Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2022/078

National Capital Region

Information needs for considering cumulative effects in fish and fish habitat decision-making

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December 2022

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-46215-8 Cat. No. Fs70-5/2022-078E-PDF

Correct citation for this publication:

Hodgson, E., Chu, C., Mochnacz, N., Shikon, V. and Millar, E. 2022. Information needs for considering cumulative effects in fish and fish habitat decision-making. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/078. ix + 59.

Aussi disponible en français :

Hodgson, E., Chu, C., Mochnacz, N., Shikon, V. et Millar, E. 2022. Besoins en renseignements pour la prise en compte des effets cumulatifs dans la prise de décisions concernant le poisson et son habitat. Secr. can. des avis sci. du MPO. Doc. de rech. 2022/078. x + 69 p.

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ABSTRACT

The 2019 revisions to Canada's *Fisheries Act* (FA) introduced, for the first time, the legislative mandate within the *Act* to consider cumulative effects (CE) in decision-making. Under paragraph 34.1 (1)(d) the Minister shall consider "the cumulative effects of the carrying on of the work, undertaking or activity referred to in a recommendation or an exercise of power, in combination with other works, undertakings or activities that have been or are being carried on, on fish and fish habitat". Within Fisheries and Oceans Canada (DFO), the Fish and Fish Habitat Protection Program (FFHPP) is the lead authority responsible for undertaking these considerations when reviewing proposed works, undertakings or activities (WUA). FFHPP requested Science Advice on the process for considering CE in decision-making with specific reference to the risk assessment process undertaken in project review. The following are the objectives of this report: (1) Evaluate the relevant elements within the current risk approach to determine if sufficient information is gathered to inform the consideration of CE. This includes (a) identifying recommendations for additional elements to be included in the current risk approach to inform the consideration of CE, and (b) identifying the fundamental information needed on species and habitats in the region of a project when considering CE. (2) Provide advice on key characteristics required to determine how habitat sensitivity can be determined in the context of CE. Thus, we focused on outlining the information needed to consider CE within decision-making. First, we identified the information needed for CE considerations with respect to the spatio-temporal context of a WUA. This section outlines the information needed from a scientific approach, independently from that currently used by the FFHPP. It includes the information needed about the WUA, and the species and habitats within the region of the WUA. Second, using this list we explored the current risk approach used by the FFHPP and whether there are elements missing from it that would assist in ensuring the full suite of information is included for CE considerations. Finally, we identified important elements that require follow-up research and examination through subsequent Canadian Science Advice Secretariat processes.

GLOSSARY

This glossary is separated into three parts: definitions from the Fish and Fish Habitat Protection Program (FFHPP) in DFO, definitions from other federal agencies and legislation, and definitions from scientific sources including national and international literature and government scientific technical reports.

DEFINITIONS FROM FISH AND FISH HABITAT PROTECTION POLICY STATEMENT, 2019

Avoidance (DFO, 2019a): Avoidance is the undertaking of measures to prevent the harmful impacts to fish and fish habitat. Avoidance measures may include the choice of appropriate location and design of a work, undertaking or activity. In some cases, works, undertakings or activities may need to be redesigned to avoid harmful impacts. Careful timing of certain activities may also avoid impacts to fish and fish habitat. For some works, undertakings, or activities, harm may be fully avoided while for others, it may only be partially avoided. When impacts to fish and fish habitat cannot be fully avoided, mitigation measures must be undertaken.

Cumulative harmful impacts on fish and fish habitat (DFO, 2019a): The Department defines cumulative effects as: any cumulative harmful impacts on fish and fish habitat that are likely to result from the work, undertaking or activity in combination with other works, undertakings, or activities that have been or are being carried out. The consideration of cumulative effects provides a better understanding of the challenges to the aquatic ecosystem outside of the context of the reviews of specific works, undertakings, or activities. The Department is responsible for collecting the information needed to consider the cumulative effects of a proposed work, undertaking or activity.

Harmful impacts on fish (DFO, 2019a): The Department will apply a risk-based approach when evaluating the impacts of works, undertakings or activities on fish. Where death of fish is likely as a result of a work, undertaking or activity, the Department shall consider the relative contribution of the potentially affected fish and their habitat to the productivity of the relevant fisheries before considering issuing a s.34.4(2)(b) Authorization. In doing so the Department may consider issues such as which species are likely to be affected, at what stage of their life the impacts may occur, and which life-cycle functions may be affected.

Harmful impacts to fish habitat (DFO, 2019a): The Department will apply a risk-based approach when evaluating the impacts of works, undertakings or activities on fish habitat. Following from the definition of fish habitat noted above, the Department interprets “harmful alteration, disruption or destruction” as any temporary or permanent change to fish habitat that directly or indirectly impairs the habitat’s capacity to support one or more life processes of fish.

Mitigation (DFO, 2019a): Mitigation measures reduce the spatial scale, duration, or intensity of harmful impacts to fish and fish habitat when such impacts cannot be avoided. The best available mitigation measures or standards should be implemented by proponents. Mitigation measures include the implementation of best management practices during planning, construction, operation, maintenance, temporary or permanent closures, and decommissioning of a work, undertaking or activity.

Offsetting (DFO, 2019a): After efforts have been made to avoid and mitigate harmful impacts to fish and fish habitat, any residual impact must be addressed by offsetting. An offsetting measure is one that counterbalances unavoidable death of fish and harmful alteration, disruption or destruction of fish habitat resulting from a work, undertaking or activity with the goal of protecting and conserving fish and fish habitat. Offsetting measures should support available fisheries management objectives and local restoration priorities and be conducted in a manner consistent with the department's offsetting policy.

DEFINITIONS FROM OTHER FEDERAL DEPARTMENTS

Direct or incidental effects (IAA, 2020): means effects that are directly linked or necessarily incidental to a federal authority's exercise of a power or performance of a duty or function that would permit the carrying out, in whole or in part, of a physical activity or designated project, or to a federal authority's provision of financial assistance to a person for the purpose of enabling that activity or project to be carried out, in whole or in part.

Effect (IAA, 2020): means, unless the context requires otherwise, changes to the environment or to health, social or economic conditions and the positive and negative consequences of these changes.

Effects within federal jurisdiction (IAA, 2020): means, with respect to a physical activity or a designated project,

a) A change to the following components of the environment that are within the legislative authority of Parliament: (i) fish and fish habitat, as defined in subsection 2(1) of the Fisheries Act, (ii) aquatic species, as defined in subsection 2(1) of the Species at Risk Act, (iii) migratory birds, as defined in subsection 2(1) of the Migratory Birds Convention Act, 1994, and (iv) any other component of the environment that is set out in Schedule 3;
b) a change to the environment that would occur (i) on federal lands, (ii) in a province other than the one where the physical activity or the designated project is being carried out, or (iii) outside Canada;
c) with respect to the Indigenous peoples of Canada, an impact — occurring in Canada and resulting from any change to the environment — on (i) physical and cultural heritage, (ii) the current use of lands and resources for traditional purposes, or (iii) any structure, site or thing that is of historical, archaeological, paleontological or architectural significance;
d) any change occurring in Canada to the health, social or economic conditions of the Indigenous peoples of Canada; and
e) any change to a health, social or economic matter that is within the legislative authority of Parliament that is set out in Schedule 3.

Watershed (AAFC, 2020): A watershed is the area of land that drains into rivers and lakes, which, in turn, flow to a common outlet.

Work, Undertaking or Activity or WUA (CEAA, 2014): a physical work is defined as anything that has been or will be constructed (human-made) and has a fixed location. Examples include a bridge, building or pipeline. Natural water bodies, airplanes and ships at sea are not physical works. A physical activity is defined as an activity in the life cycle of a physical work and includes construction, operation, expansion, decommissioning and abandonment.

Zone of Influence (CEAA, 2018): sets a spatial limit beyond which the residual environmental effects of the designated project and other physical activities on a given valued component are not detectable.

DEFINITIONS FROM SCIENTIFIC LITERATURE AND GOVERNMENT TECHNICAL REPORTS

Activity-footprint (Elliott et al., 2020): An activity-footprint is that area, duration, intensity and frequency of an activity which ideally has been legally sanctioned by a regulator in an authorisation, licence, permit or consent, and which should be so clearly defined and mapped in order to be legally-defendable; it should be both easily observed and monitored and attributable to the proponent of the activity.

Additive effect (Murray et al., 2020): A combined effect produced by the action of two or more agents, being equal to the sum of their separate effects, i.e. the total impact is the sum of its parts.

Antagonistic effect (Murray et al., 2020): A combined effect produced by the action of two or more agents, being less than the sum of their separate effects.

Effects-footprint (Elliott et al., 2020): An effects-footprint is the spatial (extent), temporal (duration), intensity, persistence and frequency characteristics resulting from (a) a single pressure from a marine activity, (b) all the pressures from that activity, (c) all the pressures from all activities in an area, or (d) all pressures from all activities in an area or emanating from outside the management area. They will have adverse consequences on the natural ecosystem components, but also are likely to affect the ecosystem services from which society gains goods and benefits. Hence, the determination of the effects-footprint needs to include the near-field and far-field effects and near- and far-time effects because of the dynamics and characteristics of marine areas and the uses and users of the area. Similarly, the effects-footprints may be larger in extent and more persistent than the causing activity-footprint and the resulting pressures-footprints. They also need to encompass the effects of both endogenic and exogenic pressures operating in that area.

Cumulative Effects Assessment (Noble, 2015): is a systematic process of identifying, analyzing, and evaluating cumulative effects .

Cumulative Effects (Hegmann et al., 1999): are changes to the environment that are caused by an action in combination with other past, present and future human actions.

Exposure (Turner et al., 2003): frequency, magnitude, and duration of hazard. Within context of the CE CSAS, the frequency, magnitude, and duration of past and current works, undertakings or activities and other effects in zone of influence.

Ecological threshold (Groffman et al., 2006): is the point where a small change in environmental conditions result in a major shift in ecosystem structure and function.

Habitat Resilience (Eno et al., 2013): the rate of recovery of a current habitat following an impact. It is measured as the time required for a habitat and its constituent biological, chemical and physical features to recover to their characteristic state after disturbance.

Habitat Resistance (Eno et al., 2013): the ability of the current habitat to maintain its characteristic biological, chemical and physical features in the face of a temporary or prolonged disturbance, where high resistance results in low levels of impact.

Habitat Sensitivity (Hodgson et al. 2022, this document): the degree and duration of damage caused by an external factor to the habitat in its current state, where these are measured through assessing the habitat's resilience and resistance to the external factor.

Impact (ICES, 2019): The negative effects on ecosystems or ecosystem components resulting from the effect of pressures.

Integrated Planning (Cormier et al., 2017): aka Environmental Planning; is the process of facilitating decision making to carry out land or in-water development with the consideration given to the natural environment, social, political, economic and governance factors and provides a holistic framework to achieve sustainable outcomes.

Knowledge Systems (Bartlett et al., 2012): recognizes that Indigenous Traditional Knowledge and local knowledge, in addition to western science, are important sources of information about the status of fishes, fish habitat, and cumulative effects.

Local study area (Hegmann et al., 1999): the area in which the obvious, easily understood and often mitigable effects will occur.

Pathway of Effects (DFO, 2014a): description of the mechanisms through which potential environmental effects of a threat may cause a stress on a wildlife species.

Pressure (Elliott et al., 2020; Murray et al., 2020): Is an event or agent (biological, chemical or physical) exerted by one or more human activities to elicit an effect (that may lead to harm or cause adverse impacts).

Pressures-footprint (Elliott et al., 2020): A pressures-footprint indicates the mechanism(s) of change resulting from a given activity or all the activities in an area once avoidance and mitigation measures have been employed (the endogenic managed pressures). It does not necessarily coincide with the activity-footprint and may be larger or smaller. It also needs to include the influence and consequences of pressures emanating from outside the management area (the exogenic unmanaged pressures); given that these are caused by wide-scale events (and even global developments) then these are likely to have larger scale (spatial and temporal) consequences.

Reference Conditions (Reynoldson et al., 1997): the condition that is representative of a group of minimally disturbed sites organized by selected physical, chemical, and biological characteristics.

Region (Hegmann et al., 1999): Any area in which it is suspected or known that effects due to the action under review may interact with effects from other actions. This area typically extends beyond the local study area; however, as to how far will vary greatly depending on the nature of the cause-effect relationships involved.

Risk (IPCC, 2014): the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

Stressor (Murray et al., 2020): A type of direct or indirect, human related driver that causes undesired change in an ecosystem to any physical, chemical, or biological entity that can induce adverse effects on ecosystems or human health.

Synergistic effect (Murray et al., 2020): The interaction of two or more agents or actions so that their combined impact is greater than the sum of their individual impacts. Also, other impacts are included if their manners produce new impacts.

Threat (DFO, 2014b): any human activity or process that has caused, is causing, or may cause harm, death, or behavioural changes to a wildlife species at risk, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur. A human activity may exacerbate a natural process.

Threshold (ICES, 2019): Acceptable limits determined by society, applied to pressures, effects or impacts and used as a trigger for management measures. Can relate to quality standards, capacities, tipping points.

Uncertainty (IPCC, 2014): a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Watershed Planning (Ontario, 2015): Planning that provides a framework for establishing goals, objectives, and direction for the protection of water resources, the management of human activities, land, water, aquatic life, and resources within a watershed and for the assessment of cumulative, cross-jurisdictional, and cross-watershed impacts.

1. INTRODUCTION

The 2019 revisions to Canada's *Fisheries Act* (FA) introduced for the first time the legislative mandate within the *Act* to consider cumulative effects (CE) in decision-making. Under paragraph 34.1 (1)(d) the Minster shall consider "the cumulative effects of the carrying on of the work, undertaking or activity referred to in a recommendation or an exercise of power, in combination with other works, undertakings or activities that have been or are being carried on, on fish and fish habitat". Within Fisheries and Oceans Canada (DFO), the Fish and Fish Habitat Protection Program (FFHPP) is responsible for administering the fish and fish habitat protection provisions of the *Fisheries Act.* Included in these provisions is the subsection 34.1(1) factors to consider. As such, the FFHPP is the program responsible for the consideration of cumulative effects. Given this new consideration under the FA, FFHPP requested Science advice through the Canadian Science Advice Secretariat (CSAS) on how to approach CE when making decisions that affect aquatic environments, specifically on the information needed to consider CE within decision-making.

During the scoping phase of this CSAS, it was determined that the initial focus would be placed on specific considerations for CE in freshwater ecosystems for two reasons: a) marine programs already existed for similar considerations (e.g., marine protected area programs, and previous marine focused CE research within the department) and b) the majority of WUAs occur in freshwater. Freshwater ecosystems in Canada are highly diverse, have unique features as compared to marine systems, and a coordinated national perspective on CE is lacking. A narrower scope on freshwater was deemed to be most appropriate to address this gap for this CSAS, of what was expected to be a series of CSAS processes focused on CE.

1.1. CUMULATIVE EFFECTS CONTEXT

Freshwater ecosystems across Canada have experienced both intensive and extensive alteration from human activities leading to CE on fish and fish habitat (Bradford, 1994; Dudgeon et al., 2006; Minns, 2012; Olker et al., 2016; Reid et al., 2019; Smith et al., 2019). These alterations include but are not limited to urbanization, agriculture, hydrological alterations, and resource extraction that have resulted in changes to both habitat quantity and quality. Habitat loss, fragmentation, and alteration present some of the greatest threats to freshwater ecosystems (Brinson and Malvárez, 2002). The consequences of these threats have been observed in, for example, contamination in the Great Lakes (Cornwell et al., 2015), and imperilment of 76 freshwater or anadromous fishes that have been listed on Schedule 1 of the *Species at Risk Act* (Government of Canada, 2020; Lamothe et al., 2017; Lamothe and Drake, 2019). While most human development has occurred in the southern regions of Canada, (e.g., wetland loss has been greater than 75% in many areas of southern Ontario; Mitsch et al., 2001; Whillans, 1982), northern regions are significantly threatened by climate change (Bush et al., 2019) and multiple stressors in certain regions as well (Cott et al., 2015).

There are many ways that "cumulative effects" may be referenced in journal articles and grey literature and we considered this definition broadly (see further discussion in Jones (2016)). Cumulative effects can result from (1) a single human activity that results in multiple associated pressures (e.g., a dam that may change both river hydrology and flows, ecosystem type, and water temperatures), (2) a single activity type that occurs in a cumulative manner with many small or large activities repeating (e.g., hardening of shorelines for residential or industrial purposes across multiple segments of a lake shoreline), and (3) broad scale activities with a varying suite of resulting pressures (e.g., road development in a watershed, water flow management, nutrient and contaminant inputs). Moreover, it is well documented that when a suite of activities results in different types of impacts, the interactions between those impacts can cause unexpected responses. For example, responses to two or more impacts may cause an additive response, an antagonistic response (where the effect between multiple impacts is mitigated and less than additive), or a synergistic response (where the effect becomes magnified and worse than expected) (Crain et al., 2008).

There has long been recognition that CE assessments are key to watershed management and to understanding the impact of an individual or sets of WUA(s) on fish and fish habitat (Kenchington et al., 2013; Koops et al., 2013; Murray et al., 2020; Randall et al., 2013). Moreover, not considering the consequences of CE may undermine policy priorities of FFHPP (DFO, 2014a), in particular, the priority of "effective and efficient conservation and protection of fish and fish habitat" (DFO, 2019a p.5). Minns (2012) highlighted that the Policy of "no net loss" (Goodchild, 2004) can also be compromised when CE are not considered. That is, the assumption that the combination of mitigation, avoidance, and offsetting are able to result in no net loss to ecosystems (or no residual impacts) requires scrutiny, given the uncertainty that is a component of any decision-making or management process and potentially exacerbated by an accumulation of many small decisions with associated residual impacts. The recent revisions to the FA demonstrated an intention to strengthen opportunities for effective freshwater management. For example, reintroducing the "HADD" (harmful alteration, disruption or destruction) of fish habitat in addition to introducing considerations of CE. With this, there is a need for a fuller but practical understanding of how to approach CE when making decisions that affect aquatic environments.

Outside of the *Fisheries Act,* CE have been a part of the *Impact Assessment Act* (formerly the *Canadian Environmental Assessment Act*) since 1992, and their consideration has been legislated in other countries (Canter et al., 2012). As a result, many frameworks for assessing CE exist (e.g., EPA, 1999; Hegmann et al., 1999; YESAB, 2019) and decades of research on tools and methodologies to support these frameworks (Duinker et al., 2012; Hodgson and Halpern, 2018; Murray et al., 2020; Smit and Spaling, 1995; Stelzenmüller et al., 2018). For example, Murray et al. (2020) document four different approaches that are commonly used for CE assessments, based on the focal priority: activity, stressor, species or habitat, or area. The framework most relevant to WUA review is the activity-focused approach, however, an ecosystem approach (Cormier et al., 2022; ICES, 2019) would necessitate a combination of approaches, such as an area or habitat-level focus. This long history of past work on CE assessments provides a foundation of knowledge and approaches upon which FFHPP can build CE considerations into policy and management.

It is important to recognize, however, that even with a foundation of frameworks, tools, and examples, understanding and managing CE remains a challenge due to complexities in the jurisdictional landscape and uncertainties in many aspects of any individual assessment (Canter et al., 2012). While there has been extensive research linking single and paired stressors to species responses (Crain et al., 2008; Darling and Côté, 2008; Przeslawski et al., 2014) and tools to map multiple layers of human impact in a diversity of ecosystems (Danz et al., 2007; Halpern et al., 2008; Host et al., 2011; Murray et al., 2015; Smith et al., 2019), there remain challenges in understanding the interactive effects across multiple landscape changes (Hodgson and Halpern, 2018). These broader challenges highlight the crux of the issue for any project-level decision-making process: how does the addition of one additional WUA within the existing landscape contribute to the state of the system? When is a tipping point crossed? This research question was identified as the top priority when it comes to freshwater management in Canada (Dey et al., 2021) and is related to recent shifts in marine policy in the European Union (EU, 2017, 2008) where there is an increasing shift towards an assessment of collective or cumulative pressures.

1.2. PURPOSE AND SCOPE

The FFHPP requested Science Advice through the CSAS to support the consideration of CE when making decisions related to the *Fisheries Act*. To ensure compliance with the prohibitions against the death of fish or HADD, the FFHPP is responsible for reviewing proposed WUAs and working with proponents to avoid and mitigate harm to fish and fish habitat. If a proposed WUA cannot avoid or mitigate death of fish or HADD through standards and codes of practice, the WUA is reviewed using a risk-based tool that is outlined in the Risk Management Guide (RMG; Figure 1). The result of the risk assessment is a decision to provide a Letter of Advice (a non-legally binding set of recommendations) indicating the reviewer concludes that a WUA is not likely to cause death of fish or HADD, or a regulatory tool (a *Fisheries Act* authorization) indicating the reviewer concludes that a proposed WUA is likely to cause death of fish or HADD (Goodchild, 2004). Project review also involves identifying species at risk within the vicinity of the WUA and thus assessment biologists work under both the *FA* and the *Species at Risk Act* (SARA). This document focuses on the request for Science Advice on how to consider CE in a project review when applying the RMG. While this document covers the risk process, it is important to note that there are a number of proposed projects that will not be considered by FFHPP for review, because the WUA is outside of DFO's jurisdiction, or alternative tools such as standards and guidelines for lower risk projects are deemed relevant and review does not occur (DFO, 2016). These alternative tools are more recent and subsequently there was a substantial decline in the number of *Fisheries Act* authorizations and Letters of Advice issued by the Fish Protection Program (the former name for FFHPP) during the period 2003-2016 (Figure A1). Thus, the process we discuss covers DFO's role in considering CE prior to making a regulatory decision related to a WUA under the current DFO jurisdiction. The paired document by Cormier et al. (2022) developed for the same CSAS process focuses on the landscape context of CE within integrated planning (where from here on we consider the landscape in a freshwater system to be the watershed). The two documents and processes (watershed and WUA site-specific considerations) are intrinsically linked. Although WUA review is conducted on a project by project basis, the watershed context is crucial for CE considerations as the watershed level provides the broader context and an understanding of the current state of the habitat. Information on both scales, i.e., project and watershed level, needs to flow between the organizational units (as shown in Figure 2).

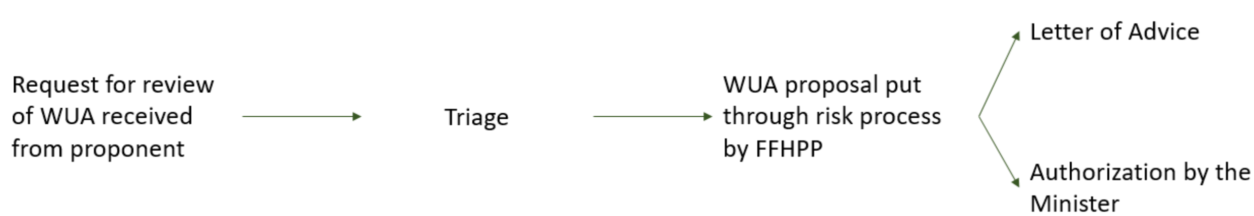

Figure 1. Schematic showing the process of project review from the time the request is submitted to FFHPP through the final decision. Not all projects go through a full review, as the triage phase is undertaken to identify whether a request for review is required, and if yes, whether information is complete; thus, not every project that goes through triage requires further review. If further review is required, the proposal goes through the risk process to determine if a LoA or full authorization is needed.

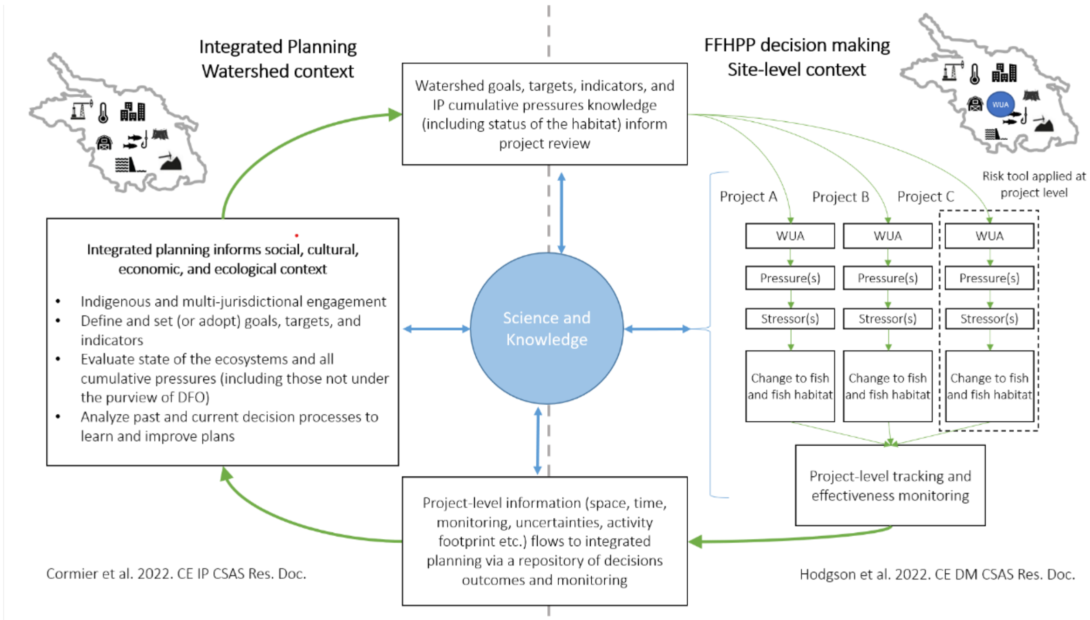

Figure 2. Cyclical flow of information between types of activities in the Fish and Fish Habitat Protection Program (FFHPP) of Fisheries and Oceans Canada with Science support and knowledge transfer is needed within and at each level of information exchange (i.e. human activity decision making and watershed level planning). Projects range from numerous small to large projects within the integrated planning spatial unit.

As noted earlier, this is likely to be the first in a series of requests to the CSAS for processes related to CE; thus, the focus here is on *information needed* to consider CE within decision-making at a project level. This applies to what we need to know about both species and habitats in the region of the WUA and how this information factors into the risk process used by FFHPP. A follow-up process may focus on *how* to use this information and implement a consistent approach to decision-making, which we highlighted in Section 4. We also focused on habitat sensitivity within a CE context as this came out of discussions in development of the Terms of Reference (ToR). While we focused on the risk process, it is not within the scope of this CSAS process to provide a full review of the RMG. Moreover, using a risk-based approach implies recognizing that there are substantial uncertainties that factor into decision-making (DFO, 2014a), which includes uncertainties associated with the impacts of the project, and those associated with the regulatory process and avoidance, mitigation and offset measures chosen. In order to scope this research document to be tractable and practical, we focused on information needs, but uncertainties should be reviewed critically in the future.

In collaboration with other members of the steering committee including both Science and FFHPP, the following objectives were identified in the ToR for this report:

1. Evaluate the relevant elements within the current risk approach to determine if sufficient information is gathered to inform the consideration of cumulative effects.
   a. Identify recommendations for additional elements to be included in the current risk approach to inform the consideration of cumulative effects.
   b. Identify the fundamental information needed about species and habitat in the region of a project when considering cumulative effects.
2. Provide advice on key characteristics required to determine how habitat sensitivity can be determined in the context of cumulative effects.

We presented the information in two main sections with a third section discussing future research needs. First, we identified the information needed for CE considerations with respect to the spatio-temporal context of a WUA. This section outlines the information needed independently from the approach currently used by the FFHPP. We then used this list to explore the current RMG and whether there are elements missing that would assist in ensuring a full suite of information is included for CE considerations. Finally, we identified some important next steps, especially what we expect would be addressed in follow-up research and in CSAS processes to address remaining gaps.

2. INFORMATION NEEDED FOR CONSIDERING CUMULATIVE EFFECTS

A number of core pieces of information are needed to thoroughly consider the individual and CE of a WUA. We outlined three essential lines of information: (1) details about the region of the WUA, (2) information on the species in the region, and (3) information on the habitats in the region. The main goal here is to identify the information needed for CE considerations so project reviews can be approached in a consistent manner across regions. This section directly addresses objective 1(b) *Identify the fundamental information needed about species and habitats in the region of a project when considering CE*.

The information to fill in these three key elements can come from a variety of sources and knowledge. Within the current framework used by FFHPP, much of the information is provided by the proponent. As a means to provide independent information, we identified example datasets that can be used to supplement or verify relevant details using a western science lens. In addition to western science, Indigenous knowledge or other forms of local knowledge could provide an understanding of the ecosystem in question. A holistic approach would involve both Indigenous knowledge and western science as equal but separate knowledge forms, in a two-eyed seeing approach to understand an ecosystem (Bartlett et al., 2012; Reid et al., 2021). However, in this document our discussion focuses on tools and approaches from western science.

In order to identify the necessary information for CE considerations, we build on past DFO efforts (Canter et al., 2012) and incorporate elements of existing frameworks for cumulative effects assessments (CEA) (Hegmann et al., 1999; Murray et al., 2020; US EPA, 2010). While these frameworks are prescriptive approaches to cumulative effects assessment, the FA requires “consideration” of CE and does not explicitly state “assessment”. However, the information needed to appropriately consider CE is the same as that to assess. The approach for how to then use that information may differ when “considering” and not “assessing” CE, though that subsequent step is outside of the scope of this document.

Many CEA have a similar set of information gathering steps, and often use the language of valued ecosystem component (VEC) regarding the particular ecosystem endpoints of interest. VECs may be biotic or abiotic and include for example, a fish species, a habitat forming species, or an abiotic factor such as water quality. We reviewed a suite of existing government and academic CEA frameworks, all of which lay out a series of steps for considering or assessing CE. We provide details of these frameworks in Appendix Table A1; however, the general steps are largely consistent among the different CEA guides and processes: 1) scoping – identifying the temporal and spatial bounds to consider, identifying the VECs that may be affected by the proposed action, and determining if there are other actions within the geographic and temporal zone of influence that may affect the same VECs, 2) describing a baseline for the VECs using historical data/trends, 3) conducting a risk analysis (i.e. analysis of potential CE) – considering CE over the entire geographical and temporal scale determined in step 1 and evaluating significance of impacts on VECs against thresholds 4) developing mitigation measures and a monitoring plan to allow for adaptive and effective management.

Canter et al. (2012) further identified a common suite of steps to cumulative effects assessment and management (CEAM) for VECs in relation to proposed projects: (1) identify incremental effects of the proposed work, (2) identify other works within the temporal and spatial scope of the proposed project, (3) gather necessary information about the VECs (4) connect the proposed project and other impacts in the study area to the VECs, (5) assess the significance of CE on the VECs and (6) where impacts are expected to be adverse, develop mitigation strategies. The core information gathering phases of any CEA or consideration of CE are items 1-3 identified by Canter et al. (2012) and remain our focus here. Items 1-2 include information about the project itself and the region of the work (Section 2.2 in this document). Item 3 includes information about the VECs—we do not use the language of “VECs” but rather discuss the fish and fish habitat in the region of the WUA—thus have broken it down into information needed on the fish species (Section 2.3) and information needed on the habitat (Section 2.4).

2.1. INFORMATION ON THE WUA AND REGION

Information needed on the project and region includes both the activities that are associated with the project and their pressures, and for CE considerations, the background condition of the ecosystem (Bradford et al., 2014), sometimes also called the level of impairment of the ecosystem. In order to identify these elements, the first step is outlining clear spatial and temporal scopes (Bradford et al., 2014; Kenchington et al., 2013; Randall et al., 2013), then compiling the watershed level information. One additional element as identified in Cormier et al. (2022), ideal for CE considerations, though not always available are the goals and targets for the management of the region more broadly. That is, if the WUA is occurring within a watershed that has a watershed management plan or previous assessment, the WUA could be considered within the context of what has been deemed allowable within the watershed.

2.1.1. Spatial and temporal scope

In a proposal review process, there needs to be a clear determination of the project footprint (Elliott et al., 2020); hereafter referred to as the “zone of influence” of the WUA. The boundaries used to define the zone of influence will have a substantial impact on the information gathered on species and habitats, and is a core step of all CEA processes (Table A1). Canter et al. (2012) wrote that the “[s]patial boundaries should minimally encompass the geographic area wherein the proposal’s effects are likely to occur.” Others have stated that the landscape-level scale is appropriate when considering CE (CEQ, 1997; Randall et al., 2013). For example, a watershed approach allows for consideration of the transport of pressures (lateral/downstream) and the movement of fishes within the watershed. In lakes, this would include lateral and vertical movements, whereas in stream networks fish can move laterally and longitudinally within rivers. This allows for a fuller consideration of the background context of the habitat, species within it, and both the direct and indirect effects of the pressures.

While recommendations for methods to identify the zone of influence is beyond this document, we briefly summarized information documented elsewhere. Identifying the zone of influence allows assessment biologists to determine what fish and fish habitat are within the scope of the project and its impacts, and therefore need to be included in the risk based determination. There are three spatial boundaries defined in guidance for implementing the *Canadian Environmental Assessment Act* 2012 (CEAA). The zone of Influence (ZOI) “sets a spatial limit beyond which the residual environmental effects of the designated project and other physical activities on a given VC are not detectable” (CEAA, 2018). The local study area “in which the obvious, easily understood and often mitigable effects will occur” (Hegmann et al. 1999). The regional study area that includes the areas where there could be possible interactions with other pressures (Hegmann et al. 1999). Similarly, Elliot et al. (2020) described three different spatial scales that should be considered (1) the activity footprint wherein the activity occurs, (2) the pressure footprint where the pressures associated with the project are felt, and (3) the effects footprint, the area where adverse effects are experienced. Within both of these definitions there are two important spatial scales: where the local project is at the smallest scale, and where the pressures are distributed at the broadest scale.

For the timeframe of consideration, although many CEA include consideration of past, present, and future actions within the region, the essential timeframe to be considered is the legacy effects of the activity itself. That is, the time it would take for the system to rebound from the disruption to habitat. If the impact is complete alteration and specific habitat type is lost, then a rebound will not occur and timeframes are even more important to consider, as not recognizing the change as a permanent loss would be highly consequential in a CE context.

Previous CSAS processes have discussed three physical scales of projects (Bradford et al., 2014; Randall et al., 2013). These include (a) local projects more likely to influence habitat quantity, (b) diffuse projects that may influence habitat quality, and (c) large scale projects that may result in "ecosystem transformation", which can also be thought of as ecological thresholds. It may also be the case that some projects result in both local habitat quantity impacts through direct effects, and diffuse impacts on habitat quality through direct or indirect effects. Where Randall et al. (2013) and Bradford et al. (2014) mentioned that small scale projects may have such an inconsequential impact that they do not warrant detailed review by assessment biologists, from a CE perspective, this is not necessarily the case. Whether it is a single large project or a series of small projects, each may lead to an ecosystem transformation (i.e., change in ecosystem structure and/or function). The consequences of ignoring a buildup of minor modifications may be substantial. Minns (2012) highlighted that at the time, the focus on large projects ignored this build-up and "fail[ed] to take account of the high frequency of smaller projects whose aggregate impacts likely outweigh those of large projects." We explored the importance of considering many small projects through examples for lake and river systems.

In lake systems, examples include accumulation within the waterbody of many small inputs from external factors such as pollutants or physical habitat modification such as shoreline alteration. Land use change including agriculture, deforestation, and developments of impervious surfaces can lead to excessive nutrient loading and losses or significant alteration of fish habitat (e.g., Cornwell et al., 2015; Evans et al., 1996). Increases in total phosphorous, for example, can lead to reduction in water quality and declines in intolerant fish species (Jennings et al., 1999). Alternatively, the incremental increase of shoreline development for residential and commercial use, such as erosion control structures, can lead to a diversity of lake ecosystem changes (Engel and Pederson Jr, 1998). These include changes in hydrodynamics, species community composition (Jennings et al., 1999), physical habitat alteration (Jennings et al., 2003), and biological habitat alteration (Elias & Meyer, 2003). In some cases there may be a mixture of land use of varying scales, leading to the shifts observed.

In river environments, examples include an accumulation of water extraction or loss in connectivity from many small activities that can add up to substantial habitat change. Substantial alterations to flow in Canadian river systems has occurred (DFO, 2013; Linnansaari et al., 2012). A past DFO CSAS process determined that flow reduction of <10% of the natural flow is considered unlikely to cause an impact on fisheries productivity (DFO, 2013; Linnansaari et al., 2012), recognizing that an accumulation of flow reductions greater than this can have ecosystem consequences. Although an individual project may result in a small amount of water extraction, the addition across many projects can result in a substantial change to instream flows. With respect to connectivity, while dams are recognized as large scale projects that cause ecosystem transformation, small scale alterations such as culverts associated with road and rail crossings when accumulated in large numbers, can reduce habitat accessibility for fishes (Sheer and Steel, 2006). Beechie et al. (1994) reported a loss of 37 km of tributaries due to culverts that blocked fish passage in the Skagit Watershed, USA. Therefore, the buildup of many small changes can have substantial consequences on lake and river habitats, and thus entire watersheds. Small projects should be considered along with mid to large size projects with respect to their cumulative effects.

2.1.2. Identify pressures associated with the WUA

The next set of information needs are about the WUA itself. All pressures associated with the project need to be identified. This is currently done using the [Pathways of Effects (PoE)] tools, which is under revision in a separate CSAS process (Brownscombe and Smokorowski, 2021). That separate CSAS process is assessing the accuracy and completeness of updated PoE diagrams to ensure that the linkages between WUAs and their potential impacts on fish and fish habitat are comprehensive. The information on particular impacts or pressures associated with a WUA is core to the following sections where species and habitat sensitivity are identified. It is important to CE considerations in particular to identify the specific pressures, as these will be considered when assessing whether other activities in the region have similar effects (CEQ, 1997) or whether there are multiple pressures with varying system responses that may be antagonistic or synergistic.

2.1.3. Identify the reference conditions of the region

Essential to CE considerations is the need to understand the reference conditions and the current landscape of human modifications in the zone of influence. This can be thought of as the level of past disturbance. Reference conditions help provide an understanding of how impacted the region is, what activities and associated pressures are currently present, and therefore, how the habitat in the zone of influence may respond to additional stress. This information is closely linked to those below on fish and fish habitat sensitivity, as sensitivity to additional stress may be influenced by how stressed a fish species or habitat is already.

Although there is a diverse jurisdictional landscape in Canada and many activities impacting freshwater systems are not managed by DFO (e.g., some forestry and water licensing are managed at the provincial level), these activities and their associated pressures are highly relevant to understanding the condition of any individual watershed. The broader suite of activities and associated pressures that are outside the purview of DFO still contribute to understanding the current state of fish and fish habitat within the context of any further modification and should be considered in each WUA review. While resources for identifying the reference condition are discussed in Section 2.3.2, in many situations the reference condition is not known for a given watershed, and therefore requires an integrated planning approach to address this knowledge gap at the watershed scale (see Cormier et al. 2022).

2.2. INFORMATION ON FISH SPECIES

The integration of CE into fish habitat decision-making for project review requires fundamental information on the fish species that inhabit the area of the WUA for all or some of their life processes. Specific information needs are: (1) fish species lists including native, introduced, at-risk, extirpated (for reasons explained below), and aquatic invasive species, (2) characteristics of those species, (3) the status of those species (although a species at risk has a known status, native species may or may not be assessed and information needs to be collated), and (4) their sensitivity to relevant pressures. Although a thorough set of information from this list would be ideal, it may be challenging to obtain for all components. The following sub-sections outline the relevance of this information and a growing volume of resources that can be leveraged to fill information gaps. We ended this section with a discussion of how to use the information sources that have been compiled (Tables 1 and 2), to independently determine a likely list of species within the region of the WUA.

The focus of examples and past literature cited in this section is on freshwater fish species, but it is recognized that the *Fisheries Act* is more inclusive and defines fish as "a) parts of fish, b) shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals, and c) the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans or marine animals." The methods outlined below may be beneficial for similar information needs for shellfish, crustaceans, and marine species.

2.2.1. Identify species present

The spatial distributions of freshwater fish species in Canada are shaped by several environmental factors. These include historical factors such as post-glacial recolonization, broad-scale factors such as climate and geology, and local factors such as lake size or river morphology, biotic community, and local habitats (Jackson et al., 2001; Mandrak and Crossman, 1992; Tonn, 1990). The full suite of fish species within the area of the proposed work should be identified as part of the project review; in the current approach, this list is provided by the proponent which may be based on a single sampling event. Having this validated full list is important because the magnitude of CE is dependent upon the traits and tolerances of the fish community within the WUA area, and focusing on a subset of species brings the risk of missing important prior impacts. This includes native (both extant and extirpated), introduced, invasive species (AIS), and species at risk (SAR), where information for some species are already available, such as species at risk in the SARA Registry. In many project review processes, the species included are those that are considered VECs (Hegmann et al., 1999), however, as the *Fisheries Act* applies to all fish and fish habitat, the list should include all fish species in the area of the WUA.

Extirpated species should be included where applicable because their extirpation may be indicative of previous human activities and stress in the region (Limburg and Waldman, 2009). For example, Lake Sturgeon (*Acipenser fulvescens*) have been extirpated from much of the Lake Winnipeg drainage area due to commercial overexploitation and habitat alteration, usually associated with hydroelectric dam construction and operation (Ferguson and Duckworth, 1997). Therefore, their extirpation reflects patterns of riverine fragmentation and watershed development. Brook Trout (*Salvelinus fontinalis*) are another species that has been extirpated throughout much of their native range (Hudy et al., 2008). In this case, their extirpations are indicative of the loss of cold-water habitats in rivers associated with the development of forested watersheds (Flebbe et al., 2006).

In addition to proponent supplied species lists, several data sources can be mined to understand freshwater fish species distributions in Canada and within the region of a WUA (Table 1). A jurisdictional internet scan was conducted to compile a list of resources that can be used to identify native and non-native species, AIS and SAR within the region of the WUA. The compiled datasets are the products of local, provincial, national, and global monitoring and inventory assessments of species distributions. Non-native species (defined here as native species introduced outside their native range) records are typically acquired from stocking records and in some jurisdictions, genetic analysis. AIS are tracked by many government agencies and non-governmental organizations. SAR are tracked federally and provincially, and by non-governmental organizations (Table 1). Although effort was made to identify readily available sources of information, more information may exist in the grey literature or internal data repositories at various institutions.

2.2.2. Determine species characteristics

Once species within the area of the WUA have been identified, information on species characteristics should be compiled and reviewed because they have bearing on the scope of habitat use. Freshwater fish species have ontogenetic shifts in habitat associated with changing diet, shelter, and spawning needs as they progress through their life cycles (Hayes & Landis, 2004). There are four key species characteristics to consider: (1) life history stage, (2) life processes undertaken, (3) duration of presence, and (4) functional traits. The life history stage present within the area of the WUA is related to how the habitat is being used (life process) and the duration of that habitat use. For example, if the project area overlaps with spawning habitat, there will be both adults and eggs present (if not more life stages), and the timing and duration of that habitat use will be consistent with their life history. Functional traits are morphological, biochemical, physiological, phenological, or behavioural characteristics of organisms that shape their growth, reproduction, and survival (Nock et al., 2016; Violle et al., 2007). Traits that are often measured for fishes include: trophic position, body size, temperature preferences, fecundity, growth rate, and longevity (Keck et al., 2014). Functional traits can dictate habitat use. For example, large-bodied fishes tend to have larger home range sizes than small-bodies species due to greater dispersal abilities (Minns, 1995), and the former may frequent different habitat types or make forays to different patches of similar habitat types more often than small-bodied species (Troia et al., 2019).

From a project review and CE perspective, it is important to understand the complexity of species characteristics that influence community-level habitat use. Many resources for this exist and have been compiled (Table 2), and these data will aid assessment biologists when evaluating the sensitivity of species and communities to habitat perturbations associated with proposed WUAs or aid in determining the lasting effects (temporal scope) of past or proposed WUAs. For example, species with longer generation times will have a slower recovery rate from declines in population size. Literature and internet resources for freshwater fish species life history and functional traits were synthesized here to inform project evaluations (Table 2) and needed tool development.

2.2.3. Determine species status of all fish species in impact footprint

In addition to core information about the species within the project area, knowing the status of the populations or community present will assist in providing a full understanding of the system. This includes not only the status of SAR, where the status is already known, but also native species, which may not have been assessed. Status reflects how well species traits respond to habitat conditions and can provide insights into how past impacts may have (or have not) resulted in population shifts. Understanding whether a fish population or community is healthy, increasing in abundance, in decline, or at risk will help provide context for knowing whether further habitat modification may or may not have population level impacts.

There have been a number of methods used to determine species status, including both models of population size and trajectory, and indices of status when direct estimation is not feasible. Population trends are often estimated in stock assessments (e.g., Pacific Salmon Explorer) using metrics such as catch-per-unit-effort, density, biomass or habitat occupancy. Other metrics used to describe community status include indices of biotic integrity, biodiversity indices, and biomass size spectra (see De Kerckhove et al., 2008; Fausch et al., 1990; Gaston et al., 2000; Medley et al., 2009). Internet and jurisdictional scans were conducted to identify readily available sources of species status information (Table 1). Several local, regional, national, and international resources have been compiled, and this information can be used for project evaluations and decision-making, when available for the area of the WUA. Status data also may be readily available for SAR assessed by the International Union for Conservation of Nature's

(IUCN) Red List or the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Table 1).

To evaluate CE, assessment biologists need an understanding not only of the species and habitat present and their statuses, but also of the relationship between habitat and population or community status. That is, although we discussed the processes for compiling species information and habitat information separately, the two are intrinsically linked, as species status depends on habitat (in addition to other activities, like fishing), and the level of both the habitat availability and species dependence will influence status. However, the heterogeneity in fish communities, habitats, and stresses as well as the dynamic nature of ecosystems make these species-habitat relationships difficult to decipher. Many empirical examples exist (e.g., Anlauf-Dunn et al., 2014; Downing and Plante, 1993; Rosenfeld et al., 2000), and many ecological models also have been developed to uncover some of these relationships. For example, Bradford et al. (2014) provide a synthesis of models that relate productivity ($kg^{-1}\cdot ha^{-1}\cdot yr^{-1}$) to life history traits such as body size (population growth rate; r), growth parameter (k), fecundity, and age at maturity (T, years). Randall and Minns (2000) developed a Habitat Productivity Index that can be used to measure the productive capacity of habitats as the sum of production of all cohabiting fishes over a defined time period within a defined area. Hayes et al. (2009) described how habitat can be quantified within a study area and linked to age-structured population models to determine how habitat availability and pressures impact fish. DFO (2014b) outlined productivity-state response relationships that describe the likely response of fisheries productivity to various types of habitat changes linked to PoE . Many of the PoE diagrams were developed using surrogates of productivity, and gaps still remain in our knowledge of the relationships between habitat condition and species status.

2.2.4. Determine species sensitivity to relevant pressures

The plasticity of species traits shapes their tolerances and ability to respond to impacts from individual and cumulative perturbations. More sensitive species exhibit greater responses to external pressures than less sensitive species. Variation in species sensitivity can directly influence their probability of decline, endangerment, and ultimately extinction (Keinath et al., 2017). Some factors to consider when evaluating species and communities within the area of the WUA are the tolerances and adaptive capacity of those species, their habitat specialization, and environmental triggers for their life processes (e.g., spawning phenology).

Cumulative effects can amplify the magnitude of certain pressures or increase the number of pressures that test the tolerances of fishes. In an ideal case, the pressures resulting from the WUA and the sensitivities of all species within the area of the WUA to those pressures would be known. Unfortunately, this is rarely the case, but knowledge is growing. Many of the models described above (2.2.3) can be used to provide insight when data are lacking to determine the sensitivity of different species to different perturbations. The trait databases identified here can be used to understand the sensitivities of species (e.g., Jarić et al., 2019), and empirical databases for the sensitivity of some species to certain perturbations are readily available (Table 2). For example, Trebitz et al. (2007) derived turbidity tolerance estimates for 54 fish species in Great Lakes coastal wetlands and Tang et al. (2019) summarize oxygen tolerance and sensitivity for assemblages of fish species in the Great Lakes.

2.2.5. How to consistently determine the species in the area of the WUA

Local and proponent supplied information should provide a robust understanding of the species present in the area of the WUA, but if this information is not available or is incomplete, a combination of broader-scale data and the species traits identified above can be used to determine which species are likely present. An example decision tree illustrates how the information may be prioritized to determine the likelihood of species presence or absence (Figure 3). In some cases, the habitat characteristics and traits evaluated may be dependent upon the habitat information supplied by the proponent therefore, the series of filters (e.g., substrate, vegetation) should be modified accordingly. The first filter of the tree is the tertiary watershed species list available in Habitat Ecosystem Assessment Tool (HEAT) (DFO, 2019b) (Table 1). Species lists for the tertiary watersheds can be thought of as regional species pools. Filtering species by watershed will ensure that species with ranges limited to, for example, the Great Lakes basin, would not all be found in the area of the WUA in western Canada. The second filter can be aquatic ecosystem preference, e.g., lake, river, wetland, which can be determined using resources such as Coker et al. (2001) and HEAT (Table 2).

Habitat characteristics within the zone of influence can then be compared to the species traits (Table 2) to determine which species are likely to occur within the relevant area. As ectotherms, fish communities and individual species distributions in Canada are strongly influenced by the availability of suitable thermal habitat (Caissie, 2006; MacDougall et al., 2018). Water temperature governs the metabolic processes that allow species to persist in different habitats. Therefore, the third filter for identifying species within the area of the WUA is thermal guild and several references are available that identify the guilds of different species (Table 2). The physical characteristics of the area of the WUA can be used to infer or determine the likely thermal conditions within the project area and differential impacts of thermal change on guilds (e.g., Wenger et al., 2011). For example, if the area of the WUA is within a small shallow lake in southern Ontario, it is unlikely that lake-dwelling cold-water species such as Lake Trout (*Salvelinus namaycush*) would be found within that lake even if it may be found in deep lakes within the same tertiary watershed. Likewise, some species known to occur in cold, headwater regions of rivers are less likely to be found in the warm outlet reaches. Several studies, monitoring programs, and models exist to understand or estimate the likely thermal conditions within the area of the WUA if that information is not readily available (e.g., the seasonal temperature-profile model for dimictic lakes, Minns & Shuter, 2012; the empirical model of maximum weekly average stream temperature in British Columbia, Moore et al., 2013).

The next series of filters use finer-scale habitat conditions such as flow regime, water chemistry, vegetation or substrate to determine species presence or absence (Figure 3). For example, in rivers, flow regimes (magnitude, frequency, timing, duration, and rate of change in flows) shape their ecological integrity and species are adapted to different regimes (Macnaughton et al., 2016; Poff et al., 1997). Therefore, the flow regime within the area of the WUA (national synthesis of gauged rivers in Canada available via Jones et al. (2014)) can be used to filter which species are present. Alternatively or additionally, if the project area includes sand habitats, one could filter the species list to those who use sand for some or all of their life cycle. Likewise, if some of the project area is covered in emergent and submergent macrophytes, the species list can be further filtered to those preferring vegetation for some or all of their life cycle (Figure 3). HEAT can be used to determine the habitat supply for species present within a project area based on matrices of depth, vegetation, and substrate associations (DFO, 2019b). The number of filters included in the decision tree is ultimately dependent on what is known about the habitat conditions within the area of the WUA. Although a riverine, cold water example is presented for simplicity (Figure 3), multiple habitat types (e.g., rivers and lakes; or thermal regimes, such as cold and cool-water) can be considered simultaneously and used for practical decisions based on fisheries and habitat goals and which groups or life stages are more likely to benefit or be impacted.

This approach may also work for determining which SAR or AIS are within the project area if information on their habitat preferences are known. But as this information is often not known for newly invaded species, habitat information from their countries of origin can be used to define their habitat preferences. Because SAR are rare, it can be difficult to determine their habitat preferences, in these cases information from closely related species or species that share similar niches or guilds may improve understanding of their habitat preferences. Datasets available within DFO, ECCC, COSEWIC, and other regional or local agencies may be used to determine which SAR or AIS are present or absent (Table 1).

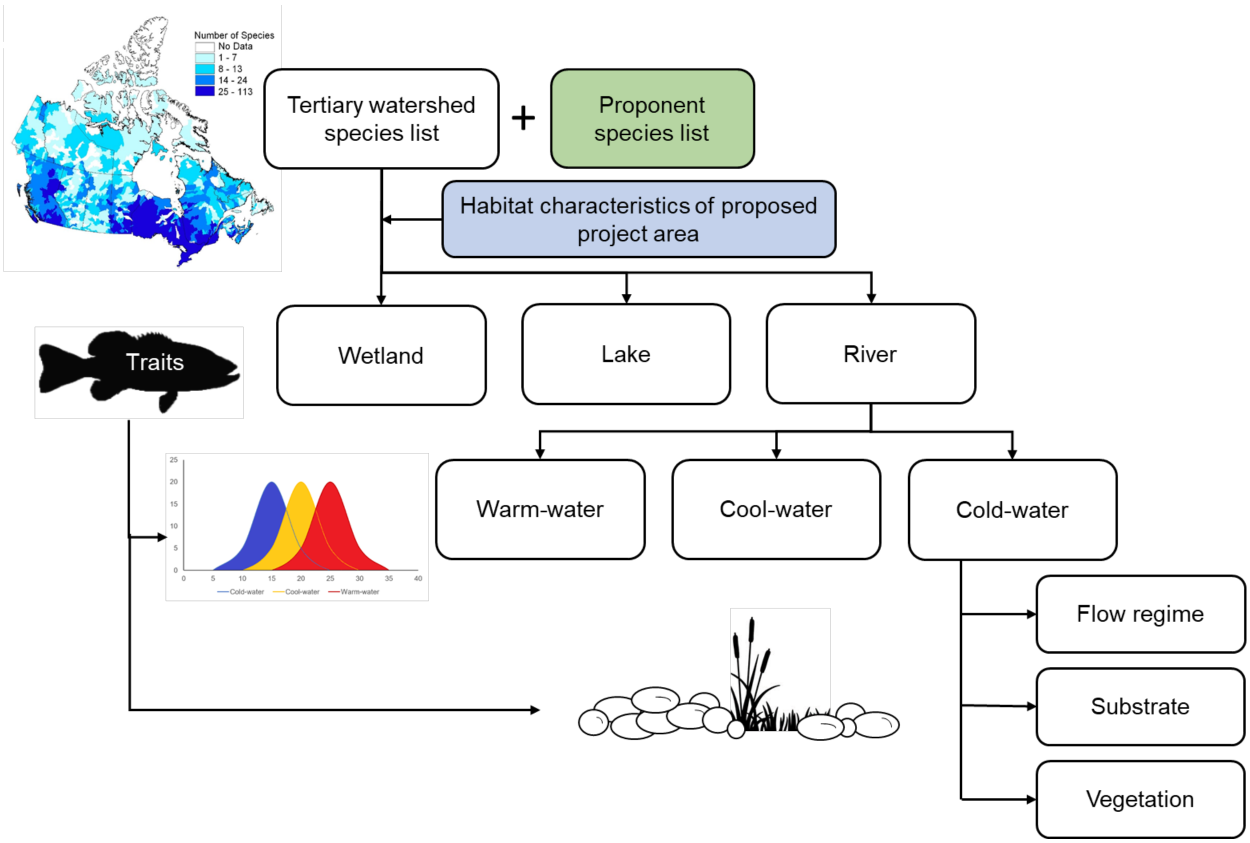

Figure 3. Example decision tree demonstrating how trait data can be used to determine which fish species are likely to be found within the area of the WUA or different habitat types within WUA area, when proponent species lists are incomplete or require verification.

2.3. INFORMATION ABOUT HABITATS

Habitat is defined in the *Fisheries Act* as “water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life processes, including spawning grounds and nursery, rearing, food supply and migration areas.” Information on habitats includes the mosaic of conditions created by the interactions among the physical (e.g., substrate type), chemical (e.g., water chemistry), and biological (e.g., habitat forming plants, competition with other individuals) variables within the project area (Minns and Wichert, 2005). Thus, unlike the process of identifying fish species and their characteristics, habitats can be thought of as a suite of characteristics spanning multiple dimensions. This makes habitats more complicated to understand in the context of their responses to stress. Consider a case where there is a shift in stream temperature from a new project. When considering a fish species’ response to a change in stream temperature, we would consider the life stages present and their sensitivity to this change. However, when considering a habitat response to a change in stream temperature, we may be interested in both aquatic plants that are habitat forming and how they respond to temperature, but also may consider temperature itself as a characteristic of the habitat. In this case, there is more to consider regarding habitat responses than there are for fish responses, creating challenges when trying to understand habitat responses to an individual pressure, and even more so with cumulative pressures. Moreover, habitats are not constant in their characteristics through time, they are dynamic with variations due to natural fluctuations and also from persistent pressures (e.g., climate change). Thus, any understanding of a habitat at one point in time is only a snapshot and will likely not characterize their dynamic.

In this section, we focused on three main information needs: (1) identify the habitat(s) within the zone of influence, (2) determine the current status of that habitat, and (3) determine the sensitivity of that habitat to relevant pressures. These pieces all contribute to understanding how a habitat may change from the addition of the WUA(s) under consideration. As with the species information needs above, this list is ideal, however, in many cases a comprehensive suite of information is not feasible at this point. Regardless, the following sub-sections highlight the relevance of this information for FFHPP in the context of CE, and the growing volume of resources that can be leveraged to fill information gaps.

2.3.1. Identify the characteristics of the habitats present

Freshwater habitats in Canada are vast, diverse, and numerous with approximately 2 million lakes, millions of kilometers of streams and rivers, and roughly 1.29 million km^2 of wetlands. National and regional datasets of the spatial distributions of watersheds, lakes, rivers, and wetlands are available for the impacts of WUA evaluations (Table 1). These data are periodically refined as more advanced monitoring technology (e.g., inexpensive data loggers), and satellite imagery and mapping make it possible to see and map developed and remote areas of the country with greater accuracy. Depending on the scale of the proposed WUA, it may be necessary to understand which waterbodies are hydrologically connected to the proposed area. This connectivity is important when evaluating CE because lateral and longitudinal effects can be lessened or amplified depending on the location of the proposed WUA relative to other aquatic ecosystems (Lapointe et al., 2014).

Descriptions of specific habitat types within the area of the WUA are currently determined from information submitted by proponents using a variety of means to identify those habitats. Should independent evaluation be conducted, they could be mapped using spatial data collected via remote sensing, hydroacoustics, or underwater video (Bakelaar et al., 2004; Koops and Chu, 2001). From a CE perspective, the number of species and complexity of effects may increase as the number of habitat types increase within the area of the WUA, so it is critical to have a good accounting of habitat. In addition, it is important to recognize that because habitats are dynamic, effects may manifest differently across spatial-temporal scales (e.g., Eelgrass, Murphy et al., 2021).

Understanding the habitat characteristics within the area of the WUA is necessary to evaluate how existing and future CE may disrupt the quantity, quality, and functioning of those habitats. Habitat classifications, which are groupings of habitat characteristics, are informative for project evaluations because they identify similarities and differences among habitat variables, provide a framework for making predictions about the impacts of CE in similar systems elsewhere, and provide a common language for effective monitoring and management. However, our predictive capacity is limited by knowledge of the system, which is typically driven by the extent of ongoing monitoring and assessments before and after WUAs have been undertaken. Although a national freshwater habitat classification does not currently exist, some regional classifications do (Table 1). Similarly, although a consistent approach to monitoring does not exist nationally, ensuring similar data is tracked for all projects will contribute to a broader and more comprehensive understanding of the state of the habitat.

Quantifying the extent and quality of habitat requires an understanding of the abiotic features of a particular habitat type that are necessary for the growth, survival, and persistence of individuals and/or populations of fish (i.e., fundamental niche; Peterson et al., 2011; Rosenfeld, 2003). However, determining habitat requirements for these life processes is challenging. Therefore, ecologists often focus on demonstrating habitat selection; this is done by relating occupancy of a particular habitat with density or frequency of use (Rosenfeld, 2003). But because habitat selection does not directly inform consequences on biological processes (e.g., growth rate) or avoidance of a particular habitat, it is not necessarily a reflection of an individuals' habitat requirements. In the absence of these data, there has been a movement to quantify habitat associations (i.e., habitat use) across broad spatial-temporal scales and then use a class of advanced statistical models to infer the relative importance of habitat types based on species-habitat response relationships (Guisan and Thuiller, 2005). These models evolved from previous iterations of habitat suitability models, can handle a wide range of data types (e.g., presence only, presence-absence, abundance), and are capable of accounting for important processes that can hinder accurate understanding of species-habitat relationships (Guisan and Thuiller, 2005; MacKenzie et al., 2002; Rosenfeld, 2003). For example, occupancy-detection models are a form of generalized linear models that can provide more precise species-habitat relationships by accounting for imperfect detection during sampling (Comte and Grenouillet, 2013; MacKenzie et al., 2017, 2002). Habitat suitability indices (HSI) have also been used for decades to determine the quality and quantity of habitat available for a species in a given area (De Kerckhove et al., 2008; Wakeley, 1988). These indices are based on species–habitat relationships that score the suitability of variables from 0 to 1 with 0 indicating poor or unsuitable habitat and 1 indicating good habitat (Wakeley, 1988). However, HSIs are no longer used as extensively because they often yield less precise species-habitat relationships than those derived using other advanced statistical modelling methods (Railsback, 2016).

Habitat associations are foundational elements of habitat accounting tools. Specifically, both the quality and quantity of habitat for a species, or fish community, can be quantified using habitat associations within a WUA or a subset of habitats within the broader ecosystem. For example, HEAT can be used to identify the habitat types within the area of the WUA (DFO, 2019b). The tool uses databases on fish species distributions, and their habitat associations at different life stages to quantify the suitability of an aquatic site or sub-area for those species. The main output is weighted habitat supply (weighted suitable or usable area) (DFO, 2019b). HEAT integrates user-defined habitat characteristics provided through different information sources (e.g., proponent environmental assessments; publicly available reports, papers, and/or databases). Users enter their project location and information on water depths (0-1, 1-2, 2-5, 5-10, and 10+ m classes), vegetation types (emergent, submerged, no cover), and substrate types (bedrock, boulder, cobble, rubble, gravel, sand, silt, clay, and hardpan-clay) within the project area as well as other factors that can be input as quality adjust factors. HEAT then uses this information to create habitat patches and quantify the weighted habitat supply for the fish community (DFO, 2019b). From a CE perspective, HEAT can be parameterized using different habitat scenarios (e.g., pre- and post-project) to understand potential changes in habitat supply.

An internet scan was used to identify additional sources of readily available freshwater fish habitat characteristic and classification information (Table 1). For example, Nature Conservancy of Canada has developed a classification for the Northern Appalachian–Acadian Region of Canada that categorizes all streams and rivers in the region based on five ecological variables: size, gradient, temperature, alkalinity, and tidal influence (Millar et al., 2019).

2.3.2. Determine habitat status

After the habitat and its characteristics have been described, the available information in combination with additional sources can be used to determine the habitat status within the zone of influence. Reference conditions (in line with those discussed in 2.1.3) help provide an understanding of how impacted the region is, what activities and associated pressures are currently present and therefore, the nuances of how the system may respond to additional stress. Habitats in remote, pristine regions of Canada that are minimally perturbed by anthropogenic activities, are likely to be in relatively good condition but in more developed regions, current habitats may reflect repeated waves of disturbance (Harding et al., 1998). For example, southern Ontario watersheds where natural forest cover was replaced with agricultural lands, and more recently, impervious cover with urban and suburban development are most degraded (Allan et al., 2013).

Habitat status can be determined in different ways. First, monitoring databases describing the state of habitat or certain habitat variables are available for different regions of the country. The status and trends reported in those databases can be used to determine the condition of the proposed work area, should the project area overlap with monitored sites (Table 1). For example, past approved projects have been input into Program Activity Tracking for Habitat (PATH) in recent years and the data for some projects could be extracted to provide context for historical reference (DFO, 2014) or ECCC's National Long-term Water Quality Monitoring Data can be used to determine water quality and status. Other national datasets such as HydroATLAS include habitat data that can be used to evaluate habitat condition via metrics such as upstream watershed land use or instream fragmentation (Linke et al., 2019; see additional resources in Table 1).

Second, many of the tools described for evaluating species or community status above (2.2.3) can also reflect the state of habitat. Outputs from these tools (e.g., abundance, presence-absence) can also be parameterized for different habitat scenarios to determine how current conditions in the area of the WUA compare to the expectations under near pristine or other relevant habitat conditions. For example, generalized linear models can be used to develop species-response curves across habitat gradients to identify the range of environmental conditions that are best for an individual species or community assemblage. Response curves based on abiotic parameters (e.g., temperature, dissolved oxygen) can be linked to physiological thresholds (Eliason et al., 2011; Tang et al., 2020) and productivity indices (Koops et al., 2013). A range of optimal conditions can be used to guide determination of the state of habitat in the absence of empirical data. HEAT can also be scenario tested to determine the current state of habitat in the area of the WUA. If pristine, past, or another relevant habitat condition is known, HEAT can be used to compare the weighted suitable areas between the current habitat and those reference conditions (DFO, 2019b).

Lastly, geospatial datasets are available for some stresses across Canada and can be used to report on current river, lake or wetland states, should the area of the WUA overlap with the extents of those databases (Table 1). For example, the National Road Network can be used to determine the degree of fragmentation associated with crossings within the proposed work area however, we acknowledge that provincial or territorial, i.e., local data sources, may include higher resolution information, e.g., the road networks in British Columbia and Ontario include logging roads not captured in the national dataset, and data quality should be considered when applying to project reviews. Because freshwater ecosystems are intrinsically linked to their watersheds, watershed stress indices can be used as proxies for the state of habitat (e.g., Chu et al., 2014; Millar et al., 2019; WWF-Canada, 2020; Table 1). Where habitat status information is not available, or are provided at a scale that is coarser than that needed by assessment biologists, it should be a priority item for the Integrated Planning section within DFO to undertake watershed level planning processes to redress data gaps (see Cormier et al. 2022).

2.3.3. Determine habitat sensitivity to relevant pressures

Habitat sensitivity is a concept frequently used to define or measure how a particular habitat will respond to changes driven by external factors, either anthropogenic or natural. In parallel to species sensitivity, more sensitive habitats will exhibit greater responses to external stress whether that is in relation to the size of response or the duration of time until the habitat is able to recover. However, how habitat sensitivity has been assessed in the past is more variable than species sensitivity; this may be in part because habitats often consist of multiple components (physical, chemical, and biological). We detail how habitat sensitivity has been defined and assessed by authors studying both freshwater (Rood and Hamilton, 1995; Webb et al., 1994) and marine (Eno et al., 2013; ICES, 2003; Korpinen and Andersen, 2016; MacDonald et al., 1996) ecosystems. The definitions included here were pulled from both journal articles and grey literature found using both the Federal Sciences Library and Web of Science.

There is substantial range in how habitat sensitivity has been assessed and defined (Table 3). Authors vary between considering the sensitivity of a habitat to a particular pressure or suite of pressures (e.g., Aneseyee et al., 2020; Eno et al., 2013), and considering the general characteristics of a habitat and its overall sensitivity level (DFO, 2007). In addition, while some authors explicitly integrate measures of existing land use into habitat sensitivity assessments (e.g., Rood and Hamilton, 1995), others do not. The most important difference between approaches is the variation in metrics used to assess habitat sensitivity. Some authors assessed habitat sensitivity based on a combination of habitat characteristics and fish species present in the habitat (DFO, 2007; Hatfield Consultants, 1996; Webb et al., 1994). For example, the 2007 version of the risk framework included species sensitivity, species' dependence on habitat, habitat rarity, and habitat resilience as the suite of metrics representing habitat sensitivity (DFO, 2007). Alternatively, others considered only habitat characteristics (Aneseyee et al., 2020; MacDonald et al., 1996). For example, MacDonald et al. (1996) defined habitat sensitivity as a combination of the fragility of the habitat, its recovery from stress, and the intensity of the stressor activity. A limiting factor in some cases is that the metrics used may only apply to particular habitat types, for example, flow as a metric in Rood and Hamilton (1995) applies to riverine ecosystems and not necessarily lakes. Finally, it is important to note that very few studies directly include uncertainty in measuring habitat sensitivity or its component parts (Rood and Hamilton, 1995).

A previous CSAS process (Vandermeulen, 2005) used the definition proposed by the International Council for the Exploration of the Seas (ICES, 2002):

> "Habitat sensitivity can be defined in relation to the degree and duration of damage caused by a specified external factor. Sensitivity may refer to structural fragility of the entire habitat in relation to a physical impact, or to intolerance of individual species comprising the habitat to environmental factors, such as exposure, salinity fluctuations or temperature variation" (ICES, 2002).

Here, we propose defining habitat sensitivity as the degree and duration of damage caused by an anthropogenic factor(s) to the habitat in its current state, where these are measured through assessing the habitat's resilience and resistance to the external factor. This definition builds on the ICES (2002) definition, adapted to include language used in a more recent publications (Eno et al., 2013; Kenchington et al., 2013) and concepts that have been previously applied to freshwater assessments (MacDonald et al., 1996; Webb et al., 1994). That is, the focus is on the two metrics of *resilience* and *resistance*, which can be thought of in parallel to terms in ICES

(2002). The *degree* of damage caused by an external factor is determined by the *resistance* of a habitat to that factor. A more resistant habitat will have a greater ability to withstand changes in structure and function caused by a pressure(s) than a less resistant habitat. Similarly, the *duration* of damage in the ICES definition can be assessed by considering *resilience* of the habitat to external factors. A more resilient habitat will revert back to the previous unperturbed state in a shorter time frame than a less resilient habitat.

Based on the approach by Eno et al. (2013), we defined resilience and resistance as follows.

> **Resistance** is the ability of the current habitat to maintain its characteristic biological, chemical, and physical features in the face of a temporary or prolonged disturbance, where high resistance results in low levels of impact.
>
> **Resilience** is the rate of recovery of a current habitat following an impact. It is measured as the time required for a habitat and its constituent biological, chemical, and physical features to recover to their characteristic state after disturbance.

While this definition does not explicitly include the level of stress in the region of the habitat, we included reference to the *current state* of the habitat. This is an important consideration to account for potential shifts in reference conditions (Harding et al., 1998; Pauly, 1995). Therefore, measures of resilience and resistance depend on the habitat in its current state, where a highly altered ecosystem may exhibit characteristics of a less (or more) resistant or resilient habitat.

In the process of exploring the literature for definitions of habitat sensitivity, two additional terms frequently arose: habitat quality and habitat quantity. Many authors assess the current state of habitat quality (Aneseyee et al., 2020; Pirhalla, 2004; Yao et al., 2017), its response to land use, and the resulting connection to fish sensitivities. Quality changes include shifts like changes in flow, sediment, or nutrients (Randall et al., 2013). The terms habitat quality and quantity can be thought of as equivalent to terms in the *Fisheries Act*: a reduction in quantity is equivalent to habitat “destruction”, where a reduction in quality is equivalent to “alteration” (Bradford et al., 2014; Randall et al., 2013).

Habitat quality in this case can be considered an output, as one might measure the current habitat quality and an expected change in quality after an external factor has been added to the system. Alternatively, one might measure current habitat quality and estimate how it changed as a result of previous land use. A habitat that experienced previous changes that have lowered the quality might also be referred to as habitat that has been degraded. This change in quality then relates to both resilience and resistance. If the change in quality is short term, then we would refer to this as a more resilient habitat as it is able to rapidly recover (and the reverse for a long-term change in quality). Similarly, if the habitat experiences a substantial external factor, but does not change in quality, then we would call this a resistant habitat. The same connections can be made to habitat quantity; however, habitat quantity would be more extreme. For example, if there is a loss of habitat from a human activity (e.g., diking, Beechie et al., 1994); dam installation, Bradford, 2020)) then there is a change in habitat quantity. This substantial change means that the habitat was not resistant to the activity/pressure and if it is a permanent loss of habitat then the habitat has no resilience because it will never rebound.

Understanding the resilience and resistance of habitats is challenging because habitat quality and quantity have historically not been assessed prior to disturbance, and in many regions of Canada, the natural variation in habitat condition is unknown. Such uncertainty is compounded by the fact that resilience and resistance are likely to change in cases where past land use (or cumulative effects) have occurred. Long-term datasets, effectiveness monitoring, and restoration activities such as the information data for some projects in PATH could provide empirical data upon which resilience and resistance can be derived for different waterbodies given known disturbances or restoration actions. For example, 30-yr observations of species abundance data for freshwater zooplankton biomonitoring data from Ontario, Canada were used to quantify the relative resilience and resistance of their communities to disturbance (Lamothe et al., 2017). In order to ground these concepts in real world contexts, we considered examples that connect resilience and/or resistance to past levels of impact.

2.3.3.1. Examples

In the Baptiste and Gluskie watersheds an experiment was undertaken in the late 1990s and early 2000s to discern the scale of response (resistance) and time to recovery (resilience) of stream flows, temperatures, and sediment inputs from controlled logging (Macdonald et al., 2003b, 2003a). This involved a full before-after-control-impact (BACI) design where different sections of the watersheds were logged with low-retention of canopy cover in the watershed (higher impact), high-retention of cover or no logging (control). The researchers found immediate responses in peak discharge, stream temperatures, and total suspended sediments (TSS) in the year immediately after logging. The “largest increase in mean daily discharge during freshet relative to the control stream exceeded 100%” (Macdonald et al., 2003a) and in one case a 74% increase in TSS. Stream temperatures were 2-4°C higher in the low-retention system and <1°C higher in the high-retention system demonstrating that changes in habitat features were substantial and that the watersheds logged were not resistant to the change. However, the scale of the impact was mediated by the extent of land use alteration, so that in the low retention system the impact was more substantial. The authors similarly observed impacts in resilience, as within the five year study period stream temperatures did not recover, nor did peak discharge, though TSS did decrease after two years in the high-retention system and three years in the low-retention system. Thus, similar to resistance, the system’s resilience to changes in TSS were mediated by the extent of land use alteration (total canopy cover lost). Although these logging activities were a single type of activity and occurred at one point in time, the two scenarios – of low and high retention – provide a comparison for when cumulative land use alteration worsens the resilience and resistance of aquatic habitat features.

In a more complex and nuanced example, recovery from past impacts of acid rain in lakes around Sudbury have demonstrated varying levels of recovery due to a combination of lake watershed characteristics, proximity to urban land use, and climate change (Keller et al., 2018). There are lakes closer to the city that have shown recovery in pH levels, which appear to have been mediated by land use that contributed to nutrient inputs that have increased alkalinity generation (counteracting acidification). However, these same lakes near urban development also experience metal inputs from run-off, contributing to ongoing metal contamination and a lack of recovery in certain metals. There are also lakes far from the city that have been slow to recover, in part due to their longer water retention times. Similar to how species with long generation times take a longer time to recovery from impacts, these lakes are slower to recover to a less acidified state (Keller et al., 2018). Although more nuanced, this example shows how past impacts, in combination with fundamental system characteristics (e.g., water retention time) interact to change recovery times and thus resilience. Given the varying states of these lakes now, it will change how sensitive they are (how resilient and resistant) to future impacts, that may also contribute to pressures that change acid levels or metal contamination further.

Unlike species sensitivities that have been studied much more extensively, habitat sensitivity assessments are less frequent and use differing approaches (Table 3) (Logan et al., 2020). Moreover, assessing habitat status (a contributing factor to sensitivity) can be a highly intensive process if done at a high resolution scale (e.g., Beechie et al., 2017). Additionally, quantifying habitat resilience and resistance pose their own challenges to perform on large scales, when there may be varying factors that influence these characteristics.

3. CUMULATIVE EFFECTS AND THE RISK ASSESSMENT PROCESS

The current project review process used by FFHPP has a set number of steps within a risk assessment framework; in this section we used the discussion above to identify where additional information needs to be gathered for consideration of CE in project review. As assessment biologists undertake a project review, they apply this risk approach using a Risk Documentation Form (RDF). Previous versions of the risk approach are available online (DFO, 2007), but the most recent version, revised in 2019, the Risk Management Guide (RMG), is not yet publicly available.

3.1. THE PROJECT REVIEW PROCESS AND CONSIDERING CE

The FFHPP policy statement (DFO, 2019a) defines CE as: “any cumulative harmful impacts on fish and fish habitat that are likely to result from the work, undertaking or activity in combination with other works, undertakings, or activities that have been or are being carried out.” And notes that “The Department is responsible for collecting the information needed to consider the cumulative effects of a proposed work, undertaking or activity.”

This risk process is used to determine whether a WUA requires a Letter of Advice (a non-legally binding set of recommendations) or a regulatory tool (a *Fisheries Act* authorization) before the project can proceed (Goodchild, 2004). In the process of applying the RMG, the assessment biologists will compile the relevant information on the WUA (most of which is provided by the proponent) and in some circumstances may go back to the proponent to request additional information needed. This information is then summarized in the RDF, outlining the details of the risk assessment process. In this context, the added consideration of CE is to be made on a project-by-project basis. However, we noted in section 2.1.1 and other sections herein the importance of watershed level approaches to CE considerations and the two-way flow of information from project-specific decision-making to watershed planning and assessment (see Figure 2 for a schematic diagram connecting watershed and site specific processes). This is discussed in further detail in Cormier et al. (2022).

We provide a brief overview of the main risk assessment steps within the RMG from the FFHPP perspective, which parallels the information gathering process that assessment biologists undertake when filling out the RDF. The steps include a series of phases to compile necessary information that is then put into a set of risk matrices to identify the level of risk and decide whether a regulatory tool is needed. The risk decision is ultimately based on a combination of the spatial extent of the impact (site, local or widespread), the persistence of the pressures (low, moderate or high), and the habitat sensitivity of the habitat component in question (low, moderate or high). For each of the steps in information compilation of the RMG, we identified associated elements needed to consider CE from a scientific perspective to inform project review in order to address objective 1(a) *Identify recommendations for additional elements to be included in the current risk approach to inform the consideration of cumulative effects*. We provided additional detail in the step associated with habitat sensitivity to further address objective 2 *Provide advice on key characteristics required to determine how habitat sensitivity can be determined in the context of cumulative effects*.

3.1.1. RMG Step 1: Identifying habitat components

This step in the RMG developed by FFHPP involves identifying the structural features supporting the life processes of fish and can include identification of multiple habitat components. This section by default includes identification of the fish species present in the habitat, as the means to then identify habitat components used. However, from a scientific perspective, identification of habitat components is possible if a species is not present at a local site, based on known habitat requirements, as long as it is within the species broader distributional range.

3.1.1.1. CE considerations

From a scientific perspective, as listed in the earlier sections of this document a full suite of information would be ideal to have for all species within the zone of influence (2.1 and 2.2). When it comes to species lists, this should include native species (extant and extinct), introduced species, SAR, and AIS. The information on these species is then their characteristics (e.g., life stage present), statuses and sensitivity to relevant pressures. The RMG already includes discussion of identifying species and their status, thus, when it comes to CE considerations, additional information needed includes understanding the sensitivity of the species present to the pressures associated with the WUA (e.g., thermal tolerance). If this information is not available from proponents, then an internal process driven by the IP program could be used summarize the information from DFO documents and/or publicly available external resources (Table 2).

Similar to species, a full suite of information is needed on the habitat(s) in the zone of influence, some of which is compiled in the current process. The information needed includes a full list of the habitats (and their characteristics) in the zone of influence, habitat status, and habitat sensitivity. As part of the process for identifying habitat components present and those that will be used to consider the level of risk from the project, the RMG states that the “most significant” component(s) will be identified. This could be one or more that are then used in further steps including habitat sensitivity and spatial extent. This approach of focusing on a subset of the habitat components in the zone of influence poses the risk that important information may not be included in the assessment process. We caution against using this approach because CE assessment requires considering not just those habitats that are most significant but also habitats that could be most sensitive. A consistent approach would require that input information includes details on extent and habitat features changed for all components of the WUA as a standard input.

A habitat may not be considered “significant” because it is not used as frequently as others, however, if that habitat is highly sensitive, it may act as a limiting factor supporting key life processes of a species or the fish community. For example, if an assessment biologist were to identify a spawning area as the “significant” component, ensuring minimal impacts on spawning adults and their eggs is important. However, population persistence also requires suitable rearing habitat. If rearing habitat is highly sensitive and substantially altered (e.g., habitat loss), population productivity could decline from poor recruitment due to limitations in quality and extent of rearing habitat. Thus, it is important to identify a process for how to determine the most significant habitat components, to ensure consistency of application among practitioners and across regions so important information is not missed. Moreover, CE consideration requires that sensitive habitats are considered and may result in broader spatial habitat components being included than in the current risk approach when indirect and diffuse impacts result from the pressures associated with the WUA.

We also stress that while the current RMG includes reference to documenting the status of species in the region of the WUA, it does not do the same for habitat. For consideration of CE, as we have discussed above, understanding the current state of the habitat (i.e., reference condition) is fundamental. Impacted habitats may have a higher likelihood of reduced resilience or resistance to added stress. Consideration of CE necessitates identifying habitat status (or level of past alteration) during a risk assessment process and any information gathering phase. The State of Habitat initiative currently underway within FFHPP would be informative here, and we note that there are many documents, which clearly outline how to document reference conditions (Braun et al., 2019).

3.1.2. RMG Step 2: Spatial extent

The spatial extent considered in the current RMG is the overlap between the area impacted by the WUA and the habitat component in question and ranges between site, local, and widespread. Thus, FFHPP uses two components when considering space – the spatial extent of the WUA impacts and the spatial distribution of the habitat(s). When the WUA overlaps with ≥ 5% of the habitat unit, it is considered a site specific impact, when the overlap ranges between 5-50% it is considered local, and any overlap over 50% is considered widespread (numbers came from Borgwardt et al. (2019)). As part of the process in the RMG, the "smallest geographical extent" of the habitat is identified. This is noted to be a precautionary measure, such that when the smallest habitat unit is assessed and compared to the spatial distribution of the WUA, it is more likely that there will be substantial overlap (exceeding 50%) between the WUA and the habitat feature, just by that habitat unit being smaller. When overlap exceeds 50% the risk level is more likely to be increased as it is considered a widespread impact. We note here that the project review process considers the temporal extent of the impacts in a separate step (Step 4: Persistence of pressures).

3.1.2.1. CE considerations

From a scientific perspective, we stress that the geographic extent of the impacts when considering CE should be at a broader watershed level, given the possibility of interactions between other impacts in the region and the connectivity among many aquatic habitats. For example, while an individual culvert may have a small geographic footprint, the impacts of an additional alteration should be considered within context of previous alterations where habitat has been lost or degraded (e.g., Beechie et al., 1994). This underscores the importance of the spatial scale outlining the range from both the project footprint, to the zone of influence of all associated pressures, in line with the spatial scales outlined in the IAA.

How this information is gathered will be operationalized by the FFHPP through synergies between IP and Reg Review (which could be informed by Science Advice) and the guidelines provided to assessment biologists, however, placing the spatial extent of the proposed work in the larger watershed context is fundamental to CE considerations (see content in Cormier et al. 2022).

Above, we described how the RMG includes a process to categorize the spatial extent ranging from site level to widespread using % overlap thresholds. It is outside the scope of this document to discuss the values that contributed to determining the thresholds between site level and widespread; however, they are based on (Borgwardt et al., 2019) and assessing the scientific basis for those values could be part of a future CSAS process.

3.1.3. RMG Step 3: Habitat sensitivity

In the RMG, FFHPP determines habitat sensitivity using a suite of information about the habitat component(s) (or multiple habitat types within the WUA; Table 4) and the ways in which it is used by fish species. The elements in Table 4 are similar to a previous risk tool used by the program (DFO, 2007) that included habitat rarity, habitat resilience, and species dependence on the habitat.

3.1.3.1. CE considerations

Section 2.3.3 above outlines the ways that habitat sensitivity has been defined in a past CSAS process (Vandermeulen, 2005) and the literature (e.g., Eno et al., 2013); and we used that information to propose a revised definition that is focused on the key characteristics of resilience and resistance. Whether the FFHPP employs the definition that Science has proposed, or continues to use habitat sensitivity as outlined in the RMG, important information that assessment biologists will require to consider CE in the context of habitat sensitivity include:

1. A clear definition of habitat sensitivity with components that can consistently be applied,
2. Steps for *how* to determine and aggregate habitat sensitivities using that definition, and
3. Clear scope and method for factoring the past/current level of impact within the system into a sensitivity determination for consideration of CE.

From a scientific perspective, we outline two approaches for considering CE within the assessment of habitat sensitivity. First, we discuss how CE could be considered using our proposed definition of habitat sensitivity, and second, we discuss where CE could factor into the existing RMG habitat sensitivity approach. This is intended to address objective 2; *Provide advice on key characteristics required to determine how habitat sensitivity can be determined in the context of cumulative effects*.

3.1.3.2. Habitat sensitivity and CE using the proposed definition

As a refresher, habitat sensitivity is defined as a function of the current habitat's resilience and resistance to the degree and duration of damage caused by an anthropogenic factor(s).

As a conceptual framework, we break the process into steps by first identifying the current *realized* habitat sensitivity, and then using that realized habitat sensitivity to assess the habitat's vulnerability given exposure to the proposed WUA. For realized sensitivity, we consider that the level of past disturbance to the watershed in question may change the underlying natural (or intrinsic) sensitivity of the habitat (Figure 4). For example, if a habitat was recently dredged, it may still be in the process of recovery and thus could have lower resistance and/or resilience to subsequent dredging. In this case, the past disturbance would elevate the realized habitat sensitivity above the natural sensitivity of the habitat. However, it is also possible that either past disturbance or sensitivity (or both) could be negligible in cases where no past disturbance to the habitat has occurred, or if the habitat is not sensitive to the type of disturbance in question.

In order to add in the current proposed WUA and its associated pressures, one would use the realized habitat sensitivity combined with the exposure associated with the new proposed WUA (Figure 5). This provides a measure of vulnerability, a common tool used to combine sensitivity and exposure measures (will add citations).

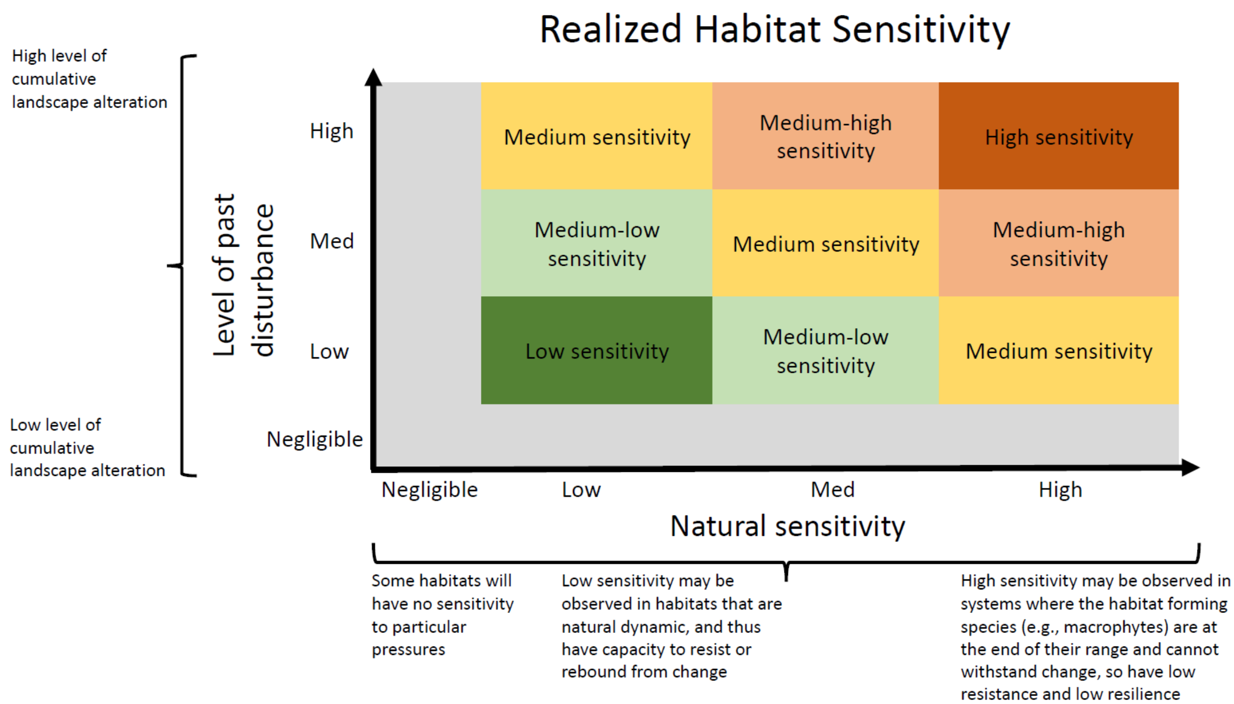

Figure 4. Schematic diagram (for illustrative purposes only) showing how the level of past disturbance of a habitat may be considered separate to resilience and resistance, and alter the natural sensitivity of the habitat to express its' realized sensitivity.

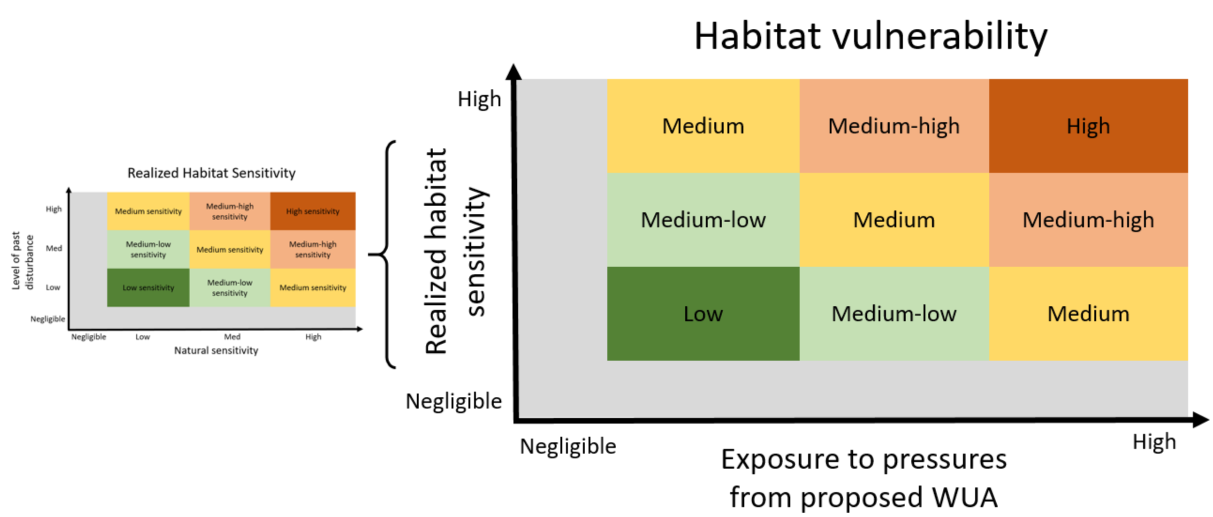

Figure 5. Schematic diagram (for illustrative purposes only) showing how realized habitat sensitivity in combination with exposure contributes to a habitat vulnerability value.

This framing of considering natural habitat sensitivity and past/current disturbance to inform the current realized habitat sensitivity can be built on to also include species sensitivity (Figure 6). In this case, we provide equal weighting of habitat and species sensitivity to inform an overall system sensitivity, as compared to assuming that species sensitivity is a component within habitat sensitivity (Table 4). Equal weighting of habitat and species sensitivity is especially important in areas where species are known to be extirpated because of past and on-going disturbance or where more tolerant AIS have flourished in degraded habitats (Havel et al., 2015; Limburg and Waldman, 2009).

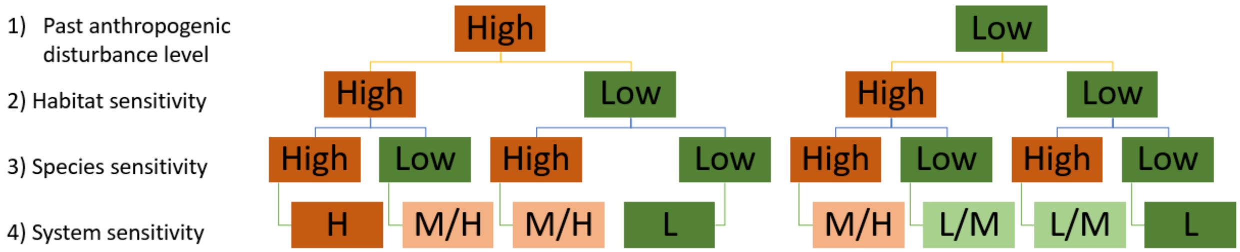

Figure 6. Simplified schematic showing how the combination of past anthropogenic disturbance in the system, habitat sensitivity, and species sensitivity combine to inform a system level sensitivity to the WUA. This could be completed for an example species or community, or within a habitat ecotype. Note that full consideration would involve high, medium and low options for all levels – but were not included here to keep the visualization simple.

We recognize that determining habitat resilience and resistance, even in a qualitative manner, is challenging due to a lack of previous work and standardized approaches in this area. Moreover, determination can be further complicated by factors that are often specific to each case study. However, there is emerging literature quantifying habitat/species vulnerability to stressors (e.g., climate vulnerability assessments, Troia et al. 2019; Comte and Olden 2017), and there would be value in Science exploring these topics to determine a consistent approach that could be used to quantify habitat resilience and resistance, and overall sensitivity (see Section 4).

3.1.3.3. Habitat sensitivity and CE using the existing RMG approach

Should FFHPP continue with the current approach outlined in the RMG for determining habitat sensitivity, there are multiple steps where CE may be considered. Similar to the two approaches above, CE could be factored into specific elements including: species resilience, habitat resilience, aggregation, habitat contribution to productivity, abiotic and biotic suitability, and SAR (see explanations in Table 4). In this way, CE considerations would be embedded within the assessment of the components of habitat sensitivity. Alternatively, rather than intrinsic to the elements in habitat sensitivity, the level of past disturbance could be thought of as separate and be added as a metric on its own that contributes to habitat sensitivity overall (e.g., by adding a row to the table summarizing habitat sensitivity). Further exploration of *how* to factor CE into these metrics will involve further research and needs to be guided by the input deemed most relevant.

3.1.4. RMG Step 4: Persistence of pressures

The persistence of pressures is the final information gathering phase in the RMG, where FFHPP determines the length of time needed before a pressure will no longer be present. This is a combination of the duration of time where there is an active pressure from the WUA and the time the habitat will take to rebound if there is an alteration or destruction.

3.1.4.1. CE considerations

As we noted in our discussion of CE considerations associated with Step 2: Spatial extent, this section relates back to our discussion of the zone of influence establishing both the spatial and temporal boundaries of the project, and its associated impacts. The risk guide includes the important element of the time horizon before the pressure (or stressor) is no longer present. However, the way that persistence is discussed in the RMG may be redundant with the concept of habitat resilience and thus warrants consideration if the full RMG is to be reviewed in a CSAS process or working group. Moreover, what remains missing from this section of the RMG is a process to identify what other persistent pressures (from unrelated activities e.g., agricultural run-off, water takings etc.) may be within the zone of influence of the WUA. Identifying these will allow for the exploration of how the pressures may interact to amplify or mitigate the impacts associated with the new project.

3.1.5. Step 5: Matrices

As noted above, the information gathered and the rankings determined for spatial extent, persistence of pressures and habitat sensitivity are then used to identify the appropriate risk matrix and where the project falls on the matrix.

3.1.5.1. CE Considerations

We do not provide further commentary from a scientific perspective on the format of the risk matrices, as it is beyond the scope of this document's focus on CE in the risk process. Previous forms of these curves have been critiqued (Minns, 2012) and the risk guide may benefit from a full assessment by Science such that the form and approach to the matrices is more fully reviewed.

4. CONSIDERATIONS FOR IMPLEMENTATION AND FUTURE WORK

4.1. LINKING INTEGRATED PLANNING AND PROJECT REVIEW

Integral to moving forward in CE considerations is recognizing that the project-level and watershed-level are intrinsically linked, and that information needs to flow between the two (Figure 2). Although DFO considers proposed WUAs on a project-by-project basis, and some in-water works do not even go through project review if they meet certain criteria, most projects do not occur in isolation. While WUA considerations are largely reactive to determine whether approval should occur and what mitigation or other requirements there will be, integrated planning provides the process for both forward and backward looking lens; planning for future while considering the existing and past watershed context in which that WUA sits.

A major factor in linking these two contexts is in identifying the suite of information needed for watershed level planning, and in identifying responsible bodies for undertaking monitoring for ongoing data collection. Past projects and future WUAs would benefit if a consistent approach to monitoring for compliance and effectiveness of measures taken (such as mitigation) are incorporated into project management. Regulatory review within FFHPP should play the role of monitoring the former, whereas IP should lead on effectiveness monitoring (with input on design from Science). The information provided from ongoing monitoring would improve our understanding of how the project is carried out and whether any residual impacts were more or less substantial than expected; this would feed back into the watershed level planning.

4.2. RECOMMENDATIONS FOR FUTURE WORK

Recognizing that the incorporation of CE considerations into decision-making is not a simple process, this research document was intended to be the first in a series of processes to address the many needs on this front. During the development of the research document, through the research to develop the content and the many conversations to flesh out the key sections, a number of priority research areas were identified. We identify what we see as the four top priorities, and then a fuller list of future considerations for implementation of CE assessment, that would help address the challenges identified during this process. The list is not intended to be exhaustive but includes elements that have come up in development of this research document.

Top priorities:

- Outline a scientific basis/framework identifying how to use the information provided in this CSAS in a consistent manner for CE considerations. This could be undertaken using a series of workshops focused on case studies for proposed WUAs of varying scales and would benefit from consideration of the minimum information needs to undertake CE consideration.
- In many cases the full suite of information for considering CE may not be available. This may be due to uncertainty from stressors/pressures outside of the purview of DFO and how those pressures will be managed. This will result in what is referred to as “uncertainty about impact prediction” (DFO, 2014a), which can be resolved to some extent by consideration of IP (see Cormier et al. 2022). There remain substantial knowledge gaps on how to address uncertainty, but future work would benefit from a focus on how to consider uncertainty within the assessment process.
- Undertake a scoping exercise to outline how to define the spatial and temporal scope of a WUA consistently.
- Undertake a process (e.g., CSAS or other) to review the RMG (e.g., science for defining matrices, methods for determining spatial extent) in more detail.

Data needs:

- We note that the list of data sources is not exhaustive and may benefit from ongoing updates. Moreover, there are caveats (e.g., schedule for updating information, regional versus local knowledge) to working with some of the sources listed, which would be beneficial for biologists to know before applying them.
- PATH inputs would benefit from inclusion of project latitude and longitude (or an explicit polygon) and to transition over to a spatially explicit tracking system so that any new WUA can be considered in the context (at minimum) of other approved works by FFHPP. Although an extensive undertaking, including legacy projects not currently in PATH in this map would be highly relevant. Alternatively, a new system for including all projects (past, present, and upcoming) would allow for thorough tracking and post-hoc analysis to inform RMG methods and CE inclusion in the review process, and provide the data necessary to evaluate the effectiveness of habitat management decisions.
- There is currently no national database or toolbox for assessing and understanding habitat status and sensitivity (or the component parts of resilience and resistance), this poses a substantial knowledge gap for applying habitat sensitivity assessment in a consistent manner through the RMG. A similar recommendation was provided by Randall et al. (2013) “Improve and develop ecological spatial analysis tools. Link mapping of physical habitat (e.g., acoustic seabed mapping) to biological productivity both with respect to habitat utilization and quality.”

Other process and science needs:

- Many works on water will not make it into the project review process (and associated risk consideration) because they are small or are dealt with using other tools (e.g., codes of practice). These still factor into the CE watershed and consideration should be placed on how to manage these projects under CE.

- Consider how to factor in multiple pressures that result in different types of responses when they accumulate (synergistic and antagonistic impacts).
- Undertake a process (CSAS or other) to address how to consider mitigation measures in the context of CE, as it is an important factor in risk considerations (DFO, 2014a).
- Undertake research to assign species into sensitivity categories based on functional traits, where these are not currently available. This could be done at a coarse level, for example, “r” vs “k” species.
- An approach to addressing CE at a larger spatial scale could be application of strategic or regional environmental assessment, see Cormier et al. (2022).
- Consistency in information inputs may be improved if FFHPP required a particular set of information when a WUA is proposed so that there is data that can be used to analyse CE in the future. This would include standard data before and after the WUA occurs.
- Research focusing on ecological thresholds related to habitat perturbations (i.e., at what point do perturbations result in a change in structure and/or function of the ecosystem).
- We did not discuss in any detail climate change and the role it will play in changing both species and habitat sensitivity to added stress. Many watersheds are already experiencing climate change and as it is only expected to worsen, it is an important area for future focus as part of watershed planning and understanding reference conditions.

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6. TABLES

Table 1. Readily available freshwater fish species, habitat, and stress data resources that can inform project evaluations in Canada. Datasets include species and habitat status, and geospatial data of waterbody and stress (e.g., watershed stress) information.

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
British Columbia	https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/fish/fish-and-fish-habitat-data-information	portal to fish related data	X	X	X
	https://catalogue.data.gov.bc.ca/organization/geobc?q=freshwater+atlas	BC freshwater atlas waterbody, habitat, species data	X	X	X
	https://catalogue.data.gov.bc.ca/dataset?tags=EcoCat	species distributions and abundance patterns	X	-	-
	http://a100.gov.bc.ca/pub/eswp/search.do	species distribution	X	-	-
	http://a100.gov.bc.ca/pub/fidq/viewFdisProjects.do	Fish inventory projects (waterbody surveys and fish collections)	X	X	-
	http://a100.gov.bc.ca/pub/eirs/basicSearch.do	species distributions and abundance patterns	X	-	-
	https://www.salmonexplorer.ca/#!/	salmon distribution, status, habitat, stress	X	X	X
Yukon	https://www.cmnbc.ca/atlasgallery/yukon-fish-and-fish-habitat-atlas/	FISS database, species distributions	X	X	-
	https://cmnmaps.ca/fiss_yukon/	waterbody, habitat, species data	X	X	-
	https://geoweb.gov.yk.ca/geoportal/catalog/search/resource/details.page?uuid=%7B982FEE8A-935B-4F4D-A947-2AA520F596CF%7D	Chinook and chum salmon spawning areas	X	X	-
Northwest Territories	https://www.maps.geomatics.gov.nt.ca/Html5Viewer_PROD/Index.html?viewer=CIMP_ILC_Webmap.ILC_Viewer	Species at risk fish distributions	X	-	-

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
	https://www.enr.gov.nt.ca/en/services/cumulative-impact-monitoring-program-nwt-cimp/inventory-landscape-change-webviewer	landscape information	X	-	X
	http://data.nwtresearch.com/Scientific/Search?SY=1986&EY=2020&q=fish&Search=&iTi=true&iTi=false&iPI=true&iPI=false&iDe=true&iDe=false&iPT=true&iPT=false&R=0	species distributions and abundance patterns	X	-	-
	https://www.srrb.nt.ca/index.php?option=com_k2&view=item&id=460:nwt-fish-and-fish-habitat-database&Itemid=985	NWT Fish and Fish Habitat Database (fish species, waterbody characteristics)	X	X	X
	https://www.researchgate.net/publication/263541442_Distributions_of_Freshwater_and_Anadromous_Fishes_from_the_Mainland_Northwest_Territories_Canada	freshwater fish distributions mainland NWT	X	X	-
Nunavut	https://oceansnorth.org/wp-content/uploads/2018/07/en-04-canadas-arctic-marine-atlas-chapter-four-fish.pdf	Map of occurrence of marine and anadromous fish species in Arctic	X	-	-
	https://open.canada.ca/data/en/dataset/24aaaf38-c546-4df0-9eaa-7ccfd1178ffd	Location of Arctic char	X	X	-
	https://www.ngmp.ca/eng/1424180769840/1424180806031#chp8	Freshwater fish monitoring plans	X	-	-
Alberta	https://www.alberta.ca/fisheries-and-wildlife-management-information-system-overview.aspx	portal to fish related data	X	X	X
	https://maps.alberta.ca/FWIMT_Pub/Viewer/?TermsOfUseRequired=true&Viewer=FWIMT_Pub	fish inventories	X	-	-
	https://www.alberta.ca/fsi-metrics-and-mapping.aspx	fish densities	X	-	-
	https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/formain15755/$file/anc_dfmp_Chp_2_Pg_85-98.pdf?OpenElement	distribution descriptions	X	-	-
	https://www.ab-conservation.com/programs/fish/fish-annual-summaries/	species distributions and abundance	X	-	-

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
	https://www.biodiversitylibrary.org/item/198335#page/243/mode/1up	SAR fish in Milk and St Marys drainages	X	-	-
	https://open.alberta.ca/dataset?audience=Scientists&tags=fish	species distributions and abundance	X	-	-
	https://www.nswa.ab.ca/get-involved/watershed-planning-advisory-councils/	habitat and stress information	-	X	X
Saskatchewan	http://biodiversity.sk.ca/HABISask.htm	species distributions	X	-	-
	http://biodiversity.sk.ca/iNaturalist.htm	species distributions	X	-	-
	https://www.saskatchewan.ca/residents/parks-culture-heritage-and-sport/hunting-trapping-and-angling/angling/fish-populations-management-and-research	portal to fish related data	X	X	X
	https://publications.saskatchewan.ca/#/categories/158	fish survey data	X	X	-
Manitoba	https://gov.mb.ca/fish-wildlife/fish/commercial_fishing/netting_data.html	Lake Winnipeg fish populations	X	X	X
	http://130.179.67.140/dataset/fish-com	Agricultural streams - fish communities	X	X	-
	https://open.canada.ca/data/en/dataset?q=manitoba+fish&sort=&page=1	DFO studies	X	-	-
Ontario	https://geohub.lio.gov.on.ca/	species distribution, habitat, stress information	X	X	X
	https://www.comap.ca/fwis/	stream and river species distribution and habitat information	X	X	X
	https://data.ontario.ca/dataset/provincial-stream-water-quality-monitoring-network	habitat (water quality) information	-	X	X
	https://foca.on.ca/program-mapping-multiple-stressors-on-inland-lakes/	inland lake stress data	X	X	X
	http://sobr.ca/	species, habitat, and stress information	X	X	X

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
	https://www.watershedcheckup.ca/conservation-authority-map	watershed report cards for southern Ontario	X	X	X
Quebec	http://www.environnement.gouv.qc.ca/eau/eco_aqua/suivi_mil-aqua/comm_pois-riv.htm	portal to fish related data	X	X	X
	http://www.environnement.gouv.qc.ca/eau/bassinversant/bassins/index.htm	water body locations of fish communities	X	X	-
	https://ogsl.ca/bio/?lg=en	fish species abundance and distribution	X	X	-
New Brunswick	https://www2.gnb.ca/content/gnb/en/departments/10/open-data/direct_access.html#vector_aqua	portal to fish related data	X	X	X
	https://www2.gnb.ca/content/gnb/en/departments/erd/natural_resources/content/open-data/web_mapping_applications.html#erd_fish	fish stocking areas (salmon, brook trout)	X	X	-
	http://canadarivers-gis.maps.arcgis.com/apps/MapJournal/index.html?appid=96a4db019a2048d9aa050e0197aa945a	rainbow trout distribution	X	X	-
	https://open.canada.ca/data/en/dataset/17bda544-dd77-99c4-5785-74315d9badaa	salmon smolt distribution	X	X	-
	http://canadarivers-gis.maps.arcgis.com/apps/webappviewer/index.html?id=f81911fbd3d3474c9a36488cc436bf9a	atlantic salmon e-fishing sites	X	X	-
Prince Edward Island	https://open.canada.ca/data/dataset/192ccf66-987a-4f95-9c69-910383d9875b?=undefined&wbdisable=true	abundance and distribution data	X	X	-
	https://data.princeedwardisland.ca/Environment-and-Food/OD0002-Pesticide-Analysis-for-Finfish-and-Shellfis/4bk3-u3rm	brook and rainbow trout distribution from nine rivers	X	X	-
	https://www.princeedwardisland.ca/sites/default/files/publications/coles_creek_watershed_flow_and_fisheries_monitoring_year_1_report_.pdf	brook and rainbow trout density and biomass	X	X	-
	https://www.princeedwardisland.ca/sites/default/files/publications/coles_creek_watershed_-	brook and rainbow trout density and biomass	X	X	-

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
	_flow_and_fisheries_monitoring_year_2_report.pdf				
Nova Scotia	https://data.novascotia.ca/browse?Detailed-Metadata_Department=Fisheries+and+Aquaculture&page=1	portal to fish related data	X	X	X
	https://data.novascotia.ca/Fishing-and-Aquaculture/Nova-Scotia-Freshwater-Fish-Species-Distribution-R/jgyj-d4fh	fish distribution records	X	-	-
Newfoundland and Labrador	https://www.gov.nl.ca/ffa/wildlife/wildlife-research/arfm/	portal to fish related data	X	X	X
	https://www.gov.nl.ca/ffa/wildlife/all-species/animals/inland-fish/	some information on species provincial distribution	X	X	-
	https://www.gov.nl.ca/ffa/wildlife/all-species/inlandfish/	status and presence of freshwater fishes in NL	X	X	-
	https://fish.mongabay.com/data/Newfoundland.htm	presence of freshwater fishes in NL	X	-	-
Other					
Fisheries and Oceans Canada	https://open.canada.ca/data/en/dataset?q=distribution&organization=dfo-mpo&sort=metadata_modified+desc	abundance and distribution	X	X	-
	-	Program Activity Tracking for Habitat (PATH)	X	X	X
	https://waves-vagues.dfo-mpo.gc.ca/Library/40872051.pdf	Habitat Ecosystem Assessment Tool	X	X	-
	https://open.canada.ca/data/en/dataset/e0fabad5-9379-4077-87b9-5705f28c490b	SAR species distributions	X	X	-
Environment and Climate Change Canada	https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html	SAR recovery strategies and management plans	X	X	X
iNaturalist	https://www.inaturalist.org/observations?place_id=6712&iconic_taxa=Actinopterygii	fish distributions	X	X	-
NatureServe	https://explorer.natureserve.org/Search#q	fish distributions	X	X	-

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
BOLD Systems	http://v3.boldsystems.org/index.php/Public_SearchTerms	Public Data Portal, search terms "Cyprinidae Salmonidae Percidae Canada". Fish distributions	X	X	-
FishBase	https://www.fishbase.se/Country/CountryChecklist.php?what=list&trpp=50&c_code=124&csub_code=&cpresence=present&sortby=status&vhabitat=fresh	species distributions, traits, habitat preferences	X	X	-
Aquamaps	https://www.aquamaps.org/OtherSpeciesList.php	affiliate of FishBase with species distributions	X	X	-
GBIF - Freshwater Biodiversity Network database	https://www.gbif.org/dataset/3633e0e7-8c25-4c3d-b9c7-078c0be25665#taxonomicCoverages	Fish occurrence dataset	X	X	-
	https://www.gbif.org/dataset/2f46fe6f-b9fd-4dba-8ca2-2cb1368ceed8	Fish occurrence dataset	X	X	-
	https://www.gbif.org/dataset/d97d8a15-3b12-4519-92bf-e4cf9e764514	Arctic fish occurrence dataset	X	X	-
	https://www.gbif.org/dataset/813b435e-f762-11e1-a439-00145eb45e9a	Fish occurrence dataset	X	X	-
	https://www.gbif.org/dataset/dc3bfd08-0141-45ae-9603-91ac50cdc33b	Canadian Museum of Nature fish occurence dataset	X	X	-
	https://www.gbif.org/dataset/afc30a94-6107-488a-b9c0-ba9c4fa68b7c	Fish occurrence dataset	X	X	-
VertNet	http://portal.vertnet.org/search?q=country:%22canada%22+collectioncode:FISH	species distributions	X	X	-
IUCN RedList	https://www.iucnredlist.org/resources/grid	species distributions, traits, conservation status	X	X	-
FishBASE Aquamaps	https://www.aquamaps.org/	global species distributions	X	X	-
EDDMaps	https://www.eddmaps.org/	invasive species distribution information	X	X	-
Canadian National Aquatic	https://obis.org/dataset/139db389-055f-477b-a743-1ca1fd01c092	invasive species distribution information	X	X	-

Province, territory or organization	Freshwater fish data source (link to data)	Description of data available	Species data	Habitat data	Stress data
Invasive Species Database					
WWF-Canada	https://hydrosheds.org/page/hydroatlas	habitat and stress information	-	X	X
WWF-Canada	https://watershedreports.wwf.ca/?&_ga=2.29449782.84964162.1607189852-2042445578.1607189852#ws-19/by/threat-overall/profile	watershed stress data	-	X	X
National Hydrographic Network	https://www.nrcan.gc.ca/science-and-data/science-and-research/earth-sciences/geography/topographic-information/geobase-surface-water-program-geeau/national-hydrographic-network/21361	spatial watershed, waterbody, river data	-	X	X
The BEACONs Project	https://databasin.org/search/#query=BEACONs	Boreal habitat, species, stress data	X	X	X
NRCAN land cover and land use	https://www.nrcan.gc.ca/maps-tools-publications/satellite-imagery-air-photos/application-development/land-cover/21755	land cover, land use stress data	-	X	X
NRCAN National Road Network	https://open.canada.ca/data/en/dataset/3d282116-e556-400c-9306-ca1a3cada77f	road network (fragmentation) data	-	-	X
Nature Conservancy of Canada	https://2c1forest.databasin.org/datasets/3fa5eb769b99496fad0c05c838c8823d	species, habitat, and stress for the Northern Appalachian–Acadian Region of Canada	X	X	X
CANFISHPASS: Inventory of Canadian fish passage facilities	http://www.fecpl.ca/projects/canfishpass-inventory-of-canadian-fish-passage-facilities/	dataset of fish passage facilities in Canada	-	X	X
COSEWIC status reports	https://www.cosewic.ca/index.php/en-ca/status-reports	species distributions and status	X	X	X

Table 2. Readily available data sources with freshwater fish species traits and sensitivity information.

Reference	**Data source**	**Spatial scale**
Froese, R. and D. Pauly. Editors. 2019. FishBase. World Wide Web electronic publication. (12/2019)	http://www.fishbase.org/search.php	Global dataset of occurrences, traits, habitat preferences
Thorson, J. T., S. B. Munch, J. M. Cope, and J. Gao. 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications. 27(8): 2262–2276.	https://github.com/James-Thorson-NOAA/FishLife	Global dataset of growth, size, maturity, mortality, stock-recruit, and population-dynamics parameters
Eakins, R. J. 2020. Ontario Freshwater Fishes Life History Database. Version 5.03. Online database, accessed 05 December 2020	http://www.ontariofishes.ca/home.htm	Ontario dataset of fish occurrences, traits, habitat preferences, tolerances
Coker, G.A, C.B. Portt, and C.K. Minns. 2001. Morphological and Ecological Characteristics of Canadian Freshwater Fishes. Can. MS Rpt. Fish. Aquat. Sci. 2554: iv+89p.	https://waves-vagues.dfo-mpo.gc.ca/Library/254364.pdf	National dataset of fish habitat preferences, traits
IUCN RedList of Threatened Species	https://www.iucnredlist.org/resources/grid	Global dataset of species status, traits, habitat preferences
Winemiller, K.O. and Rose, K.A., 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. Canadian Journal of Fisheries and aquatic sciences, 49(10), pp.2196-2218.	-	Dataset of North American fish life history traits
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. Fisheries, 34(10), pp.487-495.	http://www.fishtraits.info/	Dataset of US species traits
Chu, C. and M.A. Koops. 2007b. Life history invariants of lean and siscowet lake trout, lake whitefish, bloater, walleye and yellow perch populations in the Great Lakes. Can. Man. Report Fish. Aquat. Sci. #2816:vii +38p.	https://science-catalogue.canada.ca/record=4027319~S6	Dataset of some Great Lake fishes
Chu, C. and M.A. Koops. 2007a. Life history parameters of Great Lakes populations of lake trout,	https://science-catalogue.canada.ca/record=4027317~S6	Dataset of some Great Lake fishes

Reference	Data source	Spatial scale
lake whitefish, bloater, walleye, and yellow perch. Can. Man. Report Fish. Aquat. Sci. #2811:vii +43p.		
Mims, M.C., Olden, J.D., Shattuck, Z.R. and Poff, N.L., 2010. Life history trait diversity of native freshwater fishes in North America. Ecology of Freshwater Fish, 19(3), pp.390-400.	-	North American dataset
Trebitz, A.S., Brazner, J.C., Brady, V.J., Axler, R. and Tanner, D.K., 2007. Turbidity tolerances of Great Lakes coastal wetland fishes. North American Journal of Fisheries Management, 27(2), pp.619-633.	-	Dataset of turbidity tolerance for Great Lakes coastal wetland fishes
Whittier, T.R. and Hughes, R.M., 1998. Evaluation of fish species tolerances to environmental stressors in lakes in the northeastern United States. North American Journal of Fisheries Management, 18(2), pp.236-252.	-	NE US dataset of tolerances
Habitat Ecosystem Assessment Tool	https://waves-vagues.dfo-mpo.gc.ca/Library/40872051.pdf	National dataset of fish habitat preferences, traits

Table 3. Summaries of how habitat sensitivity has been defined and assessed in previous research in both freshwater and marine ecosystems.

Source	Ecosystem	Key terms/variables	Brief description
Triton 1991	Marine	Fisheries values Biophysical factors Resource Uses	Impacts from resource development, biophysical factors, (and fisheries values once completed) are summed together to give a total value representative of the Impact severity rating (a term used interchangeably with Habitat sensitivity).
Rood and Hamilton 1995	Freshwater	Flow characteristics Land use Water use	This is one of a series of reports assessing salmon stream habitats in the Fraser Basin. Habitat sensitivity was defined in relation to flow including natural flow variation and exiting levels of human impact.
Webb et al. 1996	Freshwater	Human activity Environmental variables	Habitat sensitivity defined using the five sub-indices listed in the key terns column. The authors explore ways to roll up the components within the sub-indices (for example, resistance includes flow, alkalinity, gradient, etc.) and then how to combine across sub-indices.

Source	Ecosystem	Key terms/variables	Brief description
		Watershed resistance Habitat characteristics Fish stock characteristics	
MacDonald et al. 1996	Marine	Fragility Intensity Recovery	Assessing sea bed sensitivity to fishing impacts based on habitat fragility, recovery time and intensity level of the activity.
Mason and Knight 2001	Freshwater	Species composition as indicator of stream health	No direct habitat sensitivity assessment, though stream health and condition assumed to be defined based on fish species composition.
ICES 2002	Marine	"degree and duration of damage caused by a specified external factor"	Relates to the habitat's response to a specific stressor, including habitat fragility and intolerance.
CSAS 2005 (Vandermeulen)	Marine	NA	This CSAS document did not propose a definition of habitat sensitivity, but rather in the associated meeting, they decided to use the ICES definition. They did conduct a review of kelp and seagrass responses (as habitat forming species) to different thresholds of change.
DFO 2007	Freshwater	Species sensitivity Species dependence on habitat Rarity (of habitat) Resilience (of habitat)	FPP (or Habitat) definition of habitat sensitivity for the risk assessment tool within proposed WUA assessments, includes for attributes listed. Each attribute has categorical scales and is further defined, e.g., resilience includes flow regimes, thermal regimes and physical characteristics.
Eno et al. 2013	Marine	Resistance Resilience	Habitats assessed in relation to specific activities, and their resilience and resistance to the occurrence of the activity. Habitats in this case include a mixture of habitat forming species (e.g., oysters) and physical features (e.g., rock pools).

Source	Ecosystem	Key terms/variables	Brief description
Trumbo et al. 2014	Freshwater	Temperature	Restricted definition, in relation to stream sensitivity to air temperature increases. In this case, sensitivity relates to landscape characteristics.
Korpinen and Anderson 2016	Marine	Resilience Resistance	This is a review paper, they did not directly measure habitat sensitivity, though define it as based on resilience and resistance of the ecosystem component (categorically).

Table 4. Criteria for determining habitat sensitivity in the Risk Management Guide and the rationales for considering cumulative effects (past and on-going disturbance) for a subset of the criteria.

-	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Rationale for considering CE
Species Resiliency	Species present are resilient to change and perturbation.	Species present are moderately resilient to change and perturbation.	Species present are highly sensitive to perturbations.	There is a continuum of species and community resiliency to disturbance, such that we can think of different levels of past and on-going CE. In near pristine systems, species resilience is driven by their sensitivity to novel perturbations; in areas with moderate levels of past disturbance species may be stressed and further disturbance could push the limits of their tolerances; in systems that have been disturbed for some time, species may be more tolerant to the WUA because the sensitive species have already been extirpated. However, as noted earlier, for this last case the inclusion of extirpated species within the full assessment is important for recognizing these past shifts that may have occurred and their consequences.

-	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Rationale for considering CE
Species Dependence on Habitat	Habitat not used by fish for any life stage except occasionally transiting through or feeding in the area. Habitat characteristics used in a generalist way by fish.	Habitat is suitable and may be used as migratory corridor, rearing or spawning habitat. Habitat characteristics used in a variable way by fish.	Habitat is limited and the fish are dependent upon it for survival of the species (e.g. groundwater upwelling zone supporting spawning habitat or deep pools providing the only overwintering habitat). Habitat characteristics used in a specific way by fish.	-
Habitat Rarity	Habitat is prevalent and widespread with many areas that are similar in features.	Habitat is neither widespread or unique, rare or distinct.	Habitat is unique, rare and distinct.	-
Habitat Resiliency	The habitat is robust, resistant to perturbation, or rapidly recovers.	The habitat is neither robust nor sensitive, is somewhat resistant to perturbation and recovers at a moderate rate.	The habitat is highly sensitive, easily perturbed, and slow to recover.	As with species resiliency, the resiliency of current habitats are dependent on the past and on-going levels of Past and on-going CE and disturbance.

-	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Rationale for considering CE
Aggregation	Habitat does not support a specific function, fish densities typically low.	Habitat supports a minimum of one function, fish densities periodically high.	Habitat supports more than one function, fish densities frequently high.	Past and on-going CE can impact the functioning of habitats and thus the fish densities using the habitat as compared to previous time periods.
Habitat Contribution to Fisheries Productivity (DFO 2013)	Habitat`s contribution to fisheries productivity is low. Large amounts of change to the affected species or habitat is expected to have relatively low impacts on fisheries productivity.	Habitat`s contribution to fisheries productivity is moderate. Amount of change to the affected species or habitat is proportional to impacts on fisheries productivity (small change/small impacts; large change/large impacts).	Habitat`s contribution to fisheries productivity is high. Small amounts of change to the affected species or habitat is expected to have relatively large impacts on fisheries productivity.	Past and on-going CE can alter both habitat productivity and fisheries productivity. Habitats with previous impacts (as noted above) may no longer function as they did in the past, possibly reducing fish production. These changes in fish production can be particularly consequential for slow maturing, long-lived species or communities where tolerant species disproportionately benefit from habitat changes associated with disturbances/CE.
Abiotic and Biotic Suitability of Habitat	No key structure –providing species (abiotic) in area of WUA.	Key structure providing species is present in location of the WUA but is not a limiting component.	Key structure providing species present in location of WUA and is a limiting component.	Past and on-going CE can alter the physical, chemical, and biological conditions within the area of the WUA and overall abiotic and biotic suitability of the habitat.

-	Low Sensitivity	Moderate Sensitivity	High Sensitivity	Rationale for considering CE
Species at Risk	Not within distribution area of a listed aquatic species at risk.	Within distribution area of an aquatic species at risk, but not critical habitat. Non-critical habitat of aquatic species at risk that supports their lifecycle functions within their distribution area.	Critical Habitat and/or residence of aquatic species at risk identified in the proposed or final Recovery Strategy or Action Plan. Habitat supporting species of special concern.	Past and on-going CE can negatively alter SAR habitats and may have contributed to the SAR status itself.

7. APPENDIX A

Table A1. Example cumulative effects assessment processes from existing government documents and published papers.

Region	Report	CEA Steps	Key components & considerations
Canada	Cumulative Effects Assessment Practitioners Guide (Hegmann et al., 1999)	1. Scoping	• Identify regional VECs that may be impacted • Identify spatial and temporal boundaries • Identify other actions that may affect the same VECs • Identify potential impacts due to actions and possible effects
		2. Analysis of effects	• Compile regional baseline data • Assess effects of proposed action on selected VECs • Assess effects of all actions on selected VECs
		3. Identification of mitigation	• Recommend mitigation measures
		4. Evaluation of significance	• Evaluate the significance of residual effects (after mitigation) • Compare these results against thresholds
		5. Follow-up	• Recommend regional monitoring and effective management
Yukon	Consideration of Cumulative Effects in YESAB Assessments (2019)	1. Determine VCs that may be impacted	• Includes both environmental and socioeconomic
		2. Describe current condition of those VCs	• Typically reflects CE of all past and current activities affecting that VC • May be close to, or past, a significance threshold
		3. Determine significance of likely adverse project effects	• Consider magnitude, duration, timing, likelihood, spatial extent, and context in which effects occur • Consider likely impacts of WUA in connection with other current or past WUAs in the area

BC	Fish Habitat Assessment Procedures (Johnston and Slaney, 1996)	1. Set geographical boundaries	• Delineate watershed of interest
			  ○ Larger watersheds can be subdivided into a size appropriate for assessment
			  ○ Coastal areas have higher precipitation so use smaller watersheds, while in drier interior locations can use larger watersheds

		2. Assemble watershed data	• Occurrence and distribution of sportfish, threatened species, or regionally significant species • Historic trends in abundance and distribution of fish • Historic trends in fish habitat quantity and quality • Historic trends in water quality and quantity
		3. Determine habitat conditions and evaluate habitat sensitivity	• Habitat types (e.g. pool, glide, riffle, cascade) • Stream metrics (e.g. gradient, mean wetted width, water temp, water quality, turbidity, etc) • Dominant bed materials • Riparian zone • Overstream canopy cover
		4. Identify areas of particular concern	• Reaches that contain the only habitat available for species or life stage • Reaches with known or suspected habitat degradation • Reaches that are at risk to logging impacts, particularly altered sediment input and large woody debris • Reaches with potential barriers with normal movement among habitats. ○ Potential barriers include culverts and disused bridges, landslides or bank sloughing, and log jams
		5. Suggest restorative and mitigation measures	• Establish spatial bounds and timescale of mitigation
US	EPA – Consideration of CE in EPA	1. Determine affected VECs	• Is the VEC is vulnerable to incremental changes? • Is the proposed action one of several similar actions in the area?

	Review of NEPA Documents (1999)		• Do other activities in the area have similar effects on the VEC? • Have these effects been historically significant for the VEC?
		2. Determine spatial and temporal boundaries	Geographic: • Identify a geographic area that includes all resources potentially affected by the WUA • When necessary, extend area to include the same or other resources affected by the combined impacts of the WUA and other actions Temporal: • Consider past, present, and foreseeable future actions • Provides context – whether VECs have already been degraded, whether ongoing activities are causing impacts, and the trends for future activities and impacts
		3. Describe baseline / natural state of environment or VEC	• If not possible, include description of modified but ecologically sustainable condition
		4. Suggest mitigation measures	• Should be realistic and technically feasible • At a minimum, should address the WUA's contribution to CE • Ideally, should address CE caused by other actions as well
		5. Compare potential impacts to thresholds	• Thresholds should be practical, scientifically defensible, and fit the scale of analysis
	CEQ – Considering Cumulative Effects Under the National	1. Scoping	• Define direct and indirect effects of proposed action • Define which VECs are effected • Determine which effects on VECs are important from CE perspective • Establish geographic scope of analysis

	Environmental Policy Act (1997)		○ Determine project impact zone ○ List all resources within that zone that could be affected ○ Determine geographic areas occupied by those resources outside project impact zone. ○ Largest area of all of the above should generally be used for analysis • Establish timeframe of analysis • Identify other actions affecting VECs
		2. Describe affected environment	• Characterize VECs in terms of their response to change and capacity to withstand stress • Ideally will include data • Define baseline for VECs using historical trends • Characterize stresses affecting VECs and their relation to regulatory thresholds
		3. Determine environmental consequences	• Determine magnitude and significance of CE ○ May include geographic extent, duration, and frequency • Tables, checklists, matrices, and overlay mapping/GIS are useful • Significance of impacts is relative to environmental baselines and relevant resource thresholds (e.g. regulatory standards) • Historical context surrounding resource is crucial
		4. Developing mitigation measures & monitoring effectiveness	• Modify or add alternatives to avoid, minimize, or mitigate significant CE • Monitoring program should include measurable indicators and appropriate spatial scale and timeframe • Allows for adaptive management
	Department of Agriculture –	1. Identify VCs that might be impacted	• Determine geographical scale

	Research and cumulative watershed effects (Reid, 1993)	2. Identify types of impact likely to be of concern	• What land-use activities are present or planned in the area? • What types of changes in watershed processes might occur from these land uses?
		3. Establish baseline	• Collect data on environmental parameters and land-use history
		4. Set tolerable impact levels and establish monitoring	• Use published tolerance levels, public input, and local studies
Journal (peer-reviewed) articles	Stelzenmüller et al., 2018	1. Risk identification	• Identify vulnerable ecosystem components and pressures • Establish cause and effect relationships, or pathways of risks ○ Includes magnitude, geographic extent, duration and frequency of effect, and reversibility
		2. Risk analysis	• Determine probability of risks (impacts), taking into account presence and effectiveness of mitigation measures • Estimate severity of impacts relative to management objectives or thresholds • Consider uncertainty
		3. Risk evaluation	• Evaluate impacts, considering sensitivity, resilience, and rarity of ecosystem component • Consider management options
	Roudgarmi, 2018	1. Identify likely impacts of WUA	• Identify VECs likely to be impacted • Determine geographic range and timescale of impacts
		2. Identify other actions that could contribute to CE	• Include past, present, and foreseeable future actions within spatial and temporal boundaries previously established
		3. Assemble historical data and establish baseline	• Describe indicators for selected VECs • Assemble information on historical and current state of VECs

		4. Consider aggregation of effects	• Prediction of CE
			  ○ Connect impacts of proposed action, other past, present, and foreseeable future actions with VECs and their indicators
			  ○ Suggested tools include checklists and matrices, questionnaires and interviews, indicators and indices, spatial analysis, and trends analysis, among others

		5. Assess significance of CEs	• Consider impacts of CE on each VEC over established timescale • This assessment should begin with effects of proposed action and incorporate effects of other actions in established geographic area
		6. Develop mitigation measures	• Develop for VECs or their indicators for which it is determined that significant CE are likely to occur as a result of negative impacts from the WUA • Factor in uncertainty by including monitoring • Apply adaptive management

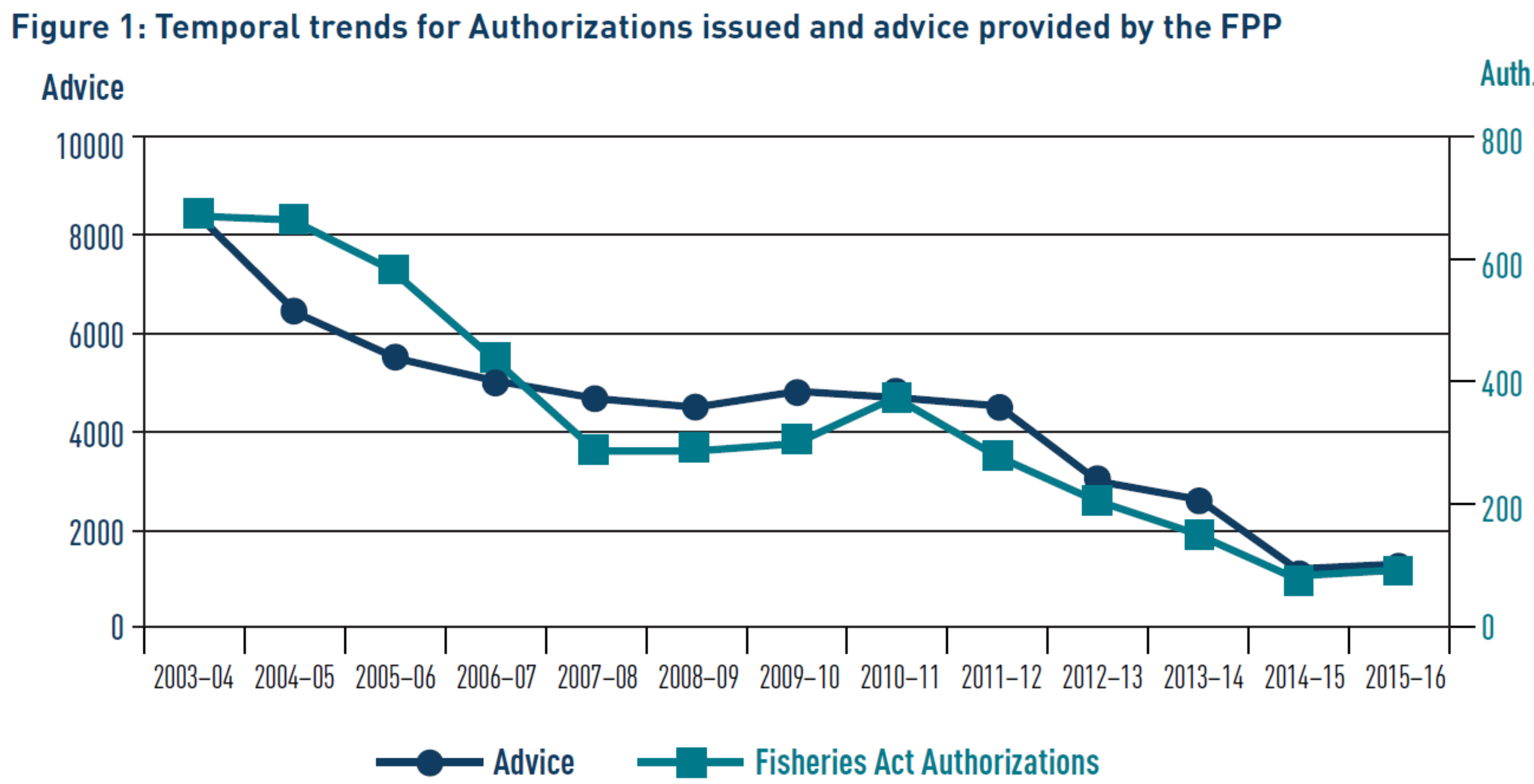

Figure A1. Trend in authorizations and letters of advice issued by the FFP (former FFHPP), from (DFO, 2016).