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Proceedings of the Regional Peer Review on Threshold Approaches and Status of Metrics Selected to Report on the State of Fish and Fish Habitat in the Ontario and Prairie Region Priority Areas: Part 2

Meeting dates: August 23–25, 2022
Location: Virtual

Chairpersons: Amanda Winegardner and Gavin Christie
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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

Fisheries and Oceans Canada (DFO) has committed to producing area-based reports on the State of Fish and Fish Habitat (SOFFH) in Canada by March 31, 2023. Two reporting areas have been selected by the Fish and Fish Habitat Protection Program (FFHPP) in the Ontario & Prairie (O&P) Region to develop a SOFFH report for the Lower Great Lakes Area in Ontario (LGLA), and the Eastern Slopes Region of Alberta (AESA) reporting areas. As a follow-up to a first regional SOFFH Canadian Science Advisory Secretariat (CSAS) meeting (DFO 2022), this second CSAS meeting was held August 23–25, 2022, to elicit input from academic, environmental practitioners, FFHPP, and DFO Science. The intention of this regional Science Advisory process was to review the indicators and associated metrics used to report on the SOFFH rather than compare the results for the reporting areas to each other, and review approaches that can be used to develop thresholds and classification schemes for SOFFH reporting. Data presented for the five indicators (Biodiversity, Water Quality, Connectivity, Land Use and Land Cover, and Climate Change) and associated metrics were reviewed and science advice on assessing the SOFFH in these reporting areas was also provided. This Proceedings report summarizes the relevant discussions and recommendations received on the indicators and metrics proposed during this second part of this SOFFH CSAS process. Additional publications from this process will be posted on the DFO Canadian Science Advisory Secretariat (CSAS) website as they become available.

INTRODUCTION

The modernized *Fisheries Act* came into effect on August 28, 2019, to help safeguard fish and protect the environment. Fisheries and Oceans Canada (DFO) has committed to area-based reports on the State of Fish and Fish Habitat (SOFFH) in Canada by March 31, 2023. Within Ontario and Prairie (O&P) Region, two reporting areas have been selected as the focus of the regional SOFFH efforts (henceforth referred to as the SOFFH-OPR). These reporting areas are the Lower Great Lakes Area in Ontario (LGLA) and the Eastern Slopes Region of Alberta (AESA). Information produced via SOFFH-OPR will feed into the national reporting initiative alongside content produced by other DFO regions.

The LGLA refers to the Lake Ontario and Lake Erie Drainage Basins and the nearshore areas of each lake in southern Ontario, whereas the AESA encompasses the East Slopes of the Rocky Mountains and immediate downstream areas within the province. The intention of this Science Advisory process was not to compare the SOFFH for these reporting areas to each other, but rather to separately report on the indicators and associated metrics associated with the SOFFH within priority areas.

The current Science Advisory process was the second part of a larger Science Advisory effort. The first Canadian Science Advisory Secretariat (CSAS) meeting was held on June 29–30, 2021, to broadly discuss the environmental indicators that could be used to measure SOFFH in the O&P Region. The O&P Region's 'State of Fish and Fish Habitat' (SOFFH)- Part 1 report focused on the identification of environmental indicators and associated metrics, and data sets that may be available to provide a snapshot assessment of the current SOFFH in the two reporting areas (DFO 2022).

As a follow-up to this first meeting, a second CSAS meeting was held August 23–25, 2022, to elicit input from academics, environmental practitioners, FFHPP, external researchers, and DFO Science (Appendix 1) to review the five indicators (i.e., Biodiversity, Water Quality, Connectivity, Land Use and Land Cover, and Climate Change) and associated metrics in the reporting areas, and evaluate the approaches that were applied or could be applied in the future to categorize the status of environmental metrics and associated thresholds for reporting on SOFFH in the LGLA and AESA. Specific objectives of the Science Advisory process were to: (1) present a synthesis of the available data and status of each environmental metric within the Lower Great Lakes and East Slopes of Alberta reporting areas; (2) review the approaches used to categorize the status of each environmental metric, including approaches to determine threshold values for reporting; (3) review approaches used to assess data quality for reporting on the SOFFH-OPR; and (4) identify uncertainties and knowledge gaps with respect to data availability and the methods used for developing classification schemes for the SOFFH-OPR. These objectives are also described in the Terms of Reference for this CSAS process (Appendix 2). The meeting followed the agenda outlined in Appendix 3.

STATE OF FISH AND FISH HABITAT REPORTING- ONTARIO AND PRAIRIE REGION UPDATE

Presenter: Sarah Matchett

Rapporteurs: Camille Macnaughton (LGLA) and Regina Sobowale (AESA)

Summary

The origin of the national SOFFH reporting project was described, outlining the goal of the project and the main drivers for improved reporting in FFHPP. Participants were informed that the intended audience for these reports includes the general public, government agencies, and those with a scientific/technical background. The experience of the National Task Team in planning and designing the reports in the various regions was recounted, highlighting that variations in regional conservation work leads to either data-rich (indicator-style) reporting, narrative (storytelling) reporting, or a mixture of both. The advice on state metrics and data sources received in the first report of the process (DFO 2022) was reviewed briefly, and the indicators and metrics chosen to report on in the two reporting areas and some of the results were described. The presentation concluded with an update for participants on the proposed timelines for the publication of the national SOFFH report. Overview and clarification of errors in the Indicators and Metrics Research Document circulated for review prior to the meeting were also discussed.

Discussion

Considering a concurrent national reporting initiative on SOFFH, several participants inquired about the application of the indicators (and metrics) approach presented for their respective regions (e.g., province-wide for Nova Scotia or area-specific for Pacific Region), pending data availability for their given region. Questions surrounding the immediate timelines and long-term planning for national and regional (O&P) SOFFH reporting also arose. Despite the absence of an official direction for long-term planning, O&P's specific reporting on SOFFH currently underway should provide the critical baseline information that will help guide future assessments. The best available data was used to derive indicators and metrics for the LGLA and AESA, but that fact does not preclude the use of other relevant indicators in future assessments for SOFFH in the O&P Region or elsewhere.

There was some discussion if, from the habitat management perspective, these indicators for SOFFH reporting would be used in the review of Works, Undertakings and Activities (WUA), as regulated by DFO under the *Fisheries Act*. FFHPP staff replied that SOFFH information is just one source of information that could be used in making decisions on WUAs and caution was advised to the audience about making inferences about specific metrics and regulatory actions.

Questions were raised about the management metrics and how they would be used in the O&P SOFFH reporting. FFHPP staff described the management metrics that will be incorporated: mapping of Outcome of WUA Project Reviews (Low Risk, Letters of Advice, Authorization, *Species at Risk Act* [SARA] Authorization) and Grants and Contribution Agreements in the two reporting areas. While the information presented in management metrics have already been presented in different formats by DFO in Annual Reports to Parliament, the choice was made to have more meaningful visualizations for these two reporting areas.

PRESENTATION

INDICATORS AND METRICS (BIODIVERSITY, WATER QUALITY, CONNECTIVITY, LAND USE/ LAND COVER, AND CLIMATE CHANGE)

Presenters: Cody Dey (LGLA) and Cindy Chu (AESA)

Rapporteurs: Camille Macnaughton (LGLA) and Regina Sobowale (AESA)

Summary

Participants were reminded that their feedback was being sought on the data selected for the metrics analyzed, the analyses themselves, the results presented, and the thresholds chosen for the metrics. The indicators selected to describe the SOFFH for both reporting areas were the same: Biodiversity, Water Quality, Connectivity, Land Use and Land Cover (LULC) and Climate Change. The majority of metrics used to report on each of those indicators were the same. The data sources, analytical methods, results and classification of the results for each metric were presented. Participants reviewed and discussed each of these aspects.

DISCUSSION

BIODIVERSITY INDICATOR (METRICS: FISH SPECIES RICHNESS; BENTHIC INVERTEBRATE – EPT INDEX; SPECIES AT RISK (SAR) RICHNESS; AND AQUATIC INVASIVE SPECIES (AIS) RICHNESS)

LGLA breakout session

Most participants acknowledged the huge effort that went into compiling and synthesizing the most up-to-date data for the biodiversity metrics in both reporting areas. However, there were several points of contention and further suggestions for improvement for this section. These items generally focused on 1) the choice of biodiversity metrics used for SOFFH reporting in LGLA; 2) the context for which metrics were calculated; and 3) the data sources used to compile biodiversity metrics.

A primary concern from participants arose around the use of diversity metrics, rather than considering metrics that quantified species composition (e.g., trophic guilds or proportion of generalists, some metric of representativity), abundance, or Catch Per Unit Effort. Some participants cautioned that richness metrics lacked the nuance needed to represent the state of fish for a given assessment unit. Participants asked for clarification on the definitions for AIS in the report versus Naturalized species and whether increasing or decreasing biodiversity “scores” for assessment units could help improve overall comprehension and comparison among units. Some debate was also had over the inclusion of AIS and SAR occurrence data to represent the biodiversity indicator, but rather than exclude these metrics, the decision was made to provide details of the data that made up the metrics (i.e., native vs. non-native species). It was also decided that specific geographic regions within each reporting area should be considered separately and compared to baseline data, rather than comparing disparate locations. Likewise, it was suggested that an improvement or decline in a species’ position on the Schedule 1 of SARA or Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designation could infer some information on the effectiveness of DFO management decisions and actions.

It was acknowledged that data availability constrained the biodiversity metrics, however, some considerations for improving the context for which the metrics were calculated might be important for SOFFH reporting in the LGLA. Specifically, participants proposed that biodiversity metrics should be scaled for the various climatic areas or scaled from a historical reference (i.e., deviations from state). For example, species richness and SAR could be compared against what should be expected for that watershed or regional pool, rather than with SAR data for all assessment units within the LGLA. Similarly, Ephemeroptera, Plecoptera, Trichoptera (EPT) indices should be scaled down to river continuum or relevant scales. Participants also indicated that some information is needed on how sampling was collected on the landscape and where the data for the analyses came from. For example, SAR and AIS species and/or their known habitat may not always be sampled consistently, potentially biasing detection probabilities for these species among assessment units. In addition, fish assessments may show transient use of specific habitats, which should be taken into consideration when comparing biodiversity metrics among units. Overall improvement on communicating the value and direction of state was recommended for all metrics.

The last discussion points focused on the data sources used to derive the biodiversity metrics, with several suggestions to source alternative data sets (e.g., COSEWIC assessments, including other aquatic SAR taxa, traits-based data sets used for HEAT assessment conducted internally, and provincial and municipal databases to improve AIS metrics (Appendix 4). There was some consensus on the value added in using data sets that included species traits relevant to the state of habitats (e.g., functional diversity index that accounts for a species' thermal guild - cold, cool, warm - and link these traits to migratory classification or dissolved oxygen sensitivity) or using EPT nearshore assessment data from other governmental agencies to fill in the data gaps. In the same vein, several participants suggested focusing on a specific region so that monitoring agencies could reliably collect information over time, thus reducing the frequency of missing data (i.e., targeted approach).

Moving forward, some discussion focused on prioritizing the monitoring effort (i.e., data collected) needed to quantify the future SOFFH, between targeted vs. broader landscape contexts, or between known vs. new areas of interest. Once there is consensus on the biodiversity metrics, further thought on how best to classify the metrics from "poor," "moderate" to "fair" will be needed to establish thresholds for management.

AESA breakout session

Biodiversity indicator and metrics discussion centered greatly on species richness data sources and gaps. There was significant discussion regarding fish community composition, and there was enormous support to separate native and non-native species to avoid data misinterpretation. Some participants recommended applying the Jaccard dissimilarity index, while some recommended adding the hybridization scores in the Alberta Fish and Wildlife database (FWMIS) database to the biodiversity summaries. One participant, however, cautioned that although FWMIS data has many advantages, it does have some shortcomings including gaps in spatial coverage and frequency of sampling.

One participant suggested including species spatial turnover, as turnover could highlight when fish join the East slope mix. The participant explained that summaries of temporal change could speak to the implications of management activities; for example, the speed of change could indicate good or poor management effectiveness. This potential SOFFH story could highlight productivity and habitat diversity changes. Another participant agreed that the turnover perspective helps us identify and predict when change happens and could help us prepare for it. One participant questioned the age of the data and cautioned against using a limited 5-year time window because the sensitivity of a metric like this is low; the Chair clarified that for this indicator, the report did not use a time window, but depended on reliable records of species occurrences.

A few participants expressed the desire to include other biodiversity metrics and have data sets that consider different traits, such as functional diversity and relative abundance, as they may be more sensitive to change. Some participants highlighted the importance of expert solicitation to fill some data gaps and improve alignment of SOFFH with local management actions.

Some participants raised concerns over the inclusion of EPT data in this report because EPT works well on agriculture and industrial systems but may not be appropriate across a range of habitat types. Participants agreed that EPT data gaps were an issue; contacting groups like Parks Canada, Living Lakes Canada, and local watershed groups may help bridge this. The group discussed possible river classifications and if an intra-class gradient should be included; one participant expressed that comparing ecosystems as high and low may be tough because ecosystems are vastly different. One participant suggested filtering EPT by Strahler stream order and productivity indices.

Many participants also questioned if the AIS and SAR data sources captured provincial listings. The Chair clarified that the province did provide the list of species considered invasive in Alberta. Other suggestions include expanding the SAR list to include species considered for listing and non-fish SAR, such as Banff Spring snails. Participants also mentioned using the COSEWIC listing rather than the SARA Schedule 1 listing.

One participant mentioned that although AIS is a big concern in the East Slopes, the map does not tell that story because non-native species are distributed throughout the reporting area, but not listed as AIS. Participants also advised including definitions of invasive species considered. One participant suggested using hot colors (e.g., red or darker shades) to show areas of concern and cool colors (e.g., blue or lighter shades) for areas of lower concern.

Summary of main group

General feedback from both breakout groups centered on the appropriateness of the data used to calculate the various biodiversity metrics (i.e., representativeness of data) and improving the message about the ecological contrasts among regions (e.g., pristine versus impacted; native versus non-native and invasive). Likewise, value statements that would better contextualize the various classifications, such as “low” or “high” biodiversity, were recommended to improve comparisons among reporting areas and inform a management approach. As it stands, there was no mention of the expected range of biodiversity values and the types of habitats that would be expected to produce variable species diversity. Despite these comments, most agreed that the progress made thus far on establishing indicators had been tremendous.

WATER QUALITY INDICATOR (METRICS: CONDUCTIVITY, TOTAL PHOSPHORUS, CHLORIDE, NITRATES, TEMPERATURE, AND DISSOLVED OXYGEN)

LGLA breakout session

A presentation of the various water quality metrics (six metrics for LGLA) preceded the discussion from participants on the selection of metrics, the analyses conducted to represent SOFFH, and thresholds chosen to classify SOFFH “scores” for the 195 assessment units across watersheds. Like with the previous discussion, participants made several comments on 1) the selection of metrics and the data used to calculate metrics, as well as 2) the need to further contextualize the range of values for each of the metrics calculated, emphasizing the inter-regional differences and the distinction between lotic and lentic systems, nearshore and open water. Data representing coastal wetlands was suggested to be teased out, or at a minimum, discussed narratively when discussing trends among ecotypes.

The challenge of limited data was raised after an initial description of the criteria for selecting water quality data. Participants generally cautioned the use of averaged metrics for a few data points as they would often mislead results and overall interpretations. The same was said for averaging data over the course of the year (April-November) because seasonal trends for water quality metrics would be lost. Certain participants suggested that metrics be calculated using the frequency of threshold exceedance or tri-means for a given sampling unit, rather than medians. In general, some caution was expressed over the use of point measurements that were not reflective of the systems sampled instead of the use of continuous data. In the absence of sufficient data, however, it was suggested that authors provide explicit details of the data collected when making statements of the SOFFH for a given metric. For example, the frequency of sampling was likely a reflection of the concern over impacts in a particular system, where at risk systems were evaluated more intensively than systems of little concern. Furthermore, it was suggested that having a good sense of the relationships between each of the metrics and fish responses, including residence time, may eliminate the need for calculating metrics that may not impact aquatic life (e.g., nutrient and oxygen level impacts on aquatic life would be negligible for rivers on account of short residence time). Similarly, some explanation as to how or why specific metrics might impact fish habitat would serve to improve comprehension of SOFFH for public audiences. Similar to previous discussions on limited data, it was suggested that the focus be placed on representative data rich areas rather than on the full LGLA.

The overarching point of contention when discussing water quality metrics arose around the use of the same thresholds for lentic and lotic systems, since water quality metrics, like water temperature, behaved differently among ecotypes. Moreover, most quality metrics vary over the course of the year, especially between winter vs. non-winter conditions, thus the time of year when water quality parameters were measured would have varied impacts on the systems evaluated. More extensive data (e.g., continuous data) are needed to explore analytical solutions to control for intra-annual variation and exploring potentially new metrics such as turbidity, specific conductance, flow, and contaminants (i.e., metals and organo-chlorides). In fact, it was strongly suggested that a turbidity metric (Total Suspended Solids and Total Dissolved Solids) be included as it was relevant for assessors evaluating the effects of sediment load in WUA.

Lastly, some participants discussed the thresholds used and the process to develop thresholds for regions within the LGLA. Specific concerns centered over the frequency of updates for thresholds and the relevance for management purposes.

AESA breakout session

Water Quality metrics discussions focused on 1) ‘Goldilocks’ thresholds (lower and upper limits of species preferences); 2) Selection of appropriate thresholds; 3) Spatial variability; and 4) Data sources and gaps.

There was a robust conversation around ‘Goldilocks’ thresholds as metrics such as temperature and dissolved oxygen fall into this category, where metric values can be described as ‘just right’ (optimal) or undesirable (sub-optimal) for fishes; analogous to habitat suitability curves that have been developed for different habitat variables and species. Thus, it may be worth including some aspects of temporal (diurnal and seasonal) fluctuations in the report. The temperature threshold for this report is 19˚C; the Chair asked the group if they felt 19˚C was an appropriate threshold and if they could suggest an alternate threshold for consideration. Participants did not provide specific threshold values; one however recommended smaller water temperature categories to show that all systems in AESA are cold-water systems. Another person suggested using tri-means temperature as an alternative temperature metric. Other suggestions include considering Mean Weekly Average Temperature (MWAT), including an upper and lower threshold limit, utilizing temperature loggers (grey data sources provided), and temperature rate of change.

Several participants expressed that chloride may not be of significant concern in the East Slopes, and there may not be a need to include this metric. The Chair clarified that because chloride is a known concern in the LGL, it was included in AESA for consistency. Another participant argued that chloride might be of concern as it is a by-product of fracking, a common activity in Alberta.

One participant questioned the data set's spatial variability and availability, asking if the values were representative of the whole watershed because the long-term river monitoring sites for the AEP are far East and not representative of the East Slopes, particularly in Central/South. Another participant pointed out that some data points seemed to be missing and suggested this as a potential reason why chloride concentration do not appear to be a concern in the East Slopes.

Discussions on data sources followed. Participants suggested alternative data sets, such as FWMIS, and contacting Environmental Non-Government Organizations (ENGOs) (e.g., Trout Unlimited Canada and the Blackfoot Confederacy) as they may have helpful temperature data sets.

Participants also proposed including other water chemistry data sources such as selenium, total suspended solids, total dissolved solids, sediments, and total phosphorus. Potential data sources for sediments include a sediment modeling approach for some streams [e.g., Road Erosion and Sediment Delivery Impact (READI model)]. Other suggestions include refining the map legend as groupings were broad and including data sampling time for dissolved oxygen and other metrics.

CONNECTIVITY INDICATOR

LGLA METRICS: DENSITY OF WATERFALLS, DAMS, AND FISHWAYS, AND THE NUMBER OF BARRIERS THAT ARE NOT PASSABLE, PARTIALLY PASSABLE OR HAVE UNKNOWN PASSABILITY.

AESA Metric: Alberta Environment and Park (AEP) Stream Connectivity Metric

LGLA breakout session

The Canadian Aquatic Barriers Database (CABD) was sourced for data on connectivity metrics in the LGLA. Some participants were concerned over the definitions for dams and waterfalls, as the current mapping of these barriers was largely underrepresented or did not match up for specific watersheds. Participants discussed excluding natural barriers like waterfalls since they were not included in the AESA connectivity metric, the representation in the research document was misleading, their occurrence may be negatively interpreted by public audiences, and the occurrence of waterfalls did not inform on the state of fish habitats. One participant mentioned that because the metric of passability likely represented barriers that were not passable, like waterfalls, the density of waterfalls may not be needed. Some estimate of fish passability (i.e., success of passing a barrier) would be relevant to complement the current passability metric. Despite these discussions around waterfalls, there was some discussion about its usefulness for management and discussions with proponents of WUA because they had a smaller impact on connectivity relative to anthropogenic barriers. The point that waterfall density provided some information on the connectivity of the watershed was also restated by members of the steering committee.

There was consensus on the inclusion of a new metric, the density of road crossings per watershed, which would consider potential anthropogenic problems (e.g., perched culverts). Some suggestions were made for including the proportion of stream upstream from a barrier like dams, as was done for watersheds in the Maritimes region, and using a dendritic connectivity index (DCI). For the proportion of stream upstream from a dam, the extent of impacts of dams are thought to be more related to their geographic location in the watershed, with greater impacts felt as you decrease in stream order (i.e., move towards the mouth of a river). Moreover, there was some discussion on the analysis of the type of barrier (i.e., partial, or seasonal barriers, inflatable barriers) and the timing that they were in place, as well as whether the dam was privately or publicly owned. These last suggestions would add a layer of complexity for this indicator, but would depict, respectively, the positive role of barriers for AIS control in the LGLA (i.e., sea lamprey) and role of maintenance and removal of barriers that would be important for negotiations with proponents.

Shifting away from longitudinal connectivity, lateral connectivity in lake ecosystems, which was related to the variability in lake levels and the resilience of these systems to recover from changing water levels, was largely overlooked in the current analysis. Many participants agreed that lateral connectivity would be a meaningful metric and would also capture connectivity between coastal wetlands (e.g., spawning to nursery areas), which were critical for extirpation and colonization/ recovery of SAR. In fact, urbanized wetlands were noted to be especially susceptible to water level variation. Several additional data sources were recommended by participants, and they restated the added value in overlaying different data sets to improve interpretations of regional patterns.

Members of the steering committee agreed that analyses of connectivity metrics could be further refined by providing information on the extent of habitat that was inaccessible due to the barriers and also identifying the benefit of some barriers for AIS control.

AESA breakout session

Extensive conversation occurred around defining barriers and including the types of barriers, for example, weirs, culverts, and dykes. For the benefit of the system, barriers should be considered as a substitute for direct human intervention. Participants deliberated whether waterfalls are barriers and whether the differences between privately owned and government dams should be considered.

Several participants agreed that the report should distinguish between good and bad barriers, as well as natural and non-natural barriers. Another participant suggested that knowing good and bad barriers could assist in controlling introgression and remediating habitats. A participant questioned why natural barriers should be included; the Chair clarified that it could provide baseline understanding of the overall connectivity possible within each assessment unit. The removal of natural barriers and waterfalls was recommended.

The Chair inquired if there were any connectivity thresholds in Alberta, participants suggested exploring the Alberta Watercourse Crossing Inventory App (AbWCI) and LIDAR. Contact information for individuals with more information in these areas was provided (see Appendix 4).

Most participants expressed support to incorporate the AB watercourse crossing data or CABD data summaries, considering the AEP stream connectivity data set is not used broadly across Alberta. A participant suggested changing the stream connectivity map color scheme.

Summary of main group for water quality and connectivity indicators

General feedback from both breakout groups centered on the appropriateness of the data used to calculate the various water quality and connectivity metrics. Specifically, participants agreed that spatial and temporal variation had yet to be captured and the scale of the analysis should accurately represent whole assessment units (i.e., sufficient sample size). Several metrics were recommended to be included in the analysis: turbidity, TSS, TDS, passability estimates for barriers, and density of road crossings. Participants generally wanted to see water quality thresholds that better reflect species-specific preferences and lower limits for the CCME thresholds, and more context of the overall effect of barriers for ecosystem management. Participants also stressed the importance of capturing stochasticity within the assessment units by measuring deviation from natural flow and water quality regimes, deriving a multi-metric regime that may better inform on the ability of some organisms to respond to deviations from natural state. Finally, AESA participants mentioned that metrics and interpretations for the region could align with an ongoing SOFFH assessment conducted in the Pacific region.

Land Use, Land Cover Indicator (Metrics: Land Use and Land Cover, Proportion of Riparian Cover, and Proportion of Protected Areas)

LGLA breakout session

ESA Sentinel-2 imagery data were used to map nine different land cover classes across the entire area while data from the World Database of Protected and Conserved Areas were used to identify protected areas. Many comments centered on the validation of the data with respect to the limitation and accuracy of the pixels, as natural buffered areas that included rangeland and flooded vegetation were not accurately depicted. The consensus among participants was to validate the accuracy of protected areas currently mapped for the LGLA using conserved areas data from Conservation Authorities, other conserved areas captured in the Canadian Protected and Conserved Areas Database (CPCAD), and aquatic-based protection mapping or critical habitats.

Like for the connectivity indicator, it was suggested that the density of roads may be a more suitable surrogate of land use because it directly impacts water quality and that other sources of data may also be available to overlay with the current land use data set (e.g., wetland maps; LULC: land cover X water quality index; mapping of the agricultural tile drains from drain management). Similarly, participants suggested using the CPCAD rather than the one currently used. Respective to the range of coverage for protected areas by assessment, it was recommended that the level of resolution be changed, as the scale currently represented was too coarse.

AESA breakout session

Land use and cover metrics discussions centered around identifying historical conditions, trends, and patterns. Several participants mentioned that the report should focus on the current land use situation and include information such as land-use monitoring trends and patterns. Percent disturbed within the riparian buffers should be added to the data sets to better reflect deviations from expected and the impacts of human activities. Other suggestions included: adding information on road density, road crossings, intactness, and contiguousness (for example, Ferjuc et al. 2022).

It was broadly acknowledged to distinguish the scale and types of protected areas in the report as questions about what kinds and levels of protection arose. One participant even suggested showing areas protected by protected area type on the map legend. One participant recommended using the CPCAD as a data source rather than the world database.

One participant flagged that anthropogenic factors were not picked up at this scale in the report and it may be helpful to understand how some activities influence land use. Other recommendations included looking into the Alberta Biodiversity Monitoring Institute (ABMI) data and revising the characterization of land use and land cover types such as the inclusion of wetlands. Again, the suggestion to use hot colors to show areas of concern and cool colors for areas of lower concern was brought forward.

Summary of main group

General feedback from both breakout groups centered on the validation for some area-based reporting and the trade-offs between the level of detail provided vs. the accuracy required to represent SOFFH. Some interest focused on the land use data, in how it could be represented as the proportion of disturbance. Like for other indicators, there were suggestions for including additional data from the province (e.g., wetland areas), protected areas databases (e.g., Conservation Authorities and critical habitat databases). More detail on the type of protected areas and their boundaries would also help illustrate relationships with Hydrologic Unit Codes (HUCs) in Alberta and the type of fishing that is allowed in the area.

CLIMATE CHANGE INDICATOR (METRICS: BIOCLIMATIC VELOCITIES AND FLOODPLAIN PROJECTIONS AND FLOOD HEIGHTS)

LGLA breakout session

After a brief introduction to the bioclimatic velocities and 100-year flood height metrics, participants mainly commented on improving the definitions, contexts surrounding the metrics, and how to interpret the results. Some confusion over forward and backward climate change velocities provoked some discussion over the interpretation of the projections (i.e., risk or vulnerability vs. state indicator) and their impact on aquatic ecosystems. For example, the forward velocity metric depicted a projection in the 2050s, but there was some confusion as to the baseline on climate change. Likewise, added context as to the management perspective regarding flooding was suggested to help inform their intentions (i.e., flood risk vs. benefit). While it was generally understood that discussions on the direction of the flood risk may be out of scope for the current SOFFH process, participants acknowledged that more context surrounding the metrics and the importance of floods, like the distinction between resilience vs. resistance, was needed to ensure that the interpretations were more accurate.

Moreover, several participants recommended the use of a range of water levels instead of the single metric that was deemed too static and including ice cover as it was relevant to fish habitats. Specific comments surrounding the 100-year flood figures suggested that the figures and text did not seem to complement each other and that the panels within the figure should be standardized.

AESA breakout session

Bioclimatic velocity and change in height of 100-year floodplain are the metrics reported for climate change in the SOFFH report. The Chair noted the limitations of the bioclimatic velocity metric as it focuses on larger systems; discussions followed on how to strengthen the data set; one participant suggested including other parameters such as disturbance of change and a measure of climate change to date (e.g., velocity of change between 1981 and 2020). This information can be captured using heat maps that include maximum thermal temperature. Air temperature modeling can be also used to show historical changes and current conditions.

One participant mentioned that remodeling stream temperature and flow could also provide additional information on climate change; it would be helpful to add historical bioclimatic velocity; capture a longer window and include time and thermal maximum or optimal growth temperature ranges. Calculating differences between current and future bioclimatic velocities and modeling future flooding scenarios could also improve the data set. Another participant seconded that modeling stream temperature is the approach used in the Pacific region. Additional information on flood flow stage, water withdrawals, extremely low flow, and its frequency should also be included.

It was also noted that climate velocity models, coupled with connectivity and temperature information, could be integrated to provide managers with priority areas for protection and restoration priorities. It was also recommended to show a greater distinction between forward and reverse climate velocities and what that means.

Participants acknowledged the need to simplify and describe flood modeling results as the content is a bit technical. Another suggestion included making the color bar (and associated flood values) consistent among panels.

Summary of main group

With respect to climate change discussions, there was consensus on further defining bioclimatic velocities, their interpretation from a historical perspective, and including some idea of rate of change, vulnerability, and predictive capacity. Moreover, it would be important to draw parallels with the Pacific region's SOFFH process, as that report will focus on mapping the vulnerability of salmonids in the region. Further interpretations about the positive and negative aspects about flooding were also suggested. Finally, there were some concerns about the climate change differences between the LGLA and AESA.

PRESENTATION

REVIEW OF METHODS FOR ESTABLISHING CLASSIFICATION SCHEMES AND THRESHOLDS FOR REPORTING FOR SOFFH RESEARCH DOCUMENT

Presenter: Cody Dey

Rapporteurs: Camille Macnaughton (LGLA) and Regina Sobowale (AESA)

Summary

The second research document, 'Methods for Establishing Classification Schemes and Thresholds for Reporting on the State of Fish and Fish Habitat,' was summarized for the participants. This summary met the second objective of the CSAS process, which was to "review the approaches used to categorize the status of each environmental metric, including approaches to determine threshold values for reporting." Classification schemes were categorical descriptions of state based on 'binning' into categories for an underlying quantitative measurement. Thresholds were organized according to a reporting limit (upper or lower) or according to a value of ecosystem function, structure, or composition.

Classification schemes could be based on functional relationships with management objectives (e.g., objective determined *a priori*, potentially with a precautionary cushion), previously established thresholds (e.g., the Canadian Council of Ministers of the Environment's Canadian Water Quality Guidelines for the Protection of Aquatic Life), relative ranking (e.g., Jenks' natural breaks classification method), or expert elicitation (e.g., structured elicitation protocol). Where functional relationships were unknown or management objectives were not quantitatively defined, a relative ranking could be used to establish classification schemes. Many environmental reporting initiatives also provided information on the quality of data used to derive estimates of state, based on a data quality checklist (e.g., temporal or geographic coverage) or quantitative review of data (e.g., power analysis).

The research document also considered the key uncertainties that permeated the process of establishing classification schemes and thresholds for reporting on SOFFH in O&P. One important uncertainty was how to interpret 'pristine' (i.e., undeveloped) watersheds that may still be impacted by climate change, pollution, or loss of keystone species. Shifting baselines or a loss of perception of change that occurred when each generation redefined what was 'natural,' was another key uncertainty. An additional uncertainty related to emerging stressors in these systems, and how they could be accommodated in SOFFH reporting due to a lack of data or gaps in perception of functional relationships. Lastly, an important gap related to the inclusion of Indigenous information and knowledge, separate from Western science was raised. The research documents noted that adapted approaches based on ethical space (Ermine 2007) and/or two-eyed seeing (Reid et al. 2022) could be used to bring together Indigenous and scientific data for reporting purposes.

General Discussions

Participants acknowledged that considerable effort was put into producing the document. Discussions mostly focused on reporting thresholds, addressing uncertainties, and further suggestions to improve the documents.

There was consensus to incorporate another type of reporting threshold, shifting to outcome-based thresholds, where the focus is placed on the outcome of interest rather than the individual metric. An outcome-based threshold is a holistic reporting approach that references other thresholds and provides linkages between parameters. In Alberta, for example, the connection between sediment concentration and the number of harvests was more evident because an outcome-oriented threshold approach was applied. Outcome-based thresholds may also contribute to the understanding of cumulative effects, as it would be easier to derive connections-interaction relationships from expert opinion and account for shifting thresholds in response to changing stressors. It was generally agreed that it may be worth considering thresholds based on their response to other threats. Moreover, participants emphasized that outcome-based thresholds may be more suitable for the integration of local and Indigenous knowledge. For example, engagement with an Indigenous group in Alberta supported evidence of a decline of pike populations. They plotted a graph of fish camps against time and converted this data to road density in the area through GIS. In this example, stories provided by the community were used to produce an Indigenous stressor-response curve, which was used for a cumulative effects model.

Several participants voiced concerns about how uncertainty was discussed in the document and integrated throughout the process of reporting on SOFFH. Uncertainties stemmed from data quality, the robustness of evidence, and the degree of agreement across experts (e.g., as done for the International Panel on Climate Change). It was suggested to integrate processes to factor in the uncertainties as part of the entire reporting procedure and not as an afterthought, however, guidance for to the tools used to interpret uncertainty is still needed. A few participants suggested taking a precautionary approach and incorporating information about fish tolerance and suitability. Suitability curves can provide information about functional relationships. Data variability, interactions, and primary drivers are important to understand. Patterns of uncertainty may be understood by examining relationships between individual items. Management decisions needed to be aided by the processes that incorporated and interpreted uncertainties. Despite these challenges with interpreting uncertainties, participants agreed that having certain information from management, such as risk tolerance, may be helpful.

Another point of consideration centered on the appropriateness of metrics that would determine the types of thresholds established. Conservative, absolute thresholds may be suitable for certain metrics (e.g., Chloride), but natural variations in water temperature may preclude the use of a point-source or absolute threshold approach. Combining self-referent and control thresholds would be ideal. For example, if a self or controlled reference for a system was unknown, assigned thermal biology parameters (i.e., temperature preferences, optima values) to each species could be applied and specific temperature thresholds for a given community could be derived (a.k.a., derived thresholds).

Concerns over the alignment of results with an upcoming Alberta Environment and Parks (AEP) Cumulative Effects Report were also raised. This report will describe the overall state of habitat for Westslope Cutthroat Trout, Athabasca Rainbow Trout, and Bull Trout based on a cumulative effects model. Therefore, if indicators for this report were reported individually, there may be discrepancies with the current SOFFH-OPR report. It was clarified that DFO would take care to clearly express that the 'state' presented in the SOFFH-OPR report is based on single metrics and caution the reader against jumping to conclusions. In addition, if the AEP reports lead to provincial management objectives, then it was noted that FFHPP would be likely to use those objectives for decision making. The weight of evidence from multiple knowledge systems, other collaborative or parallel work, including management actions and interventions, should all be considered after publishing the SOFFH-OPR Report to prevent inconsistencies with reported results.

SCIENCE ADVISORY REPORT BULLETS

Prior to discussing the draft Science Advisory Report (SAR) summary bullets, a list of recommendations and actionable items were discussed with the participants. Draft SAR summary bullets were then provided by the steering committee and finalized on the third day of the meeting. Major discussions focused on clarifying terminology and precise wording to ensure that changes aligned with comments made during the meeting and were reflected in the SAR bullets. The MS Teams Chat feature was used by participants to propose alternative phrasing for drafting SAR bullets. Suggestions were made to add synergies with other reports, including the Alberta Species at Risk report, further specify the bounds of the report as an O&P approach, and weave Indigenous knowledge for future SOFFH reporting. There were also discussions surrounding the management goals, FFHPP objectives for reporting, and data quality concerns. Sources of uncertainty to be included in the body of the SAR were also developed and agreed to as a group. All agreed that the proposed SAR bullets should be accepted and published in the SAR with the revisions discussed as a group.

CONCLUDING REMARKS AND NEXT STEPS

The Chair thanked all participants for all their comments on the two research documents, and next steps were discussed. The finalized SAR and Proceedings documents would be sent to all participants for a final review before publication on the CSAS website.

REFERENCES CITED

DFO. 2022. Proceedings of the Regional Peer Review on the Validation of Metrics Selected to Report on the State of Fish and Fish Habitat in the Ontario and Prairie Region Priority Areas: Part 1; June 29–30, 2021. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2022/017.

Ermine, W. 2006. The Ethical Space of Engagement. Indig. Law J. 6(1): 193–203.

Ferjuc, R., Marshall, H.J., and Shain, M.E. 2022. Data Meets Action: The Riparian Web Portal. [online]. Water Canada. (Accessed September 2022)

Reid, A.J., Eckert, L.E., Lane, J.F., Young, N., Hinch, S.G., Darimont, C.T., Cooke, S.J., Ban, N.C., and Marshall, A. 2021. “Two-eyed seeing”: An indigenous framework to transform fisheries research and management. Fish and Fish. 22(2): 243–261.

APPENDIX 1. TERMS OF REFERENCE

Threshold Approaches and Status of Metrics Selected to Report on the State of Fish and Fish Habitat in the Ontario and Prairie Region Priority Areas: Part 2

Regional Peer Review – Ontario and Prairie Region

August 23–25, 2022
Virtual Meeting

Chairperson: Amanda Winegardner

Context

Fisheries and Oceans Canada (DFO) has committed to area-based reports on the State of Fish and Fish Habitat (SOFFH) in Canada by March 31, 2023. These will serve as a means of reporting on the progress of implementing a modernized *Fisheries Act*, and demonstrating results of a revitalized Fish and Fish Habitat Protection Program (FFHPP). As part of this initiative, the FFHPP in the Ontario & Prairie (O&P) Region have selected two (2) priority areas to develop their own SOFFH reports: the Lower Great Lakes Area in Ontario, and the Eastern Slopes Region of Alberta.

A Science Advisory meeting was held on June 29–30, 2021 to discuss possible indicators, metrics, and data available for inclusion in the O&P regional SOFFH report. After the discussions, it was decided that the report will include five (5) indicators: biodiversity, water quality, connectivity, land use, and climate change. Each indicator will be described using different metrics (biodiversity, water quality, connectivity, land use, and climate change), which would be quantified for each assessment unit (e.g., watersheds) within the two reporting areas. O&P's contribution to the larger National SOFFH report will therefore summarize the state of each metric specifically, each indicator broadly, as well as qualitative descriptions of DFO programs that inform both metrics and indicators. The proceedings report (DFO, 2022) summarizes the relevant discussions and recommendations received on the indicators and metrics proposed during this first part of this CSAS process.

FFHPP is seeking science advice on approaches that can be used to define classification schemes and associated thresholds for reporting on the SOFFH in the Lower Great Lakes and East Slopes of Alberta reporting areas. In addition, science advice on quantifying and assessing the SOFFH in these reporting areas, is also requested. Possible approaches to address uncertainties and fill knowledge gaps in the future will be discussed.

It is expected that this process will have synergies with recent CSAS processes focusing on the assessment of impacts and offsets for the death of fish, and the renewal of Pathways of Effects models used to assess risks to fish and fish habitat. Furthermore, this peer-review meeting may help to inform future CSAS requests related to risk management and the establishment of environmental benchmarks. Information produced through this process will also help to inform national SOFFH reporting.

Objectives

The objectives of the peer-review meeting are to:

1. Present a synthesis of the available data and status of each environmental metric within the Lower Great Lakes and East Slopes of Alberta reporting areas;
2. Review the approaches used to categorize the status of each environmental metric, including approaches to determine threshold values for reporting

3. Review approaches used to categorize data quality for reporting on the SOFFH; and
4. Identify uncertainties and knowledge gaps with respect to data availability and the methods used for developing classification schemes for the SOFFH

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document(s)

Expected Participation

- Fisheries and Oceans Canada (DFO) (Science and Aquatic Ecosystem sectors)
- Province of Ontario
- Province of Alberta
- Academics
- Other invited experts

References

DFO. 2022. Proceedings of the Regional Peer Review on the Validation of Metrics Selected to Report on the State of Fish and Fish Habitat in the Ontario and Prairie Region Priority Areas: Part 1; June 29–30, 2021. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2022/017.

APPENDIX 2. LIST OF MEETING PARTICIPANTS

Name	Organization/Affiliation
Gavin Christie (Co-Chair)	DFO Science, Ontario and Prairie Region
Amanda Winegardner (Co-Chair)	DFO Science, National Capital Region
Jacob Brownscombe	DFO Science, Ontario and Prairie Region
Cindy Chu	DFO Science, Ontario and Prairie Region
Jan Ciborowski	University of Calgary
Cody Dey	DFO Science, Ontario and Prairie Region
Sue Doka	DFO Science, Ontario and Prairie Region
Andrew Doolittle	DFO FFHPP, Ontario and Prairie Region
Doug Geiling	DFO Science, Ontario and Prairie Region
Kristin Gravelle	DFO FFHPP, Pacific Region
Josephine Iacarella	DFO Science, Pacific Region
Jack Imhof	Trout Unlimited Canada
Richard Kavanagh	DFO FFHPP, Ontario and Prairie Region
Marten Koops	DFO Science, Ontario and Prairie Region
Colin Lake	Ministry of Natural Resources and Forestry - Lake Ontario Management Unit
Dave Lawrie	Toronto and Region Conservation Authority
Jennifer MacDonald	DFO FFHPP, Maritimes Region
Camille Macnaughton (Rapporteur)	DFO Science, National Capital Region
Laura MacPherson	Alberta Environment and Parks
Sarah Matchett (Rapporteur)	DFO FFHPP, Ontario and Prairie Region
Amy McLeod	Cows & Fish, Alberta Riparian Habitat Management Society
Jon Midwood	DFO Science, Ontario and Prairie Region
Joclyn Paulic	DFO Science, Ontario and Prairie Region
Scott Parker	Parks Canada, Protected Areas Establishment and Conservation
Bev Ross	DFO FFHPP, Ontario and Prairie Region
Todd Schwartz	DFO IPO, Ontario and Prairie Region
Justin Shead	DFO Science, Ontario and Prairie Region
Jason Shpeley	DFO FFHPP, Ontario and Prairie Region
Regina Sobowale (Rapporteur)	DFO FFHPP, Ontario and Prairie Region
Mike Sullivan	Alberta Environment and Parks
Jeff Tyson	Great Lakes Fishery Commission

APPENDIX 3. MEETING AGENDA

Threshold Approaches and Status of Metrics Selected to Report on the State of Fish and Fish Habitat(SOFFH) in the Ontario and Prairie Region Priority Areas: Part 2

August 23-25, 2022 (Virtual via Microsoft Teams) 12:00 – 3:00 pm EST each day

Tuesday, August 23		
12:00 – 12:45	Chair welcome, round table introductions, CSAS process, objectives of meeting	Amanda and Gavin
12:45 – 1:15	SOFFH Ontario and Prairie Region project update	Sarah
Break 1:15 – 1:30		
1:30 – 1:45	Explain next steps and expectations of breakout sessions – review indicators and metrics	Cindy
1:45 – 2:45	Break out indicators and metrics – Biodiversity LGLA AESA	 Cody Cindy
2:45 – 3:00	Return briefly to plenary at end of day for any final instructions for day 2.	All
Wednesday, August 24		
12:00 – 1:15	Break out indicators and metrics – Water quality and connectivity LGLA AESA	 Cody Cindy
Break 1:15 – 1:30		
1:30 – 2:30	Break out indicators and metrics – – Land use/land cover and climate change LGLA AESA	 Cody Cindy
2:30 – 3:00	General discussion of indicators and metrics	All
Thursday, August 25		
12:00 – 12:10	Plan and objectives for 3rd day	Amanda and Gavin
12:10 – 12:30	Review of Approaches res doc	Cody
12:30 – 1:00	Feedback on Approaches res doc	General Discussion
Break 1:00 – 1:15		
1:15 – 3:00	Science Advisory Report • Constructive comments on indicators and metrics • Guidance for threshold development for unclassified metrics • Overview/agreement on draft bullets • Overview of contents of rest of SAR	Amanda and Gavin

APPENDIX 4. REFERENCES AND DATA SETS LISTED CHRONOLOGICALLY IN THE MS TEAMS CHAT

1. Benthic data and tolerance analyses (Windsor-Essex data and lower Thames)
2. Coker, G.A., Portt, C.B. and Minns, C.K. 2001. Morphological and ecological characteristics of Canadian freshwater fishes. Can. MS Rpt. Fish. Aquat. Sci. 2554: iv + 89 p.
3. Frimpong, E.A. and Angermeier, P.L. 2009. Fish traits: a database of ecological and life-history traits of freshwater fishes of the United States. Fish. 4(10): 487–495.
4. Kovalenko, K.E., Johnson, L.B., Brad, V.J., Ciborowski, J.J.H., Cooper, M.J., Gathman, J.P., Lamberti, G.A., Moerke, A.H., Ruetz, C.R., and Uzarski, D.G. 2019. Hotspots and bright spots in functional and taxonomic fish diversity. Freshwater Science. 38(3): 480–490.
5. Lamothe, K.A., Alofs, K.M., Jackson, D.A., and Somers, K.M. 2018. Functional diversity and redundancy of freshwater fish communities across biogeographic and environmental gradients. Divers. Distrib. 24(11): 1612–1626.
6. Government of Newfoundland and Labrador. Canadian Water Quality Index (CWQI) - CCME Calculator (online).
7. DFO 2021. Fish Biodiversity Database (online).
8. ECCC/USEPA nearshore framework significant LIDAR assessments have occurred in Erie and Ontario.
9. Choy, M., Lawrie, D., and Edge, C.B. 2018 Measuring 30 years of improvements to aquatic connectivity in the Greater Toronto Area, Aquatic Ecosystem Health & Management, 21(3): 342–351.
10. Ontario GeoHub. 2022. Aquatic ecosystem classification (AEC) for Ontario (online).
11. Ontario GeoHub. 2022. Ontario Dam Inventory (online).
12. Atlantic DataStream 2023. NCC Aquatic Connectivity Tool (online).
13. ArcGIS 2022. Sentinel-2 Land Use/Land Cover Time Series (Mature Support) (online).
14. DeCatanzaro, R., Cvetkovic, M. and Chow-Fraser, P., 2009. The relative importance of road density and physical watershed features in determining coastal marsh water quality in Georgian Bay. Environ. Manag. 44(3): 456–467.
15. EarthData 2016. Global Human Modification of Terrestrial Systems, v1: Land Use and Land Cover (LULC) | SEDAC (online).
16. The Nature Conservancy's resilient lands mapping tool to assess the resilience of natural landscapes to climate change: Resilient Land Mapping Tool (online).
17. Tang, R.W.K., Doka, S.E., Gertzen, E.L., Neigum, L.M. 2020. Dissolved oxygen tolerance guilds of adult and juvenile Great Lakes fish species. Can. Manuscr. Rep. Fish. Aquat. Sci. 3193: viii + 69 p.
18. Rahel, F.J. 2022. Managing Freshwater Fish in a Changing Climate: Resist, Accept, or Direct. Fisheries. 47 (6): 245–255.
19. Great Lakes Nearshore Webinar Series (online), with a methodology partly based on USEPA's 'Weight of evidence in ecological assessment' (2016).

20. Rogers and Biggs 1999 called the development of hypothesis of change as "Thresholds of Probable Change" and use these suggested metrics as a hypothesis to be tested over time with monitoring data.
21. Potential data sources for intactness: Data Meets Action: The Riparian Web Portal - Water Canada.
22. Contact Dr. Axel Anderson (axel.anderson@gov.ab.ca) for Alberta Environment and Park (AEP) Stream Connectivity Metric.
23. Contact Dr. Kim Green, who works on ecohydraulics on the Oldman River, at Apex Geoscience Consultants Ltd. (info@apexgeo.ca).