Treatment of climate change in extinction risk assessments and recovery plans for threatened species

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Abstract
The ongoing threat of climate change poses an increasing risk to biodiversity, especially for currently threatened species. Climate change can both directly impact species and interact with other pre-existing threats, such as habitat loss, to further amplify species’ risk of extinction. Recognizing the threat of climate change in extinction risk assessments and recovery planning for imperilled species is essential for tailoring and prioritizing recovery actions for climate-threatened species. Using species legally listed in Canada we show that 44.1% of species’ risk assessments identify the threat of climate change, nonetheless, 43.5% of assessments completely omit climate change. Species assessed more recently were more likely to be identified as climate-threatened, however, the strength of this relationship varied across taxonomic groups. The likelihood that climate change was identified as a threat was also strongly affected by the use of a standardized threat assessment process. Of the climate-threatened species, less than half (46.0%) of species’ recovery plans specified actions aimed explicitly at minimizing climate impacts and only 3.8% of recovery plans recommended habitat or population management actions. Climate-targeted recovery actions were more likely to be included in more recent plans, and were marginally more likely for species where climate change was considered a major threat. Our findings highlight the urgent need for consistent and standardized assessments of the threat of climate change, including the consideration of potential synergies between climate change and other existing threats. Performing species-specific climate change vulnerability assessments may serve to complement existing assessment and recovery planning processes. We provide additional recommendations aimed at threatened species recovery planners for improving the integration of the threat of climate change into species extinction risk assessments and recovery planning processes for listed species.
1 | INTRODUCTION

Climate change is now considered by many to be the primary threat to global biodiversity (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; Fischlin et al., 2007; Thomas et al., 2004). There is mounting evidence that across all taxa, species are responding to anthropogenic climate change (Chen, Hill, Ohlemuller, Roy, & Thomas, 2011; Walther et al., 2002). Some species have been able to keep pace with climate changes through rapid range shifts (Chen et al., 2011), but species unable to adapt could face extinction (Thomas et al., 2004; Urban, 2015). Due to the pervasive nature and ongoing amplification of this threat, identifying species that are threatened with extinction due to climate change is fundamental to selecting effective conservation strategies (Murray, Verde Arregoitia, Davidson, Di Marco, & Di Fonzo, 2014; Stewart et al., 2018).

Extinction risk assessments are carried out to identify species that are likely to become extinct or extirpated without conservation actions, assign conservation status, and inform legal listing decisions. Threat identification is a critical part of the extinction risk assessment process as minimizing the impact of threats is necessary to achieve conservation objectives and species recovery (Lawler et al., 2002; Stewart et al., 2018). Recent reviews of legally listed threatened species identify habitat modification, overexploitation, pollution, and invasive species as top-ranked threats with climate change ranked as a less important threat (Kearney et al., 2019; Leu et al., 2019; McCune et al., 2013). Furthermore, independent assessments of climate change vulnerability suggest that the importance of climate change is underestimated for species listed under the U.S.A. Endangered Species Act (Delach et al., 2019). Despite this, scientific evidence on the pervasive negative consequences of climate change across species and ecosystems is increasing (Pecl et al., 2017; Thackeray et al., 2016), including identification of climate-vulnerable species (Foden et al., 2013) and attributing extinctions to climate change (Gynther, Waller, & Leung, 2016). The omission of climate change from extinction risk assessments suggests the potential for mismatches between available knowledge and listed species threat considerations. Delays in listing decisions and in developing recovery plans (Malcom & Li, 2018) can further amplify disconnections between the current availability of scientific evidence related to climate change impacts and the integration of this knowledge into extinction risk assessments and recovery documents. These knowledge lags and biases in identifying climate-vulnerable species in formal extinction risk assessment and listing processes is concerning as consistent and systematic threat identification is a prerequisite for guiding effective recovery strategies.

Recovery planning for threatened species is critical for improving the conservation status of listed species. In countries such as Canada, Australia, and the United States, recovery plans are legally required documents for listed threatened species. These plans provide general strategic direction for achieving conservation objectives alongside more specific actions aimed at abating threats impacting species, and the identification of habitat critical for the survival and recovery of species where applicable. Recovery actions may range from more direct interventions, such as actions that target habitats (e.g., restoration) or manage populations (e.g., assisted migration), to more indirect actions such as knowledge dissemination (e.g., outreach and stewardship) and gathering information to refine scientific understanding (e.g., research or monitoring) (Hoeppner & Hughes, 2019). While actions focusing on research and monitoring may reduce knowledge gaps related to a threat’s mechanism of action, it is key that such knowledge acquisition be placed in context of other possible strategic actions that could more directly lead to threat abatement and improved population viability (Garnett et al., 2019). While aligning actions to climate impacts is needed to improve the status of climate-threatened species, even where climate impacts are unknown, integrating climate change adaptation strategies, such as protecting climate refugia into current conservation approaches and managing for threats in concert are likely to amplify the success of threatened species recovery (Mawdsley, O’Malley, & Ojima, 2009; Stralberg et al., 2019).

Incorporating climate change into species’ extinction risk assessments and recovery planning processes can be challenging due to factors related to the nature of the threat itself. Compared to other threats, climate change has more recently been identified as a cause of species’ extinctions and our understanding of how it is affecting species and entire ecosystems represents a rapidly evolving landscape (Harris et al., 2018; Scheffers et al., 2016).
Climate change can directly affect organisms (e.g., via changes in behavior or reproduction and ultimately survival (Cahill et al., 2012)), and can interact with other threats, such as habitat loss, resulting in synergistic effects (Brook, Sodhi, & Bradshaw, 2008; Mantyka-Pringle, Martin, & Rhodes, 2012). The potential for climate change to interact and exacerbate the effect of ongoing threats is of particular concern for threatened species. Species currently at risk of extinction due to non-climate change related threats may be more sensitive to the negative impacts of climate change, potentially linked to attributes such as declining or small population size, or restricted ranges (Pearson et al., 2014). Despite this, for many already threatened species both the direct effects of climate change and how it might interact with other threats, such as habitat loss and fragmentation, remain unknown. Furthermore, an understanding of climate change impacts is biased across taxonomic groups, which amplifies already existing data deficiencies and biases (Akçakaya, Butchart, Watson, & Pearson, 2014; Pacifici et al., 2015; Trull, Böhm, & Carr, 2018). These knowledge shortfalls can hamper conservation efforts: increased knowledge and understanding of the impact of threats on species, including information on the timing, severity, and magnitude of threats, can lead to more informed actions that target threats in recovery plans (Lawler et al., 2002).

Knowledge gaps related to the impacts of climate change on threatened species may be compounded by factors related to legal extinction risk assessment and recovery planning processes. For example, transparency and consistency in assignments of species’ conservation status is improved by the use of standardized classification criteria, including the systematic identification of relevant threats (Mothes et al., 2020). The International Union for Conservation of Nature (IUCN) Red List of threatened species is a process to quantify the global extinction risk of species, and uses a standardized threats classification scheme to identify and calculate the impact of threats on species (Mace et al., 2008; Salafsky et al., 2008). Despite the advantages of a standardized threat classification system, its application into national-scale legal listing processes has not been ubiquitous, which can increase the potential for inconsistent treatment of threats across extinction risk assessments. The Canadian risk assessment process, which adopted the threat classification scheme in 2012 (COSEWIC, 2012), provides an opportunity to study the impact of this classification system since assessments made with and without it can be compared. Improving our understanding of factors influencing how climate change is treated in extinction risk assessments and recovery planning processes can help inform solutions and guidance aimed at improving these processes.

Using information contained in species status assessments and recovery plans for species legally listed as at risk of extinction in Canada, we investigated the following questions: (a) is climate change consistently addressed as a threat across species and what factors contribute to this pattern?; and (b) for climate-threatened species, do actions recommended in species recovery documents target the threat of climate change and what factors influence whether climate-targeted actions are recommended? Our research complements recent findings from other jurisdictions that have highlighted inconsistent assessments of the threat of climate change in recovery planning processes (Delach et al., 2019; Hoeppner & Hughes, 2019). However, our work is the first to apply such assessments to Canadian listed species at risk, to our knowledge. While (Woo-Durand et al., 2020) consider changes in threat prevalence over time for a subset of Canadian species at risk, we distinguish our research by focusing on species legally listed as at risk of extinction to assess drivers of patterns in threat identification and include novel assessments of factors influencing the inclusion of climate-targeted actions in recovery planning documents. Our results highlight the increasing number of extinction risk assessments that address climate change over time, however, few recovery documents include specific climate-targeted actions. Furthermore, the most commonly recommended actions were more indirect (e.g., research and monitoring actions). Based on these outcomes, we provide general guidance and recommendations to facilitate consistent integration of the threat of climate change in extinction risk assessments and the identification of relevant climate change adaptation strategies to inform recovery planning and ensure survival of threatened species.

2 | METHODS

We compiled information from status reports for the 510 species listed under Schedule 1 of the Canadian Species at Risk Act, (SARA, 2002), as of February 22nd 2018, that were classified with the status of “Endangered,” “Threatened,” or “Special Concern” (Government of Canada, 2018). This included both species and “designatable units,” the latter of which refers to evolutionarily or geographically distinct populations. Hereafter, both groups are referred to as “species.” The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an independent body of experts that is responsible for initial assessments of wildlife species’ risk of extinction, assesses candidate species for legal listing.
and protection. COSEWIC members synthesize the best available information to date into species’ status reports containing elements such as population size and trends, habitat availability, and documentation of threats. These reports are then used as the basis for a recommended status (SARA, 2002). Under SARA, a recovery strategy must be created for every species listed as “Threatened,” “Endangered,” or “Extirpated,” and a management plan created for every species listed as “Special Concern”. Hereafter, we refer to recovery strategies and management plans collectively as “recovery documents.” All publicly available recovery documents were downloaded for all species listed under Schedule 1 of SARA as of March 26th, 2018.

We considered a suite of variables that might influence the treatment of climate change in species’ risk assessments. We extracted the following information from species’ status reports: (a) taxonomic group and species identity, (b) publication year of the status report, (c) whether climate change was identified as a threat, (d) whether a standardized threat assessment tool was used, (e) the number of threat classes identified other than climate change, and (f) the species’ SARA status. To test for potential differences in the treatment of climate change across taxa, we recorded taxa into one of the following groups: birds, plants, terrestrial mammals, herpetofauna, invertebrates, freshwater fishes, marine fishes, or marine mammals.

Based on each species’ status report, we determined whether climate change was identified as a threat. In 2012, COSEWIC began applying the IUCN standardized threat classification system, which consists of 11 level one threat classes, including climate change and severe weather (Salafsky et al., 2008; Table S1), into species’ extinction risk assessments. We herein refer to this standardized process as the “threats calculator” following COSEWIC (2012). For each of the level one threat classes, the threats calculator includes an evaluation of the impact, severity, scope and timing of the threat. Impact is defined as the degree to which the species is threatened by the threat class, and is determined based on the severity and scope; severity is the level of damage to the species from the threat class that is expected within 10 years or three generations, whichever is longer; scope is the proportion of the species or ecosystem that is expected to be affected within 10 years; and timing is the immediacy of the threat (COSEWIC, 2012). In cases where the threats calculator was not applied, we extracted information from the section detailing threats and limiting factors, and examined all other sections of the report for discussion of the threat of climate change. This led to three categories: (a) species where climate change was identified as a threat, (b) species where climate change was mentioned but not considered a threat, and (c) species where climate change was not mentioned anywhere in the status report. We also tallied the number of threat classes other than climate change, for each species. For species without a threats calculator, we allocated threats described in status reports into one of the 11 level one threat classes in version 1.1 of the IUCN threats classification system (Salafsky et al., 2008) based on the definition of each class (Table S1). For species with a threats calculator, this was determined based on the number of level one threat classes that had an impact level negligible or greater. Negligible threats were considered “identified as a threat” to be consistent with species without a threats calculator where the level of impact was not explicitly assessed. Climate change was considered a threat if the “Climate change and severe weather” threat class had an impact that was more than negligible or if climate change was described outside the threats calculator as a threat or potential threat.

To investigate the factors that influenced whether species’ recovery actions addressed the threat of climate change, we extracted information from recovery documents for those species where climate change was identified as a threat and a recovery document was available (n = 176). From recovery documents, we recorded: (a) the type of actions recommended to achieve conservation objectives, (b) actions that directly addressed the threat of climate change, and (c) the year that the recovery document was published. Canadian recovery documents include a suite of strategies and actions that aim to reverse species’ declines. We classified actions included in recovery strategies into four categories that broadly reflect those applied in Canadian recovery planning processes: outreach and stewardship, research and monitoring, habitat management, and population management (Environment Canada, 2015a) (Table 1). These action categories represent a continuum from more indirect actions (i.e., outreach) to more direct actions (i.e., population management) (Hoeppner & Hughes, 2019). A small number of recovery documents recommended climate change mitigation actions of reducing greenhouse gases. We included this under the outreach and stewardship category as it can be linked to awareness and education. For each species, we noted whether any actions targeted the threat of climate change, and which types of action targeted climate change. We recorded the publication year of recovery documents to determine whether the likelihood of inclusion of climate-targeted actions changed over time.

We extracted additional information from status reports representing potential factors influencing whether species’ recovery actions addressed the threat of climate change. These included: (a) whether scientific
evidence was used to evaluate the threat of climate change; (b) the relative impact of climate change compared to other threats; and (c) whether any aspects of the threat of climate change were unknown. We recorded whether any form of scientific evidence was used when providing statements about the threat of climate change. We expected that the inclusion of climate change research would be associated with the specification of climate-targeted recovery actions. Examples of scientific evidence included, but were not limited to, empirical evidence based on historical trends, population (simulation) modeling, and climate change vulnerability analyses. We recorded instances where status reports clearly demarcated the threat of climate change as unknown, to reflect the degree of uncertainty around epistemic knowledge. This included unknowns specified in relation to climate change threat impact, scope, severity, or timing.

We included a measure of the importance of the threat of climate change in relation to other threats, as we expected that a higher relative rank importance would be positively associated with the likelihood of specifying climate-targeted actions. We classified the threat of climate change into three categories of increasing relative impact: minor threat (“1”), moderate threat (“2,” i.e., if climate change was considered a threat but not the most important threat), and major threat (“3,” i.e., climate change was considered the most important or one of the most important threats). To determine the

| Type of action                  | Example actions                          | Description                                                                 |
|--------------------------------|------------------------------------------|-----------------------------------------------------------------------------|
| Outreach and stewardship       | Education                                | Community outreach, stewardship or education activities including providing information, hosting meetings, and coordinating with stakeholders |
|                                | Mitigate climate change                  | Actions aimed at reducing or preventing greenhouse gas emission              |
| Research and monitoring        | Monitoring                               | Gathering data to document trends over space and time, including population, harvesting, or habitat trends, and to assess effectiveness and track progress towards conservation and population objectives |
|                                | Research                                 | Producing new knowledge that contributes to improved understanding of a species, including but not limited to life history, population size and distribution, response to threats and response to actions |
| Habitat management             | Regulate human activities                | Imposing restrictions on direct human threats such as changing logging, fishing or hunting rules, or legislation to manage other threats like pollution |
|                                | Habitat restoration                      | Modifying habitat to improve suitability for species, including connectivity features like fish ladders, and culverts |
|                                | Invasive species removal                 | Removing invasive species that have negative impacts on species or habitats |
|                                | Protection                               | Protecting habitat in any way including by zoning or creating protected areas. Including when a large portion of the population exists inside a protected area |
|                                | Treat disease                            | Treating individuals or populations to prevent disease                      |
|                                | Manage native species                    | Relocating, culling, or excluding native predators including herbivores and cormorants |
| Population management          | Seed storage                             | Storing plant seeds in case of a need for reintroduction                    |
|                                | Feeding                                  | Artificially increasing the amount of prey or food available                |
|                                | Emergency response                       | Emergency measures to prevent extinction or extirpation, or prevent mortality by taking direct action |
|                                | Captive breeding                         | Ex situ breeding to recover or maintain the population                      |
|                                | Re-establishing populations              | Artificially reintroducing or augmenting populations at inhabited or previously inhabited sites |
|                                | Translocation or assisted migration       | Moving species to previously unoccupied sites                               |

TABLE 1  Categories used to group actions described in recovery documents
relative impact score we interpreted statements in species’ status reports, including the impact and severity sections of the threats calculator, where applied, and thus this relative impact reflects knowledge contained in the status reports which may or may not correlate with broader scientific knowledge.

2.1 Statistical analyses

We used a generalized linear model with binomial family and logit link to examine the probability that climate change was identified as a threat across all species’ status reports. The explanatory variables included whether the threats calculator was used, publication year, number of other threats identified, and taxonomic group. We included two-way interactions between publication year and number of threats, and publication year and taxonomic group to assess whether patterns over time were moderated by these variables.

We also applied a generalized linear model with binomial family and logit link to estimate the probability of actions addressing climate change being specified in recovery documents for species where climate change was identified as a threat. The explanatory variables included publication year, taxonomic group, specification of scientific evidence related to the threat of climate change, degree of uncertainty associated with climate change threat, and the relative impact of climate change compared to other threats. We did not include an interaction term between publication year and taxonomic group (7-levels) due to insufficient data. The marine fishes taxonomic group was removed from both analyses before modeling due to too few observations ($n = 13$) to be included in the interaction term without destabilizing the model.

We ran all statistical analyses in R version 3.6.2 (R Core Team, 2020). For both models, we standardized all explanatory variables to facilitate the interpretation of the relative importance of estimated model coefficients, including interaction terms (Schielzeth, 2010). We interpreted the standardized model coefficients as estimates of relative effect sizes, and considered effects strongly supported when the 95% confidence interval did not cross zero. For both models, we created marginal effects plots using the sjPlot package, which calculates marginal effects for each variable while holding numeric variables at their mean and factors at their proportions (Lüdecke, 2020).

3 RESULTS

Based on our synthesis of information from 510 status reports, 44.1% of all species’ assessments identified climate change as a threat, 12.4% mentioned climate change but did not consider it a threat to the species and 43.5% did not mention climate change anywhere in the status report. Climate change was the third least common level one threat identified in status reports, followed by energy production and mining (30.2% across all species) and geological events (5.9%), in decreasing order. The top three most frequently identified level one threats were invasive species and other problematic species and genes (78.8%), followed by threats from natural system modifications (67.2%) and residential and commercial development (59.4%) (Figure S1). Based on our classification of the relative impact of climate change, a small proportion of species’ considered climate change as a major threat (13.3%), and this proportion increased with a decrease in relative impact category (moderate threat: 33.8%; minor threat: 52.9%). Species classified in lower risk categories (i.e., “Special Concern”) had the highest proportion of species with climate change identified as a threat relative to species in higher risk categories (Figure S2).

Based on our statistical model outcomes, the publication year and the application of a standardized threat classification system (i.e., threats calculator) both had strong positive influences on whether climate change was identified as a threat (Figure 1, Table S2). Species with status reports published more recently were more likely to be identified as climate-threatened, however, the strength of this relationship varied across taxonomic groups. The interaction between taxonomic group and publication year was strongest (and positive) for plants and herpetofauna while it had little effect for the other taxonomic groups (Figure S3). The percentage of species’ status reports that mentioned climate change increased from 0 to 100% from the early 2000s to 2017 (Figure S4). When other explanatory variables were held at their means, plants, herpetofauna and invertebrates were less likely to have climate change specified as a threat when compared to the reference class, birds (Figure 1, Figure S5). There was no evidence that the number of other threats identified in a status report influenced whether or not climate change was identified as a threat.

Of the 510 status reports reviewed, 176 species had both climate change identified as a threat and a recovery document available. Actions directly addressing the threat of climate change were recommended for fewer than half (46.0%) of these species. Based on logistic regression model outcomes, the year of publication had a strong positive effect on the probability that recovery documents included climate-targeted actions (Figure 2, Table S3, Figure S6). Climate change being considered a major threat also had a positive effect, although the 95% confidence interval narrowly crossed zero. There was also a weak negative effect of the taxonomic group freshwater.
fishes but no effect for the other taxonomic groups. Finally, there was no evidence that epistemic uncertainty around climate change impacts or the inclusion of scientific evidence related to climate change influenced our response variable.

While our statistical model considered all classes of action collectively, there was substantial variation in the type of actions specified in recovery documents of climate-vulnerable species. Both climate-targeted and non-targeted indirect actions were most frequently recommended across all taxa relative to direct actions. Across all actions, research and monitoring was the most recommended action (100% of species), followed by outreach and stewardship (94.6%), habitat management (94.6%), and population management (29.7%; Figure 3). Species with higher extinction risk designations (i.e., “Endangered”) more frequently included population management actions in recovery documents (Figure S7). Climate-targeted actions primarily fell into indirect action categories, such as research and monitoring (44.9% of species), while more direct climate-targeted actions, such as habitat management and population management, were rarely recommended (2.2% and 1.6% of species, respectively; Figure 3). Outreach and stewardship actions specifically targeting climate change were also

**FIGURE 1** Standardized effect sizes (coefficients and 95% confidence intervals [CIs]) from the logistic regression model of the likelihood that climate change was identified as a threat in species’ status reports as a function of: publication year of status report (Year), whether the threats calculator was used (Threats calculator; “Y” = Yes and “N” = No, with No as the reference class), the number of threat classes other than climate change identified per species (Other threats), and taxonomic group (7 levels, with “Birds” specified as the reference as). We tested interactions between year of publication and each of “Other threats” and taxonomic group, separately (indicated by a “×”). Symbols reflect modeled covariate groupings and factor levels. For model details see Table S2.

**FIGURE 2** Standardized effect sizes (coefficients and 95% confidence intervals [CIs]) from the logistic regression model of the likelihood that climate-targeted actions were recommended in species recovery documents as a function of: publication year of recovery document (Year), whether scientific evidence was available in the status report (Scientific evidence; “Y” = Yes and “N” = No, with No as the reference class), the relative impact of climate change compared to other threats (Relative impact; “1” = minor threat, “2” = moderate threat, and “3” = major threat, with “1” as the reference level), whether any aspect of the threat of climate change was considered unknown in the status report (Impact unknown; “Y” = Yes and “N” = No, with No as the reference class) and taxonomic group (7 levels, with “Birds” as the reference level). For model details see Table S3.

**FIGURE 3** Number of climate change threatened species with each recommended type of action specified in recovery documents. For each type of action, actions are delineated based on whether they were specific to the threat of climate change (climate-targeted) or targeted other threats. Actions are ordered from passive/indirect actions (outreach and stewardship) to more active/direct actions (population management). The total number of actions is greater than the total number of species (n = 176) as more than one type of action may be recommended for each species.
infrequent (3.2%). Regardless of the relative impact of the threat of climate change, research and monitoring was the most recommended climate-targeted action (Figure 4). However, direct climate-targeted actions were recommended more often for species where climate change was considered a major threat than when the threat was considered minor or moderate.

4 | DISCUSSION

Climate change is contributing to substantial impacts on biodiversity and is recognized as an accelerant of extinctions (Scheffers et al., 2016; Urban, 2015). Our understanding of the consequences of this newer emergent threat is evolving rapidly; extinction risk assessments need to integrate this knowledge into formal assessment processes. Despite this, our results indicate that climate change was the third least identified threat in Canadian extinction risk assessments and that for nearly half (43.5%) of all reports climate change was not mentioned at all. Further, we found that the threat of climate change was inconsistently assessed over time and across taxonomic groups. While more recent recovery documents increasingly recommended climate-targeted actions, the majority were indirect actions not specifically aimed at threat abatement or improving population viability. Given the pervasive nature and ongoing amplification of this threat its inclusion in species risk assessments is imperative to improve the status of climate-threatened species. Failure to integrate knowledge of climate change impacts into formal assessment processes and subsequent recovery plans could magnify extinctions risks for all species.

Our results point to the importance of applying standardized methods, such as the IUCN threat classification scheme (i.e., threats calculator), in extinction risk assessment processes. We found a strong positive relationship between the use of the threats calculator and the probability that climate change was identified as a threat. Application of standardized processes helps to ensure that decision-making practices, such as listing species for legal protection, are informed by consistent, repeatable and transparent criteria (Mace et al., 2008; Mothes et al., 2020). Despite the importance of using standardized criteria for threat classification, it has been typically overlooked (Hayward, 2009; Murray et al., 2014). Use of standardized threat classifications could reduce taxonomic bias as species are assessed across a similar set of criteria in a transparent manner. We did not focus our analysis on whether interactions between threats were considered, yet accounting for potential interactions between climate change and non-climate change driven threats is salient given the potential for synergistic effects (Foden et al., 2018). Although current guidance recommends that cumulative impacts be considered when using the threat classification scheme (COSEWIC, 2019), it is not clear whether this occurs in practice, and previous work on IUCN Red List assessments suggests threats are primarily considered independently (Trull et al., 2018).
While the use of the threat calculator has been recommended since 2012 in the species assessment process in Canada (COSEWIC, 2012), its impact had not, to our knowledge, been assessed. Our results provide evidence of its importance for specification of threats and their relative impact with particular relevance to climate change.

Considerable shortfalls exist in assessing climate change risks for currently listed species, in particular for species assessed longer ago. This trend over time is corroborated by research on listed threatened species in other jurisdictions; in Australia, less than 60% of recovery plans acknowledged climate change as a threat for species listed as threatened under the Environment Protection and Biodiversity Conservation Act, but the recognition of climate change as a threat increased over time (Hoeppner & Hughes, 2019), while in the United States, only 64% of species listed as endangered under the Endangered Species Act (ESA) had climate change considered as a threat, though the number of ESA documents mentioning climate change also increased over time (Delach et al., 2019; Leu et al., 2019). The increased prevalence of climate change as a threat in status reports is likely influenced by mounting evidence of the impact of climate change on wildlife species and their habitats (Pecl et al., 2017; Scheffers et al., 2016). Despite this, integrating newly acquired knowledge of climate change impacts into listing and recovery planning processes can be affected by process time lines (Dorey & Walker, 2018). These mismatches regarding integration of best available information are likely amplified due to the still prevalent, but inaccurate, idea that climate change occurs only over the longer-term and in the distant future (Chapman et al., 2014). For species with shorter generation times, consideration of exposure to shorter-term weather fluctuations, including extreme events, associated with climate change alongside climate trends is needed (Harris et al., 2018). In cases where climate change impacts develop over the longer-term, underestimation of climate change risk may occur because assessment processes consider extinction risk over relatively short time frames (three generations or 10 years, whichever is longer) (Keith et al., 2014) but see (Stanton, Shoemaker, Pearson, & Akçakaya, 2015). Despite the complexities in understanding biological responses to climate change, extinction risk assessments need to keep pace with knowledge acquisition to avoid accelerated species extinctions (Urban, 2015).

Recovery of climate-threatened species hinges on conservation strategies aimed at addressing climate change impacts. Strikingly, the majority of recovery plans for climate-threatened species did not include targeted actions aimed at minimizing the risk of climate change, and even fewer included direct actions ($n = 6$), suggesting that actions in recovery documents may be insufficient to address the threat of climate change. The prevalence of indirect actions in recovery documents, particularly research and monitoring, is consistent with reviews of recovery actions in other jurisdictions leading to suggestions of a disconnect between available knowledge of climate impacts and management responses in recovery documents (Hoeppner & Hughes, 2019). While recovery strategies clearly identified a need for improved understanding of the effect of climate change on listed species, it will be important to consider research and monitoring needs in the context of other actions. Prioritizing efforts towards knowledge accumulation takes away resources from strategic interventions (Buxton et al., 2020), and thus should include transparent trigger points as to when monitoring should be replaced by alternative actions (Lindenmayer, Piggott, & Wintle, 2013). Nevertheless, our finding that inclusion of climate-targeted actions in recovery documents increased over time suggests an improved awareness of available conservation options for climate change adaptation amongst those responsible for developing recovery strategies, many of which reflect traditional conservation strategies, such as habitat protection or restoration adapted to reflect climate change impacts (Oliver, Smithers, Beale, & Watts, 2016). Examples of climate-targeted actions included the protection of habitat to increase climate change resilience for the coastal tailed frog (Ascaphus truei) (Environment and Climate Change Canada, 2018) and assisted migration of individuals to habitat that is projected to become suitable under climate change for whitebark pine (Pinus albicaulis) (Environment and Climate Change Canada, 2017) (Table 2).

Improved understanding of biological responses to climate change and their causal mechanisms can inform and facilitate the selection of climate change adaptation strategies (Foden et al., 2018; Prugh, Sinclair, Hodges, Jacob, & Wilcove, 2010). Surprisingly, our model did not support our expectation that the inclusion of scientific evidence on climate change impacts in status reports increased the probability of specifying climate-targeted actions. The lack of a significant effect in our analysis may be attributed to our relatively broad definition of scientific evidence. For example, we did not discriminate between status assessments that included attribution of recent historical climate change impacts versus those that indicated a trait-based temperature sensitivity. Furthermore, scientific evidence of climate change impacts may be provided in status reports but if those impacts are uncertain or long term they may not be addressed by actions in the recovery document. In addition, recovery strategies can be published up to 2 years after a species is listed depending on the species status (SARA, 2002). Since our measures of scientific evidence were retrieved
from status reports, which are produced before listing decisions, they may not capture the full breadth of available scientific evidence due in part to this temporal mismatch in publication date. Future research could refine characterizations of scientific evidence for listed species to reflect information contained within all relevant risk assessment and recovery planning documents.

Based on our analysis several recommendations emerge for improving the integration of climate change considerations into the assessment and recovery planning processes. Although we focused our work on Canadian listed species, given similar findings from the United States (Delach et al., 2019) and Australia (Hoeppner & Hughes, 2019) and similarities across national-scale threatened species legislation, our recommendations are relevant more broadly. Our findings suggest that species being considered for formal legal protection would benefit from the application of a systematic threats

| Type of action                      | Species Description                                                                 |
|-------------------------------------|--------------------------------------------------------------------------------------|
| Outreach and stewardship            | Rusty blackbird (*Euphagus carolinus*), piping plover *Charadrius melodus melodus*, common Hoptree (*Ptelea trifoliata*), tri-colored bat (*Perimyotis subflavus*), little Brown Myotis (*Myotis lucifugus*), and northern Myotis (*Myotis septentrionalis*) |
|                                     | Encourage mitigation of climate change by reducing greenhouse gas emissions. This is categorized as outreach since it requires actions by the broader community |
| Research and monitoring             | All 83 species with climate-targeted actions in recovery documents                    |
|                                     | Research into or monitoring of the effects of climate change on the species (e.g., Burrowing owl (*Athene cunicularia*): “Examine the influence of climate change on patterns of inclement weather,” such as periods of heavy rain that can flood nests; Western silvery minnow (*Hybognathus argyritis*): “Conduct scientific studies to better understand the potential threats associated with human activities including... climate change”; and eastern ribbonsnake (*Thamnophis sauritus*): Monitor sites over time to document changes in habitat, water level, and climate.) |
| Habitat management                  | Whitebark pine (*Pinus albicaulis*)                                                   |
|                                     | Protection and restoration of suitable and potentially suitable sites given climate change |
|                                     | Killer whale Northeast Pacific northern and southern resident populations (*Orcinus orca*) |
|                                     | Ensure management plans for prey consider climate change in maintaining adequate supply |
|                                     | Coastal tailed frog (*Ascaphus truei*)                                                  |
|                                     | Consider the cumulative effects of climate change and land use in habitat protection |
| Population management               | Whitebark pine (*Pinus albicaulis*)                                                   |
|                                     | Consider assisted migration by planting into potentially suitable sites                  |
|                                     | Banff springs snail (*Physella johnsoni*)                                             |
|                                     | Develop response plan to rescue and preserve snail populations in the event of thermal spring drying |
|                                     | Beach pinweed (*Lechea maritima*)                                                     |
|                                     | Store seeds as a precaution against local extirpation caused by storm events            |

| TABLE 2 Examples of climate-targeted actions recommended in Canadian recovery documents |
|-------------------------------------------|---------------------------------------------------------------------------------|
| **Type of action** | **Species** | **Description** |
|---------------------|-------------|-----------------|
| Outreach and stewardship | Rusty blackbird (*Euphagus carolinus*), piping plover *Charadrius melodus melodus*, common Hoptree (*Ptelea trifoliata*), tri-colored bat (*Perimyotis subflavus*), little Brown Myotis (*Myotis lucifugus*), and northern Myotis (*Myotis septentrionalis*) | Encourage mitigation of climate change by reducing greenhouse gas emissions. This is categorized as outreach since it requires actions by the broader community |
| Research and monitoring | All 83 species with climate-targeted actions in recovery documents | Research into or monitoring of the effects of climate change on the species (e.g., Burrowing owl (*Athene cunicularia*): “Examine the influence of climate change on patterns of inclement weather,” such as periods of heavy rain that can flood nests; Western silvery minnow (*Hybognathus argyritis*): “Conduct scientific studies to better understand the potential threats associated with human activities including... climate change”; and eastern ribbonsnake (*Thamnophis sauritus*): Monitor sites over time to document changes in habitat, water level, and climate.) |
| Habitat management | Whitebark pine (*Pinus albicaulis*) | Protection and restoration of suitable and potentially suitable sites given climate change |
|                      | Killer whale Northeast Pacific northern and southern resident populations (*Orcinus orca*) | Ensure management plans for prey consider climate change in maintaining adequate supply |
|                      | Coastal tailed frog (*Ascaphus truei*) | Consider the cumulative effects of climate change and land use in habitat protection |
| Population management | Whitebark pine (*Pinus albicaulis*) | Consider assisted migration by planting into potentially suitable sites |
|                      | Banff springs snail (*Physella johnsoni*) | Develop response plan to rescue and preserve snail populations in the event of thermal spring drying |
|                      | Beach pinweed (*Lechea maritima*) | Store seeds as a precaution against local extirpation caused by storm events |

| **Legend** |
|-------------|
| *a*Recovery document citations: (Environment Canada, 2015b); |
| *b* (Environment Canada, 2012a); |
| *c* (Parks Canada Agency, 2012a); |
| *d* (Environment Canada, 2015a); |
| *e* (Environment and Climate Change Canada, 2017); |
| *f* (Fisheries and Oceans Canada, 2011); |
| *g* (Environment and Climate Change Canada, 2018); |
| *h* (Lepitzki & Pacas, 2010); |
| *i* (Environment Canada, 2013); |
| *j* (Environment Canada, 2012b); |
| *k* (Fisheries and Oceans Canada, 2017); |
| *l* (Parks Canada Agency, 2012b). |
classification scheme in jurisdictions where this has not yet been adopted. In addition, including species-specific climate change vulnerability assessments (CCVAs) could complement existing assessment processes.

CCVAs are a framework used to assess vulnerability to climate change and are typically based on three components: exposure, sensitivity and adaptive capacity (Foden et al., 2018). CCVA methods vary with respect to data requirements and complexity and include trait-based, correlational and mechanistic approaches, as well as hybrid methods drawing on combinations of different types of data and models (Pacifici et al., 2015). Initial stages of vulnerability assessments may include developing a conceptual model of the possible mechanisms of action of direct and indirect effects of climate change, which provides a foundation for modeling impacts and identifying knowledge gaps (McClure et al., 2013). Modeled projections of climate change impacts, which were found in very few of the status reports included in our assessment, can also be integrated into some CCVA frameworks. Modeled projections or metrics of climate change, such as climate velocity, not only contribute to understanding impacts of climate change but can inform the identification of effective recovery actions (Brito-Morales et al., 2018). For example, selection of climate adaptation actions may differ depending on whether a local population is already located outside of its climate envelope (Gilbert et al., 2020). Furthermore, certain CCVA frameworks can accommodate species interactions and cumulative effects resulting from interactions between multiple threats (Urban et al., 2016). Climate change can exacerbate the effect of other threats and increase extinction risk beyond what would be expected if threats were additive (Brook et al., 2008), and the addition of a CCVA framework that can identify potential synergies between climate change and other threats is essential for improving projections of species’ responses to all threats. Given limited resources, a vital consideration will be to identify those biological mechanisms that are key to both predicting extinction risk and informing the identification of adaptation strategies required to ensure successful recovery planning efforts. Overall, the adoption of a CCVA framework would lead to a clearer, targeted assessment of species-specific climate change impacts and increase the transparency of how this threat is assessed.

Our findings also point to the need for reassessment of risk status for listed species focused on climate change vulnerability, especially where the threat of climate change is underestimated. Given the resources required for reassessment of listed species, it will be key to develop a framework allowing for rapid, consistent, and transparent prioritization of climate change targeted reassessments (Bland et al., 2017). Reassessment efforts could prioritize species with higher extinction risk rankings and be adapted to include specific traits associated with increased vulnerability, such as small range or population size and shorter generation length (Thomas et al., 2011; Trull et al., 2018).

Though the application of a CCVA framework is critical for identifying climate-vulnerable species, practitioners will still be confronted with challenges in achieving recovery objectives. These include, but are not limited to, incomplete knowledge of how species’ will respond to climate change adaptation actions and lack of evidence on the effectiveness of actions, both of which are amplified by uncertainty in climate change projections and modeled impacts (LeDee, Handler, Hoving, Swanston, & Zuckerberg, 2021; Prober, Doerr, Broadhurst, Williams, & Dickson, 2019). These challenges, though daunting, should not result in inaction. Several strategies can be applied by practitioners, including adaptive management informed by continuous monitoring to assess the effectiveness of actions and responses of species to climate change, and simulation modeling that accounts for various sources of uncertainty while evaluating alternative actions aimed at climate-vulnerable species (Naujokaitis-Lewis, Pomara, & Zuckerberg, 2018; Stein et al., 2013).

Improving knowledge amongst practitioners around options for climate change adaptation will be instructive for recovery planning. Integrating concepts from the rapidly emerging field of climate change adaptation, such as strategies focusing on (a) persistence of current conditions, (b) acceptance of change, or (c) directing change towards a future endpoint, may facilitate the selection of recovery actions for climate-vulnerable species (Fischelli, Schuurman, & Hoffman, 2016). This resistance-accept-direct change framework is increasingly applied as a management framework for ecosystem transformation, and lends itself to the dynamic changing conditions occurring globally while remaining relevant to local climate adaptation needs of recovery planners (Thompson et al., 2020).

Listed species present additional legal considerations, and management goals might include retaining a threatened species in a given place, necessitating a focus on persistence strategies. Persistence strategies and specific actions might vary depending on factors, such as the magnitude of projected climate change and the proportion of the threatened species range exposed to substantial future changes. For example, where the magnitude of expected change is lower, persistence strategies might include protection of climate refugia (i.e., areas relatively buffered from contemporary climate change (Morelli et al., 2020)), a low-regret approach that aims to optimize
protection of current and future suitable habitats (Prober et al., 2019). Conversely, where climate change impacts are expected to be severe and species’ are ranked as highly climate-vulnerable, persistence strategies might require increased management interventions, such as population augmentation or direct habitat management (Stralberg et al., 2019). Additionally, practitioners may need to complement traditional adaptation actions, such as habitat protection and restoration, with novel strategies that accommodate the dynamic nature of the threat of climate change. These could include the integration of dynamic and flexible actions to protect mobile species and ecological processes, alongside complementary static habitat protections (D’Aloia et al., 2019). Although beyond the scope of this article, prioritizing climate adaptation actions for legally listed threatened species will require acknowledging the inherent social, political, and economic complexities associated with conservation decision-making alongside species’ vulnerability to climate change. Although formal legislative responsibilities will influence specific recovery objectives and management goals, a discussion of climate adaptation strategies through the lens of frameworks that explicitly acknowledge ecosystem transformations will benefit threatened species recovery planning.

There are many opportunities to improve on existing extinction risk assessment and recovery planning approaches to more effectively consider climate change. Significant changes must be made to the current extinction risk assessment and recovery planning process to ensure that treatment of climate change aligns with the amplitude of this threat. Threatened species recovery planning aims to recover and ultimately delist species; integrating climate change vulnerability assessments as a complement to existing risk assessments will be a key step to identifying and prioritizing options to assist recovery of climate-vulnerable species.

ACKNOWLEDGMENTS

We thank Christie Whelan, Sybil Feinman, Karen Timm, and Jan Beardall from the Canadian Wildlife Service, Environment and Climate Change Canada (ECCC) for discussions and access to earlier versions of species-at-risk data. We thank Sarah Ouimette for providing comments on an earlier draft, and the Landscape Ecology Research Section at ECCC for feedback at earlier stages of project development. Finally, we would like to acknowledge the efforts of all COSEWIC members who contribute substantial time and expertise to assessing species under consideration for listing in Canada.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.
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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Naujokaitis-Lewis, I., Endicott, S., & Guezen, J. (2021). Treatment of climate change in extinction risk assessments and recovery plans for threatened species. *Conservation Science and Practice*, e450. [https://doi.org/10.1111/csp2.450](https://doi.org/10.1111/csp2.450)