IUCN threats calculator results for COSEWIC-assessed aquatic species in Canada, 2012-2021

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by

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A global, standardized approach for assessing threats, the IUCN-CMP Unified Classification of Direct Threats, was formally implemented in 2012 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). After a decade of use, an inventory was created to describe threat scores across all 11 Level 1 and 44 Level 2 threats categories for aquatic species assessed by COSEWIC between 2012 and 2021, which included 73 freshwater fishes, 24 marine fishes, 18 marine mammals, and 12 freshwater molluscs. Among these taxa, freshwater species were more frequently threatened by Invasive Non-Native/Alien Species, while marine species were more frequently threatened by Fishing and Harvesting Aquatic Resources. Marine fishes had the lowest threats calculator completion rate, while freshwater molluscs had the highest. Freshwater fishes had the most diverse suite of assigned threats categories, while marine mammals had the least. The most common threat to marine fishes was Other Ecosystem Modifications, a catch-all category that captures a wide variety of direct threats. The most common threats to freshwater molluscs were Household Sewage and Urban Waste Water and Agricultural and Forestry Effluents. While Climate Change was indicated as a potential threat to the majority of aquatic species, the impact was often unknown. Overall, this inventory may be used to better understand the application of the threats calculator to aquatic species assessments in Canada.

RÉSUMÉ

Potts, L.P., Castañeda, R.A., Grant, P., Reid, S.M., Lepitzki, D.A.W., Mandrak, N.E., May-McNally, S.L., Robert, K., and Drake, D.A.R. 2024. IUCN threats calculator results for COSEWIC-assessed aquatic species in Canada, 2012 – 2021. Can. Manuscr. Rep. Fish. Aquat. Sci. 3272 : vii + 47 p.

La classification unifiée des menaces directes de l'UICN-PMC, une approche mondiale et normalisée pour l'évaluation des menaces, a été officiellement mise en œuvre en 2012 par le Comité sur la situation des espèces en péril au Canada (COSEPAC). Après une décennie d'utilisation, un répertoire a été créé pour décrire les cotes de menace dans les 11 catégories de menaces de niveau 1 et 44 catégories de menaces de niveau 2 pour les espèces aquatiques évaluées par le COSEPAC entre 2012 et 2021, dont 73 poissons dulcicoles, 24 poissons marins, 18 mammifères marins et 12 mollusques dulcicoles. Parmi ces taxons, les espèces dulcicoles étaient le plus souvent menacées par les espèces non indigènes ou exotiques envahissantes, tandis que les espèces marines étaient davantage menacées par la pêche et récolte de ressources aquatiques. Les poissons marins affichaient le plus faible taux d'achèvement du calculateur des menaces, tandis que les mollusques dulcicoles affichaient le taux d'achèvement le plus élevé. Les poissons dulcicoles présentaient l'ensemble le plus diversifié de catégories de menaces assignées, tandis que les mammifères marins en présentaient le moins. La menace la plus fréquente pour les poissons marins était les autres modifications de l'écosystème, une catégorie fourre-tout qui englobe une grande variété de menaces directes. Les menaces les plus courantes pour les mollusques dulcicoles étaient les eaux usées domestiques et urbaines, ainsi que les effluents agricoles et sylvicoles. Le changement climatique a été indiqué comme une menace pour la majorité des espèces aquatiques, mais son incidence était souvent inconnue. Dans l'ensemble, ce répertoire peut être utilisé pour mieux comprendre l'application du calculateur des menaces à l'évaluation des espèces aquatiques au Canada

INTRODUCTION

In 2008, the International Union for the Conservation of Nature (IUCN) released a global classification scheme for threats to species at risk of extinction (Salafsky et al. 2008). The goal of this new framework was to unify threats classifications and develop a standard lexicon for biodiversity conservation (Salafsky et al. 2008). In principle, this new classification scheme was designed to be "simple, hierarchical, comprehensive, consistent, expandable, exclusive, and scalable" and support species recovery by synthesizing threat patterns and facilitating information sharing among conservation practitioners (Salafsky et al. 2008). It proposed sorting direct threats to species, defined as proximate human activities, into eleven major threats categories (Level 1), subdivided into smaller threats categories (Level 2) (for complete definitions, see Appendix A1). The impact of each threats category would then be scored based on scope (proportion of individuals affected), severity (% reduction in number of mature individuals within the scope), and timing (immediacy) of each threat. While an early response paper challenged Salafsky et al.'s framework, notably arguing that it collapsed threat source and threat mechanism into a single concept of direct threat (Balmford et al. 2009), it was ultimately adopted by the IUCN and continues to be applied to species around the world as the IUCN-CMP Unified Classification of Direct Threats, version 3.3 (IUCN 2023).

In 2012, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) formally incorporated the IUCN-CMP Unified Classification of Direct Threats into its own species assessment process (COSEWIC 2015a). COSEWIC is an independent advisory body originally formed in 1977 prior to being established under section 14 of the *Species at Risk Act* (SARA), the primary legislation providing for the federal protection of at-risk wildlife species (COSEWIC 2021a; SARA 2002). The functions of COSEWIC are to assess the risk of extinction of wildlife species in Canada and to identify existing and potential threats to the species. COSEWIC members, including government scientists, academics, non-government scientists, and Traditional Knowledge holders, determine a species status based on the best scientific and Traditional Knowledge available compiled in status reports (COSEWIC 2021a). The ten Species Specialist Subcommittees (SSCs), encapsulating major species groups such as Marine Fishes, Terrestrial Mammals, Marine Mammals, and Molluscs, and their species experts are responsible for the production of status reports, which includes the threats calculator. In November 2012, COSEWIC recommended that a "threats calculator" be completed for every status report and guidelines were established to help train facilitator-led discussions to properly score and assign threats categories based on the IUCN classification scheme (Master et al. 2012; COSEWIC 2014a).

Two versions of the threats calculator have been used since it was introduced in Canada, although the basic format has remained the same. Briefly, the COSEWIC threats calculator is a spreadsheet with drop-down menus for scoring scope, severity, and timing of threats across eleven broad (Level 1) threats categories and more specific, finer (Level 2) threats categories. The 11 Level 1 and 44 Level 2 threats categories are listed and described in Appendix A2. The impact of Level 2 threats is determined by scope and severity scores, which are only calculated when threats are currently occurring or expected to occur within the next ten years (COSEWIC 2014a). The scores for scope, severity, and timing of the highest impact Level 2 threat within the Level 1 threat category are then typically used as the scores for the Level 1 threat. An overall threat impact is assigned that takes into consideration the accumulated impacts of the applicable Level 1 threats. The threats calculator process is typically completed via

teleconference, with a trained facilitator and opportunities for participants to discuss and provide input ahead of, during, and after the call and is typically based on a draft status report. Participants are invited to attend the teleconference based on their taxonomic expertise, knowledge of local environmental conditions/stressors, and/or expert knowledge on threats relevant to the species. The final threats calculator table is published in the species' status report, available online through the Species at Risk Public Registry (Government of Canada 2022). The current threats calculator version (2.3) builds upon the original version (1.1) by including four additional Level 2 threats categories (Appendix A2).

Despite nearly a decade of use, there have been few formal attempts to summarize threats calculator results since the adoption of the IUCN scheme by COSEWIC, which limits the ability to explore the Canadian-specific context of IUCN threat classification. Furthermore, there may be variation in how specific threats have been assigned to threats categories (i.e., among threats calculator participants and/or broad taxonomic groups). Focusing on species managed by Fisheries and Oceans Canada (DFO), the objectives were to 1) create a central inventory of threats calculator results for aquatic species in Canada, 2) review how frequently the threats calculator has been applied to aquatic species in Canada since 2012, and 3) assess the frequency of occurrence of assigned threats for aquatic species in Canada, noting differences among taxonomic groups (freshwater fishes, marine fishes, marine mammals, and freshwater molluscs).

METHODS

INVENTORY OF THREATS CALCULATOR RESULTS FOR AQUATIC SPECIES IN CANADA

To address the first objective, aquatic species assessed by COSEWIC were identified through the Government of Canada's Species at Risk Public Registry (https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html). Wildlife species are defined under SARA as "a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and (a) is native to Canada; or (b) has extended its range into Canada without human intervention and has been present in Canada for at least 50 years (SARA 2002). Furthermore, wildlife species includes units below the biological species level, including subspecies, varieties, and distinct populations (SARA 2002) and are defined as designatable units (DU) by COSEWIC with each DU being discrete and evolutionarily significant (COSEWIC 2020a). Full definitions of key terms are provided in Appendix A1. A custom species list was downloaded from the registry on May 5, 2022 that included all species within the taxonomic groups of freshwater fishes, marine fishes, marine mammals, molluscs (only freshwater and marine species retained), and reptiles (only sea turtles retained) assessed by COSEWIC between 2012 and 2021. There are currently no marine plants or marine invertebrates other than molluscs included in the public registry, possibly due to no SSC representation and/or data limitations for these species. The most recent COSEWIC Status Report for each aquatic species within the timeframe was downloaded from the registry. Each species report was reviewed and the presence of a threats calculator table was recorded. Threats calculator tables were usually included as a full table but were sometimes integrated into the Threats and Limiting Factors section of the report.

An inventory was created to encompass all aquatic species with threats calculator results. The inventory included species name, taxonomic group, year of assessment, the number and names

of threats calculator participants, and individual scores for impact, scope, severity, and timing across all 11 Level 1 threats categories and all 44 Level 2 threats categories (Appendix A2). Scores were recorded exactly as they appeared in the threats calculator. Cells that were left blank and cells that were not included in the threats calculator table were scored as “Not Applicable”. In a few cases, scores were documented in Level 2 threats categories but not in the corresponding Level 1 threats categories. For more complete analysis, these Level 2 scores (or the highest Level 2 score, if multiple) were rolled up into the Level 1 score of the same threats category, as per the COSEWIC Threats Classification and Assessment Calculator guidance document (COSEWIC 2014a). When Level 1 but not Level 2 scores were documented, Level 2 scores were not derived and were recorded as “Not Applicable”. Finally, the inventory included comments for specific threats categories, when provided.

FREQUENCY OF APPLICATION OF THE THREATS CALCULATOR IN AQUATIC SPECIES ASSESSMENTS

To address the second objective and determine how frequently the threats calculator has been applied to aquatic species since it was formally incorporated into the COSEWIC process in 2012, the inventory of each wildlife species (= DU) with a completed threats calculator was compared to the total number of wildlife species assessed by COSEWIC during the study timeframe. Marine reptiles were excluded from analyses given that there were only two species assessed within the 2012 – 2021 study period (two DUs of Leatherback Sea Turtle, *Dermochelys coriacea*, assessed in 2012, neither with a threats calculator). To determine whether there were differences among COSEWIC SSCs in the proportion of threats calculators applied to aquatic species, paired bar plots were created comparing species with and without a threats calculator by taxonomic group. Similarly, paired bar plots were created to compare species with and without a threats calculator by year, to detect any differences through time. Taxonomic groupings were based on the taxonomic boundaries of COSEWIC SSCs: freshwater fishes, marine fishes, marine mammals, and molluscs. Year was a nominal factor with 10 levels: 2012 through 2021. Although year could have been treated as an ordinal or interval factor, the focus was on identifying differences among years, not necessarily a consistent pattern through time. Figures displaying these trends were created in R version 4.1.3 (2022-03-10) and R Studio Build 372 “Ghost Orchid” (2021-09-01) using ggplot2 (version 3.3.5) included in the tidyverse package set (version 1.3.1), and ggpattern (version 0.4.3-3). The viridis colour palette was used across figures to improve readability.

The Fisher’s exact test was used to test for association between use of the threats calculator for aquatic species and taxonomic group and year of assessment. Specifically, Fisher’s exact tests were used to evaluate 1) the use of threats calculator by taxonomic group (with pairwise, if significant) and 2) the use of threats calculator by year (with pairwise, if significant). The Fisher’s exact test evaluates the null hypothesis of independence of rows and columns in a contingency table with fixed marginal frequencies based on a hypergeometric probability distribution (Fisher 1934, 1970; Agresti 2002; Fleiss et al. 2003). Briefly, it compares probabilities of the observed table with all possible tables with the same marginal frequencies. Independence was rejected if the sum of all probabilities that were less than or equal to the probability of the observed table was less than or equal to 0.05. Fisher’s exact tests are more accurate tests for independence than the chi squared test when one or more expected cell frequencies are less than five (Fleiss et al. 2003), as was the case with these data. Given that contingency tables were greater than 2

x 2, Fisher's exact tests were run with Monte Carlo simulations based on 10,000 replicates (Mundform et al. 2011). Monte Carlo reduces computational requirements by randomly sampling from the full set of possible tables with the same marginal frequencies (Agresti 2002). Post-hoc pairwise comparisons with false discovery rate (FDR) corrections (Benjamini and Hochberg 1995) were completed to detect significant differences between levels of each factor. FDR correction reduces type I error rates (false positives) when running multiple significance tests and may be preferred over the Bonferroni correction because it has greater power at detecting true positives (Verhoeven et al. 2005). A Fisher's exact test was also used to account for associations between taxonomic group and year of COSEWIC assessment. Fisher's exact tests were run using the base stats package in R (version 4.1.3) and pairwise comparisons were run using RVAideMemoire (version 0.9-81-2) (Hervé 2022).

FREQUENCY OF OCCURRENCE OF ASSIGNED THREATS CATEGORIES TO AQUATIC SPECIES

To address the third objective and determine the relative frequency of occurrence of threats categories assigned to different aquatic species, stacked bar plots were created with impact scores for each Level 1 and Level 2 threat category (11 and 40 categories, respectively) for species with a threats calculator between 2012 and 2021. For consistency across years, the four Level 2 categories added in version 3.3 were not included in analyses. While individual scores for scope, severity, and timing were also recorded for each species across all threats categories in the inventory, only impact scores are presented. Impact scores represent a composite score of scope and severity values when timing is moderate or high, and therefore capture information across the other three parameters; impact estimates a population level decline that is expected to occur in the next 10 years, or 3-generations, whichever is longer, based on the individual threats acting in the next 10 years. Threat impact score was a nominal factor with 14 levels: Very High, Very High-High, Very High-Medium, High, High-Medium, High-Low, Medium, Medium-Low, Low, Negligible, Not a Threat, Not Calculated, Unknown, and Not Applicable (full definitions available in Appendix A1). To determine the relative frequency of dominant threats categories to aquatic species, separate bar plots were created for threats categories with impact scores equal to or greater than "Medium".

The Fisher's exact test with Monte Carlo simulations based on 10,000 replicates was used to test for the association between threat impact scores and Level 1 and Level 2 threats categories. Analyses were conducted to assess the frequency of occurrence of 1) threat impact score by Level 1 threats categories; 2) dominant Level 1 threats categories (with pairwise comparisons, if significant); 3) threat impact score by Level 2 threats categories; and, 4) dominant Level 2 threats categories. Differences in impact scores across Level 1 and Level 2 threats categories were analyzed separately, given that Level 1 scores are typically generated from Level 2 scores (except in a few circumstances where threats were only assigned a Level 1 category). This process was repeated for dominant threats, treated as a binary factor: dominant threat and not a dominant threat. Post-hoc pairwise comparisons with FDR corrections were completed for Level 1 dominant threats categories. Post-hoc pairwise comparisons were not completed when significant associations were found in contingency tables containing all impact score values or for Level 2 categories because the combined number of pairs was too large to be meaningfully interpreted.

TAXONOMIC DIFFERENCES IN ASSIGNED THREATS CATEGORIES TO AQUATIC SPECIES

To address the third objective and evaluate differences in threat impact scores among taxonomic groups, stacked bar plots were created with impact scores among taxonomic groups within each Level 1 and Level 2 threat category. The Cochran-Mantel-Haenszel test was used to test for the association between threat impact scores and taxonomic group, while accounting for Level 1 and Level 2 threat categories. Cochran-Mantel-Haenszel (CMH) uses the hypergeometric distribution to test the null hypothesis that two nominal variables are independent in multiple stratum of a third confounding variable (Cochran 1954; Mantel and Haenszel 1959; Agresti 2002). In this case, the confounding variable was threats category. By maintaining the original structure of data, CMH addresses Simpson's Paradox (strata-level associations may have a different direction than overall associations), reduces type II error (improves power), and works well over sparse datasets (Simpson 1951; Agresti 2002). To test the assumption of no three-way interactions (homogeneity across strata), Woolf tests were used (Woolf 1955). Cochran-Mantel-Haenszel tests were run using the base stats package in R (version 4.1.3). Groupwise comparisons were run using rcompanion (version 2.4.15) (Mangiafico 2022). Woolf tests were run using the package vcd (version 1.4-9) (Meyer et al. 2022).

As above, bar plots were created with dominant threats (impact scores equal to or greater than medium) among taxonomic groups within Level 1 and Level 2 threat categories. CMH was also used to test for differences in dominant threats among freshwater fishes, marine fishes, marine mammals, and molluscs. To test for taxonomic differences in dominant threats within each threats category, groupwise comparisons were made using Fisher's exact test in each strata, with FDR corrections. Within significant threat categories (strata), pairwise comparisons were made to identify specific differences between taxonomic groups. Groupwise and pairwise comparisons were not made across full threat impact scores because the combined number of pairs was too large to be meaningful.

RESULTS

INVENTORY OF THREATS CALCULATOR RESULTS FOR AQUATIC SPECIES IN CANADA

Since 1977, COSEWIC has assessed 430 aquatic species, including 171 freshwater fishes, 149 marine fishes, 74 marine mammals, 32 aquatic molluscs (mostly mussels, family Mytilidae or Unionidae), and four marine reptiles (sea turtles). For the study period between 2012 and 2021, 237 species have been assessed (102 freshwater fishes, 91 marine fishes, 26 marine mammals, 16 aquatic molluscs, and two marine reptiles). A threats calculator was completed for 127 of 237 aquatic species assessed between 2012 and 2021 (54% of eligible species). A full list of the 127 species with a completed threats calculator is included in Appendix A3 and covers 73 freshwater fishes, 24 marine fishes, 18 marine mammals, and 12 aquatic molluscs (11 freshwater mussels and one freshwater snail, Shortface Lanx; no marine molluscs assessed by COSEWIC have a completed threats calculator). For those 127 species, a full inventory summarizing impact, scope, severity, and timing scores across threat categories, as well as comments included within the original threats calculator table, is presented in Supplementary Information S1. No species were included twice in our study (i.e., no species were reassessed with a different threats calculator).

FREQUENCY OF APPLICATION OF THE THREATS CALCULATOR IN AQUATIC SPECIES ASSESSMENTS

The proportion of threats calculators completed for aquatic species assessed by COSEWIC between 2012 and 2021 varied among taxonomic group (Fisher's exact test with Monte Carlo simulation with 10,000 replicates, $p < 0.001$) and year of assessment ($p < 0.001$) (Figure 1). Among taxonomic groups, significant differences were detected between marine fishes and all other groups ($p < 0.001$ with FDR correction), with marine fishes exhibiting the lowest completion rate (24 out of 91, or 27%). Among years, significant differences were detected between 2012 and all years except 2021 ($p < 0.05$), between 2016 and the years 2013, 2017, 2018, and 2021, and between 2020 and 2021 (Appendix A4). 2016 exhibited the highest completion rate of 23 out of 26 species (88%), while 2012 had the lowest completion rate of two out of 34 species (6%). However, there were also associations between year and taxonomic group ($p < 0.001$) and results are interpreted within this context. Pairwise results are listed in Appendix A4.

FREQUENCY OF OCCURRENCE OF ASSIGNED THREATS CATEGORIES TO AQUATIC SPECIES

Among 127 aquatic species with a completed threats calculator between 2012 and 2021, threat impact was scored at least once within each Level 1 threats category (Figure 2A). However, no species had dominant threats (impact score equal to or greater than medium) within threat category 10, Geological Events (Figure 2B). Within Level 2 threats, approximately half (22 out of 40) were scored as a dominant threat for aquatic species, including 1.1 Housing and Urban Areas, 1.2 Commercial and Industrial Areas, 2.1 Annual and Perennial Non-Timber Crops, 3.1 Oil and Gas drilling, 3.2 Mining and Quarrying, 4.1 Roads and Railroads, 4.3 Shipping Lanes, 5.4 Fishing and Harvesting Aquatic Resources, 6.1 Recreational Activities, 7.2 Dams and Water Management/Use, 7.3 Other Ecosystem Modifications, 8.1 Invasive Non-Native/Alien species, 8.2 Problematic Native Species, 8.3 Introduced Genetic Material, 9.1 Household Sewage and Urban Waste Water, 9.2 Industrial and Military Effluents, 9.3 Agricultural and Forestry Effluents, 9.5 Air-Borne Pollutants, 11.1 Habitat Shifting and Alteration, 11.2 Droughts, 11.3 Temperature Extremes, and 11.4 Storms and Flooding (Figure 3).

There was a significant difference in threat impact scores among Level 1 threats categories ($p < 0.001$, Figure 2A) and Level 2 threats categories ($p < 0.001$, Figure 3A). There was also a significant difference in dominant threats among Level 1 and Level 2 threats categories ($p < 0.001$, Figure 2B and $p < 0.001$, Figure 3B, respectively). Within Level 1 dominant threats, significant differences were detected between many pairs, including between the three most commonly applied threats categories and all others: 8. Invasive and Other Problematic Species and Genes (34 species), 9. Pollution (27 species), and 7. Natural System Modifications (23 species). Additionally, the next most commonly applied categories, 11. Climate Change and Severe Weather (16 species) and 5. Biological Resource Use (11 species) exhibited significant differences between many other threats categories (Appendix A5). The most commonly applied Level 2 dominant threats categories were 8.1 Invasive Non-Native/Alien Species (32 species), 9.3 Agricultural and Forestry Effluents (19 species), 7.3 Other Ecosystem Modifications (17 species), 9.1 Household Sewage and Urban Waste Water (14 species), and 5.4 Fishing and Harvesting Aquatic Resources (11 species).

Post-hoc, it was observed that among Level 1 threats categories, 11. Climate Change and Severe Weather exhibited a very high proportion of unknown threat impact scores (almost half, 60 out of 127 species) (Figure 2A). This finding was statistically significant, with overall differences in the proportion of unknown threats scores across Level 1 threats categories (Fisher's exact test with Monte Carlo simulation with 10,000 replicates, $p < 0.001$), and pairwise differences between 11. Climate Change and Severe Weather and all other threats categories, among others (Appendix A5). Furthermore, Level 2 threats categories within climate change were often incomplete: in 34 species, threat impact was scored to the Level 1 threats category of climate change but not Level 2 threats categories. In contrast, just three species were only scored to Level 1 threats categories in Residential and Commercial Development (1), three species in Agriculture and Aquaculture (2), four species in Natural System Modifications (7), one species in Invasive and Other Problematic Species and Genes (8), and four species in Geological Events (10).

TAXONOMIC DIFFERENCES IN ASSIGNED THREATS CATEGORIES TO AQUATIC SPECIES

Among the 10 out of 11 Level 1 threats categories that were scored as dominant threats to aquatic species, all 10 Level 1 threats categories were dominant for freshwater fishes, with fewer for other taxonomic groups. Five Level 1 threats categories were dominant for marine fishes, five included marine mammals, and eight included molluscs (Figure 4B). Associations were detected among taxonomic groups and threat impact scores across Level 1 threats categories (CMH test, $p < 0.001$, $M^2 = 172.58$, $df = 39$) and dominant threats ($p < 0.001$, $M^2 = 29.246$, $df = 3$) (Figure 4). Groupwise comparisons of dominant threats revealed significant associations within 5. Biological Resource Use ($p = 0.005$), 7. Natural System Modifications ($p = 0.032$), 8. Invasive and Other Problematic Species and Genes ($p = 0.001$), and 9. Pollution ($p = 0.001$) (Figure 4B, Appendix A6). Freshwater fishes exhibited significantly fewer dominant threats within 5. Biological Resource use compared to marine fishes and marine mammals (Figure 4, Appendix A6). Marine fishes exhibited significantly more dominant threats within 7. Natural System Modifications than freshwater fishes and marine mammals (Figure 4B, Appendix A6). Mussels exhibited significantly more dominant threats within 8. Invasive and Other Problematic Species and Genes and 9. Pollution categories compared to all other taxonomic groups (Figure 4B, Appendix A6). Additionally, 8. Invasive and Other Problematic Species and Genes and 9. Pollution were never listed among dominant threats to marine mammals. No three-way association was detected among all threat impact scores (Woolf test, $p = 1$) or dominant threats ($p = 0.85$).

Among 22 out of 40 Level 2 threats categories that were scored as dominant threats to aquatic species, 20 Level 2 threats categories were dominant for freshwater fishes, eight included marine fishes, five included marine mammals, and 13 included molluscs (Figure 5B). Notably, the only dominant threats to marine mammals were 3.1 Oil and Gas Drilling, 4.3 Shipping Lanes, 5.4 Fishing and Harvesting Aquatic Resources, 7.3 Other Ecosystem Modifications, and 11.1 Habitat Shifting and Alteration due to Climate Change and Severe Weather. The most common dominant Level 2 threat category for freshwater fishes was 8.1 Invasive Non-Native/Alien Species (24 out of 73 species, 33%); the most common dominant Level 2 threats for marine fishes was 7.3 Other Ecosystem Modifications (10 out of 24, 42%). Dominant threats to aquatic molluscs were very consistent, with the majority of species threatened by 8.1 Invasive

Non-Native/Alien species (eight out of 12 species, 66%), 9.1 Household Sewage and Urban Waste Water (six out of 12 species, 50%), and 9.3 Agricultural & Forestry Effluents (six out of 12 species, 50%). Associations were detected among taxonomic groups and threat impact scores across Level 2 threats categories (CMH test, $p < 0.001$, $M^2 = 376.34$, $df = 39$) and dominant threats across Level 2 threats categories ($p < 0.001$, $M^2 = 55.511$, $df = 3$) (Figure 5).

Groupwise comparisons of dominant threats revealed significant associations in 1.1 Housing and Urban Areas ($p = 0.041$), 4.3 Shipping Lanes ($p = 0.045$), 5.4 Fishing and Harvesting Aquatic Resources ($p = 0.013$), 7.3 Other Ecosystem Modifications ($p = 0.001$), 8.1 Invasive Non-Native/Alien Species ($p < 0.001$), 9.1 Household Sewage and Urban Waste Water ($p = 0.001$), and 9.3 Agricultural and Forestry Effluents ($p = 0.023$) (Appendix A7). Marine fishes exhibited more dominant threats within 7.3 Other Ecosystem Modifications than other taxonomic groups (Figure 5B, Appendix A7), Marine fishes and marine mammals exhibited more dominant threats within 5.4 Fishing and Harvesting Aquatic Resources than freshwater fishes and molluscs (Figure 5B, Appendix A7). Molluscs exhibited more dominant threats in both pollution categories (9.1 Household Sewage and Urban Waste Water and 9.3 Agricultural and Forestry Effluents; Figure 5B, Appendix A7). Only freshwater fishes and molluscs had dominant threats within 8.1 Invasive Non-Native/Alien Species (Figure 5B, Appendix A7). There were no pairwise differences within 1.1 Housing and Urban Areas and 4.3 Shipping Lanes. No three-way association was detected among all threat impact scores (Woolf test, $p = 1$) or dominant threats ($p = 1$).

DISCUSSION

Standardized approaches for threat assessment allow conservation practitioners to reliably identify threats, develop suitable approaches for threat mitigation, and track changes in threat severity through time. Prior to adopting the IUCN-CMP Unified Classification of Direct Threats, COSEWIC assessment of threats to species was largely qualitative, based on a literature review. The relative risks associated with/among different threats were not often apparent and important considerations for individual threats such as magnitude, scope, and frequency were not explicitly considered. The threats calculator forces experts to further interpret the risk of plausible threats to Canadian populations of the species and document those scores in a table. Since 2012, close to two thirds of aquatic species assessments have included a threats calculator. This paper provides an inventory of 127 aquatic species for which threats have been categorized and scored by species experts and trained facilitators using a globally recognized framework. However, the threats calculator may not always be applied equally across COSEWIC SSCs. Summarized results from this threats calculator inventory provided insight into the dominant threats categories assigned to aquatic species in Canada and revealed strong differences among four major taxonomic groups, corresponding with four COSEWIC SSCs: freshwater fishes, marine fishes, marine mammals, and molluscs.

Among aquatic species assessed by COSEWIC with a completed threats calculator, 8. Invasive and Other Problematic Species and Genes was most frequently scored as a dominant threat to freshwater fishes and aquatic molluscs, which may be representative of the broader threat of invasive species in freshwater environments relative to marine environments. This Level 1 threat category was largely represented by 8.1 Invasive Non-Native/Alien Species and was widely scored as a dominant threat for two thirds of aquatic molluscs and one third of freshwater fishes. Aquatic molluscs that scored 8.1 Invasive Non-Native/Alien Species as a dominant threat

category were all freshwater mussels and primarily identified invasive dreissenid mussels that outcompete or smother native species, including Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*D. bugensis*) (Supplementary Information S1). Threats listed under this threat category for freshwater fishes were more diverse. For example, identified factors within 8.1 Invasive Non-Native/Alien Species for fishes included non-native trout and bass species introduced to facilitate recreational fisheries that prey on Little Quarry Lake Threespine Stickleback (*Gasterosteus aculeatus*) populations (COSEWIC 2015b), invasive Round Goby (*Neogobius melanostomus*) that feeds on the eggs of Channel Darter (*Percina copelandi*) (COSEWIC 2016), and invasive Tench (*Tinca tinca*) that may compete with Copper Redhorse (*Moxostoma hubbsi*) (COSEWIC 2014b).

In contrast to the freshwater results, 8.1 Invasive Non-Native/Alien Species was never scored as dominant threat to either marine fishes or marine mammals. However, two dominant threats were classified for marine fishes under different Level 2 categories. Specifically, 8.2 Problematic Native Species was scored as a High to Medium impact threat category for two populations of Steelhead Trout (*Oncorhynchus mykiss*), Chicotlin River and Thompson River populations, because their reduced population abundance has increased their vulnerability to predation from otters, whitefish species, and Bull Trout (*Salvelinus confluentus*) in freshwater habitats, pinnipeds in inshore habitats, and from Harbor Porpoise (*Phocoena phocoena*) and White-sided Dolphin (*Lagenorhynchus obliquidens*) in offshore habitats (COSEWIC 2020b). Additionally, 8.3 Introduced Genetic Material was scored as a dominant threat to Chinook Salmon (*Oncorhynchus tshawytscha)* West Vancouver Island-Ocean-Fall South (DU24) and Nootka and Kyuquot (DU25) populations from salmon hatchery activity affecting populations genetics (COSEWIC 2020c).

Invasive species may threaten native species through predation, competition, hybridization, and ecosystem alteration (Mack et al. 2000; Simberloff 2010; Elton 2020); however, under the IUCN-CMP scheme, only direct impacts through species interaction are included within threats category 8.1. Invasive species that do not have a direct or rapid effect on the species at risk (e.g., modifying habitat, disrupting food webs) are not included in this threat category and are instead included under 7.3 Other Ecosystem Modifications. All species and modes of action identified as dominant threats within 8. Invasive and Other Problematic Species and Genes were consistent with this definition. A notable distinction was Spiny Water Flea (*Bythotrephes* cederströmii), an invasive invertebrate planktivore, which was listed as a threat to Lake Whitefish (*Coregonus clupeaformis*) populations under threats category 8.1 Invasive Non-Native/Alien Species (COSEWIC 2018). Within invaded lakes, Spiny Water Flea proliferates quickly, preys on and/or outcompetes native zooplankton, and has become a significant diet component for some Lake Whitefish populations (Macpherson et al. 2010; Rennie et al. 2011). This change in food web structure has been linked to changes in growth rates of Lake Whitefish and the extinction of Como Lake small-bodied and large-bodied populations (Reid et al. 2017; COSEWIC 2018). Given the direct and fast-acting impacts of Spiny Water Flea on Lake Whitefish, this threat was included under 8.1 Invasive Non-Native/Alien Species, rather than 7.3 Other Ecosystem Modifications, highlighting the nuance of assigning threats categories and the importance of threats facilitators in guiding those decisions.

Compared to other taxonomic groups, aquatic molluscs, with all the mussels included in this analysis being confined to southern Ontario except for one DU in Manitoba (Appendix A3), were most impacted by 9. Pollution, specifically 9.1 Household Sewage and Urban Waste Water and 9.3 Agricultural and Forestry Effluents. These Level 2 threat categories were each assigned as

dominant threats to half of all aquatic molluscs. Threats calculator comments and information contained within the COSEWIC assessment reports frequently identified multiple sources of pollution within these threat categories. For example, the impact of 9. Pollution on Kidneyshell (*Ptychobranchus fasciolaris*) was scored as Very High and identified many pollutants, including polyaromatic hydrocarbons and organic contaminants from runoff, manure, agricultural wastewater, ammonia, copper, chloride from road salt, herbicides and pesticides, pharmaceuticals, sediments, and thermal pollution (COSEWIC 2013). Similarly, Round Pigtoe (*Pleurobema sintoxia*) included many of the same pollutants, with additional threats from oil drilling and pipelines crossings scored under 9.2 Industrial and Military Effluents (COSEWIC 2014c). While both 9.1 Household Sewage and Urban Waste Water and 9.3 Agricultural and Forestry Effluents were listed among dominant threats to freshwater fishes, 9.1 Household Sewage and Urban Waste Water was never listed for marine fishes, and 9. Pollution (the entire Level 1 threat category) was never scored as a dominant threat to marine mammals. However, pollution has been cited as a prominent threat to some marine mammals assessed by COSEWIC without a completed threats calculator. For example, due to their location downstream of highly industrialized and densely populated areas, the endangered St. Lawrence Estuary Beluga (*Delphinapterus leucas*) is “among the most contaminated marine mammals” in North America (COSEWIC 2014d). This emphasizes the importance of completing threats calculators to more accurately describe overall threats patterns in Canada.

In contrast to 8. Invasive and Other Problematic Species and Genes and 9. Pollution, which were primarily assigned as dominant threats to freshwater species (freshwater fishes and freshwater molluscs), 5. Biological Resource Use (exclusively 5.4 Fishing and Harvesting Aquatic Resources) was listed as a Medium to Very High threat impact for one quarter of marine fishes and marine mammals, but only one freshwater fish (Lake Sturgeon, *Acipenser fulvescens*, Western Hudson Bay population) and one freshwater mussel (Kidneyshell) (Supplementary Information S1). Targeted and non-targeted harvest are both included in 5.4 Fishing and Harvesting Aquatic, and were both identified as a threat for a number of marine species. For example, unsustainable fishing was identified as the primary threat facing Yelloweye Rockfish (*Sebastes ruberrimus,* Pacific Ocean inside and outside populations) and, although commercial fishing quotas were reduced by 75% in 2002, the threat impact was still listed as Medium (COSEWIC 2020d). Similarly, although commercial harvest of Beluga Whale has been prohibited for decades due to historical declines and local extirpations, subsistence harvesting may be preventing recovery in some populations (e.g., Cumberland Sound and Ungava Bay populations) (COSEWIC 2020e). Non-targeted harvest was also captured within this threats category. For example, two populations of Steelhead Trout (Chilcotin River and Thompson River populations) were recently assessed as Endangered, in part, due to reduced survival rates from incidental capture in other Salmonidae fisheries during migration from the ocean to inland spawning grounds (COSEWIC 2020b).

Although 5.4 Fishing and Harvesting Aquatic Resources was a more common dominant threat for marine mammals and marine fishes, the most common dominant threat category for marine fishes was 7.3 Other Ecosystem Modifications. This threats category is broadly defined as “other actions that convert or degrade habitat in service of ‘managing’ natural systems to improve human welfare” (COSEWIC 2014a). For aquatic species, 7.3 Other Ecosystem Modifications may be used as a catch-all category for habitat impacts from a wide variety of proximate human activities. Within this inventory, there was a wide diversity of dominant threats classified under 7.3 Other Ecosystem Modifications and, in some cases, many different threats

were captured within this threats category for the same species. For example, specific threats cited under 7.3 Other Ecosystem modifications for Steelhead Trout populations included ocean ranching leading to competition from other Salmonidae and reduced ocean production, as well as logging and water extraction leading to the loss of riparian vegetation, sedimentation, and thermal issues (COSEWIC 2020b). Specific threats cited under 7.3 for Chinook Salmon populations included loss of riparian area, conversion of agriculture to residential area resulting in loss of overwintering and rearing habitat, changes in groundwater recharge from shifting snowmelt and snowpack, dyking and ditching leading to loss of backwater/off channel habitat, and El Nino affecting marine survival (COSEWIC 2020c).

Despite the wide range of threats captured in threat category 7.3 Other Ecosystem Modifications, this category was rarely identified as a dominant threat to freshwater fishes, marine mammals, or aquatic molluscs. The prevalence of 7.3 Other Ecosystem Modifications among marine fishes may correspond to internal biases within this inventory, including the low completion of threats calculators for marine fishes and the over-representation of Salmonidae species. First, less than one third of marine fishes assessed by COSEWIC between 2012 and 2021 included a completed threats calculator, likely related to the perceived simplicity of the threat landscape for many non-Salmonidae marine fishes. Specifically, there may be low perceived value of applying the threats calculator to marine fishes primarily affected by targeted and accidental harvest, biasing overall patterns for marine fishes. As a consequence, the marine fishes SSC was slower to adopt the threats calculator, and these trends are evident in comparisons through time. For example, the observed high threats calculator completion rate in 2016 may be attributed, in part, due to low overall assessment of marine fishes that year. Conversely, the low rate of completion in 2021 may be the result of a high relative proportion of marine fishes assessments by COSEWIC, in combination with capacity limitations due to COVID-19. Second, most marine fishes assessed by COSEWIC between 2012 and 2021 were Salmonidae (63 out of 91 overall; 21 out of 24 species with a completed threats calculator, 42 out of 67 species without). While Salmonidae are assessed by the Marine Fishes SSC of COSEWIC and are listed as marine species under SARA, these anadromous species may be more likely to experience diverse habitat threats throughout their marine and freshwater life stages relative to marine-only species. Consequently, this inventory may only capture threats calculator results from a subset of marine fishes that have complex threat landscapes and life histories. Freshwater fishes had the most diverse suite of threats, with 10 out of 11 Level 1 and 19 out of 40 Level 2 threats categories scored as Medium to Very High impact. In part, this may be due to the fact that freshwater fishes dominated this inventory, representing more than half of aquatic species with a threats calculator. In contrast, dominant threats to marine mammals were binned into just five Level 2 threats categories: 3.1 Oil and Gas Drilling, 4.3 Shipping Lanes, 5.4 Fishing and Harvesting Aquatic Resources, 7.3 Other Ecosystem Modifications, and 11.1 Habitat Shifting and Alteration (due to climate change). Interestingly, the average number of threats per species was highest for freshwater molluscs (post-hoc, Appendix A8), highlighting differences in relative diversity of threats among taxonomic groups across all species compared to within single species threats calculator results.

Although it was one of most frequently assigned threats for aquatic species, 11. Climate Change and Severe Weather had impacts that were frequently scored as Unknown. Climate change has widely been identified as a prominent threat to aquatic species (Heino et al. 2009; Sydeman et al. 2015; Ross et al. 2016; Avila et al. 2018; Reid et al. 2019; Albouy et al. 2020), and recent reviews have summarized the predicted response of aquatic taxa to climate change

in Canada including freshwater (Lynch et al. 2016; Poesch et al. 2016) and marine species (Hutchings et al. 2012; Talloni-Álvarez et al. 2019). Although climate change is increasingly identified as a threat by COSEWIC (Woo-Durand et al. 2020), especially for species with a completed threats calculator (Naujokaitis-Lewis et al. 2021), a well-developed understanding of the impacts of climate change on aquatic species at risk in Canada is lacking (Talloni-Álvarez et al. 2019; Drake et al. 2021). Therefore, it may be especially challenging to score severity in this threats category.

Results presented in this review may be limited by procedural restrictions within the structure of COSEWIC. First, SARA requires a review of classification of previously assessed species at risk to be completed at least once every 10 years (SARA 2002, section 24). Although, COSEWIC has recommended the use of a threats calculator for all species assessed, the lack of a threats calculator for some species in this dataset may be because the abbreviated status report that COSEWIC can use for species that are not likely to change status typically does not require a threats calculator (COSEWIC 2021b). Second, a threats assessment could have been done one or more years before the COSEWIC assessment was completed, and then it could be several months before the report is posted. For example, reports for species assessed in November will not be posted until the following year, perhaps as late as September. For example, some of the Chinook Salmon DUs assessed in 2020 (Appendix A3) had threats assessments completed in 2017. Consequently, the delay between when a threats calculator teleconference occurs and when a species is assessed may confound our results, specifically the trends among years.

Overall, this inventory forms the basis to understand the application of the IUCN threats calculator by COSEWIC for aquatic species in Canada. It identifies key differences among taxonomic groups, including higher threat impact from 8.1 Invasive Non-Native/Alien Species, 9.1 Household Sewage and Urban Waste Water, and 9.3 Agricultural and Forestry Effluents for freshwater species (freshwater fishes and molluscs); 5.4 Fishing and Harvesting Aquatic Resources for marine species (marine fishes and mammals); the widespread use of threats category 7.3 Other Ecosystem Modifications for marine fishes, specifically anadromous marine fishes; and, a comparatively simple threats landscape for marine mammals. These results also indicate widespread challenges in scoring climate change impacts to aquatic species in Canada under the IUCN system. Although this review did not evaluate the precision and accuracy of the threats calculator, specific examples highlight the need for clear guidelines and the role of threats facilitators to help standardize threats assessments conducted by COSEWIC in Canada.

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FIGURES

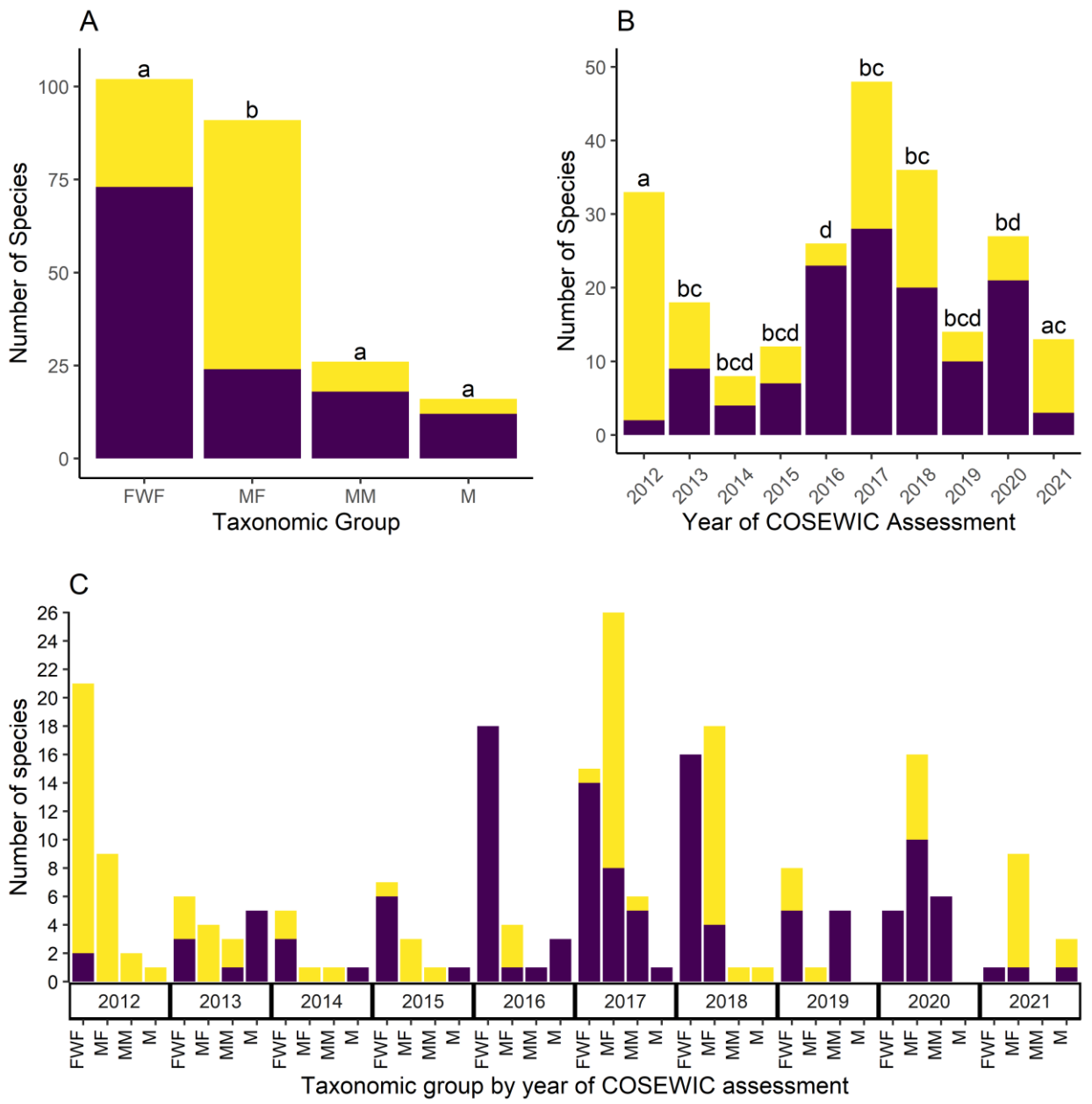


Figure 1. *Number of aquatic species assessed by COSEWIC between 2012 and 2021 (n = 237) with (n = 127, purple) and without (n = 110, yellow) a completed IUCN threats calculator by (A) taxonomic group, (B) year of COSEWIC status report, and (C) taxonomic group within year. Taxonomic group is abbreviated: FWF is freshwater fishes, MF is marine fishes, MM is marine mammals, and M is molluscs. Fisher's exact tests revealed significant association ($p < 0.05$) between threats calculator completion and taxonomic group and year. Letters indicate pairwise significance, where groups with shared letters are not significantly different from each other. Significant association was also detected between taxonomic group and year of assessment (Fisher's exact test $p < 0.001$).*

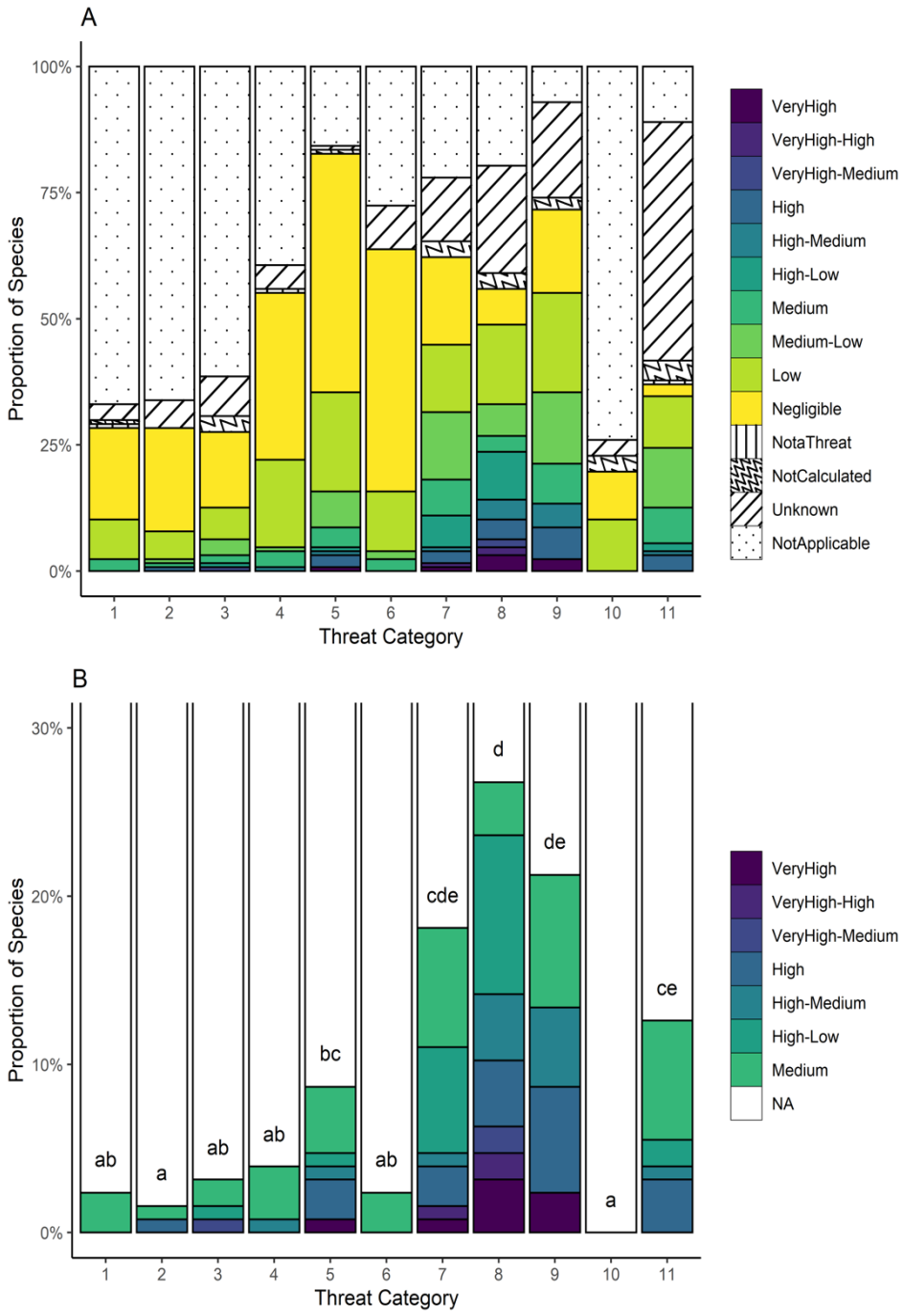


Figure 2. *Proportion of aquatic species assessed by COSEWIC between 2012 and 2021 with a completed threats calculator (n = 127) sorted by A) all impact scores within Level 1 threats categories and B) dominant threats within Level 1 threats categories (only score values equal to or greater than "Medium"). Level 1 categories are listed in Appendix A2. Fisher's exact tests revealed significant association ($p < 0.05$) between Level 1 threats categories and threats scores and dominant threats. Letters indicate pairwise significance for dominant threats.*

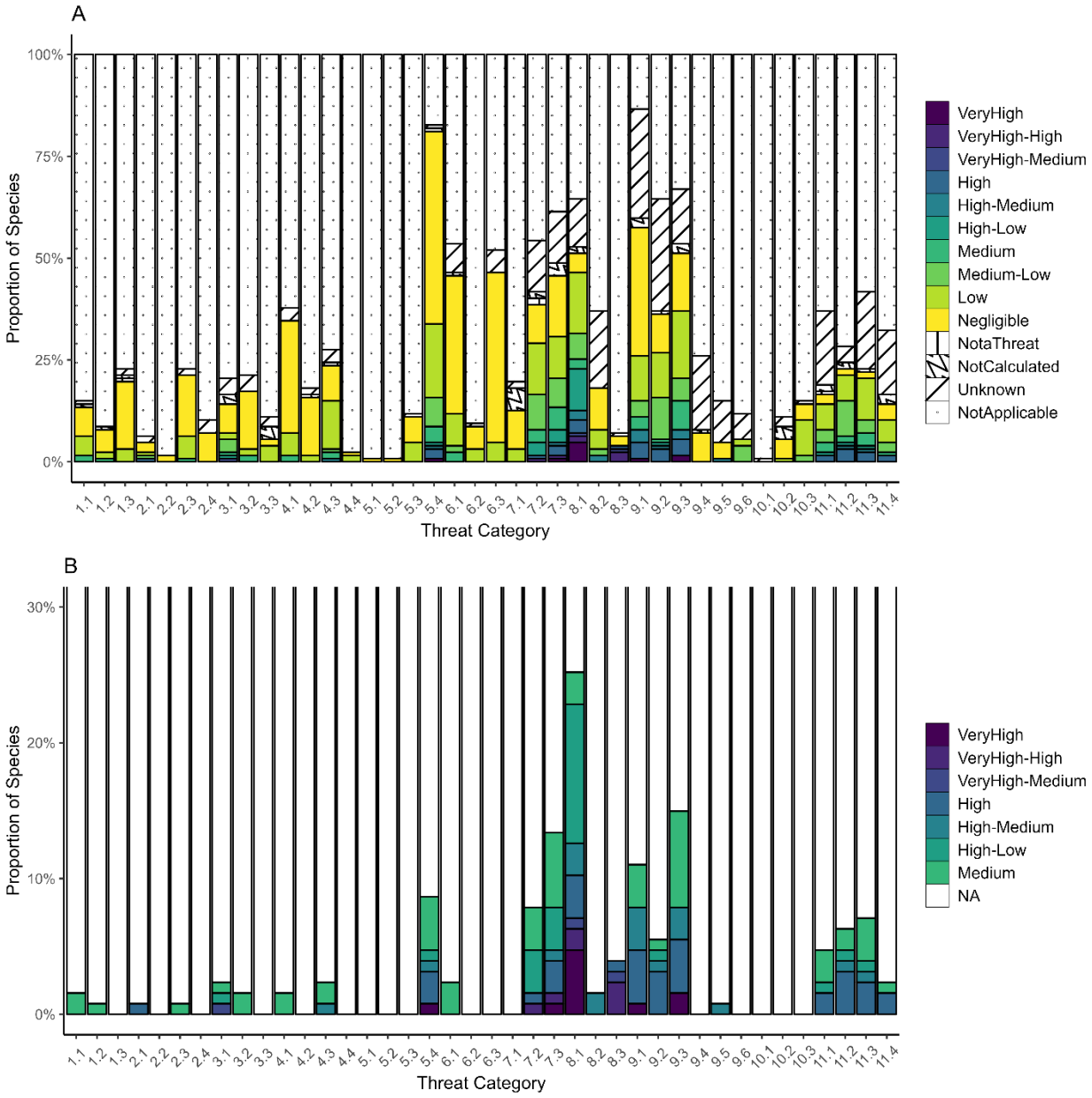


Figure 3. *Proportion of aquatic species assessed by COSEWIC between 2012 and 2021 with a completed threats calculator (n = 127) sorted by A) all impact scores within Level 2 threats categories and B) dominant threats within Level 2 threats categories (score equal to or greater than "Medium"). Level 2 threats categories are listed in Appendix A2. Fisher's exact tests revealed significant association ($p < 0.05$) between Level 2 threats categories and threats scores and dominant threats.*

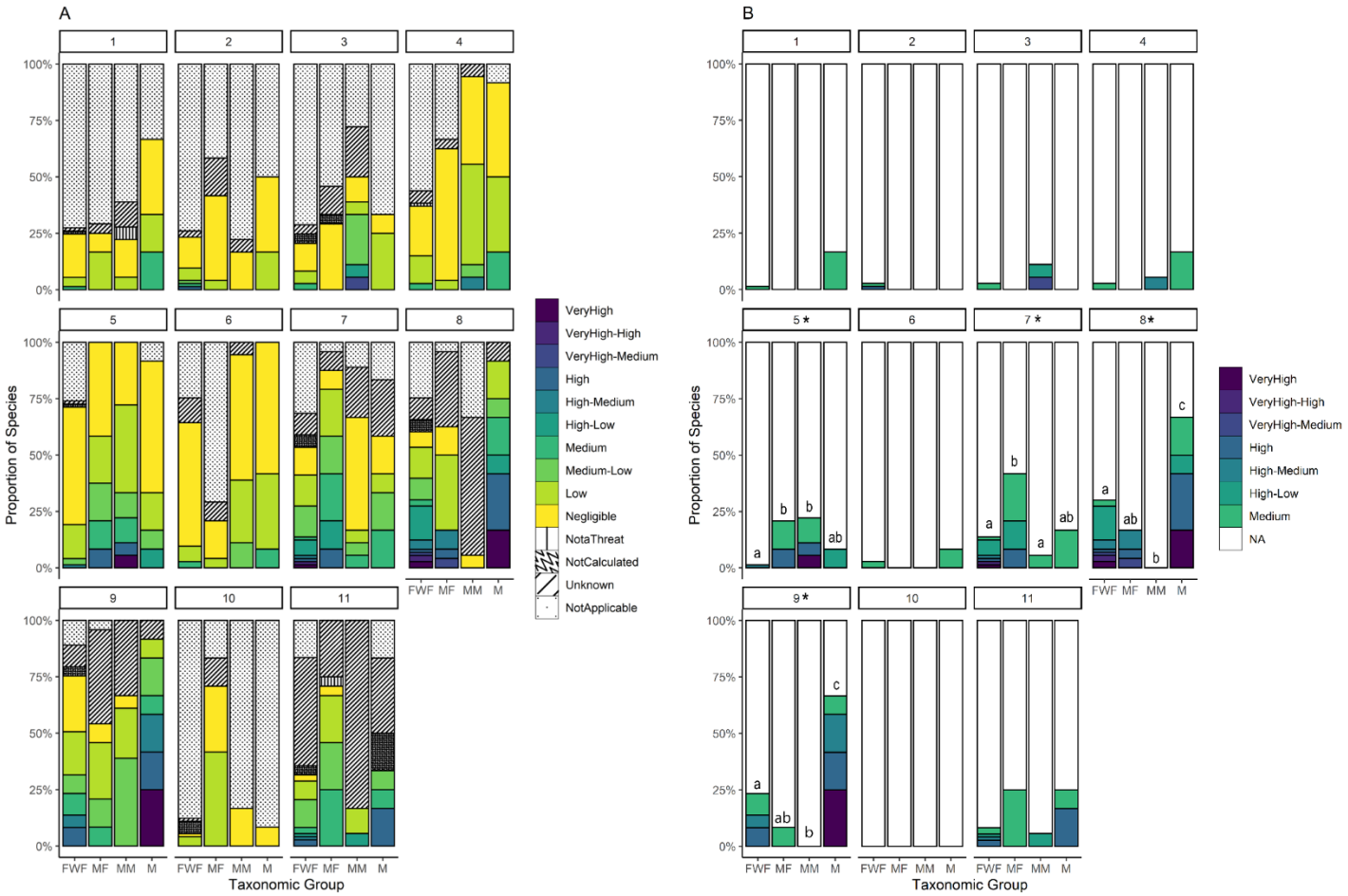


Figure 4. *Aquatic species assessed by COSEWIC between 2012 and 2021 with a completed threats calculator (n = 127) sorted by A) impact scores (by percentage) within each Level 1 threat category among taxonomic groups and B) dominant threats (impact score equal to or greater than "Medium") within each Level 1 threat category among taxonomic groups. Taxonomic groups are abbreviated: FWF is freshwater fishes (n = 73), MF is marine fishes (n = 24), MM is marine mammals (n = 18), and M is molluscs (n = 12). Level 1 categories are listed in Appendix A2. Cochran-Mantel-Haenszel test revealed significant association (p < 0.05) between taxonomic group and threats scores among Level 1 threats categories. Fisher's exact tests revealed significant association (p < 0.05) between taxonomic group and dominant threats within some threats categories (indicated by an asterisk "*"). Letters indicate pairwise significance for dominant threats between taxonomic groups within significant Level 1 threats categories.*

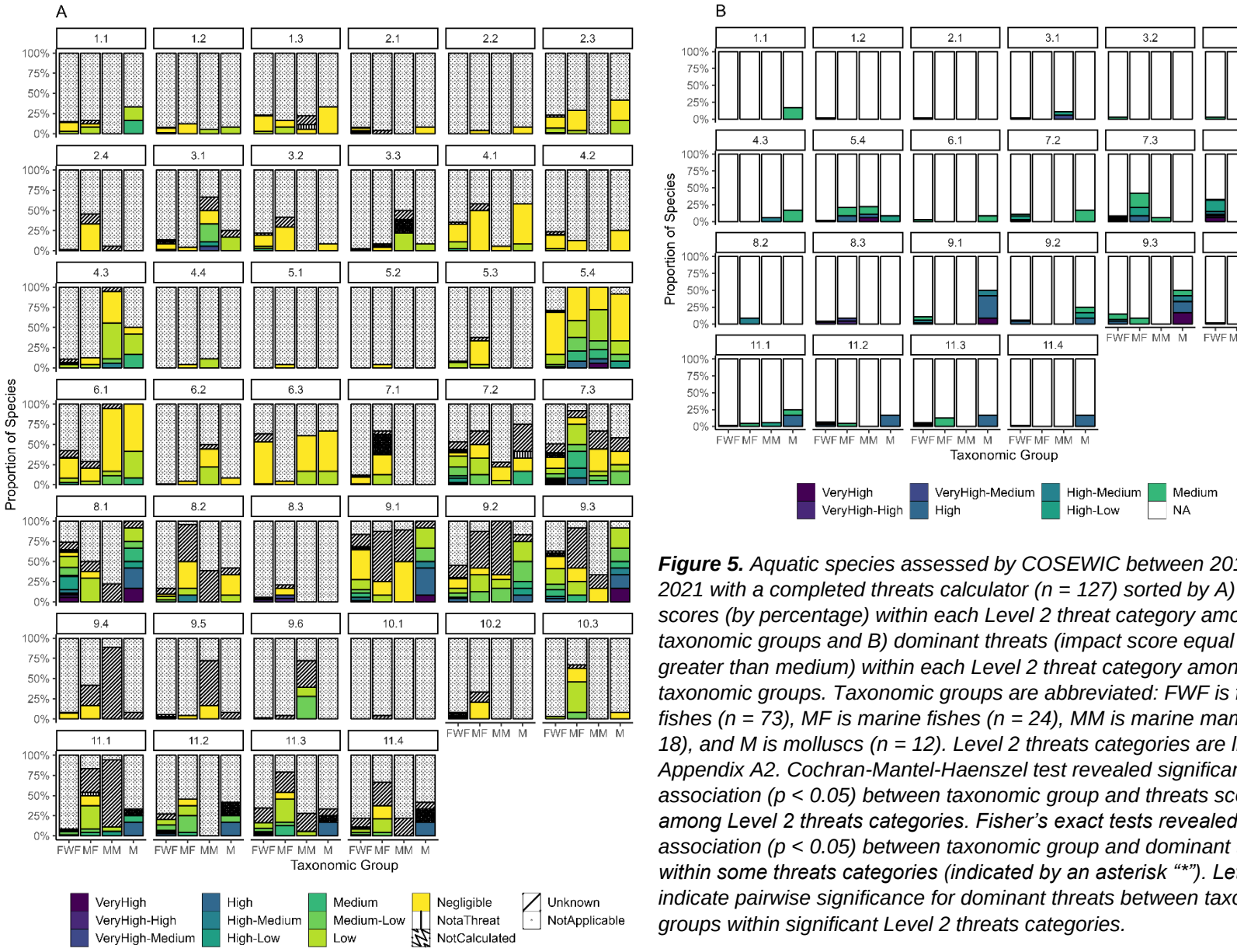


Figure 5. *Aquatic species assessed by COSEWIC between 2012 and 2021 with a completed threats calculator (n = 127) sorted by A) impact scores (by percentage) within each Level 2 threat category among taxonomic groups and B) dominant threats (impact score equal to or greater than medium) within each Level 2 threat category among taxonomic groups. Taxonomic groups are abbreviated: FWF is freshwater fishes (n = 73), MF is marine fishes (n = 24), MM is marine mammals (n = 18), and M is molluscs (n = 12). Level 2 threats categories are listed in Appendix A2. Cochran-Mantel-Haenszel test revealed significant association (p < 0.05) between taxonomic group and threats scores among Level 2 threats categories. Fisher's exact tests revealed significant association (p < 0.05) between taxonomic group and dominant threats (B) within some threats categories (indicated by an asterisk "*"). Letters indicate pairwise significance for dominant threats between taxonomic groups within significant Level 2 threats categories.*

APPENDICES

Appendix A1. Terminology

Assigned Threat = Level 1 or Level 2 threat assigned using COSEWIC's threats calculator process

Aquatic Species = a wildlife species that is a fish, as defined in section 2 of the *Fisheries Act*, or a marine plant, as defined in section 47 of that Act (*Fisheries Act* R.S.C., 1985, c. F-14); fish includes (a) parts of fish, (b) shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals, and (c) the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals (*Fisheries Act* R.S.C., 1985, c. F-14); marine plants includes all benthic and detached algae, marine flowering plants, brown algae, red algae, green algae and phytoplankton (*Fisheries Act* R.S.C., 1985, c. F-14). Fisheries and Oceans Canada (DFO) is responsible for aquatic species under the *Species at Risk Act* (SARA).

Committee on the Status of Endangered Wildlife in Canada (COSEWIC) = Established in 1977 to provide a single, scientifically-sound classification of wildlife species at risk of extinction in Canada and later as an advisory body for the 2002 SARA (COSEWIC 2021a - https://cosewic.ca/index.php/en-ca/about-us.html). COSEWIC determines the national status of wild Canadian species, subspecies, varieties or geographically or genetically distinct populations (e.g., designatable units) that are suspected of being at risk of extinction or extirpation. COSEWIC uses a process based on science, community and Traditional Knowledge to assess wildlife species at risk. All native mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses and lichens are included in COSEWIC's current mandate.

Designatable Unit (DU) = a unit of Canadian biodiversity below the taxonomic species level (i.e., Wildlife Species) that is discrete and evolutionarily significant, where discrete means that there is currently very little transmission of heritable (cultural or genetic) information from other such units, and evolutionarily significant means that the unit harbours heritable adaptive traits or an evolutionary history not found elsewhere in Canada (COSEWIC 2020a).

Dominant Threat = Level 1 or Level 2 threat category with an impact score equal to or greater than medium.

Endangered Species = a wildlife species that is facing imminent extirpation or extinction (*SARA* S.C. 2002, c. 29).

Extirpated Species = a wildlife species that no longer exists in the wild in Canada but exists elsewhere in the wild (SARA S.C. 2002, c. 29).

Level 1 Threats Categories = broad categories of threats defined by COSEWIC (2014a), adapted from the IUCN - CMP Unified Classification of Direct Threats (Table 1 in Salafsky et al. 2008). See Appendix A2 for detailed descriptions of each Level 1 and Level 2 category.

Level 2 Threats Categories = more specific, finer categories of threats within Level 1 threats defined by COSEWIC (2014a), adapted from the IUCN - CMP Unified Classification of Direct Threats (Table 1 in Salafsky et al. 2008). See Appendix A2 for detailed descriptions of each Level 1 and Level 2 category.

Limiting Factor = generally not human induced and includes characteristics that make the species or ecosystem less likely to respond to recovery/conservation efforts (e.g., likelihood of regeneration, recolonization for ecosystems) (COSEWIC 2014a); OR 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) (DFO 2014).

Location = a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present. The size of the location depends on the area covered by the threatening event and may include part of one or many subpopulations (COSEWIC 2014).

Recovery Potential Assessment (RPA) = a process developed by DFO Science to provide the information and scientific advice required to meet the various requirements of the *Species at Risk Act* (SARA). The RPA process relies on best available scientific information, data analyses and modelling, and expert opinions (DFO 2014). The objectives of the RPA are to assess current/recent species status, evaluate scope for management to facilitate recovery, and outline scenarios for mitigation and alternative to activities (DFO 2007); or RPA provides science advice to the department to aid in the development of Listing Recommendations, Recovery Strategies, and Actions Plans (DFO 2014).

Species = see Wildlife Species and Designatable Unit.

Species at Risk = an extirpated, endangered or threatened species or a species of special concern (*Species at Risk Act*, S.C. 2002, c. 29).

Species at Risk Act (SARA) = Established in 2002 SARA provides legal protection of wildlife species and conservation of biological diversity in Canada. It applies to all federal lands in Canada; all wildlife species listed as being at risk; and their critical habitat (if under federal jurisdiction). It also applies to aquatic species and migratory birds regardless of where they are located, or other wildlife species on federal lands. It is administered primarily by Environment and Climate Change Canada (ECCC), although Fisheries and Oceans Canada (DFO) is responsible for aquatic species and the Parks Canada (PC) is responsible for species occurring in national parks, national historic sites, and other federal protected heritage areas under the department (Government of Canada 2019) https://www.canada.ca/en/environment-climate-change/services/species-risk-act-accord-funding.html#toc0).

Species at Risk Public Registry = the Canadian federal registry that contains documents relating to the administration of the *Species at Risk Act* (SARA) (Government of Canada 2022 - https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html).

Species of Special Concern = a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats (*Species at Risk Act*, S.C. 2002, c. 29).

Threat = As defined by COSEWIC (2014a), “the proximate activities or processes that have caused, are causing, or may cause in the future the destruction, degradation, and/or impairment of the entity being assessed (population, species, community, or ecosystem) in the area of interest (globe, nation, or subnation)”. For purposes of threat assessment, only present and

future threats are considered. For the most part, threats are related to human activities, but they can be natural. Threats are classified into Level 1 and Level 2 threats categories based on IUCN-CMP unified threats classification system.

Threat Impact (Impact of a Threat) = the degree to which a species or ecosystem is observed, inferred, or suspected to be directly or indirectly threatened in the area of interest. The impact of a threat is based on the interaction between assigned scope and severity values, and includes categories of very high, high, medium, and low. Threat impact reflects a reduction of a species population (COSEWIC 2014a).

Using scope and severity to derive the impact of a threat:

- Very High: when the value for scope is pervasive and the severity is extreme.
- High: when the value of scope is pervasive and the severity is large, or when the value for scope is large and the severity is extreme or serious.
- Medium: when the value for scope is pervasive and the severity is moderate, or when the value for scope is large and the severity is moderate, or when the value for scope is restricted and the severity is extreme or serious
- Low: when the value for scope is slight or the severity is small, or when the value for scope is restricted and severity is moderate.
- Negligible: when the value for scope or severity is negligible.
- Unknown: used when impact cannot be determined (e.g., if values for either scope or severity are unknown).
- Not a Threat: when severity is scored as neutral or a potential benefit.
- Not Calculated: impact is not calculated if threat is outside the assessment timeframe (e.g., timing is insignificant/negligible or low, as threat is only considered to be in the past).

		Scope					
		Pervasive	**Large**	**Restricted**	**Small**	**Negligible**	**Unknown**
Severity	**Extreme**	Very High (50-100%)	High (22-70%)	Medium (8-30%)	Low (1-10%)	Negligible	Unknown
	Serious	High (22-70%)	High (10-49%)	Medium (3-21%)	Low (1-7%)	Negligible	Unknown
	Moderate	Medium (8-30%)	Medium (3-21%)	Low (1-9%)	Low (0.1-3%)	Negligible	Unknown
	Slight	Low (1-10%)	Low (0-7%)	Low (1-3%)	Low (0.1-3%)	Negligible	Unknown
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Neutral or Potential Benefit	Not a Threat	Not a Threat	Not a Threat	Not a Threat	Not a Threat	Unknown

Threat Scope = the proportion of the species that can reasonably be expected to be affected by the threat within 10 years with continuation of current circumstances and trends. The 10-year timeframe can be extended for some longer-term threats, such as global warming, that need to be addressed today. For species, scope is measured as the proportion of the species' population in the area of interest affected by the Threat (COSEWIC 2014a).

Scoring the scope of a threat:

- Pervasive = Affects all or most (71–100%) of the total population or occurrences
- Large = Affects much (31–70%) of the total population or occurrences
- Restricted = Affects some (11–30%) of the total population or occurrences
- Small = Affects a small (1–10%) proportion of the total population or occurrences
- Negligible = Affects a negligible (< 1%) proportion of the total population or occurrences

Threat Severity = the level of damage to the species from the threat that can reasonably be expected with continuation of current circumstances and trends (including potential new threats). Note that severity of threats is assessed within a 10-year or three-generation timeframe, whichever is longer (up to 100 years). For species, severity is usually measured as the degree of reduction of the species' population.

Scoring the severity of a threat:

- Extreme = Within the scope, the threat is likely to reduce the species population by 71–100%
- Serious = Within the scope, the threat is likely, to reduce the species population by 31–70%
- Moderate = Within the scope, the threat is likely to reduce the species population by 11–30%
- Slight = Within the scope, the threat is likely to reduce the species population by 1–10%
- Negligible = Within the scope, the threat is likely to reduce the species population by < 1%.
- Neutral or Potential Benefit = Within the scope, the "threat" is likely to improve or not affect the species, to be neutral or to improve (a net benefit) the species population by > 0%).

Threat Timing = Although timing (immediacy) is recorded for threats, it is not used in the calculation of threat impact. However, threat impact is not calculated for threats where timing values are low or negligible (COSEWIC 2014a).

Scoring the timing of a threat:

- High = Continuing
- Moderate = Only in the future (could happen in the short term; < 10 years or three-generations, whichever is longer), or now suspended (could come back in the short term)
- Low = Only in the future (could happen in the long term), or now suspended (could come back in the long term)
- Insignificant = Only in the past and unlikely to return, or no direct effect but limiting /Negligible

Threats Calculator = a threats classification and assessment calculator approved by COSEWIC at the November 2012 COSEWIC Wildlife Species Assessment Meeting (COSEWIC 2015a), based on the IUCN- CMP Unified Classification of Direct Threats.

Threats Calculator Facilitator = a trained COSEWIC member who has a good understanding of COSEWIC's "Guidance for Completing the Threats Classification and Assessment Calculator

and Determining the Number of Locations" and leads the threats calculator discussion (usually a teleconference) for a species status report (COSEWIC 2015a).

Threatened Species = a wildlife species that is likely to become an endangered species if nothing is done to reverse the factors leading to its extirpation or extinction (*Species at Risk Act*, S.C. 2002, c. 29).

Wildlife Species = a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and (a) is native to Canada; or (b) has extended its range into Canada without human intervention and has been present in Canada for at least 50 years (*Species at Risk Act*, S.C. 2002, c. 29).

Appendix A2. Description of threats categories, revised from COSEWIC (2014a), with additional examples and clarification provided by the authors, **in bold,** based on experience applying and facilitating COSEWIC's threats calculator framework for assessments of aquatic species in Canada**.** Level 2 threats categories included in the current threats calculator version (3.3) but not in the previous (1.1) are indicated by an asterisk (*).

Level 1 threats	Description of Level 1 threats	Level 2 threats	Description of Level 2 threats
1) Residential & Commercial Development	Threats from human settlements or other non-agricultural land uses with a substantial footprint	1.1 Housing & Urban Areas	Human cities, towns, and settlements including non-housing development typically integrated with housing **(e.g., impact of the footprints only)**
		1.2 Commercial & Industrial Areas	Factories and other commercial centres **(e.g., impact of the footprints only. Pile driving for shipping yards or ferry terminals)**
		1.3 Tourism & Recreation Areas	Tourism and recreation sites with a substantial footprint **(e.g., impact of the footprints only. New or expansion of marinas, boat launches. Effects of activities are under 6.1)**
2) Agriculture & Aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture,	2.1 Annual & Perennial Non-Timber Crops	Crops planted for food, fodder, fibre, fuel, or other uses) **(e.g., Footprints of farms, plantations, orchards, vineyards, mixed agroforestry systems)**
		2.2 Wood & Pulp Plantations	Stands of trees planted for timber or fibre outside of natural forests, often with non-

	mariculture, and aquaculture		native species **(e.g., footprint of silviculture)**
		2.3 Livestock Farming & Ranching	Domestic terrestrial animals raised in one location on farmed or non-local resources (farming); also, domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (ranching) **(e.g., footprints of cattle feed lots, dairy farms, cattle ranching, chicken farms etc.)**
		2.4 Marine & Freshwater Aquaculture	Aquatic animals raised in one location on farmed or non-local resources; also, hatchery fish allowed to roam in the wild **(e.g., footprints of shrimp or fin fish aquaculture, fish ponds, hatchery salmon competing with wild salmon in freshwater or marine environments, artificial algal beds. Note: This is the impact from the footprint itself, threats from disease/sea lice/introduced genetics are scored in section 8)**

3) Energy Production & Mining	Threats from production of non-biological resources Threats from production of non-biological resources	3.1 Oil & Gas Drilling	Exploring for, developing, and producing petroleum and other liquid hydrocarbons **(e.g., footprint of a well pad. Note: Pipeline construction impacts go under 4.2; spills under 9.2)**
		3.2 Mining & Quarrying	Exploring for, developing, and producing minerals and rocks **(e.g., coal mines, alluvial gold panning, gold mines, rock quarries, gravel extraction)**
		3.3 Renewable Energy	Exploring, developing, and producing renewable energy **(e.g., footprints of geothermal power production, solar farms, wind farms, tidal farms. This does not include hydroelectric projects including run-of-the-river, they will be dealt with in section 7.2)**

4) Transportation & Service Corridors	Threats from long, narrow transport corridors and the vehicles that use them including associated wildlife mortality	4.1 Roads & Railroads	Surface transport on roadways and dedicated tracks **(e.g., expansion of existing roads or new roads into aquatic habitat, including resource extraction roads i.e., logging, mining, forestry; replacement of culverts)**
		4.2 Utility & Service Lines	Transport of energy & resources **(e.g., new or expansion or replacement of oil and gas pipelines crossing or adjacent to aquatic habit; undersea cables)**
		4.3 Shipping Lanes	Transport on and in freshwater and ocean waterways **(e.g., transport in addition to dredging and other activities that maintain shipping lanes, wakes from cargo ships, log booms, barges; ship striking whales; grounding of log booms and barges).**
		4.4 Flight Paths	Air and space transport

5) Biological Resource Use	Threats from consumptive use of “wild” biological resources including both deliberate and unintentional harvesting effects; also, persecution or control of specific species	5.1 Hunting & Collecting Terrestrial Animals	Killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch
		5.2 Gathering Terrestrial Plants	Harvesting plants, fungi, and other non-timber/non-animal products for commercial, recreation, subsistence, research, or cultural purposes, or for control reasons
		5.3 Logging & Wood Harvesting	Harvesting trees and other woody vegetation for timber, fibre, or fuel **(e.g., dumping cut logs into habitat; forestry logging debris falling into streams)**
		5.4 Fishing & Harvesting Aquatic Resources	Harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for

			control/persecution reasons; includes accidental mortality/bycatch

6) Human Intrusions & Disturbance	Threats from human activities that alter, destroy, and disturb habitats and species associated with non-consumptive uses of biological resources	6.1 Recreational Activities	People spending time in nature or traveling in vehicles outside of established transport corridors, usually for recreational reasons
		6.2 War, Civil Unrest, & Military Exercises	Actions by formal or paramilitary forces without a permanent footprint
		6.3 Work & Other Activities	People spending time in or traveling in natural environments for reasons other than recreation, military activities, or research **(e.g., non-lethal research such as tagging or counting individuals at fences; research on other species in the same habitat)**

7) Natural System Modifications	Threats from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare	7.1 Fire & Fire Suppression	Suppression or increase in fire frequency and/or intensity outside of its natural range of variation **(e.g., removal of water to fight forest fires)**
		7.2 Dams & Water Management/ Use	Changing water flow patterns from their natural range of variation either deliberately or as a result of other activities **(e.g., dam construction, dam operations, run of river hydroelectric development, wetland infilling, levees and dikes, surface water diversion and pumping, groundwater pumping, channelization, artificial lakes)**
		7.3 Other Ecosystem Modifications	Other actions that convert or degrade habitat in service of "managing" natural systems to improve human welfare **(e.g., indirect impact to the species through habitat impact such as modification of catchment surfaces from forest fires, Mountain Pine Beetle salvage logging, etc., linear development, and invasive plants modifying habitat; rip-rap along shorelines, beach construction,**

			removal of snags from streams; human removal/reduction of prey species)

8) Invasive & Other Problematic Species & Genes	Threats from non-native and native plants, animals, pathogens/ microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance	8.1 Invasive Non-Native/ Alien Species	Harmful plants, animals, pathogens, and other microbes not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities **(e.g., a predator that kills an aquatic species; an invasive species that smothers an aquatic species or rapidly converts an aquatic environment into a terrestrial environment)**
		8.2 Problematic Native Species	Harmful plants, animals, or pathogens and other microbes that are originally found within the ecosystem(s) in question, but have become "out-of-balance" or "released" directly or indirectly due to human activities **(e.g., overabundant natural predators consuming aquatic species; a natural predator limiting factor could now be a threat due to the actions of other threats and loss of resiliency)**
		8.3 Introduced Genetic Material	Human altered or transported organisms or genes **(e.g., hatchery salmon from within or from other Wildlife Species/DUs; genetically modified salmon)**
		8.4 Problematic species/diseases of unknown origin*	Harmful plants, animals, or pathogens and other microbes of unknown origin. It is not known if they were deliberately or accidentally introduced (see 8.2) or if they were originally found within the ecosystem(s) in question (see 8.3).
		8.5 Viral/prion-induced diseases*	Viruses are small infectious agents that replicate only inside the living cells of an organism. Although viruses occur universally, each cellular species has its own specific range that often infect

			only that species. Most viruses co-exist harmlessly in their host and cause no signs or symptoms of disease. However, a number are important pathogens which can result in diseases which significantly reduce reproduction or increase mortality. Prions are infectious agents composed of protein in a misfolded form. They do not contain nucleic acids. All known prion diseases affect the structure of the brain and other neural tissue, they are mainly found in mammals, are currently untreatable and are universally fatal.
		8.6 Diseases of unknown cause*	Occasionally plants and animals are impacted by diseases of unknown origin and often it may take many years to identify the pathogen responsible. For example, it is not known what causes white-band disease (WBD) in Acroporid corals, but the disease is having a huge impact in some parts of the world.

9) Pollution	Threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources	9.1 Household Sewage & Urban Waste Water	Water-borne sewage and non-point runoff from housing and urban areas that include nutrients, toxic chemicals, and/or sediments **(e.g., discharge from municipal waste treatment plants, leaking septic systems, untreated sewage, outhouses, oil or sediment and salt from roads, domestic fertilizers, herbicides)**
		9.2 Industrial & Military Effluents	Water-borne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries that include nutrients, toxic chemicals, and/or sediments **(e.g., toxic chemicals from factories or industry, illegal dumping, spills from transportation, chronic marine spills from shipping)**

		9.3 Agricultural & Forestry Effluents	Water-borne pollutants from agricultural, silivicultural, and aquaculture systems that include nutrients, toxic chemicals, and/or sediments including the effects of these pollutants on the site where they are applied **(e.g., nutrients, herbicides, sediments, manure, soil erosion)**
		9.4 Garbage & Solid Waste	Rubbish and other solid materials including those that entangle wildlife (**e.g., ghost nets, abandoned fishing gear, microplastics, shopping carts, flotsam and jetsam from boats)**
		9.5 Air-Borne Pollutants	Atmospheric pollutants from point and nonpoint sources **(e.g., acid rain, fog, vehicle emissions, radioactive fallout, dust, smoke from forest fires or wood stoves)**
		9.6 Excess Energy	Inputs of heat, sound, or light that disturb wildlife or ecosystems **(e.g., beach lights disorienting turtles, jet boat noise, sonar from submarines or oil exploration, heated water from power plants)**

10) Geological Events	Threats from catastrophic geological events	10.1 Volcanoes	Volcanic events
		10.2 Earthquakes / Tsunamis	Earthquakes and associated events
		10.3 Avalanches / Landslides	Avalanches or landslides **(e.g., increased sedimentation caused by increased frequency and magnitude of landslides)**

11) Climate Change & Severe Weather	Threats from long-term climatic changes that may be linked to global warming and other severe	11.1 Habitat Shifting & Alteration	Major changes in habitat composition and location **(e.g., sea level rise, ocean acidification, desertification, tundra thawing, the Pacific Ocean Blob, ocean survival)**
		11.2 Droughts	Periods in which rainfall falls below the normal range of variation **(e.g., severe**

	climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat		**lack of rain or changes in seasonal precipitation patterns)**
		11.3 Temperature Extremes	Periods in which temperatures exceed or go below the normal range of variation **(e.g., heat domes, cold spells, changes in freeze-thaw cycles, disappearance of glaciers/sea ice; temperature changes in the freshwater environment)**
		11.4 Storms & Flooding	Extreme precipitation and/or wind events **(e.g., ice storms, increased scouring and erosion and deposition of woody debris into habitat)**
		11.5 Other*	Other

Appendix A3. Aquatic species assessed by COSEWIC between 2012 and 2021 with a completed threats calculator, as of May 2022. Taxonomic groups are represented by abbreviations: FWF = freshwater fishes, MF = marine fishes, MM = marine mammals, and M = molluscs.

Common Name	*Scientific Name*	Year of last Assessment	Group	COSEWIC Status	SARA Schedule Status
Banded Killifish (Newfoundland populations)	*Fundulus diaphanus*	2014	FWF	Special Concern	Special Concern
Bering Cisco	*Coregonus laurettae*	2017	FWF	Special Concern	No Status
Black Redhorse	*Moxostoma duquesnei*	2015	FWF	Threatened	Threatened
Blackstripe Topminnow	*Fundulus notatus*	2012	FWF	Special Concern	Special Concern
Carmine Shiner	*Notropis percobromus*	2018	FWF	Endangered	Endangered
Channel Darter (Lake Erie populations)	*Percina copelandi*	2016	FWF	Endangered	Endangered
Channel Darter (Lake Ontario populations)	*Percina copelandi*	2016	FWF	Endangered	Endangered
Channel Darter (St. Lawrence populations)	*Percina copelandi*	2016	FWF	Special Concern	Special Concern

Coastrange Sculpin (Cultus Lake population)	*Cottus aleuticus*	2019	FWF	Endangered	Threatened
Columbia Sculpin	*Cottus hubbsi*	2019	FWF	Special Concern	Special Concern
Copper Redhorse	*Moxostoma hubbsi*	2014	FWF	Endangered	Endangered
Cutlip Minnow	*Exoglossum maxillingua*	2013	FWF	Special Concern	Special Concern
Deepwater Sculpin (Great Lakes - Upper St. Lawrence populations)	*Myoxocephalus thompsonii*	2017	FWF	Special Concern	Special Concern
Deepwater Sculpin (Saskatchewan - Nelson River populations)	*Myoxocephalus thompsonii*	2017	FWF	Not at Risk	No Status
Deepwater Sculpin (Southern Hudson Bay - James Bay populations)	*Myoxocephalus thompsonii*	2017	FWF	Data Deficient	No Status
Deepwater Sculpin (Waterton Lake population)	*Myoxocephalus thompsonii*	2017	FWF	Special Concern	No Status
Deepwater Sculpin (Western Arctic populations)	*Myoxocephalus thompsonii*	2017	FWF	Not at Risk	No Status
Deepwater Sculpin (Western Hudson Bay populations)	*Myoxocephalus thompsonii*	2017	FWF	Not at Risk	No Status
European Whitefish (Dezadeash Lake large-bodied population)	*Coregonus lavaretus*	2018	FWF	Threatened	No Status
European Whitefish (Dezadeash Lake small-bodied population)	*Coregonus lavaretus*	2018	FWF	Threatened	No Status
European Whitefish (Little Teslin Lake small-bodied population)	*Coregonus lavaretus*	2018	FWF	Threatened	No Status
European Whitefish (Squanga Lake small-bodied population)	*Coregonus lavaretus*	2018	FWF	Threatened	No Status

Giant Threespine Stickleback	*Gasterosteus aculeatus*	2013	FWF	Special Concern	Special Concern
Lake Chub (Atlin Warm Springs populations)	*Couesius plumbeus*	2018	FWF	Threatened	No Status
Lake Chub (Liard Hot Springs populations)	*Couesius plumbeus*	2018	FWF	Threatened	No Status
Lake Chubsucker	*Erimyzon sucetta*	2021	FWF	Endangered	Endangered
Lake Sturgeon (Great Lakes - Upper St. Lawrence populations)	*Acipenser fulvescens*	2017	FWF	Threatened	No Status
Lake Sturgeon (Saskatchewan - Nelson River populations)	*Acipenser fulvescens*	2017	FWF	Endangered	No Status
Lake Sturgeon (Southern Hudson Bay - James Bay populations)	*Acipenser fulvescens*	2017	FWF	Special Concern	Special Concern
Lake Sturgeon (Western Hudson Bay populations)	*Acipenser fulvescens*	2017	FWF	Endangered	No Status
Lake Whitefish (Como Lake large-bodied population)	*Coregonus clupeaformis*	2018	FWF	Extinct	No Status
Lake Whitefish (Como Lake small-bodied population)	*Coregonus clupeaformis*	2018	FWF	Extinct	No Status
Lake Whitefish (Little Teslin Lake large-bodied population)	*Coregonus clupeaformis*	2018	FWF	Threatened	No Status
Lake Whitefish (Opeongo Lake large-bodied population)	*Coregonus clupeaformis*	2018	FWF	Threatened	No Status
Lake Whitefish (Opeongo Lake small-bodied population)	*Coregonus clupeaformis*	2018	FWF	Threatened	No Status
Lake Whitefish (Squanga Lake large-bodied population)	*Coregonus clupeaformis*	2018	FWF	Threatened	No Status
Little Quarry Lake Benthic Threespine Stickleback	*Gasterosteus aculeatus*	2015	FWF	Threatened	No Status

Little Quarry Lake Limnetic Threespine Stickleback	*Gasterosteus aculeatus*	2015	FWF	Threatened	No Status
Nooksack Dace	*Rhinichthys cataractae*	2018	FWF	Endangered	Endangered
Northern Brook Lamprey (Great Lakes - Upper St. Lawrence populations)	*Ichthyomyzon fossor*	2020	FWF	Special Concern	Special Concern
Northern Brook Lamprey (Saskatchewan - Nelson River populations)	*Ichthyomyzon fossor*	2020	FWF	Endangered	No Status
Northern Sunfish (Great Lakes - Upper St. Lawrence populations)	*Lepomis peltastes*	2016	FWF	Special Concern	Special Concern
Northern Sunfish (Saskatchewan - Nelson River populations)	*Lepomis peltastes*	2016	FWF	Not at Risk	No Status
Plains Minnow	*Hybognathus placitus*	2012	FWF	Threatened	Threatened
Pygmy Whitefish (Great Lakes - Upper St. Lawrence populations)	*Prosopium coulterii*	2016	FWF	Threatened	No Status
Pygmy Whitefish (Pacific populations)	*Prosopium coulterii*	2016	FWF	Not at Risk	No Status
Pygmy Whitefish (Saskatchewan - Nelson Rivers populations)	*Prosopium coulterii*	2016	FWF	Data Deficient	No Status
Pygmy Whitefish (Southwestern Yukon Beringian populations)	*Prosopium coulterii*	2016	FWF	Data Deficient	No Status
Pygmy Whitefish (Waterton Lake population)	*Prosopium coulterii*	2016	FWF	Special Concern	No Status
Pygmy Whitefish (Western Arctic populations)	*Prosopium coulterii*	2016	FWF	Not at Risk	No Status
Pygmy Whitefish (Yukon River populations)	*Prosopium coulterii*	2016	FWF	Data Deficient	No Status
Rainbow Smelt (Lake Utopia	*Osmerus mordax*	2018	FWF	Endangered	Endangered

large-bodied population)					
Rainbow Smelt (Lake Utopia small-bodied population)	*Osmerus mordax*	2018	FWF	Endangered	Endangered
Rainbow Trout (Athabasca River populations)	*Oncorhynchus mykiss*	2014	FWF	Endangered	Endangered
Redside Dace	*Clinostomus elongatus*	2017	FWF	Endangered	Endangered
River Darter (Great Lakes - Upper St. Lawrence populations)	*Percina shumardi*	2016	FWF	Endangered	No Status
River Darter (Saskatchewan - Nelson River populations)	*Percina shumardi*	2016	FWF	Not at Risk	No Status
River Darter (Southern Hudson Bay - James Bay populations)	*Percina shumardi*	2016	FWF	Not at Risk	No Status
Rocky Mountain Sculpin (Missouri River populations)	*Cottus sp.*	2019	FWF	Threatened	No Status
Rocky Mountain Sculpin (Pacific populations)	*Cottus sp.*	2019	FWF	Special Concern	Special Concern
Rocky Mountain Sculpin (Saskatchewan - Nelson River populations)	*Cottus sp.*	2019	FWF	Threatened	No Status
Shortnose Sturgeon	*Acipenser brevirostrum*	2015	FWF	Special Concern	Special Concern
Silver Lamprey (Great Lakes - Upper St. Lawrence populations)	*Ichthyomyzon unicuspis*	2020	FWF	Special Concern	Special Concern
Silver Lamprey (Saskatchewan - Nelson River populations)	*Ichthyomyzon unicuspis*	2020	FWF	Special Concern	No Status
Silver Lamprey (Southern Hudson Bay - James Bay populations)	*Ichthyomyzon unicuspis*	2020	FWF	Data Deficient	No Status
Speckled Dace	*Rhinichthys osculus*	2016	FWF	Endangered	Endangered

Spotted Gar	*Lepisosteus oculatus*	2015	FWF	Endangered	Endangered
Unarmoured Threespine Stickleback	*Gasterosteus aculeatus*	2013	FWF	Special Concern	Special Concern
Vancouver Lamprey	*Entosphenus macrostomus*	2017	FWF	Threatened	Threatened
Warmouth	*Lepomis gulosus*	2015	FWF	Endangered	Special Concern
Western Silvery Minnow	*Hybognathus argyritis*	2017	FWF	Threatened	Threatened
Westslope Cutthroat Trout (Pacific populations)	*Oncorhynchus clarkii lewisi*	2016	FWF	Special Concern	Special Concern
Westslope Cutthroat Trout (Saskatchewan - Nelson Rivers populations)	*Oncorhynchus clarkii lewisi*	2016	FWF	Threatened	Threatened
Eastern Pondmussel	*Ligumia nasuta*	2017	M	Special Concern	Special Concern
Kidneyshell	*Ptychobranchus fasciolaris*	2013	M	Endangered	Endangered
Lilliput	*Toxolasma parvum*	2013	M	Endangered	Endangered
Mapleleaf (Great Lakes - Upper St. Lawrence population)	*Quadrula quadrula*	2016	M	Special Concern	Special Concern
Mapleleaf (Saskatchewan – Nelson Rivers population)	*Quadrula quadrula*	2016	M	Threatened	Threatened
Purple Wartyback	*Cyclonaias tuberculata*	2021	M	Threatened	No Status
Rainbow	*Villosa iris*	2015	M	Special Concern	Special Concern
Round Hickorynut	*Obovaria subrotunda*	2013	M	Endangered	Endangered
Round Pigtoe	*Pleurobema sintoxia*	2014	M	Endangered	Endangered
Shortface Lanx	*Fisherola nuttallii*	2016	M	Endangered	No Status
Threehorn Wartyback	*Obliquaria reflexa*	2013	M	Threatened	Threatened
Yellow Lampmussel	*Lampsilis cariosa*	2013	M	Special Concern	Special Concern

Chinook Salmon (DU11: Upper Fraser, Stream, Spring population)	*Oncorhynchus tshawytscha*	2018	MF	Endangered	No Status
Chinook Salmon (DU15: Lower Thompson, Stream, Spring population)	*Oncorhynchus tshawytscha*	2020	MF	Endangered	No Status
Chinook Salmon (DU2: Lower Fraser, Ocean, Fall population)	*Oncorhynchus tshawytscha*	2018	MF	Threatened	No Status
Chinook Salmon (DU20: East Vancouver Island, Ocean, Summer population)	*Oncorhynchus tshawytscha*	2020	MF	Endangered	No Status
Chinook Salmon (DU21: East Vancouver Island, Ocean, Fall population)	*Oncorhynchus tshawytscha*	2020	MF	Special Concern	No Status
Chinook Salmon (DU23: East Vancouver Island, Ocean, Fall (EVI + SFj) population)	*Oncorhynchus tshawytscha*	2020	MF	Not at Risk	No Status
Chinook Salmon (DU24: West Vancouver Island, Ocean, Fall (South) population)	*Oncorhynchus tshawytscha*	2020	MF	Threatened	No Status
Chinook Salmon (DU25: West Vancouver Island, Ocean, Fall (Nootka & Kyuquot) population)	*Oncorhynchus tshawytscha*	2020	MF	Threatened	No Status
Chinook Salmon (DU28: Southern Mainland, Stream, Summer population)	*Oncorhynchus tshawytscha*	2018	MF	Data Deficient	No Status
Chinook Salmon (DU9: Middle Fraser, Stream, Spring (MFR+GStr) population)	*Oncorhynchus tshawytscha*	2018	MF	Threatened	No Status
Chinook Salmon (Okanagan population)	*Oncorhynchus tshawytscha*	2017	MF	Endangered	No Status

Coho Salmon (Interior Fraser population)	*Oncorhynchus kisutch*	2016	MF	Threatened	No Status
Sockeye Salmon (DU1: Anderson-Seton-ES population)	*Oncorhynchus nerka*	2017	MF	Not at Risk	No Status
Sockeye Salmon (DU11: Kamloops-ES population)	*Oncorhynchus nerka*	2017	MF	Special Concern	No Status
Sockeye Salmon (DU15: Pitt-ES population)	*Oncorhynchus nerka*	2017	MF	Not at Risk	No Status
Sockeye Salmon (DU16: Quesnel-S population)	*Oncorhynchus nerka*	2017	MF	Endangered	No Status
Sockeye Salmon (DU17: Seton-L population)	*Oncorhynchus nerka*	2017	MF	Endangered	No Status
Sockeye Salmon (DU18: Shuswap Complex-L population)	*Oncorhynchus nerka*	2017	MF	Not at Risk	No Status
Sockeye Salmon (DU20: Takla-Trembleur-EStu population)	*Oncorhynchus nerka*	2017	MF	Endangered	No Status
Steelhead Trout (Chilcotin River population)	*Oncorhynchus mykiss*	2020	MF	Endangered	No Status
Steelhead Trout (Thompson River population)	*Oncorhynchus mykiss*	2020	MF	Endangered	No Status
Tope	*Galeorhinus galeus*	2021	MF	Special Concern	Special Concern
Yelloweye Rockfish (Pacific Ocean inside waters population)	*Sebastes ruberrimus*	2020	MF	Threatened	Special Concern
Yelloweye Rockfish (Pacific Ocean outside waters population)	*Sebastes ruberrimus*	2020	MF	Threatened	Special Concern
Atlantic Walrus (Central / Low Arctic population)	*Odobenus rosmarus rosmarus*	2017	MM	Special Concern	No Status
Atlantic Walrus (High Arctic population)	*Odobenus rosmarus rosmarus*	2017	MM	Special Concern	No Status
Beluga Whale (Cumberland Sound population)	*Delphinapterus leucas*	2020	MM	Endangered	Threatened
Beluga Whale (Eastern High	*Delphinapterus leucas*	2020	MM	Special Concern	No Status

Arctic - Baffin Bay population)					
Beluga Whale (Eastern Hudson Bay population)	*Delphinapterus leucas*	2020	MM	Threatened	No Status
Beluga Whale (James Bay population)	*Delphinapterus leucas*	2020	MM	Not at Risk	No Status
Beluga Whale (Ungava Bay population)	*Delphinapterus leucas*	2020	MM	Endangered	No Status
Beluga Whale (Western Hudson Bay population)	*Delphinapterus leucas*	2020	MM	Not at Risk	No Status
Fin Whale (Atlantic population)	*Balaenoptera physalus*	2019	MM	Special Concern	Special Concern
Fin Whale (Pacific population)	*Balaenoptera physalus*	2019	MM	Special Concern	Threatened
Grey Whale (Northern Pacific Migratory population)	*Eschrichtius robustus*	2017	MM	Not at Risk	No Status
Grey Whale (Pacific Coast Feeding Group population)	*Eschrichtius robustus*	2017	MM	Endangered	No Status
Grey Whale (Western Pacific population)	*Eschrichtius robustus*	2017	MM	Endangered	No Status
Harbour Porpoise (Pacific Ocean population)	*Phocoena phocoena vomerina*	2016	MM	Special Concern	Special Concern
North Atlantic Right Whale	*Eubalaena glacialis*	2013	MM	Endangered	Endangered
Ringed Seal	*Pusa hispida*	2019	MM	Special Concern	No Status
Sei Whale (Atlantic population)	*Balaenoptera borealis*	2019	MM	Endangered	No Status
Sowerby's Beaked Whale	*Mesoplodon bidens*	2019	MM	Special Concern	Special Concern

Appendix A4. Pairwise tables using Fisher's exact test for count data and FDR corrections (with significant differences indicated in **bold**) on proportions of threats calculators completed:

a) between taxonomic groups

	FWF	MF	MM	M
MF	**1.90E-09**	-	-	-
MM	0.975	**0.000382**	-	-
M	1.000	0**.000626**	0.975	-

b) between years

	2012	2013	2014	2015	2016	2017	2018	2019	2020
2013	**0.00321**	-	-	-	-	-	-	-	-
2014	**0.0299**	1.000	-	-	-	-	-	-	-
2015	**0.00315**	0.855	1.000	-	-	-	-	-	-
2016	**2.06E-09**	**0.0293**	0.105	0.202	-	-	-	-	-
2017	**1.76E-05**	0.777	0.855	1.000	**0.0299**	-	-	-	-
2018	**8.45E-05**	0.896	1.000	1.000	**0.0275**	0.930	-	-	-
2019	**9.31E-05**	0.465	0.561	0.855	0.371	0.730	0.530	-	-
2020	**2.42E-07**	0.237	0.335	0.436	0.657	0.253	0.237	0.855	-
2021	0.253	0.297	0.530	0.237	**0.000710**	0.0935	0.152	0.0685	**0.00829**

Appendix A5. Pairwise tables using Fisher's exact test and FDR corrections (with significant differences indicated in **bold**) between Level 1 threats categories:

a) on proportion of dominant threats (impact score equal to or greater than medium)

	1	2	3	4	5	6	7	8	9	10
2	1.000	-	-	-	-	-	-	-	-	-
3	1.000	0.800	-	-	-	-	-	-	-	-
4	0.811	0.558	1.000	-	-	-	-	-	-	-
5	0.0871	**0.0378**	0.169	0.283	-	-	-	-	-	-
6	1.000	1.000	1.000	0.811	0.0871	-	-	-	-	-
7	**0.000127**	**3.54E-05**	**0.000424**	**0.00126**	0.0760	**0.000127**	-	-	-	-
8	**1.57E-07**	**5.43E-08**	**6.27E-07**	**2.48E-06**	**0.000686**	**1.57E-07**	0.196	-	-	-
9	**1.22E-05**	**2.60E-06**	**4.56E-05**	**0.000127**	**0.0163**	**1.22E-05**	0.761	0.495	-	-
10	0.340	0.609	0.187	0.100	**0.00204**	0.340	**6.27E-07**	**4.98E-10**	**5.82E-08**	-
11	**0.00722**	**0.00222**	**0.0180**	**0.0393**	0.532011	**0.00722**	0.398	**0.0152**	0.151	**7.25E-05**

b) on proportion of unknown threat impact scores

	1	2	3	4	5	6	7	8	9	10
2	0.618	-	-	-	-	-	-	-	-	-
3	0.242	0.692	-	-	-	-	-	-	-	-
4	0.798	1.000	0.537	-	-	-	-	-	-	-
5	0.473	0.117	0.0205	0.183	-	-	-	-	-	-
6	0.169	0.555	1.000	0.423	**0.0126**	-	-	-	-	-
7	**0.0187**	0.135	0.413	0.0781	**0.000538**	0.520	-	-	-	-
8	**4.56E-05**	**0.000981**	**0.00989**	**0.000398**	**3.12E-07**	**0.0176**	0.156	-	-	-
9	**0.000264**	**0.00464**	**0.0307**	**0.00195**	**2.82E-06**	0.0528	0.321	0.798	-	-
10	1.000	0.618	0.242	0.798	0.473	0.169	**0.0187**	**4.56E-05**	**0.000264**	-
11	**3.64E-16**	**8.29E-14**	**8.51E-12**	**1.67E-14**	**3.70E-19**	**3.03E-11**	**1.18E-08**	**7.80E-05**	**1.18E-05**	**3.64E-16**

Appendix A6. a) Groupwise comparisons of dominant threats among taxonomic groups across Level 1 threats categories and b) pairwise comparisons between dominant threats scores among taxonomic groups within significant threats categories: 5. Biological Resource Use, 7. Natural System modifications, 8. Invasive and Other Problematic Species and Genes, and 9. Pollution. Significance determined using Fisher's exact test and FDR corrections with significant results indicated in **bold** ($p < 0.05$).

a)

Threats Category	P value	Adjusted P value
1	0.00584	0.111
2	1.000	1.000
3	0.261	0.359
4	0.0965	0.152
5	0.00127	**0.00466**
6	0.482	0.589
7	0.0118	**0.0324**
8	0.000239	**0.00131**
9	0.0000819	**0.000901**
10	1.000	1.000
11	0.0607	0.111

b)

Cat 5	FWF	MF	MM
MF	**0.0150**	-	-
MM	**0.0150**	1.000	-
M	0.528	0.768	0.768

Cat 7	FWF	MF	MM
MF	**0.0367**	-	-
MM	0.686	**0.0367**	-
M	0.686	0.521	0.686

Cat 8	FWF	MF	MM
MF	0.289	-	-
MM	**0.0135**	0.147	-
M	**0.0336**	**0.0135**	**0.000507**

Cat 9	FWF	MF	MM
MF	0.172	-	-
MM	**0.0296**	0.498	-
M	**0.00917**	**0.00168**	**0.000507**

Appendix A7. a) Groupwise comparisons of dominant threats among taxonomic groups across Level 2 threats categories and b) pairwise comparisons between dominant threats among taxonomic groups within significant threats categories: 1.1 housing and urban areas, 4.3 shipping lanes, 5.4 fishing and harvesting aquatic resources, 7.3 other ecosystem modifications, 8.1 invasive non-native/alien species, 9.1 household sewage and urban waste water, and 9.3 agricultural and forestry effluents. Significance determined using Fisher's exact test and FDR corrections with significant results indicated in **bold** ($p<0.05$).

a)

Level 2 Category	P-value	Adjusted P-value
1.1	0.00825	**0.0471**
1.2	1.000	1.000
1.3	1.000	1.000
2.1	1.000	1.000
2.2	1.000	1.000
2.3	1.000	1.000
2.4	1.000	1.000
3.1	0.122	0.375
3.2	1.000	1.000

3.3	1.000	1.000
4.1	1.000	1.000
4.2	1.000	1.000
4.3	0.00667	**0.0445**
4.4	1.000	1.000
5.1	1.000	1.000
5.2	1.000	1.000
5.3	1.000	1.000
5.4	0.00127	**0.0127**
6.1	0.482	1.000
6.2	1.000	1.000
6.3	1.000	1.000
7.1	1.000	1.000
7.2	0.0983	0.328
7.3	0.000573	**0.00764**
8.1	0.000000535	**0.0000214**
8.2	0.0889	0.323
8.3	0.644	1.000
9.1	0.000276	**0.00552**
9.2	0.0349	0.155
9.3	0.00287	**0.0230**
9.4	1.000	1.000
9.5	1.000	1.000
9.6	1.000	1.000
10.1	1.000	1.000
10.2	1.000	1.000
10.3	1.000	1.000
11.1	0.0113	0.0565
11.2	0.306	0.816
11.3	0.155	0.443
11.4	0.0584	0.234

b)

Cat 1.1	FWF	MF	MM
MF	1.000	-	-
MM	1.000	1.000	-
M	0.111	0.303	0.303

Cat 4.3	FWF	MF	MM
MF	1.000	-	-
MM	0.396	0.643	-
M	0.111	0.314	0.657

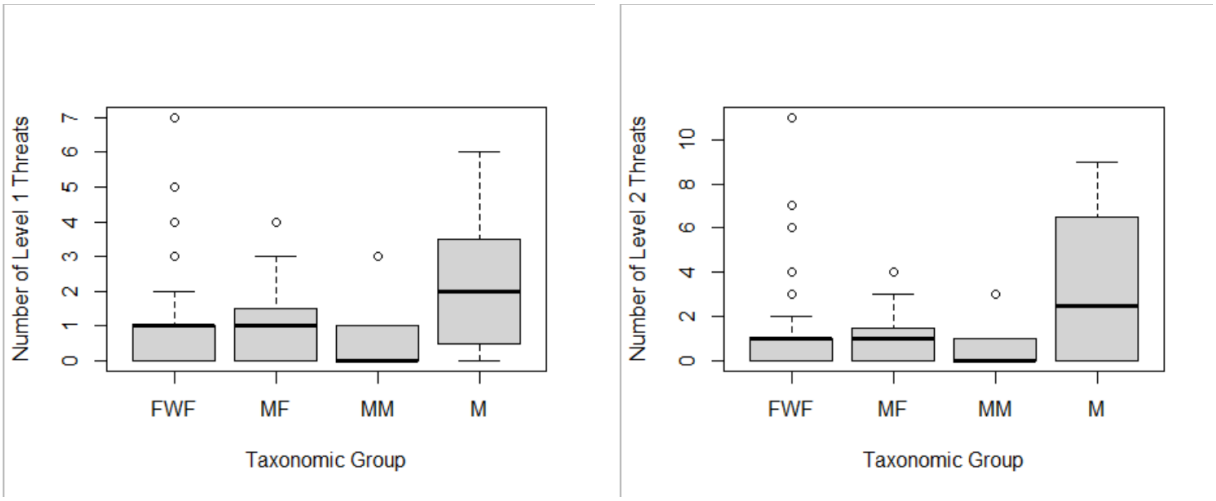
Cat 5.4	FWF	MF	MM
MF	**0.0150**	-	-
MM	**0.0150**	1.000	-
M	0.528	0.768	0.768

Cat 7.3	FWF	MF	MM
MF	**0.00283**	-	-
MM	1.000	**0.0292**	-
M	0.882	**0.0292**	1.000

Cat 8.1	FWF	MF	MM
MF	**0.00127**	-	-
MM	**0.00376**	1	-
M	0.0596	**0.0000982**	**0.000254**

Cat 9.1	FWF	MF	MM
MF	0.291	-	-
MM	0.418	1.000	-
M	**0.00726**	**0.00285**	**0.00467**

Cat 9.3	FWF	MF	MM
MF	0.509	-	-
MM	0.169	0.509	-
M	**0.0240**	**0.0240**	**0.00934**



Appendix A8. Boxplot of the number of dominant threats per species by taxonomic group for Level 1 and Level 2 threats categories. Median values are indicated by a thick solid line. Significant differences among taxonomic groups were calculated using Kruskal-Wallis test. For Level 1, p = 0.0146 with corresponding letters: a, ab, a, b (in order of taxonomic groups). For Level 2, p = 0.0393 with corresponding letters: ab, ab, b, a. Groups that share the same letter are not significantly different from each other.

SUPPLEMENTARY INFORMATION

S1. Threats calculator inventory for aquatic species assessed by COSEWIC between 2012 – 2021 (accompanying spreadsheet available upon request from the Great Lakes Laboratory for Fisheries and Aquatic Sciences).