A PROPOSED METHODOLOGY FOR CONDUCTING THREATS ASSESSMENTS WITHIN THE GREAT LAKES COREGONINE RESTORATION FRAMEWORK

RESTORING
Great Lakes
COREGONINES

THREATS ASSESSMENT SCIENCE TEAM

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EXECUTIVE SUMMARY

This document serves to fulfill the Coregonine Threats Assessment Science Team's charge of providing a written recommendation for a methodology to conduct threats assessments for Great Lakes coregonines within the Coregonine Restoration Framework (CRF). Through a series of team meetings that included presentations by experts on five candidate threats assessment frameworks followed by structured deliberations, we came to consensus to recommend the threats assessment framework used by Fisheries and Oceans Canada under Canada's *Species at Risk Act*, with three modifications: (1) a conceptual modeling step, (2) the use of a "point spreading" approach to incorporate uncertainty when scoring threats, and (3) the use of a modified Delphi or "estimate-talk-estimate" approach when scoring key elements in the assessment. We recommend that this approach be applied to the spatial units delineated by the CRF Resolve Taxonomy and Gap Analysis science teams. In brief, the assessment process includes providing background information on the spatial unit and threats under assessment, constructing a conceptual model linking threats to key processes and vital rates, and scoring or ranking threats across six elements: likelihood of occurrence, level of impact, strength of evidence, unit-level threat occurrence, unit-level threat frequency, and unit-level threat extent. We provide detailed instructions for completing each step of the assessment and generating associated results, with particular attention paid to our suggested modifications.

The Coregonine Threats Assessment Science Team also conducted two test runs to assess the applicability and effectiveness of our recommended framework for Great Lakes coregonine populations and their threats. We conducted these test runs on two examples of Great Lakes coregonines that represented two extremes of data availability, as well as two different management contexts. We chose Kiyi (*Coregonus kiyi*) in Lake Ontario as an example of a data-poor, extirpated population, and we chose Cisco (*Coregonus artedi*) in Lake Superior as an example of a data-rich, extant population. We provide the results of these test runs in Appendices 1-2. We also describe the lessons we learned from these test runs throughout this document and highlighted them in the "Recommendations for avoiding challenges during application" section.

Purpose

As part of the Council of Lake Committees-endorsed "Science-based approach to restoring coregonines in the Great Lakes" (hereafter referred to as the Coregonine Restoration Framework or CRF; Fig. 1), the Coregonine Threats Assessment Science Team was charged with *providing a written recommendation for a methodology to conduct threats assessments for Great Lakes coregonines*, to be reviewed through the Joint Strategic Plan process (GLFC 2007). This document serves to fulfill that charge. Herein, we (1) provide a general description of threats assessments, (2) describe the Threats Assessment Science Team's process for arriving at our recommendation, (3) present our recommended threats assessment framework, and (4) highlight challenges that we encountered during two test runs of our recommended framework and provide advice for overcoming them. In addition, we provide appendices containing the complete results of the two test runs that we conducted.

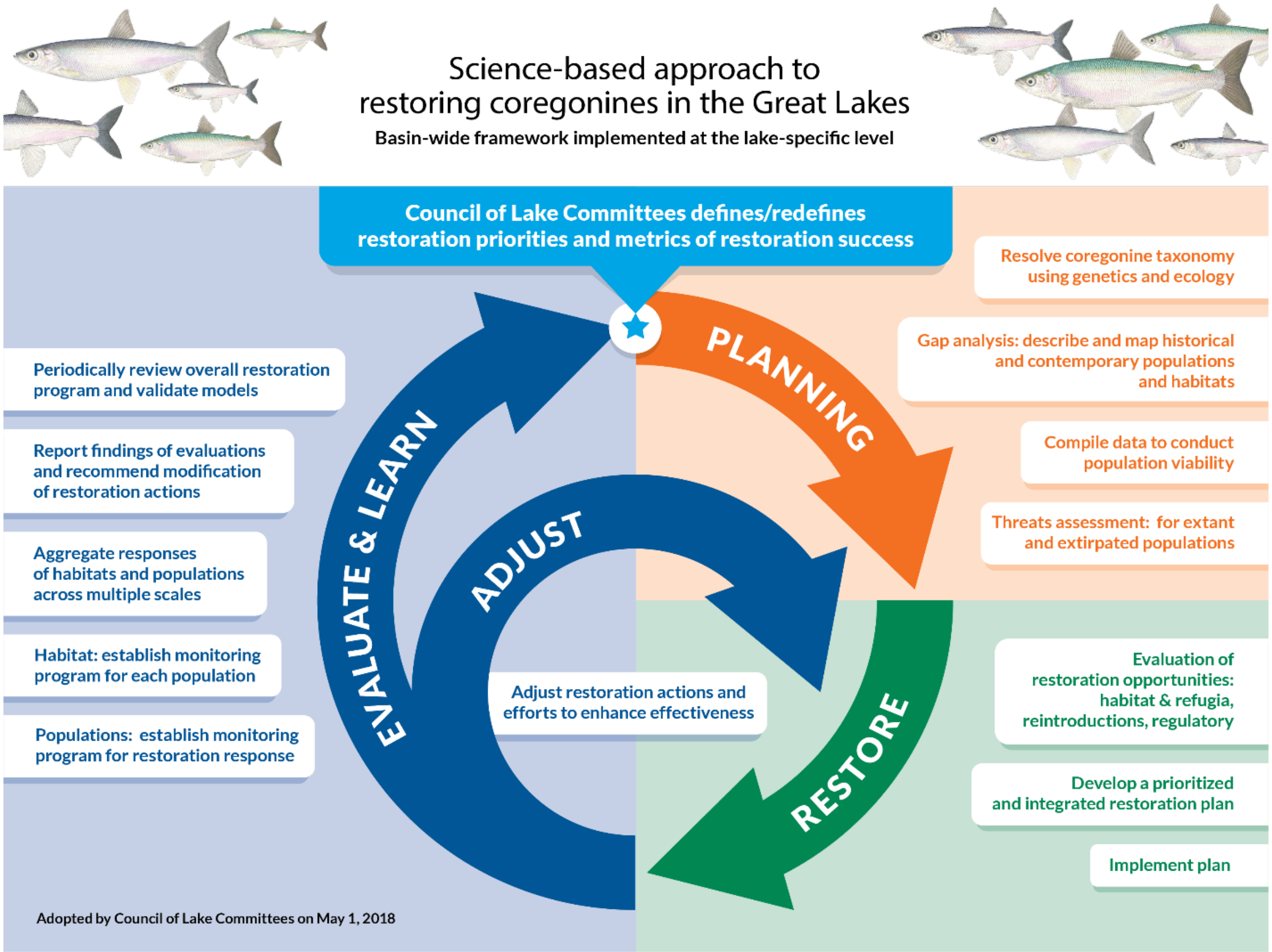


Figure 1. The Coregonine Restoration Framework.

Description of threats assessments

Threats assessments identify extrinsic, *human-driven* factors (e.g., development, overfishing, invasive species) that have caused, are causing, or may cause populations within a defined spatial unit to decline in distribution, abundance, or ecological function. Threats assessments typically account for the severity, timing, and extent of identified threats and often use a matrix combining the impact of a given threat with its extent or likelihood of occurrence to evaluate risk (DFO 2014, CMP 2020). When threats assessments occur for multiple spatial units, one can determine the extent to which threats are overlapping in time and space. A mechanistic explanation of how threats influence populations is an important component of a complete assessment (Smith et al. 2018). Actions designed to mitigate threats can be critical for conservation and restoration efforts and can be included in population viability analyses to predict viability under various threat and conservation scenarios.

Team process

The Coregonine Threats Assessment Science Team held 12 full-team meetings between 17 August 2021 and 4 October 2022, and additional meetings with subsets of the team (e.g., among co-leads or small groups) as needed. We used initial team meetings to review existing threats assessment frameworks to identify which framework(s) would be best suited for Great Lakes coregonines. These meetings included presentations by experts (including team members and non-members) to describe strengths and weaknesses of each candidate framework and provide additional information (e.g., example applications and outputs) to facilitate team deliberations. We considered five frameworks: Species Status Assessment (Smith et al. 2018); the International Union for the Conservation of Nature IUCN Green Status of Species (Akcakaya et al. 2018); Open Standards for the Practice of Conservation (CMP 2020); the framework used by Fisheries and Oceans Canada (hereafter DFO) under Canada's *Species at Risk Act* (DFO 2014); and the framework used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; e.g., COSEWIC 2016). We then discussed which framework or combination of frameworks would be best suited to meet the needs of the CRF. We also considered modifying existing frameworks or developing a novel framework. To aid and focus our deliberations, we evaluated frameworks using the following criteria:

1. The framework needs to be scientifically defensible given a range of data types, qualities, and quantities;
2. The framework needs to be consistently applicable across the Great Lakes basin, spatiotemporal scales, species/forms, multiple types of units (e.g., extant and extirpated populations, open habitats), and a variety of potential endpoints;
3. Outputs of the framework need to be compatible with other CRF scientific assessments (e.g., population viability analysis and habitat models);
4. The framework must adequately accommodate Great Lakes threats.

We formalized our deliberations via a voting procedure in which each team member indicated the candidate framework (or modified/novel framework) that they felt best satisfied the above criteria. Following these deliberations, **we came to consensus to recommend the DFO framework** for conducting threats assessments for Great Lakes coregonines, with **three modifications**: (1) the inclusion of a conceptual modeling component, (2) the use of "point spreading" when scoring the likelihood of occurrence and level of impact to better incorporate uncertainty, and (3) the use of a modified Delphi or "estimate-talk-estimate" approach for scoring threat likelihood of occurrence and level of impact. We describe this modified DFO framework in detail below (see "Recommended methodology: modified DFO framework").

We also conducted **two test runs** of our recommended framework which served as informal threats assessments that improved our understanding of and experience with the assessment process. These test runs provided an opportunity to assess the applicability and effectiveness of our recommended framework for Great Lakes coregonine populations and their threats. They also forced us to grapple with potential application issues and consider approaches to overcome them. We conducted the test runs on two examples of Great Lakes coregonines that represented two extremes of data availability, as well as two different management contexts (i.e., restoration of a currently extirpated population versus management of a robust extant population). We chose **Kiyi (*Coregonus kiyi*) in Lake Ontario** for our data-poor, extirpated population, and we conducted our test run on this example across two, three-hour team meetings on 7 April and 13 May 2022. We chose **Cisco (*Coregonus artedi*) in Lake Superior** as our data-rich, extant population, and we conducted our test run for this example across two, three-hour meetings on 8 August and 8 September 2022. We provide the results of these test runs in Appendices 1-2. Moreover, the lessons learned from them, which we consider to be among the most important and useful elements of this document, are distributed throughout the sections below and highlighted in the "Recommendations for avoiding challenges during application" section.

Recommended methodology: modified DFO framework

The DFO framework for conducting threats assessments under Canada's *Species at Risk Act* is described in detail in DFO (2014). Herein, we reproduce some of the content in that document and describe our suggested modifications to it. We recommend that this framework be applied to the spatial units delineated by the "Resolve Taxonomy" and "Gap Analysis" Science Teams within the CRF, and we operate under the assumption that that recommendation is followed throughout the remainder of this document (e.g., we use the terms "spatial unit" and "unit" to describe those delineated units below). For an example application of the DFO framework, see Andrews et al. (2021), which assesses threats to Pygmy Whitefish *Prosopium coulterii* populations in Lake Superior.

Glossary of key terminology

As noted in DFO (2014), the use of common terminology serves to benefit threats assessments in many ways, including reducing linguistic uncertainty, better linking recovery efforts to anthropogenic factors affecting species, facilitating multi-species or multi-unit assessments, and allowing for comparisons across assessments and species. We maintain the definitions from DFO (2014) listed below, with minor modifications to remove language specifically associated with the Canadian *Species at Risk Act*.

- **Threat** – any human activity or process that has caused, is causing, or may cause harm, death, or behavioral changes to a species, or the destruction, degradation, and/or impairment of its habitat, to the extent that population-level effects occur. A threat may exacerbate a natural process

- **Limiting factor** – a non-anthropogenic factor that, within a range of natural variation, limits the abundance and distribution of a wildlife species or a population (e.g., age at first reproduction, fecundity, age at senescence, prey abundance, mortality rate)

- **Jeopardize –** to place a species or population in a situation where its survival or recovery are at risk

- **Recovery –** a return to a state in which the population and distribution characteristics and the risk of extinction are all within the normal range of variation for the species

- **Survival –** the achievement of a stable or increasing state where a species exists in the wild and is not facing imminent extirpation or extinction as a result of human activity

- **Harm –** the adverse result of an activity where a single event or multiple events reduce the fitness (e.g., survival, reproduction, growth, movement) of individuals of a species

Step 1: Literature review and identification of threats

The first step in the threats assessment process involves compilation and summary of relevant literature and data for a given unit under assessment, and the development of a draft list of threats to that unit. Herein, we have termed these summaries "background threat and unit descriptions." See Appendices 1-2 for examples of these documents. Although this step is not explicitly outlined in DFO (2014), we do not consider this a modification to the DFO framework, as this process occurs in some form for DFO assessments (e.g., COSEWIC assessments are typically used as primary background documents).

Literature and data compilation and summary can take many forms and may be undertaken by one or more individuals. In general, the goal of this process should be to provide members of the assessment team with a thorough but concise synopsis of the best and most relevant information describing the unit under assessment. For our test runs, we found it useful to have two individuals with expertise on each of the units we assessed (i.e., Lake Ontario Kiyi and Lake Superior Cisco) work together to compile salient information and distill it down to a few pages of text to facilitate understanding among team members. Similar approaches could be used for formal assessments, although the number of people involved in this step and the nature of the summary should be adjusted as needed based on the composition of the assessment team and the types and amount of information available for a given unit.

We recommend that individuals responsible for data compilation and summary also provide a draft list of threats to assess, as these individuals should be among the best qualified to identify threats to a given unit based on their prior working knowledge and expertise on the species and location in question. Additionally, when sources are sufficiently rich, structuring the data and literature compilation around proposed threats can be useful for compilers and other members of the assessment team by reducing linguistic uncertainty. For example, information summaries can include descriptions of identified threats and how they relate to units under assessment, based on the best available data.

A critical aspect of threat identification is the choice of **threat classifications**. Assessment teams may choose to use standardized classifications, such as the IUCN-CMP Unified Classification of Direct Threats (https://www.iucnredlist.org/resources/threat-classification-scheme), in order to facilitate comparisons across assessments. Alternatively, assessment teams may choose to develop their own list of threats to maximize their understandability and applicability for a given assessment. If using the latter approach, we recommend that assessment team members consider the following elements for classifying threats:

- A **definition** that fits the species and their habitat. For example, it may be desirable to define threats that are specific to a given unit or species and that are tailored to its ecological context, as opposed to using a standardized threat definition that may not be well-suited to a particular application (which can lead to information loss or misuse during assessment).
- An **operative mechanism** that describes how the threat impacts the species or its habitat, including the habitat type (e.g., spawning, nursery, seasonal, migratory) and/or life stage(s) (e.g., young-of-year, juvenile, adult) affected. Conceptual modeling (see Step 2) can help to identify and communicate the operative mechanism(s) for each threat.
- The **spatiotemporal scale** over which the threat has an effect, taking into consideration the importance of that space and time to species viability.

Our recommendation for considering these elements stems from experience. For our test runs, we chose to develop non-standardized lists of threats and found that linguistic uncertainty associated with the threat classifications was often a sticking point (see "Recommendations for avoiding challenges during application"). We feel that more explicitly considering these elements for each threat in our list would have reduced confusion and uncertainty. See the background threat and unit description documents in Appendices 1-2 for examples of the threat classifications we used in our test runs.

Step 2 (Modification 1): Conceptual modeling

The next step in the process, and our first recommended modification to the DFO framework, is to construct a conceptual model linking threats to species vital rates or biological processes for the spatial unit under assessment. These models can take many forms but should involve some visualization or description of threats and how they influence and interact with vital rates and processes, and potentially with other threats. Box and arrow diagrams are commonly used for conceptual models and are well-suited to meet the needs of threats assessments.

For our test runs, we asked the same experts that led Step 1 to draft a conceptual model, which the full team then reviewed and revised as needed. We found this to be a useful approach, although conceptual model development for formal assessments may use different approaches (e.g., collective drafting of conceptual models with the full assessment team). In addition, due to time constraints, our team spent very little time (~30 min per test run) reviewing and revising draft conceptual models. We recommend that formal assessments spend considerably more time, perhaps up to half of a day in a threats assessment workshop, on this step to ensure that hypothesized mechanisms are clear and that there is general consensus on the structure of the model. See Fig. 2 and Appendices 1-2 for example conceptual models that we developed for our test runs.

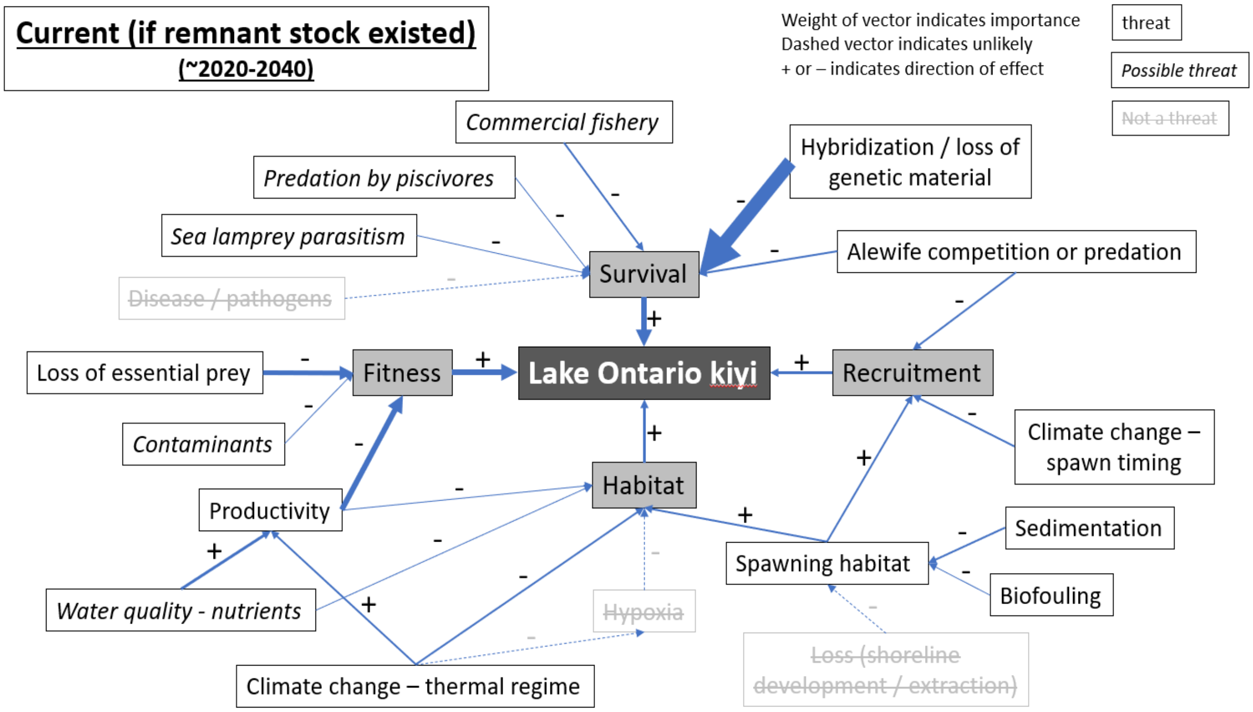


Figure 2. Example initial conceptual model developed by the Coregonine Threats Assessment Science Team describing threats to Kiyi *Coregonus kiyi* in Lake Ontario, assuming a remnant stock existed.

Conceptual modeling is useful for many reasons. First, it identifies and clarifies hypothesized mechanisms, effects, and interactions between threats and key vital rates and processes of the unit under assessment, which should reduce uncertainty and confusion in later steps. Second, it provides an opportunity for team members to come to a common understanding regarding threat classifications. Finally, it helps to ensure that outputs of formal assessments are compatible with and/or useful for other models and assessments within the CRF, including population viability analyses and habitat models. Ideally, conceptual models of threats and vital rates would be common for a given unit and shared across CRF implementation science teams. Moreover, we recommend that assessment teams consider using a standard format for conceptual models across CRF threats assessments and other science planning efforts, with minor changes if warranted (e.g., adding or removing threats, modifying hypothesized effects and interactions), to facilitate comparisons across assessments and maximize efficiency.

Step 3: Threat scoring and ranking

The next step is to rank and score each identified threat. This process includes evaluating the *likelihood of occurrence* (Table 1) and *level of impact* (Table 2) of each threat, as well as the *strength of evidence* (Table 3) associated with each threat. Also evaluated are the *occurrence, frequency,* and *extent* of each threat at the level of the assessment unit (Tables 4-6).

Table 1. Categories and definitions for threat likelihood of occurrence, per DFO (2014) with minor modifications to maintain consistency in terminology within the Coregonine Restoration Framework.

Likelihood of Occurrence	Definition
Known or very likely	Recorded to occur or > 90% chance of occurring
Likely	51-90% chance that this threat has, is, or will be occurring
Unlikely	11-50% chance that this threat has, is, or will be occurring
Remote	1-10% chance that this threat has, is, or will be occurring
Data deficient	No data or prior knowledge of this threat occurring previously, now, or in the future

Table 2. Categories and definitions for threat level of impact, per DFO (2014), with minor modifications to maintain consistency in terminology within the Coregonine Restoration Framework.

Level of Impact	Definition
Extreme	Severe unit decline (71-100% reduction in abundance) with the potential for extirpation
High	Substantial loss of unit (31-70% reduction in abundance) or threat would jeopardize the survival or recovery of the unit
Medium	Moderate loss of unit (11-30% reduction in abundance) or threat is likely to jeopardize the survival or recovery of the unit
Low	Little change in unit (1-10% reduction in abundance) or threat is unlikely to jeopardize the survival or recovery of the unit
Data deficient	No information on potential impact of this threat

Table 3. Categories and definitions for threat strength of evidence (adapted from DFO 2014).

Strength of Evidence	Definition
Very high	Very strong evidence for likelihood of occurrence and level of impact scores, given the mechanistic links established in the conceptual model
High	Substantial evidence for likelihood of occurrence and level of impact scores, given the mechanistic links established in the conceptual model
Medium	Moderate evidence for likelihood of occurrence and level of impact scores, given the mechanistic links established in the conceptual model
Low	Limited evidence for likelihood of occurrence and level of impact scores, given the mechanistic links established in the conceptual model
Very low	Little to no evidence for likelihood of occurrence and level of impact scores, given the mechanistic links established in the conceptual model

Table 4. Categories and definitions for unit-level threat occurrence, per DFO (2014), with minor modifications to maintain consistency in terminology within the Coregonine Restoration Framework.

Unit-level Threat Occurrence	Definition
Historical	Known to have occurred and negatively impacted the unit more than 10 years prior to the assessment
Current	Ongoing and currently negatively impacting the unit (within 10 years of the assessment)
Anticipatory	Anticipated to occur and negatively impact the unit in the future

Table 5. Categories and definitions for unit-level threat frequency, per DFO (2014), with minor modifications to maintain consistency in terminology within the Coregonine Restoration Framework.

Unit-level Threat Frequency	Definition
Single	The threat occurs once
Recurrent	The threat occurs periodically or repeatedly
Continuous	The threat occurs without interruption

Table 6. Categories and definitions for unit-level threat extent, per DFO (2014), with minor modifications to maintain consistency in terminology within the Coregonine Restoration Framework.

Unit-level Threat Extent	Definition
Extensive	71-100% of the unit is affected by the threat
Broad	31-70% of the unit is affected by the threat
Narrow	11-30% of the unit is affected by the threat
Restricted	1-10% of the unit is affected by the threat

The likelihood of occurrence and level of impact elements are combined to populate a <u>risk matrix</u> for each threat, while the other elements serve to provide additional information to aid management and policy decisions (i.e., they do not directly affect threat risk calculations). We propose two modifications to the process outlined in DFO (2014) that apply only to the evaluation of the likelihood of occurrence and level of impact, described below. Following the descriptions of our recommended modifications, we provide a step-by-step set of instructions for conducting this portion of the assessment process that incorporates those modifications.

Modification 2: Point spreading

In the framework outlined in DFO (2014), threat likelihood of occurrence and level of impact are evaluated based on group consensus of single categories for each element. That is, each threat is assigned one category for likelihood of occurrence and level of impact. We feel that this approach is not ideal for capturing uncertainty in threat rankings. Instead, we propose that each member of the assessment team *allocates* (*spreads) 100 percentage points across the categories* *for likelihood of occurrence and level of impact*. This approach better captures uncertainty, but still allows for all voting weight to be assigned to one category if desired. For example, if an individual feels that a threat is known to occur, with no uncertainty, then that individual can place all 100 of their points in the "Known or very likely" category. Conversely, if an individual is completely uncertain regarding the likelihood of occurrence or level of impact of a given threat, then they can evenly spread their 100 points across all categories. The most common result of this process is some uneven spread of points across categories that reflects each individual's views on the most likely category(ies), but also provides information on their uncertainty in those views. This information can then be propagated to the risk matrix. Within this point spreading framework, we recommend that the "Data deficient" categories be reserved for when there is insufficient data to know or understand the occurrence or impact of a threat, as **"Data deficient" should not be equated with "uncertain."** We also recommend that scores for a given threat's level of impact be distributed operating under the assumption that the likelihood of occurrence for that threat is "Known or very likely." We provide more information on these topics below (see "Recommendations for avoiding challenges during application").

Modification 3: Modified Delphi approach

We recommend using a modified Delphi or "estimate-talk-estimate" approach to score the likelihood of occurrence and level of impact of each threat (Burgman 2016, Hemming et al. 2018, Kahneman et al. 2021). This approach involves three steps. First, individuals cast votes (or, in our case, spread points across categories), and they are blinded to the voting/scoring of other individuals involved in the exercise (the first "estimate" step). They then view the results of the first round of voting and are given an opportunity to discuss them (the "talk" step). For example, individuals might volunteer or be asked to explain why they scored a threat in a certain way, especially if it differs from the central response theme. During these discussions, it is important to explore whether linguistic uncertainty could be influencing differences in scoring across individuals. Finally, individuals engage in a second round of voting/scoring (the second "estimate" step), and the results of this round are considered final. This process is advantageous in the context of threats assessments for many reasons. First, it provides another opportunity for the assessment team to discuss key elements of the threats and units under assessment (e.g., mechanisms and anticipated impacts), including personal judgements that were made during scoring. Second, it allows for further clarification of terminology. In our test runs, differences in scoring could often be attributed to nuanced differences in understanding regarding the definitions of the threats, or how likelihood of occurrence or level of impact should be conceptualized. The ability to first score threats and then discuss differences in scoring often helped to mitigate these problems. Finally, this approach allows for updating of scores based on the knowledge and opinions of assessment team members without straying too far toward "groupthink" (i.e., the effective forcing of individuals to agree with, e.g., the most vocal members of the team). In short, we feel that this approach provides a nice balance in that it allows individuals to clarify thinking and update their scores but does not force the group to come to consensus or unanimous agreement.

Step-by-step instructions for threat scoring and ranking

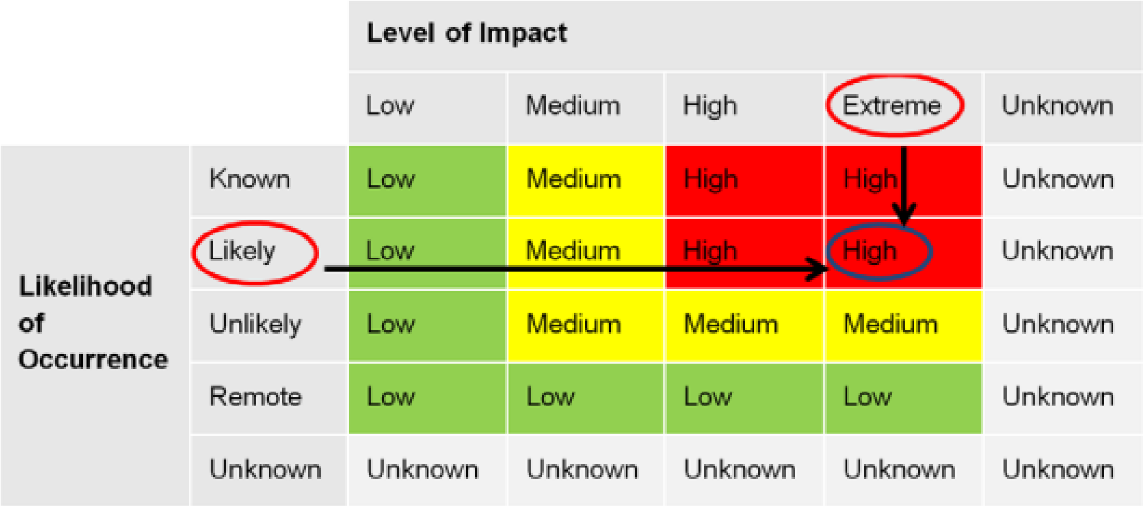
For each identified threat:

1. The assessment team reviews and discusses the material provided in the literature review and summary document(s) pertaining to the threat under consideration.

2. Each team member spreads 100 points across the categories for likelihood of occurrence and level of impact for a given threat (“round 1”; Tables 1-2). Team members are blinded to the scores of other team members. Level of impact scores should be distributed operating under the assumption that the likelihood of occurrence is “Known or very likely.”
3. Scores from “round 1” are revealed to the team members, and members are provided the opportunity to discuss scores amongst themselves.
4. Each team member again spreads 100 points across the categories for likelihood of occurrence and level of impact (“round 2”). Team members are again blinded to the scores of other team members. Level of impact scores should be distributed operating under the assumption that the likelihood of occurrence is “Known or very likely”.
5. Each team member votes for one category for threat strength of evidence (Table 3).
6. Each team member votes for between one and three of the categories for unit-level threat occurrence (Table 4). All combinations of unit-level threat occurrence categories are possible.
7. Each team member votes for one category for unit-level threat frequency (Table 5).
8. Each team member votes for one category for unit-level threat extent (Table 6).

Step 4: Risk matrix calculations and summary of results

The next step in the process is to populate a risk matrix using the likelihood of occurrence and level of impact scores for each threat, and to summarize rankings for the remaining elements. We recommend following DFO (2014) for assigning threat risk across combinations of likelihood of occurrence and level of impact categories (Fig 3).



		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	Low	Medium	High	High	Unknown
	Likely	Low	Medium	High	High	Unknown
	Unlikely	Low	Medium	Medium	Medium	Unknown
	Remote	Low	Low	Low	Low	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

Figure 3. Threat risk based on likelihood of occurrence and level of impact, reproduced from DFO (2014). This example shows that a threat that is likely to occur and expected to have an extreme impact should be considered a high risk.

Given our recommended modifications, this part of the process involves calculating the proportions of points assigned to each category and multiplying them across each pairwise combination of likelihood of occurrence and level of impact. The result is a matrix with point proportions (weights) in each cell that can then be used to calculate the total proportion or percent of point weight across risk categories for each threat. Table 7 provides an example of such a matrix from our Lake Ontario Kiyi test run. Please see Appendices 1-2 for additional examples.

Table 7. Example threat risk matrix generated from an informal threats assessment for Lake Ontario Kiyi *Coregonus kiyi* using a point spreading approach (threat = declining offshore productivity, round 2 scoring). Values indicate proportional point weights for each category. In this example, 24% of the weight falls in the “Low” risk category (green), 21% falls in the “Medium” risk category (yellow), 53% falls in the “High” risk category (red), and 2% falls in the “Unknown” category (gray).

		Level of Impact				
		Low	Medium	High	Extreme	Data deficient
Likelihood of Occurrence	Known	0.18	0.14	0.30	0.13	0.02
	Likely	0.04	0.03	0.07	0.03	0
	Unlikely	0.02	0.01	0.02	0.01	0
	Remote	0	0	0	0	0
	Data deficient	0	0	0	0	0

We note that threat scoring and risk matrix generation will be influenced by the size of the assessment team. We recommend that teams consist of approximately 5-15 scoring members. Importantly, scoring members should include key experts for a given spatial unit, species, and/or system. Including members that do not have strong expertise in the spatial unit or system under assessment may introduce noise in the scoring process.

Threat risk summaries

We recommend that assessment teams summarize threat risk distributions from risk matrices across threats to facilitate information transfer and understanding for managers and policy makers. Table 8 provides an example of such a summary, again from our test run on Lake Ontario Kiyi. See Appendix 2 for an additional example.

Table 8. Summary of threat risk distributions across threats to Lake Ontario Kiyi *Coregonus kiyi*, as assessed by the members of the Coregonine Threats Assessment Science Team. HABs = harmful algal blooms, CC = climate change. Dominant risk scores for each row are bolded for convenience. See Appendix 1 for more details.

	Threat Risk Distribution (%)					
Threat	Low	Medium	High	Data deficient	Strength of evidence	Comments
Commercial fishery	**99**	1	0	0	Low	
Invasive species	2	21	**77**	0	High	
Declining offshore productivity	24	21	**53**	2	Medium	
Hybridization/genetic loss	27	13	12	**48**	Medium	Large % data deficient
Loss of essential prey	4	36	**60**	0	High	
Predation by piscivores	**76**	19	1	4	Low	
Excess nutrients/HABs	**97**	3	0	0	Low	
Sedimentation/biofouling	**61**	37	2	0	Low	
CC – phenology	**68**	26	4	2	Low	
CC – thermal regime	**79**	19	2	0	Low	
Contaminants	**96**	4	0	0	Low	

Threat biplots

Another useful way to summarize threat risk is to generate a biplot showing threat likelihood of occurrence and level of impact. In essence, this biplot is another way of visualizing the threat risk matrix, but it allows for multiple threats to be placed alongside one another. Constructing biplots involves assigning numerical values to each likelihood of occurrence and level of impact category (i.e., “Remote” and “Low” = 1, “Unlikely” and “Medium” = 2, “Likely” and “High” = 3, and “Known or very likely” and “Extreme” = 4) and multiplying those values by the proportions of points distributed to each category to calculate means (and uncertainty, if desired) for each threat. Those means can then be plotted together, as shown in Fig. 4 and Appendices 1-2. These biplots should be used only as visual aids; the data shown in them are based on qualitative expert assessments and should not be used for statistical tests or models.

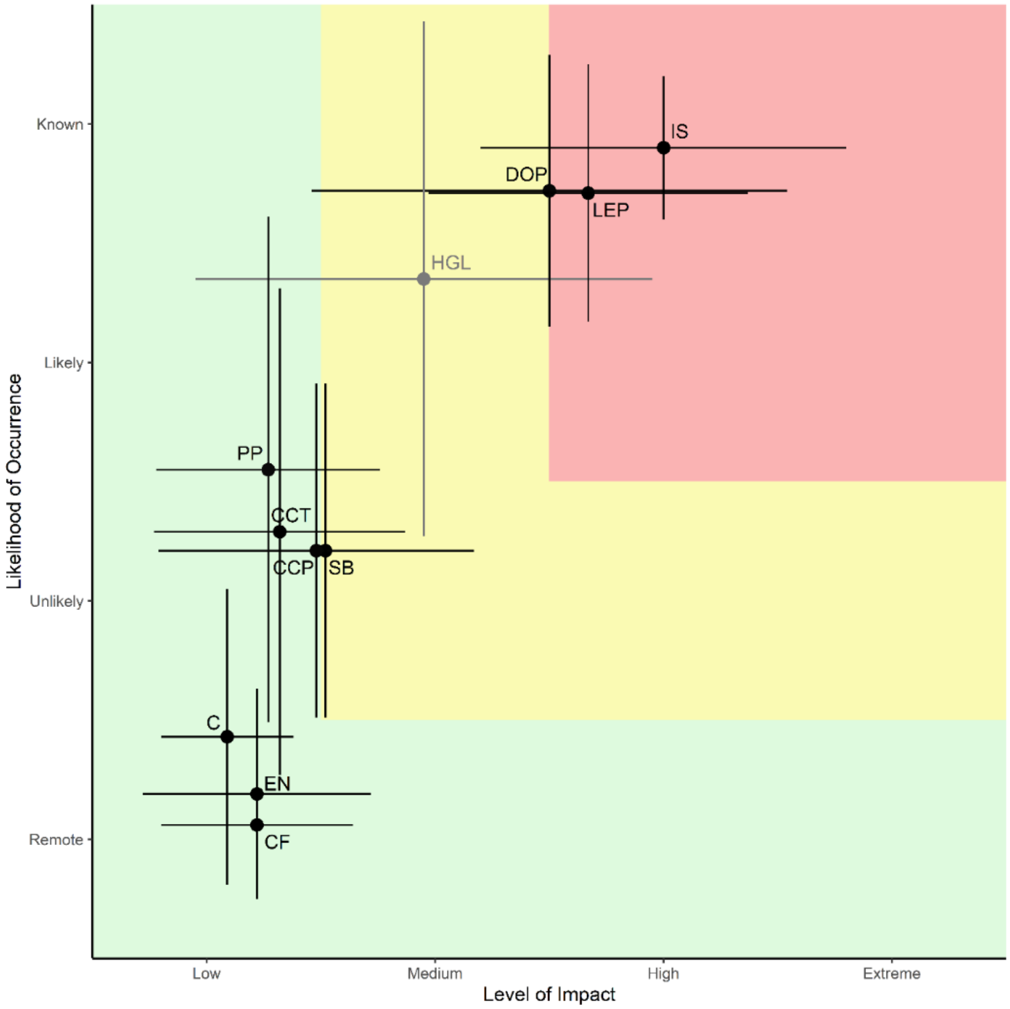


Figure 4. Biplot of threats to Lake Ontario Kiyi *Coregonus kiyi* based on mean likelihood of occurrence and level of impact from round 2 scoring. Error bars denote standard deviations. C = contaminants, CCP = climate change impacts on phenology, CCT = climate change impacts on thermal regime, CF = commercial fishery, DOP = declining offshore productivity, EN = excess nutrients and harmful algal blooms, HGL = hybridization and genetic loss, IS = invasive species, LEP = loss of essential prey, PP = predation by piscivores, SB = sedimentation and biofouling. Green shaded region = low threat risk, yellow shaded region = medium threat risk, red shaded region = high threat risk. Grayness indicates the proportion of scores placed in the “Data deficient” categories (HGL = 48% data deficient; all other threats = 0-4% data deficient). This is intended as a visual aid; points and uncertainty are based on qualitative assessments and should not be used in parametric statistical models or for significance tests.

These biplots can also serve as useful tools for visualizing differences in "round 1" and "round 2" scoring from the modified Delphi approach. As an example, we provide biplots from both scoring rounds from the Lake Ontario Kiyi test run in Appendix 1 (Figs. A1.2 and A1.3). Assessment teams may also choose to conduct statistical comparisons across scoring rounds (e.g., using Mantel tests) to assess whether the modified Delphi process has a significant impact on results or to investigate individual scoring patterns.

Summarizing remaining elements

The remaining elements in the assessment process, i.e., strength of evidence and unit-level threat occurrence, frequency, and extent, are not scored by point spreading and must therefore be summarized differently. For summarizing strength of evidence, we recommended assigning numerical values to each category (e.g., "Very low" = 1, "Low" = 2, "Medium" = 3, "High" = 4, "Very high" = 5), multiplying those values by the proportions of votes for each category, summing the products, and rounding to the nearest whole number to generate an index of overall strength of evidence. For example, if 70% of assessment team members voted for "Low" and 30% voted for "High", then the overall strength of evidence would be (0.7*2) + (0.3*4) = 2.6, which would be rounded to 3 and assigned a strength of evidence of "Medium." Alternatively, assessment teams can choose to forgo rounding and report intermediate categorizations for strength of evidence if desired (e.g., 2.6 = "medium-low"). For unit-level threat occurrence, frequency, and extent, we recommend simply reporting the percentages of votes in each category, as these elements do not lend themselves to averaging. See Appendices 1-2 for examples of summaries for these elements from our test runs.

"Rolling up" for multi-unit assessments

Results of threats assessment on single spatial units can be rolled up to higher levels for assessments of multiple spatial units (e.g., the units delineated by the Resolve Taxonomy and Gap Analysis CRF science teams), if desired. We recommend following the general guidelines in DFO (2014) for this process. Specifically, we recommend retaining the highest level of risk for a given threat across units, along with the associated strength of evidence, when rolling up to multiple units (precautionary approach). We also recommend including all categories that have been identified for unit-level threat occurrence and frequency. Finally, we recommend providing context for multi-unit-level threat extent by considering all votes cast in unit-level assessments along with the size of each unit in the roll-up. For example, a threat that is considered "Extensive" for a small unit and "Narrow" for a larger unit may be considered "Narrow" or "Broad" across both units.

Recommendations for avoiding challenges during application

Explicitly define threats

During our test runs, we found linguistic uncertainty surrounding threat definitions to be a major challenge. It is important to be as explicit and detailed as possible when defining threats, even if IUCN or other standardized classifications are used, to ensure that interpretation is consistent across assessment team members prior to scoring and ranking. As an example, the first threat we assessed in the Lake Ontario Kiyi test run was initially termed "commercial fishery." Confusion arose over whether this was intended to mean an existing fishery that would be a threat to Kiyi, or a new fishery that would potentially come into existence if Kiyi were restored in the lake. We therefore revised the threat definition to describe the former case, i.e., any existing commercial fishery that could catch or otherwise threaten Kiyi. Relatedly, some threats can be very broad and may impact species through many mechanisms. For example, evaluating the threat of "climate change" to a Great Lakes coregonine unit may prove difficult. We recommend defining threats more narrowly in these cases to facilitate assessment; for example, our Lake Ontario Kiyi test run included two climate change-related threats based on different mechanisms – "climate change impacts on phenology" and "climate change impacts on thermal regime." Being as explicit as possible when defining threats and following the guidelines listed above for elements to consider when defining threats should help to reduce associated uncertainty. The background threat and unit descriptions are the first and perhaps most important opportunity to do this, and efforts should be undertaken to ensure that those documents provide sufficient descriptions of threats for assessment.

In addition to its advantages for threat ranking and scoring, the modified Delphi approach can also help to clarify threat definitions. In our test runs, we often found that stark contrasts in point spreading in "round 1" scoring for a given threat stemmed from nuanced differences in understanding of threat definitions. The discussion period between scoring rounds provided an opportunity for team members to talk through their thought process and come to a more common understanding regarding how a threat should be interpreted and conceptualized, thereby reducing linguistic uncertainty in "round 2" scores. As such, we strongly recommend that formal assessments use the discussion period to help ensure that assessment team members have a common understanding of threat definitions.

Distinguish among elements of the assessment

Another potential challenge in the threats assessment process is cognitively distinguishing the various elements (e.g., likelihood of occurrence, level of impact, strength of evidence) of the assessment while scoring and ranking threats. In our test runs, team members often found it difficult to isolate the scored element; for example, it was difficult to ignore a given threat's level of impact when scoring its likelihood of occurrence, and vice versa. Occurrence and impact can also become cognitively commingled with unit-level threat extent. Assessors should do their best to distinguish these elements when scoring and ranking threats. Our recommendation to score the level of impact assuming that the likelihood of occurrence is "Known or very likely" should help to prevent issues in this vein. Moreover, providing detailed threat definitions (see above) should also help to mitigate these problems. Finally, facilitators should take every opportunity throughout the assessment process to check in with assessors and ensure that the various elements remain cognitively distinct, and that definitions and interpretations of elements are consistent across threats. Again, the discussion portion of the recommended modified Delphi approach is an excellent time to check in with assessors on this topic.

Avoid conflating uncertainty with data deficiency

One potential disadvantage to our recommended framework is that the point spreading process tends to make the "Data deficient" categories confusing. Some team members entered points in the "Data deficient" categories when they were uncertain about a given threat's occurrence or impact, while others expressed uncertainty by spreading points across categories. To help overcome this challenge, we recommend that points should only be spread into the "Data deficient" categories if there is insufficient information to provide any sort of assessment, however uncertain, of a given threat's likelihood of occurrence or level of impact (likely a rare situation). Assessors should therefore avoid putting some points in "Data deficient" and some points in other categories, as this is technically an expression of uncertainty. Rather, uncertainty should be expressed by spreading points across the other categories, with an even spread of points across categories representing a "completely uncertain" assessment. Although these distinctions can lead to confusion, the point spreading approach for capturing uncertainty is useful because it still allows for threat risk calculations (unlike the "Data deficient" categories), thereby preserving information that may be useful for decision makers.

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APPENDIX 1
Threats assessment test run on Lake Ontario Kiyi *Coregonus kiyi*

Description

This appendix contains results of a test run of the threats assessment framework recommended by the Coregonine Threats Assessment Science Team for application to Great Lakes coregonines as part of the Coregonine Restoration Framework. This test run was conducted on Kiyi *Coregonus kiyi* in Lake Ontario. Below, we include (1) the background threat and unit description provided to the science team by T. Johnson and D. Gorsky, including the proposed list of threats, (2) the initial conceptual model developed by the science team, and (3) the results of the threats assessment test run. We note that, for this assessment, the "Data deficient" categories were termed "Unknown," and "Strength of Evidence" was termed "Causal certainty."

BACKGROUND THREAT AND UNIT DESCRIPTION

Threats Assessment – Lake Ontario Kiyi (*Coregonus kiyi orientalis* (Koelz 1929)

Tim Johnson and Dimitry Gorsky

Summary Review:

Format of this section is original threat (marked with ●) with "status" of threat under current conditions (→). Threat matrix is at end of document.

COSEWIC (2005) Summary statement: Last recorded from Lake Ontario in 1964, the subspecies was driven to extinction by commercial exploitation, and predation/competition by introduced species.

Two designatable units (*Coregonus kiyi orientalis* occurring only in Lake Ontario, and *C. kiyi kiyi* of the upper Great Lakes) are recognized (COSEWIC 2005). Thus this review emphasises Lake Ontario data where possible.

- Historically in Lake Ontario, of total cisco catch in assessment gear was 52.8% kiyi in 1927, 0.01% in 1942, and only one individual in 1964 (last known report); none in 2002 (COSEWIC 2005) (NOTE COSEWIC says single individual in 1964, Eshenroder et al. (2016) say two). In other words, rapid collapse between ~1920s and 1940s.

  → In Lake Ontario, presently lakewide bottom trawls (n~250 spring, ~160 fall both to depths >200m) and predominantly US gillnets (n~120 but concentrated in depths <100m) so adequate effort to detect if kiyi recolonised
- Commercial exploitation identified as factor contributing to decline (Christie 1973, Miller et al. 1989) as well as COSEWIC (2005). But Eshenroder et al. (2016) states "[kiyi and hoyi] not considered commercially important (Pritchard 1931) until *C. reighardi* became scarce (Stone 1947)" and that "kiyi are less preferred by fishermen". COSEWIC (2005) makes similar statements in reference to Lake Superior: kiyi = black chub = low marketability and overall demand for chubs is low. Problem is most commercial landings report "chubs" as a group and don't discriminate species. In contrast, Miller et al. (1989) state "kiyi was probably the most important species in the Lake Ontario fishery (Pritchard 1931)" but I have not been able to verify

  → in Lake Ontario currently no offshore commercial fishery; only open lake gillnet fishery (for coregonines) happens in the fall (variable estimates of kiyi spawning date in Lake Ontario but tendency to fall spawning)

  → Reached out to Owen Gorman and Fritz Fischer to "confirm" status or fishery demand (were a fishery to resume in Lake Ontario) – Owen says kiyi are small and costly to exploit (offshore and deep) so little value to fishery
- Decline in lake trout may have prompted lamprey to switch to alternate prey including kiyi (Christie 1973)

  ➔ current scarring and wounding rates for lake trout is below target and abundance increasing thus threat from parasitism likely low

- Kiyi decline coincided with increasing abundance of alewife (Smith 1995)
  → alewife abundance currently lower than when program began (1968) and most recent years (except 2020 year-class) were poor so threat from competition likely low
- Kiyi are preyed upon by burbot and deepwater forms of lake trout (Scott and Crossman 1998)
  → neither species is (or was historically) abundant in Lake Ontario so threat from predation is low
- Preferred deepwater habitat for kiyi has changed little over time (COSEWIC 2005)
  → declining offshore productivity is a concern but offshore whole water column zooplankton has shown limited change in composition and abundance at least in past 30 years
  → climate change (warming temperatures) unlikely to affect kiyi in the near term due to size of hypolimnion (~44% of lake volume)
- Principle prey *Mysis* and *Diporeia* (COSEWIC 2005).
  → In Lake Ontario *Mysis* currently abundant (no trend) while *Diporeia* are very rare. Possible nutritional inhibition related to loss of Diporeia
- Miller et al. (1989) also list "deterioration of water quality due to eutrophication and toxic chemicals" as contributing factors but no evidence is given (nor corroborated by other primary sources)

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Threat matrix:

Threat	Historic	If existed in current time
Fisheries – commercial	Yes: Christie (1973) and Miller et al. (1989) suggest a major factor. Miller et al. (1989) state “kiyi was probably the most important species in the Lake Ontario fishery (Pritchard 1931)” but I have not been able to verify. Eshenroder et al. (2016) state “[kiyi and hoyi] not considered commercially important (Pritchard 1927) until *C. reighardi* became scarce (Stone 1947)” and that kiyi are less preferred by fishermen. COSEWIC (2005) makes similar statements in reference to Lake Superior: kiyi = black chub = low marketability and overall demand for chubs is low (COSEWIC 2005). Problem is most commercial landings report “chubs” as a group and don’t discriminate species.	No: No commercial fishery exists in offshore. Open lake fishery for coregonines (lake whitefish and cisco) occurs only in fall (kiyi offshore except to spawn – insufficient knowledge to determine if kiyi spawning habitat overlaps with that of other coregonines (where fishery is active)). I reached out to Owen Gorman and Fritz Fischer on Lake Superior (where commercial chub fishery exists) to see if statements about low value and low overall demand for chubs remain true (i.e. if kiyi were in Lake Ontario would they have a market). Owen states due to small size (in Lake Superior) and high cost to extract (due to deep offshore habitat) little market value in kiyi.
Fisheries - recreational	none	none
Food web – introduced species	Yes: Sea lamprey parasitism (Christie 1973) and / or competition with alewife or alewife predation on early life stages (Smith 1995)	No or less: Current lamprey scarring below target (for lake trout) and alewife biomass and abundance lower than historic
Food web – declining offshore productivity	none	Possibly (declining offshore production an issue but hypolimnetic zooplankton community “appears” relatively unchanged (composition and biomass) which is where kiyi reside
Food web - hybridization	No information	N/A: Currently extinct and Lake Ontario stock considered distinct to upper lakes so

		if reintroduced unlikely genetic lineage would be preserved anyway
Food web - predation	No: Burbot and deepwater forms of lake trout (Scott and Crossman 1998) but these species were and are not common in Lake Ontario	No more so than historic: Few deepwater predators (albeit DST tags show Chinook go deep and lake trout habitat does overlap)
Food web – remnant genetic material	Extinct and deemed distinct to upper lakes stocks	none
Water Quality – atmospheric deposition	none	No: Due to low trophic position not likely major threat
Water Quality - biomagnification	Unlikely: No information but declining and extinct before post WWII industrial boom	Unlikely as prey (*Mysis* and *Diporeia*) are low in food web
Water quality – nutrients / HABs	Possible: Eutrophication suggested by Miller et al. (1989) but no corroborating literature	Unlikely as HABs and excess nutrients limited to embayments and river mouths. *Cladophora* prevalence increasing in nearshore (possible fouling of spawning habitat) but typically Cladophora occurs after spawning so no habitat overlap
Physical habitat - hypoxia	none	No: Only occurs in industrial embayments in Lake Ontario which do not represent kiyi habitat
Physical habitat – sedimentation / biofouling	Sedimentation due to clearing of land	Possible: Possible spawning habitat fouling by dreissenids and sedimentation (resuspension)
Physical habitat – aggregate extraction	none	none
Physical habitat – shoreline modification	Not identified	Unlikely as former spawning habitat largely intact
Physical habitat – river flow / dams	none	none
Climate Change – ice cover	Not identified but unlikely	Unlikely as spawn in spring and offshore remainder of year

Climate change – spawn timing	Not identified but unlikely given extinct status as of 1964	Possible: Spawn in spring so Hjort mismatch hypothesis possible
Climate change – thermal regime	Not identified but unlikely given extinct status as of 1964	Possible but minor: as deep hypolimnetic species don't expect major loss of habitat(see COSEWIC 2005 technical summary – habitat currently 44% of total lake volume)
Disease / parasites	Not identified	??
Limited institutional history	Extinct as of 1964 so demise is documented but no recent records	At this point have been extinct longer than any serving employee!
NEW Food web – loss of essential prey	Alewife very selective predators on zooplankton; influence prey availability for obligate planktivores like kiyi	Possible: Diet primarily consists of *Mysis* and *Diporeia* and while *Mysis* persist, *Diporeia* have been lost

CONCEPTUAL MODEL

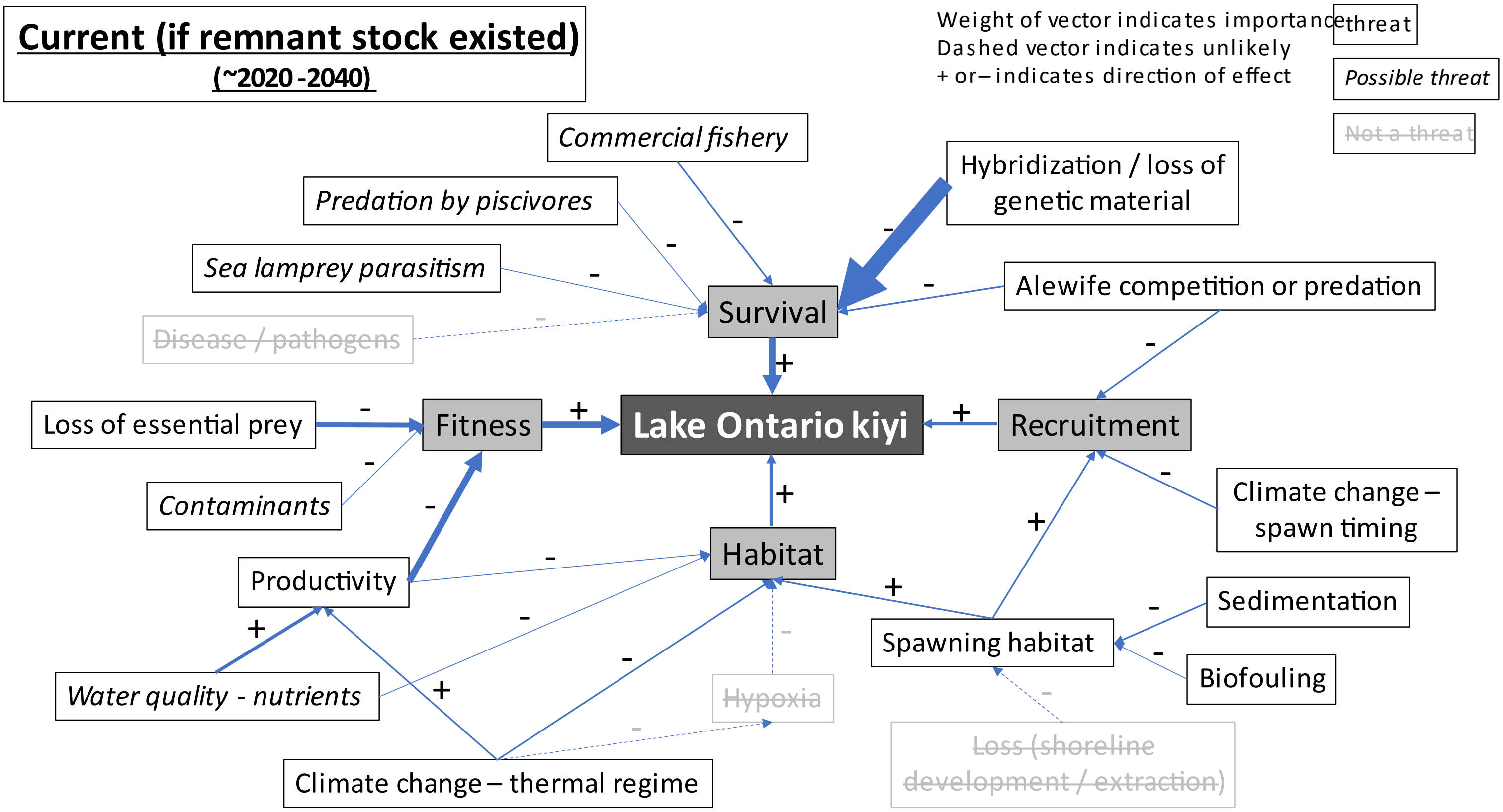

Figure A1.1. Conceptual model for threats to Lake Ontario *Coregonus kiyi*.

RESULTS OF TEST RUN

For all threat matrices, **RED = HIGH RISK, YELLOW = MEDIUM RISK, GREEN = LOW RISK, GRAY = UNKNOWN RISK** (per DFO framework).

THREAT 1: Commercial fishery (existing fishery that would catch Kiyi)

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.00	0.00	0.00	0.00	0.00
	Unlikely	0.14	0.08	0.04	0.00	0.00
	Remote	0.39	0.23	0.12	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 88%; MEDIUM = 12%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.00	0.00	0.00	0.00	0.00
	Unlikely	0.05	0.01	0.00	0.00	0.00
	Remote	0.73	0.21	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 99%; MEDIUM = 1%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: Medium (40%), Low (20%), Very low (20%). Average = Low

Pop-level occurrence (can sum to >100%): Historical (100%)

Pop-level frequency: Recurrent (80%), Continuous (20%)

Pop-level extent: Extensive (40%), Broad (40%), Restricted (20%)

THREAT 2: Invasive species (competition/predation)

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.05	0.06	0.17	0.18	0.00
	Likely	0.04	0.06	0.17	0.18	0.00
	Unlikely	0.01	0.01	0.03	0.04	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 10%; MEDIUM = 20%; HIGH = 70%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.02	0.19	0.43	0.26	0.00
	Likely	0.00	0.02	0.05	0.03	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 2%; MEDIUM = 21%; HIGH = 77%; UNKNOWN = 0%

Causal certainty: Very High (20%), High (80%). Average = High

Pop-level occurrence (can sum to >100%): Historical (100%), Current (100%), Anticipatory (100%)

Pop-level frequency: Recurrent (40%), Continuous (60%)

Pop-level extent: Extensive (80%), Broad (20%)

THREAT 3: Declining offshore productivity

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.11	0.09	0.34	0.11	0.03
	Likely	0.03	0.03	0.10	0.03	0.01
	Unlikely	0.01	0.01	0.04	0.01	0.00
	Remote	0.01	0.01	0.02	0.01	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 20%; MEDIUM = 18%; HIGH = 58%; UNKNOWN = 4%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.18	0.14	0.30	0.13	0.02
	Likely	0.04	0.03	0.07	0.03	0.00
	Unlikely	0.02	0.01	0.02	0.01	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 24%; MEDIUM = 21%; HIGH = 53%; UNKNOWN = 2%

Causal certainty: High (20%), Medium (40%), Low (40%). Average = Medium

Pop-level occurrence (can sum to >100%): Historical (20%), Current (100%), Anticipatory (100%)

Pop-level frequency: Recurrent (20%), Continuous (80%)

Pop-level extent: Extensive (60%), Broad (40%)

THREAT 4: Hybridization/loss of genetic material

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.13	0.13	0.12	0.04	0.22
	Likely	0.02	0.02	0.01	0.01	0.03
	Unlikely	0.02	0.02	0.02	0.01	0.02
	Remote	0.01	0.01	0.01	0.00	0.01
	Unknown	0.03	0.03	0.03	0.01	0.05

LOW = 19%; MEDIUM = 18%; HIGH = 18%; UNKNOWN = 45%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.16	0.10	0.07	0.04	0.28
	Likely	0.02	0.01	0.01	0.00	0.03
	Unlikely	0.02	0.01	0.01	0.00	0.04
	Remote	0.03	0.02	0.01	0.01	0.05
	Unknown	0.02	0.01	0.01	0.01	0.03

LOW = 27%; MEDIUM = 13%; HIGH = 12%; UNKNOWN = 48%

Causal certainty: Very High (20%), High (20%), Medium (20%), Low (40%). Average = Medium

Pop-level occurrence (can sum to >100%): Historical (60%), Current (80%), Anticipatory (60%)

Pop-level frequency: Recurrent (20%), Continuous (80%)

Pop-level extent: Extensive (80%), Broad (20%)

THREAT 5: Loss of essential prey

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.05	0.29	0.41	0.12	0.00
	Likely	0.01	0.04	0.06	0.02	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 6%; MEDIUM = 33%; HIGH = 61%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.03	0.26	0.40	0.07	0.00
	Likely	0.01	0.07	0.11	0.02	0.00
	Unlikely	0.00	0.01	0.02	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 4%; MEDIUM = 36%; HIGH = 60%; UNKNOWN = 0%

Causal certainty: High (80%), Medium (20%). Average = High

Pop-level occurrence (can sum to >100%): Historical (40%), Current (100%), Anticipatory (100%)

Pop-level frequency: Recurrent (20%), Continuous (80%)

Pop-level extent: Extensive (80%), Broad (20%)

THREAT 6: Predation by piscivores

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.18	0.05	0.01	0.00	0.01
	Likely	0.16	0.04	0.00	0.00	0.01
	Unlikely	0.17	0.05	0.01	0.00	0.00
	Remote	0.23	0.06	0.01	0.00	0.01
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 81%; MEDIUM = 15%; HIGH = 1%; UNKNOWN = 3%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.16	0.05	0.00	0.00	0.01
	Likely	0.23	0.07	0.01	0.00	0.01
	Unlikely	0.18	0.06	0.01	0.00	0.01
	Remote	0.15	0.04	0.00	0.00	0.01
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 76%; MEDIUM = 19%; HIGH = 1%; UNKNOWN = 4%

Causal certainty: Medium (40%), Low (60%). Average = Low

Pop-level occurrence (can sum to >100%): Historical (80%), Current (100%), Anticipatory (100%)

Pop-level frequency: Recurrent (20%), Continuous (80%)

Pop-level extent: Broad (60%), Narrow (40%).

THREAT 7: Excess nutrients/HABs

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.02	0.00	0.00	0.00	0.00
	Unlikely	0.29	0.04	0.01	0.00	0.00
	Remote	0.53	0.08	0.03	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 95%; MEDIUM = 5%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.02	0.00	0.00	0.00	0.00
	Unlikely	0.13	0.02	0.01	0.00	0.00
	Remote	0.67	0.12	0.03	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 97%; MEDIUM = 3%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: High (20%), Medium (20%), Low (20%), Very Low (40%). Average = Low

Pop-level occurrence (can sum to >100%): Historical (80%), Current (60%), Anticipatory (80%)

Pop-level frequency: Recurrent (60%), Continuous (40%)

Pop-level extent: Broad (20%), Restricted (80%).

THREAT 8: Sedimentation/biofouling

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.04	0.05	0.02	0.00	0.00
	Likely	0.16	0.18	0.07	0.00	0.00
	Unlikely	0.15	0.17	0.06	0.00	0.00
	Remote	0.04	0.04	0.02	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 45%; MEDIUM = 46%; HIGH = 9%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.20	0.15	0.02	0.00	0.00
	Unlikely	0.25	0.19	0.03	0.00	0.00
	Remote	0.09	0.06	0.01	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 61%; MEDIUM = 37%; HIGH = 2%; UNKNOWN = 0%

Causal certainty: Medium (20%), Low (60%), Very Low (20%). Average = Low

Pop-level occurrence (can sum to >100%): Historical (60%), Current (80%), Anticipatory (80%)

Pop-level frequency: Recurrent (60%), Continuous (40%)

Pop-level extent: Extensive (20%), Narrow (40%), Restricted (40%).

THREAT 9: Climate change impacts on phenology

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.25	0.09	0.04	0.00	0.01
	Unlikely	0.28	0.10	0.05	0.00	0.02
	Remote	0.10	0.03	0.02	0.00	0.01
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =68%; MEDIUM = 24%; HIGH = 4%; UNKNOWN = 4%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.23	0.10	0.04	0.00	0.01
	Unlikely	0.27	0.11	0.05	0.00	0.01
	Remote	0.11	0.05	0.02	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 68%; MEDIUM = 26%; HIGH = 4%; UNKNOWN = 2%

Causal certainty: Medium (40%), Low (60%). Average = Low

Pop-level occurrence (can sum to >100%): Current (60%), Anticipatory (100%)

Pop-level frequency: Recurrent (60%), Continuous (40%)

Pop-level extent: Extensive (40%), Broad (40%), Narrow (20%).

THREAT 10: Climate change impacts on thermal regime

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.14	0.04	0.01	0.00	0.00
	Likely	0.15	0.04	0.01	0.01	0.00
	Unlikely	0.36	0.10	0.03	0.01	0.00
	Remote	0.07	0.02	0.01	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =75%; MEDIUM = 22%; HIGH = 3%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.12	0.04	0.01	0.00	0.00
	Likely	0.14	0.04	0.01	0.00	0.00
	Unlikely	0.29	0.10	0.01	0.00	0.00
	Remote	0.17	0.06	0.01	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 79%; MEDIUM = 19%; HIGH = 2%; UNKNOWN = 0%

Causal certainty: Medium (20%), Low (80%). Average = Low

Pop-level occurrence (can sum to >100%): Current (60%), Anticipatory (100%)

Pop-level frequency: Recurrent (60%), Continuous (40%)

Pop-level extent: Extensive (40%), Broad (40%), Restricted (20%).

THREAT 11: Contaminants

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.07	0.01	0.00	0.00	0.00
	Unlikely	0.28	0.03	0.00	0.00	0.00
	Remote	0.55	0.06	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =96%; MEDIUM = 4%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.06	0.01	0.00	0.00	0.00
	Unlikely	0.26	0.03	0.00	0.00	0.00
	Remote	0.58	0.06	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 96%; MEDIUM = 4%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: Medium (20%), Low (40%), Very Low (40%). Average = Low

Pop-level occurrence (can sum to >100%): Historical (60%), Current (80%), Anticipatory (100%)

Pop-level frequency: Recurrent (20%), Continuous (80%)

Pop-level extent: Extensive (20%), Broad (40%), Narrow (20%), Restricted (20%).

Table A1.1. Summary of threat risk distributions across threats to Lake Ontario Kiyi *Coregonus kiyi*, as assessed by the members of the Coregonine Threats Assessment Science Team. HABs = harmful algal blooms, CC = climate change.

	Threat Risk Distribution (%)					
Threat	Low	Medium	High	Unknown	Causal certainty	Comments
Commercial fishery	99	1	0	0	Low	
Invasive species	2	21	77	0	High	
Declining offshore prod.	24	21	53	2	Medium	
Hybridization/genetic loss	27	13	12	48	Medium	Large % unknown
Loss of essential prey	4	36	60	0	High	
Predation by piscivores	76	19	1	4	Low	
Excess nutrients/HABs	97	3	0	0	Low	
Sedimentation/biofouling	61	37	2	0	Low	
CC – phenology	68	26	4	2	Low	
CC – thermal regime	79	19	2	0	Low	
Contaminants	96	4	0	0	Low	

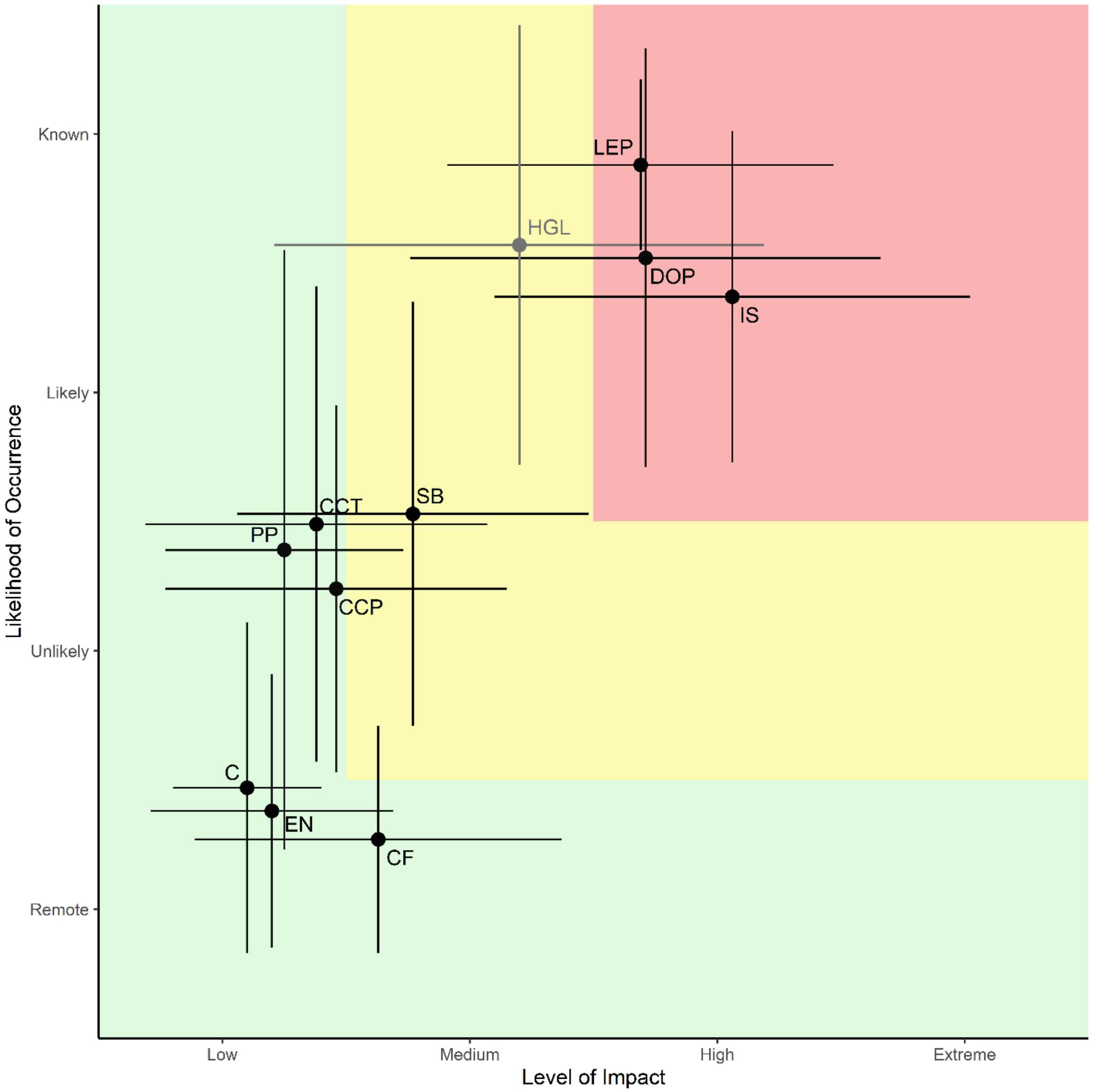

Figure A1.2. Biplot of threats to Lake Ontario Kiyi *Coregonus kiyi* based on likelihood of occurrence and level of impact from round 1 scoring. C = contaminants, CCP = climate change impacts on phenology, CCT = climate change impacts on thermal regime, CF = commercial fishery, DOP = declining offshore productivity, EN = excess nutrients and harmful algal blooms, HGL = hybridization and genetic loss, IS = invasive species, LEP = loss of essential prey, PP = predation by piscivores, SB = sedimentation and biofouling. Green shaded region = low threat risk, yellow shaded region = medium threat risk, red shaded region = high threat risk. Grayness indicates the proportion of scores placed in the "unknown" categories (HGL = 45% unknown; all other threats = 0-5% unknown). **THIS FIGURE IS INTENDED ONLY AS A VISUAL AID**; points and error bars should not be used for statistical models or significance tests.

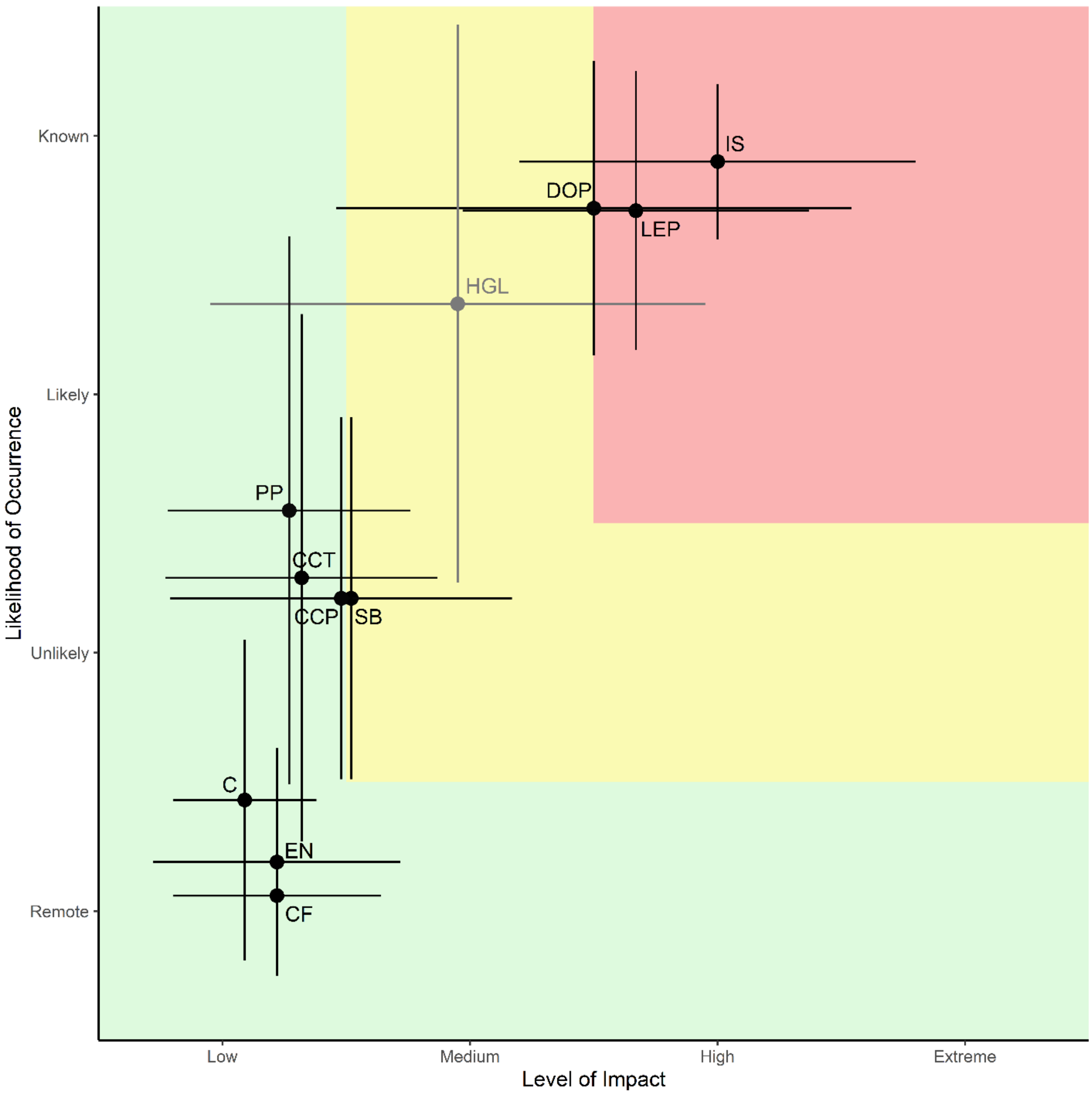

Figure A1.3. Biplot of threats to Lake Ontario Kiyi *Coregonus kiyi* based on likelihood of occurrence and level of impact from round 2 scoring. C = contaminants, CCP = climate change impacts on phenology, CCT = climate change impacts on thermal regime, CF = commercial fishery, DOP = declining offshore productivity, EN = excess nutrients and harmful algal blooms, HGL = hybridization and genetic loss, IS = invasive species, LEP = loss of essential prey, PP = predation by piscivores, SB = sedimentation and biofouling. Green shaded region = low threat risk, yellow shaded region = medium threat risk, red shaded region = high threat risk. Grayness indicates the proportion of scores placed in the "unknown" categories (HGL = 48% unknown; all other threats = 0-4% unknown). **THIS FIGURE IS INTENDED ONLY AS A VISUAL AID**; points and error bars should not be used for statistical models or significance tests.

APPENDIX 2
Threats assessment test run on Lake Superior cisco *Coregonus artedi*

Description

This appendix contains results of a test run of the threats assessment framework recommended by the Coregonine Threats Assessment Science Team for application to Great Lakes coregonines as part of the Coregonine Restoration Framework. This test run was conducted on cisco or lake herring *Coregonus artedi* in Lake Superior. Below, we include (1) the background threat and unit description provided to the science team by C. Bronte and S. Sitar, including the proposed list of threats, (2) the conceptual model developed by the science team, and (3) the results of the threats assessment test run. We note that, for this assessment, the “Data deficient” categories were termed “Unknown,” and “Strength of Evidence” was termed “Causal certainty.”

BACKGROUND THREAT AND UNIT DESCRIPTION

Threats to *Coregonus artedi* in Lake Superior

C. Bronte and S. Sitar July 2022

- Fisheries
  - **Commercial** – historically large interception fisheries on spawning aggregations in Western Lake Superior, the Apostle Islands, Keweenaw Bay, and Canadian Bays plus some year-round fisheries credited with collapse in the 1960s (Lawrie and Rahrer 1972; Selgeby 1982; Wright 1973). Smaller fisheries persisted thereafter in MN, WI, ON. Current fisheries are the largest in the Great Lakes – In Minnesota, Ontario, Wisconsin. Michigan harvest is modest and limited to only 1836 tribes; state licensed fishermen not allowed any harvest. Lake Superior total annual yield exceeds 1000 mt (2.2 million lbs) (Goldsworthy and Yule 2017). Concern of overharvest in most jurisdictions have limited harvest on standing adult stocks estimated with hydroacoustics.
  - **Recreational** – minimal to none; mostly ice fishery in bays.
- Food web changes
  - **Competition with/predation from introduced species** (Rainbow Smelt/Alewife/Sea Lamprey) – Rainbow smelt predation/competition historically was implicated in cisco demise (Anderson and Smith 1971; Swenson (1978) and supported by later studies (Myers et al. 2009) but others have argued against these hypotheses (Selgeby et al. 1978; Selgeby et al. 1994; Bronte et al. 2003). SR analysis indicated negative correlation between age-1 recruits and smelt (Rook et al. 2013). Stable isotope studies have shown little niche overlap among cisco, smelt, and bloater (Rosinski et al. 2020) allowing these pelagic and bentho-pelagic planktivores to co-exist. Sea lamprey predation likely on transformers in fall—impact unknown.
  - **Reduced productivity of pelagic zone due to phosphorus/~~Dreissenids~~** -> changes in prey --- evidence of the rise and fall of primary production (phosphorus) during the last century was correlated with cisco fishery landings suggesting that intermittent and low recruitment experienced in the last 45 years (Bronte et al. 2003; Gorman et al. 2021) may be related to lower productivity (Rook et al. 2021), and limit future population expansion.
  - **Hybridization with other Ciscoes** – recent evidence shows little hybridization among cisco, bloater, and kiyi (A, Ackiss, USGS, written communication). Clear delineations of genotypes from confident assignments of adult phenotypes, which translate well to larval assignments (Lachance et al. 2021)
  - **Predation from native predators (Lake Trout**) -> limiting factor to recruitment suggested by Hoff (2004) but not by Rook et al. (2013); both are mathematical exercises. Seems unlikely has predation would have to occur on age-0 fish. No stomach content evidence to support this.
  - **Sufficient remnant genetic material?** -> Limiting factor – no evidence but not yet compared to any historical measures of diversity. Lake Superior has the highest genetic diversity of all residual cisco populations in the Great Lakes. Parental stocks in western Lake Superior seem adequate but are far less in eastern Lake Superior. Allele effects may be possible in some areas but unlikely.
- Pollution & Water Quality

  - **Atmospheric deposition** & local inputs in some areas – Most but not all contaminants in LS are well below those for other GLs—not certain this point has been raised.
  - **Biomagnification in foodweb** (e.g., *Diporeia* and Pygmy Whitefish) -- unknown
  - **Microplastics** - found in cisco but overall much lower in LS fish than other Great Lakes (Munno et al. 2022).
- Physical habitat alteration
  - **Hypoxia** –episodic in the St Louis River but water quality has been improving significantly over time (Bellinger et al. 2016), likely not a factor lake wide.
  - **Sedimentation/biofouling of spawning substrate** – had to occur in streams and nearshore areas during deforestation from 1870-1920s resulting in the loss of certain river spawning and near shore populations but was followed by growing fisheries that persisted into the 1960s, and suggests that physical habitat was not ever limiting. Allochthonous input from deforestation and farming may have contributed to increases in primary production and more persistent and higher recruitment which fueled the historical fishery (Rook et al. 2021).
- Climate change-related impacts to life history
  - **Changes in ice cover ->** poor recruitment? The best Ricker stock-recruitment models using biotic and abiotic variables to explain R did <u>not include ice cover</u>. (Rook et al. 2013).
  - **Changes to spawn timing ->** impacts on growth and survival? None noted; lake populations now aggregate at same times (November) as those historically. Eggs are not releases though until late Nov into Dec and latter.
  - **Changes in thermal regime ->** impacts on growth and survival? Yes has been suggested by Stewart et.al 2022. Larval survival and critical thermal maximum were negatively related to incubation temperature, but larval growth was positively related to incubation temperature.

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Lake Superior Cisco Threat matrix:

Threat	Historic	If existed in current time
Fisheries – commercial	historically large interception fisheries on spawning aggregations in Western Lake Superior, the Apostle Islands, Keweenaw Bay, and Canadian Bays plus some year-round fisheries credited with collapse in the 1960s (Lawrie and Rahrer 1972; Selgeby 1982; Wright 1973). Smaller fisheries persisted thereafter in MN, WI, ON.	Current fisheries for Cisco in LS are the largest in the Great Lakes (MN, ON, WI). Michigan harvest is modest and limited to only 1836 tribes; state licensed fishermen not allowed any harvest. Lake Superior total annual yield exceeds 1000 mt (2.2 million lbs) (Goldsworthy and Yule 2017). Concern of overharvest in most jurisdictions have limited harvest on standing adult stocks estimated with hydroacoustics. Fisheries mostly under control but recruitment is limited hence harvest regulation must be maintained.
Fisheries- Recreational	minimal to none; mostly ice fishery in bays.	minimal to none; mostly ice fishery in bays.
Food Web- Invasive Spp direct, competition	Competition with/predation from introduced species (Rainbow Smelt/Alewife/Sea Lamprey) – Rainbow smelt predation/competition historically was implicated in cisco demise (Anderson and Smith 1971; Swenson (1978) and supported by later studies (Myers et al. 2009) but others have argued against these hypotheses (Selgeby et al. 1978; Selgeby et al. 1994; Bronte et al. 2003).	An invasion from alewife as the result of global warming is possible, but low productivity and high predator biomass make this unlikely. SR analysis indicated negative correlation between age-1 recruits and smelt (Rook et al. 2013). SI studies have shown little niche overlap among cisco, smelt, and bloater (Rosinski et al. 2020) allowing these pelagic and bentho-pelagic planktivores to co-exist.
Food Web- Invasive Spp indirect, productivity Lower food web (e.g., zebra/quagga)	none	Lake Superior is already an oligotrophic system. Reduced productivity of pelagic zone due to phosphorus declines. Evidence of the rise and fall of primary

		production (phosphorus) during the last century was correlated with cisco fishery landings suggesting that intermittent and low recruitment experienced in the last 45 years (Bronte et al. 2003; Gorman et al. 2021) may be related to lower productivity (Rook et al. 2020) and may limit future population expansion. Zebra/quaggas not an issue—low dissolved calcium levels limits populations to near shore harbor areas.
Food Web- Predation direct Native vs. non-native (stocking)	Cisco dominant food of item of lake trout. Salmon stocking not done in earnest until cisco stocks collapsed.	Not considered a threat. Non native predators are inconsequential. Predation from lake trout suggested limiting factor to recruitment suggested by Hoff (2004) but not by Rook et al. (2013); both are mathematical exercises. Seems unlikely has predation would have to occur on age-0 fish. No stomach content evidence to support this.
Ecological-hybridization	No evidence yet of hybridization historically but that work yet to be done.	Recent evidence shows little hybridization among cisco, bloater, and kiyi (A, Ackiss USGS, in review). Clear delineations of genotypes from confident assignments of adult phenotypes, which translate well to larval assignments (LaChance et al. 2021)
Ecological- reduced genetic diversity	Commercial exploitation may have reduced genetic diversity/life history portfolio through extirpation of selected stocks.	No evidence but not yet compared to any historical measures of diversity. Lake Superior has the high genetic diversity of all residual cisco populations in the Great Lakes. Parental stocks in western LS seem adequate but are far less in eastern Lake Superior. Allele effects may be possible in some areas but unlikely.

Environment- Pollution	Likely around town and cities; forest products waste, mining waste.	Most historical pollution remediated but still could be having impacts. Atmospheric deposition & local inputs in some areas – Most (but not all) contaminants in LS are well below those for other GLs—not certain this point has been raised . Microplastics - found in cisco but overall much lower in LS fish than other Great Lakes (Munno et al. 2016). Impacts unknown.
Environment- Lake warming, reduced ice cover	Not an issue then.	Ice cover less now than then. In Rook et al. (2013) the best Ricker SR models using biotic and abiotic variables to explain R did not include ice cover. No changes to spawn timing -lake populations now aggregate at same times (November) as those historically. Eggs are not releases though until late Nov into Dec and latter.
Environment- Lake warming, water temperature increases	Likely not a factor	Changes in thermal regime of surface waters. Effects have been suggested by Stewart et.al 2022. Larval survival and critical thermal maximum were negatively related to incubation temperature, but larval growth was positively related to incubation temperature.
Environment- Habitat reduction	Sedimentation/biofouling of spawning substrate – had to occur in streams and nearshore areas during deforestation from 1870-1920s resulting in the loss of certain river spawning and near shore populations but was followed by 40 years growing fisheries that persisted into the 1960s, and suggests that physical habitat was not ever	Hypoxia –episodic in the St Louis River but water quality has been improving significantly over time (Bellinger et al. 2016), likely not a factor lake wide. Watershed now more stabilized but sediment plumes still exist especially in western Lake Superior.

	limiting. Allochthonous input from deforestation and farming may have contributed to increases in primary production and more persistent and higher recruitment which fueled the historical fishery (Rook et al. 2020).	

CONCEPTUAL MODEL

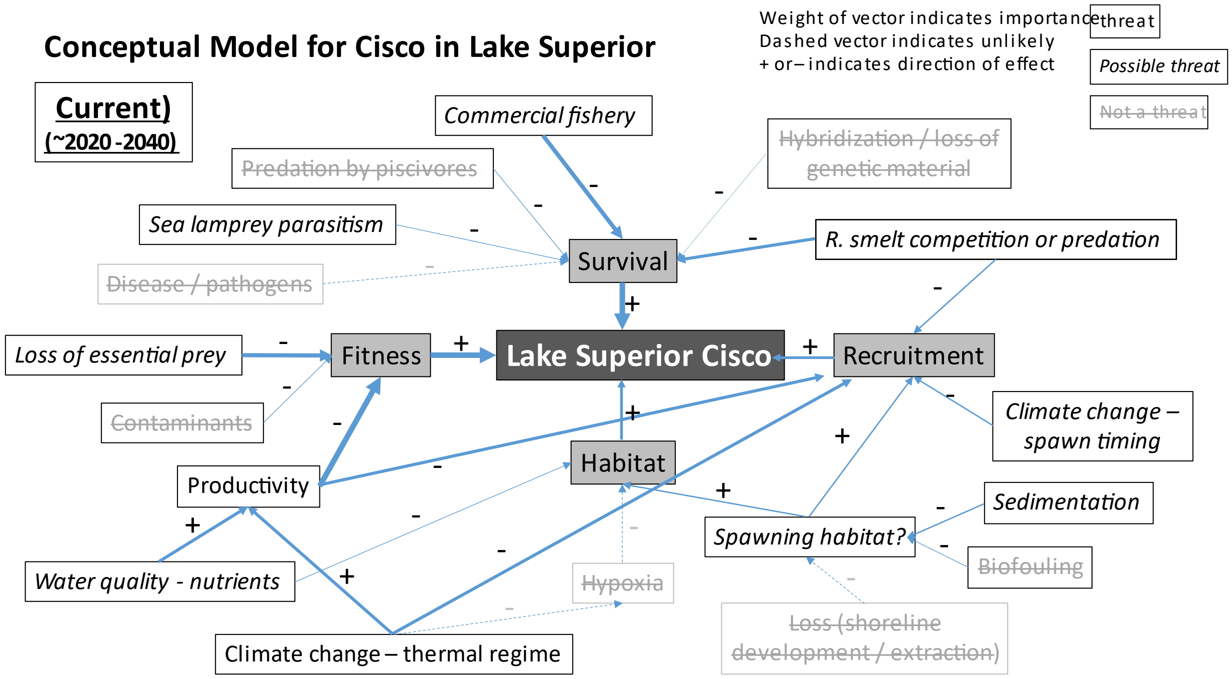

Figure A2.1. Conceptual model for threats to Lake Superior cisco *Coregonus artedi*.

RESULTS OF TEST RUN

For all threat matrices, **RED = HIGH RISK, YELLOW = MEDIUM RISK, GREEN = LOW RISK, GRAY = UNKNOWN RISK** (per DFO framework)

THREAT 1: Commercial fishery

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.42	0.33	0.14	0.00	0.00
	Likely	0.03	0.02	0.01	0.00	0.00
	Unlikely	0.02	0.03	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 47%; MEDIUM = 38%; HIGH = 15%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.47	0.35	0.18	0.00	0.00
	Likely	0.00	0.00	0.00	0.00	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 47%; MEDIUM = 35%; HIGH = 18%; UNKNOWN = 0%

Causal certainty: Very high (33%), High (67%). <u>Average = High</u>

Unit-level occurrence (can sum to >100%): Historical (100%), Current (83%), Anticipatory (83%)

Unit-level frequency: Recurrent (100%)

Unit-level extent: Extensive (83%), Narrow (17%)

THREAT 2: Recreational fishery

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.73	0.02	0.00	0.00	0.00
	Likely	0.16	0.01	0.00	0.00	0.00
	Unlikely	0.08	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 97%; MEDIUM = 3%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.76	0.02	0.00	0.00	0.00
	Likely	0.13	0.01	0.00	0.00	0.00
	Unlikely	0.08	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 97%; MEDIUM = 3%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: Very High (17%), High (33%), Medium (33%), Very Low (17%). Average = Medium

Unit-level occurrence (can sum to >100%): Historical (67%), Current (83%), Anticipatory (100%)

Unit-level frequency: Recurrent (83%), Continuous (17%)

Unit-level extent: Restricted (100%)

THREAT 3: Introduced species (competition/predation)

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.37	0.32	0.08	0.01	0.00
	Likely	0.06	0.06	0.01	0.00	0.00
	Unlikely	0.04	0.04	0.01	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 47%; MEDIUM = 43%; HIGH = 10%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.44	0.38	0.09	0.02	0.02
	Likely	0.03	0.03	0.01	0.00	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 47%; MEDIUM = 41%; HIGH = 12%; UNKNOWN = 0%

Causal certainty: Medium (67%), Low (33%). Average = Medium

Unit-level occurrence (can sum to >100%): Historical (83%), Current (100%), Anticipatory (100%)

Unit-level frequency: Recurrent (33%), Continuous (67%)

Unit-level extent: Extensive (17%), Broad (50%), Narrow (33%)

THREAT 4: Reduced pelagic productivity

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.35	0.22	0.10	0.07	0.00
	Likely	0.04	0.03	0.01	0.01	0.00
	Unlikely	0.02	0.01	0.01	0.00	0.00
	Remote	0.06	0.04	0.02	0.01	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 54%; MEDIUM = 27%; HIGH = 19%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.38	0.37	0.16	0.00	0.00
	Likely	0.04	0.03	0.02	0.00	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 42%; MEDIUM = 40%; HIGH = 18%; UNKNOWN = 0%

Causal certainty: High (33%), Medium (67%). Average = Medium

Unit-level occurrence (can sum to >100%): Historical (50%), Current (100%), Anticipatory (83%)

Unit-level frequency: Recurrent (33%), Continuous (67%)

Unit-level extent: Extensive (67%), Broad (33%)

THREAT 5: Hybridization with other ciscoes

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.06	0.04	0.00	0.00	0.01
	Unlikely	0.23	0.14	0.01	0.00	0.03
	Remote	0.19	0.11	0.01	0.00	0.02
	Unknown	0.09	0.05	0.00	0.00	0.01

LOW = 60%; MEDIUM = 19%; HIGH = 0%; UNKNOWN = 21%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.07	0.03	0.00	0.00	0.01
	Unlikely	0.28	0.12	0.01	0.00	0.02
	Remote	0.30	0.13	0.01	0.00	0.02
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 79%; MEDIUM = 16%; HIGH = 0%; UNKNOWN = 5%

Causal certainty: High (17%), Medium (50%), Low (17%), Very Low (17%). Average = Medium

Unit-level occurrence (can sum to >100%): Historical (67%), Current (83%), Anticipatory (100%)

Unit-level frequency: Recurrent (17%), Continuous (83%)

Unit-level extent: Extensive (17%), Broad (67%), Narrow (17%)

THREAT 6: Predation from native predators

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.26	0.05	0.01	0.00	0.00
	Likely	0.22	0.04	0.01	0.00	0.00
	Unlikely	0.15	0.03	0.01	0.00	0.00
	Remote	0.17	0.03	0.01	0.00	0.00
	Unknown	0.01	0.00	0.00	0.00	0.00

LOW = 84%; MEDIUM = 13%; HIGH = 2%; UNKNOWN = 1%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.28	0.03	0.01	0.00	0.00
	Likely	0.29	0.04	0.01	0.00	0.00
	Unlikely	0.16	0.02	0.01	0.00	0.00
	Remote	0.13	0.02	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 88%; MEDIUM = 10%; HIGH = 2%; UNKNOWN = 0%

Causal certainty: High (33%), Medium (50%), Low (17%). Average = Medium

Unit-level occurrence (can sum to >100%): Historical (100%), Current (100%), Anticipatory (100%)

Unit-level frequency: Recurrent (17%), Continuous (83%)

Unit-level extent: Extensive (50%), Broad (17%), Narrow (17%), Restricted (17%)

THREAT 7: Atmospheric deposition

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.34	0.04	0.00	0.00	0.10
	Likely	0.17	0.02	0.00	0.00	0.05
	Unlikely	0.08	0.01	0.00	0.00	0.02
	Remote	0.09	0.01	0.00	0.00	0.02
	Unknown	0.04	0.00	0.00	0.00	0.01

LOW = 69%; MEDIUM = 7%; HIGH = 0%; UNKNOWN = 24%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.36	0.04	0.00	0.00	0.11
	Likely	0.31	0.03	0.00	0.00	0.09
	Unlikely	0.03	0.00	0.00	0.00	0.01
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.02	0.00	0.00	0.00	0.00

LOW = 70%; MEDIUM = 7%; HIGH = 0%; UNKNOWN = 23%

Causal certainty: Low (100%). Average = Low

Unit-level occurrence (can sum to >100%): Historical (75%), Current (50%), Anticipatory (50%)

Unit-level frequency: Recurrent (50%), Continuous (50%)

Unit-level extent: Broad (25%), Narrow (25%), Restricted (50%)

THREAT 8: Biomagnification

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.09	0.02	0.00	0.00	0.02
	Unlikely	0.30	0.06	0.00	0.00	0.06
	Remote	0.28	0.06	0.00	0.00	0.05
	Unknown	0.04	0.01	0.00	0.00	0.01

LOW = 73%; MEDIUM = 8%; HIGH = 0%; UNKNOWN = 19%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.02	0.00	0.00	0.00	0.00
	Unlikely	0.29	0.04	0.00	0.00	0.06
	Remote	0.35	0.05	0.00	0.00	0.08
	Unknown	0.08	0.01	0.00	0.00	0.02

LOW = 71%; MEDIUM = 4%; HIGH = 0%; UNKNOWN = 25%

Causal certainty: Low (75%), Very Low (25%). Average = Low

Unit-level occurrence (can sum to >100%): Historical (50%), Current (50%), Anticipatory (100%)

Unit-level frequency: Recurrent (25%), Continuous (75%)

Unit-level extent: Extensive (25%), Broad (25%), Narrow (25%), Restricted (25%)

THREAT 9: Microplastics

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.12	0.03	0.01	0.00	0.21
	Likely	0.12	0.03	0.01	0.01	0.21
	Unlikely	0.01	0.00	0.00	0.000	0.01
	Remote	0.02	0.01	0.00	0.00	0.03
	Unknown	0.05	0.02	0.00	0.00	0.10

LOW =28%; MEDIUM = 6%; HIGH = 3%; UNKNOWN = 63%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.25	0.05	0.01	0.01	0.12
	Likely	0.24	0.05	0.01	0.00	0.11
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.09	0.02	0.00	0.00	0.04

LOW = 49%; MEDIUM = 10%; HIGH = 3%; UNKNOWN = 38%

Causal certainty: Low (75%), Very low (25%). Average = Low

Unit-level occurrence (can sum to >100%): Current (100%), Anticipatory (100%)

Unit-level frequency: Recurrent (25%), Continuous (75%)

Unit-level extent: Broad (25%), Narrow (25%), Restricted (50%)

THREAT 10: Hypoxia

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.05	0.00	0.00	0.00	0.00
	Unlikely	0.17	0.01	0.00	0.00	0.00
	Remote	0.75	0.02	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =99%; MEDIUM = 1%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.00	0.00	0.00	0.00	0.00
	Unlikely	0.20	0.01	0.00	0.00	0.00
	Remote	0.77	0.02	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 99%; MEDIUM = 1%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: High (20%), Medium (20%), Low (20%), Very Low (40%). Average = Low

Unit-level occurrence (can sum to >100%): Historical (100%), Current (60%), Anticipatory (20%)

Unit-level frequency: Single (40%), Recurrent (60%)

Unit-level extent: Restricted (100%)

THREAT 11: Sedimentation/biofouling

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.03	0.01	0.00	0.00	0.00
	Likely	0.14	0.05	0.00	0.00	0.00
	Unlikely	0.25	0.10	0.00	0.00	0.00
	Remote	0.31	0.12	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =85%; MEDIUM = 15%; HIGH = 0%; UNKNOWN = 0%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.07	0.01	0.00	0.00	0.00
	Unlikely	0.42	0.06	0.00	0.00	0.00
	Remote	0.39	0.05	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 93%; MEDIUM = 7%; HIGH = 0%; UNKNOWN = 0%

Causal certainty: High (20%), Low (40%), Very Low (40%). Average = Low

Unit-level occurrence (can sum to >100%): Historical (100%), Current (40%), Anticipatory (40%)

Unit-level frequency: Single (40%), Recurrent (40%), Continuous (20%)

Unit-level extent: Restricted (100%)

THREAT 12: Climate change impacts on ice cover

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.31	0.06	0.01	0.00	0.00
	Likely	0.03	0.01	0.00	0.00	0.00
	Unlikely	0.23	0.04	0.01	0.00	0.00
	Remote	0.23	0.04	0.01	0.00	0.00
	Unknown	0.02	0.00	0.00	0.00	0.00

LOW =85%; MEDIUM = 12%; HIGH = 1%; UNKNOWN = 2%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.74	0.15	0.00	0.00	0.01
	Likely	0.08	0.02	0.00	0.00	0.00
	Unlikely	0.00	0.00	0.00	0.00	0.00
	Remote	0.00	0.00	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW = 82%; MEDIUM = 17%; HIGH = 0%; UNKNOWN = 1%

Causal certainty: Medium (40%), Low (60%). Average = Low

Unit-level occurrence (can sum to >100%): Current (100%), Anticipatory (100%)

Unit-level frequency: Recurrent (100%)

Unit-level extent: Narrow (40%), Restricted (60%)

THREAT 13: Climate change impacts on spawning phenology

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.32	0.03	0.00	0.00	0.01
	Likely	0.07	0.01	0.00	0.00	0.00
	Unlikely	0.15	0.01	0.00	0.00	0.00
	Remote	0.36	0.04	0.00	0.00	0.00
	Unknown	0.00	0.00	0.00	0.00	0.00

LOW =94%; MEDIUM = 5%; HIGH = 0%; UNKNOWN = 1%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.07	0.01	0.00	0.00	0.00
	Unlikely	0.42	0.04	0.00	0.00	0.01
	Remote	0.39	0.04	0.00	0.00	0.00
	Unknown	0.02	0.00	0.00	0.00	0.00

LOW = 92%; MEDIUM = 5%; HIGH = 0%; UNKNOWN = 3%

Causal certainty: Medium (40%), Low (60%). Average = Low

Unit-level occurrence (can sum to >100%): Current (20%), Anticipatory (100%)

Unit-level frequency: Recurrent (100%)

Unit-level extent: Broad (40%), Narrow (20%), Restricted (40%)

THREAT 14: Climate change impacts on thermal regime

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.01	0.01	0.00	0.00	0.00
	Likely	0.18	0.08	0.01	0.00	0.00
	Unlikely	0.29	0.12	0.01	0.00	0.00
	Remote	0.18	0.08	0.01	0.00	0.00
	Unknown	0.01	0.01	0.00	0.00	0.00

LOW =75%; MEDIUM = 22%; HIGH = 1%; UNKNOWN = 2%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.17	0.06	0.00	0.00	0.00
	Unlikely	0.35	0.12	0.00	0.00	0.00
	Remote	0.21	0.07	0.00	0.00	0.00
	Unknown	0.02	0.00	0.00	0.00	0.00

LOW = 80%; MEDIUM = 18%; HIGH = 0%; UNKNOWN = 2%

Causal certainty: Low (100%). Average = Low

Unit-level occurrence (can sum to >100%): Current (100%), Anticipatory (100%)

Unit-level frequency: Recurrent (20%), Continuous (80%)

Unit-level extent: Extensive (20%), Broad (40%), Narrow (40%)

THREAT 15: Insufficient remnant genetic material

Round 1

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.00	0.00	0.00	0.00	0.00
	Likely	0.04	0.00	0.01	0.01	0.00
	Unlikely	0.16	0.02	0.02	0.02	0.00
	Remote	0.51	0.06	0.07	0.07	0.00
	Unknown	0.01	0.00	0.00	0.00	0.00

LOW =91%; MEDIUM = 6%; HIGH = 2%; UNKNOWN = 1%

Round 2

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known	0.01	0.01	0.02	0.01	0.00
	Likely	0.04	0.03	0.07	0.04	0.00
	Unlikely	0.05	0.04	0.09	0.06	0.00
	Remote	0.11	0.09	0.20	0.12	0.00
	Unknown	0.00	0.00	0.01	0.00	0.00

LOW = 62%; MEDIUM = 23%; HIGH = 14%; UNKNOWN = 1%

Causal certainty: Medium (40%), Low (60%). Average = Low

Unit-level occurrence (can sum to >100%): Historical (40%), Current (40%), Anticipatory (80%)

Unit-level frequency: Recurrent (20%), Continuous (80%)

Unit-level extent: Extensive (60%), Narrow (20%), Restricted (20%)

Table A2.1. Summary of threat risk distributions across threats to Lake Superior cisco *Coregonus artedi*, as assessed by the members of the Coregonine Threats Assessment Science Team.

	Threat Risk Distribution (%)					
Threat	Low	Medium	High	Unknown	Causal certainty	Comments
Commercial fishery	47	35	18	0	High	
Recreational fishery	97	3	0	0	Medium	
Introduced species	47	41	12	0	Medium	
Reduced pelagic productivity	42	40	18	0	Medium	
Hybridization	79	16	0	5	Medium	
Predation from native predators	88	10	2	0	Medium	
Atmospheric deposition	70	7	0	23	Low	Large % unknown
Biomagnification	71	4	0	25	Low	Large % unknown
Microplastics	49	10	3	38	Low	Large % unknown
Hypoxia	99	1	0	0	Low	
Sedimentation/biofouling	93	7	0	0	Low	
CC – ice cover	82	17	0	1	Low	
CC – phenology	92	5	0	3	Low	
CC – thermal regime	80	18	0	2	Low	
Insufficient remnant genetics	62	23	14	1	Low	

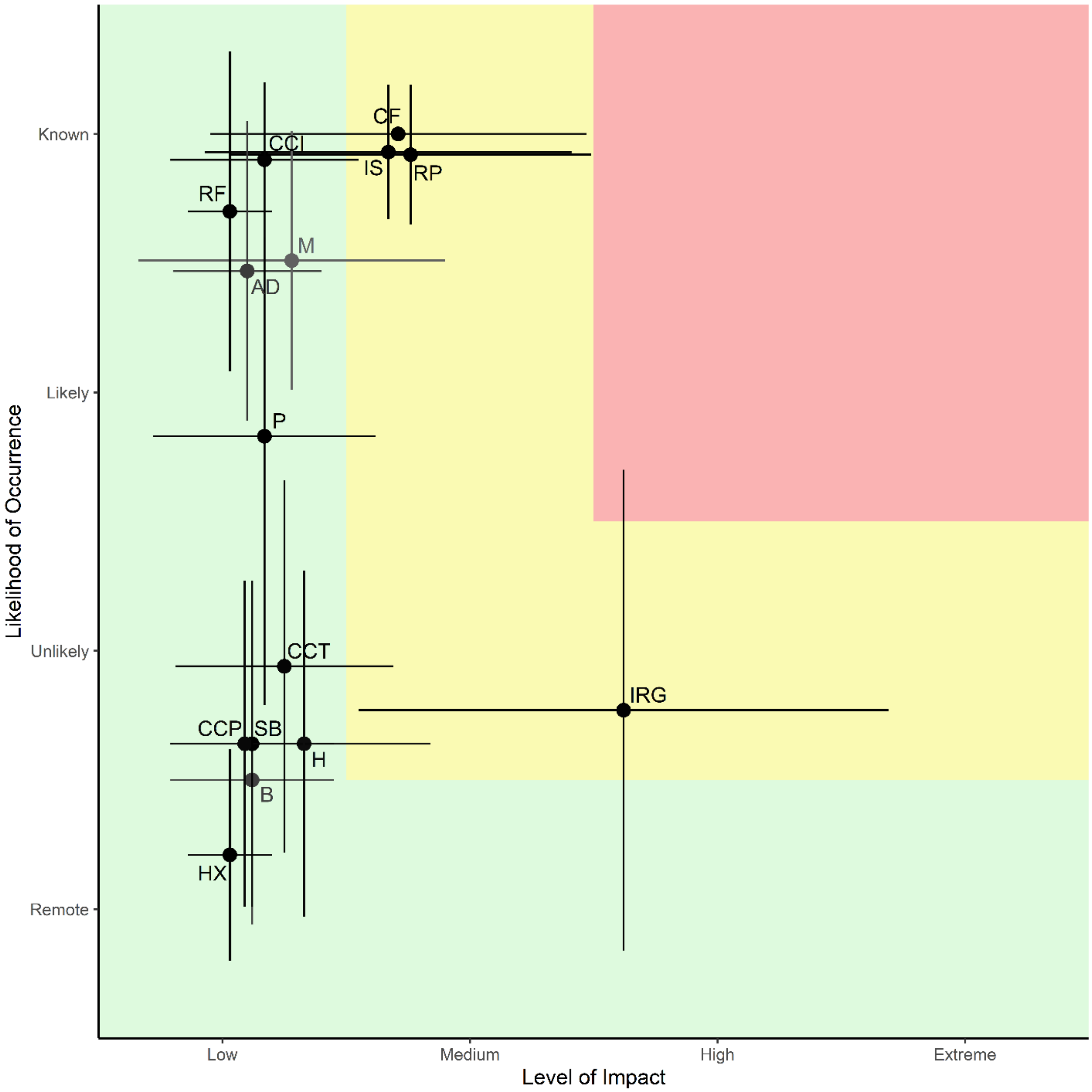

Figure A2.2. Biplot of threats to Lake Superior cisco *Coregonus artedi* based on likelihood of occurrence and level of impact from round 2 scoring. AD = atmospheric deposition, B = biomagnification, CCI = climate change impacts on ice cover, CCP = climate change impacts on phenology, CCT = climate change impacts on thermal regime, CF = commercial fishery, H = hybridization, HX = hypoxia, IRG = insufficient remnant genetic material, IS = introduced species, M = microplastics, P = predation by native predators, RF = recreational fishery, RP = reduced pelagic productivity, SB = sedimentation and biofouling. Green shaded region = low threat risk, yellow shaded region = medium threat risk, red shaded region = high threat risk. Grayness indicates the proportion of scores placed in the “unknown” categories (M = 38% unknown, B = 25% unknown, AD = 23% unknown; all other threats = 0-5% unknown). **THIS FIGURE IS INTENDED ONLY AS A VISUAL AID**; points and error bars should not be used for statistical models or significance tests.