<br>• Relevant fire and forestry timeline to include can be variable<br>• Forestry and oil and gas roads data are based on tenures (i.e., roads may not have been built or may be decommissioned); roads may be present on the landscape that were not captured by this dataset<br>• More complex context-dependencies in riparian filtering capacity not accounted for<br>• More complex and localized settling dynamics not accounted for<br>• Non-point source coefficients were derived from limited literature including from the Western US (ECCC 2022) | • Limited literature data on land use inputs to derive contribution coefficients<br>• Less literature and data available for sedimentation than for nutrients and pollution<br>• Dependent on extent of PAWPIT (ECCC 2022) data and high resolution hydrological layers | • Need high resolution hydrological layers for other basins (see 'stream flow' threat)<br>• Provided hydrological layers, feasible for the FRB, Vancouver Island, Haida Gwaii, and coastal watersheds based on PAWPIT (ECCC 2022) extent | Low (based on incomplete nonpoint source input information and generalized assumptions for downstream accumulation and riparian filtering) |
| *Flood Risk* | | | |
| • Based on models for the extent of Canada with associated uncertainty (Mohanty and Simonovic 2021)<br>• Models produced at coarser resolution compared to other used data layers (1 $km^2$)<br>• Flood models considered highly uncertain | • Limited use for finer resolution inquiry<br>• Does not assess the change in probability of occurrence for a flood of a given magnitude<br>• Metric based on a single return period | • Feasible for all Pacific Region based on model extent | Low (based on high uncertainty associated with flood projections) |

| Uncertainties | Limitations | Extension | Confidence rating |
|---|---|---|---|
| *Stream Flow – High and Low* | | | |
| • Based on hydrological models (Schnorbus 2020) with associated uncertainty and some months performing better than others<br>• Some uncertainty in downscaling the models, though a close correspondence was found between the original and downscaled resolutions<br>• Correction factor used to adjust stream flow predictions at major dams where flow regulation was monitored, not adjusted for dams without associated hydrometric data | • Downscaling currently only done for the FRB<br>• %MAD calculated based on monthly instead of daily values given current data constraints<br>• Does not include extreme events such as atmospheric rivers or droughts | • Need high resolution hydrological layers for other basins<br>• Finer scale models (fundamental watershed resolution) underway by PCIC for Salmon bearing watersheds in BC, with an estimated timeline for delivery of 2026 | High (well-established models with validated downscaling method) |
| *Stream Temperature* | | | |
| • Based on statistical stream temperature models with associated uncertainty (Weller et al. 2023)<br>• Implicitly includes effect of land use disturbances on stream temperatures based on model fitting to *in situ* data, but does not explicitly model these effects | • Models developed for catchments at least 1 $km^2$ in size based on available *in situ* data (generally 3rd order streams and higher; Weller et al. 2023)<br>• Does not include extreme events such as heat domes | • Feasible for BC based on model extent<br>• Need more extensive *in situ* stream temperature data for Yukon to produce and validate models | High (validated models that perform well relative to other largescale temperature models) |

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Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

E-Mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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