Trimming the hedges in a hurricane: Endangered Species lack research on the outcomes of conservation action

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Abstract

Given widespread biodiversity declines, there is an urgent need to ensure that conservation interventions are working. Yet, evidence regarding the effectiveness of conservation actions is often lacking. Using a case study of 208 terrestrial species listed as Endangered in Canada, we conducted a literature review to collate the evidence base on conservation actions to: 1) explore the outcomes of actions documented for each species; and 2) identify knowledge gaps. Action-oriented research constituted only 2% of all literature across target species, and for 56% of species we found no literature investigating outcomes of conservation actions. Protected areas, habitat creation, artificial shelter, and alternative farming practices were broadly beneficial for most species for which these actions were assessed. Habitat restoration actions were most frequently studied, but almost 38% of these actions were harmful, ineffective, or demonstrated mixed results. The effectiveness of prescribed burns, alternative timber harvesting approaches and vegetation control was examined for the greatest number of species, yet 17-30% of these actions demonstrated negative effects. Our synthesis yielded a dataset of conservation evidence that can be implemented to aid in recovery planning for species at risk, and highlighted alarming gaps in the conservation literature that merit further investigation.

Introduction

To avoid wasting resources on ineffective interventions, there is an urgent need to understand which conservation actions will yield positive outcomes for species at risk of extinction. Many practitioners currently lack this information, and thus risk implementing actions that are ineffective in preventing further declines and extinctions, or even harmful to species-at-risk (Cook et al., 2010). For example, regulators often approve environmental assessments simply because mitigation measures are proposed, even without strong evidence that these mitigations would have the desired effect (Collard et al., 2020). Additionally, policy is frequently based on observational studies that fail to link actions to results (Wilson et al., 2021). There is thus a critical need to identify the existing evidence base available for supporting effective conservation action.

Efforts to prioritize conservation actions on the basis of cost and effectiveness are in use in several jurisdictions. While these methods are expected to increase efficiency (e.g., (Gerber, 2016), and are widely recognized as crucial for success of endangered species programs (e.g., (Evans et al., 2016), it remains unclear whether these efforts in their current form will yield measurable improvements in performance at recovering at-risk species (e.g., (Bennett et al., 2014; Gerber & Raik, 2018; Joseph et al., 2009) Many of the approaches to date have relied on expert judgement rather than empirical data; the best or only available option in many circumstances. While structured protocols for expert elicitation can reduce bias (Hemming et al., 2018), experts' judgements can still be biased by a number of factors, and can result in overconfidence in estimates that are inaccurate (Gregory et al., 2012). Other approaches to estimate species' responses to conservation actions when empirical data are not available also demonstrate shortcomings. For example, predicted population growth rates based on simulated responses to action can overestimate true responses (Olsen et al., 2021), and using proxies such as habitat quality can be misleading if restoring habitat fails to yield meaningful improvements in species abundances (e.g., (Germino et al., 2023; Tattersall et al., 2020).

Without adequate evidence, uncertainties and assumptions can be propagated into decision making processes, leading to implementation of actions that are ineffective. For example, methods have been developed for prioritizing the costly regeneration of seismic lines to provide habitat for caribou (Yemshanov et al., 2019) based on the assumption this would enhance habitat characteristics (Filicetti et al. 2019). However, subsequent studies suggest the restoration of linear features such as seismic lines has limited impact on caribou (Beirne et al., 2021; Finnegan et al., 2021; Tattersall et al., 2020), and may even be harmful (Dickie et al., 2021). Explicitly measuring the outcomes of interventions can reveal when actions are not having the intended effects, and allow for management strategies to be adapted accordingly (Pearson et al., 2022).

Considerable conservation funding is spent on research and monitoring (Buxton et al., 2020). Consequently, it is imperative that these efforts yield insights into how population declines can be reversed. Problem diagnosis alone is insufficient: to be useful, conservation science needs to support action. However, the vast majority of conservation science remains focused on describing the state of nature, with less research on designing or implementing conservation interventions (Williams et al., 2020). Despite decades of advocacy for action-oriented research through the implementation of adaptive management approaches (McCarthy & Possingham, 2007; Rist et al., 2013; Wilhere, 2002) conservation science remains focused on the problem (Williams et al., 2020).

In this context, it is critical that we synthesize the currently available evidence for how species respond to conservation action. Our objective was to collate and summarize the peer-reviewed literature assessing the efficacy of conservation actions for species at risk. We focused on terrestrial species listed as Endangered in Canada since this represents a feasible subset of species that are all in dire need of conservation interventions. While broader ecosystem or taxonomic group-level syntheses exist (e.g., (Douglas et al., 2023); conservationevidence.org), we focus on individual species' responses since many threatened species require targeted conservation interventions to halt and reverse declines (Bolam et al., 2023). Thus, a more detailed, species-specific examination is warranted. Moreover, a species-specific investigation can allow for an improved understanding of the variation in response across species, within taxonomic groups, laying the foundation for more effective multi-species approaches. This is important when we consider that actions that benefit one species could have a range of positive to negative effects on another occupying the same habitat (Silver et al., 2023). The resulting database details actions that have been empirically tested and how they impacted each individual species, whether positively or negatively. We then assessed broad patterns in which actions were effective, as well as the capacity of current literature to adequately inform conservation action across taxonomic groups, highlighting several pressing research gaps for 208 highly imperiled species. Ultimately, our intent is to inform immediate conservation efforts and help direct new conservation research moving forward.

Methods

Literature Search

For all terrestrial "designatable units" (which include species, subspecies and distinct populations and are hereafter termed "species") listed as "Endangered" on Schedule 1 of Canada's Species At Risk Act as of January 12, 2023 (SARA; (*Species at Risk Act*, 2002; n=208), we searched the literature for all peer-reviewed research that examined the outcome of one or more conservation actions. Species were considered terrestrial if a substantial or significant portion of their life cycle was terrestrial (e.g., amphibians). The search was not restricted to actions taking place in Canada; actions could have taken place anywhere within the species' ranges. For a full list of species examined, see Table S1, Appendix A. Using the Web of Science core collection, we searched for the species by both common and scientific names as listed according to Naujokaitis-

Lewis et al., (2022). For feasibility, if a search resulted in more than 100 articles for a particular species, we also searched for the word "conservation" anywhere in the document. We acknowledge that in doing so we may have missed some relevant articles. If the listed organism was a subspecies or distinct population, we searched more broadly for literature at the species level.

For example, the search string for both significant populations of caribou (*Rangifer tarandus*) listed as Endangered in Canada (Peary Caribou (*Rangifer tarandus pearyi*) and the Atlantic-Gaspésie population; COSEWIC, 2011) was:

TS=(caribou OR "Rangifer tarandus")) AND ALL=(conservation)

This term was added to the search string to reduce the amount of screening required to find articles assessing conservation efficacy. Since there was little to no research on many of the species, but many articles on a few charismatic species that were divided into subspecies or individual populations, this approach represented the best means of capturing as much evidence as possible while still remaining logistically feasible. It was not feasible to also search for grey literature on all 208 species in our review, therefore we limited our search to the peer-reviewed literature. To establish the total research effort focused on each species (i.e., not just assessing conservation action outcomes), we also performed the search for all species without including the term "conservation" and recorded the number of total references that resulted from this search (Tables S1, Appendix A).

Screening

Articles resulting from the above search approach were screened to determine if they:

1. Examined the correct species

2. Assessed the efficacy of one or more actions in improving some metric related to the species' persistence
3. Used real data (i.e., did not use simulated data or predicted future outcomes)

An action had to be linked directly to the species, not just their habitat or any other factor assumed to be correlated with the species' persistence. For example, if an action involved restoring habitat for Sage Grouse (*Centrocercus urophasianus*), the study had to demonstrate that it had a measurable effect on Sage Grouse, not just the vegetation. This is because habitat restoration does not always have a demonstrable positive effect on the target species, even when habitat quality targets are met (Germino et al., 2023). Simulation studies were not included for similar reasons. An action could however be directed at a different species, so long as the effects on the target species were measured (e.g., wetlands managed for ducks had a positive influence on western harvest mice; Smith et al., 2020). For a study to be included, the measured response metric had to relate to species persistence. This includes factors impacting individuals, such as body condition; those impacting demographic rates, such as survival and breeding success; or more direct measures of population change such as abundance or probability of occurrence. Metrics that did not fit this description include movement and behavioural responses that did not have explicit links to increases or decreases in fitness.

Data Extraction

Our method of extracting data was designed to align closely with the established CAN-SAR database (Naujokaitis-Lewis et al., 2022), following the terminology outlined by Salafsky et al. (2008). We recorded bibliographic information on the source literature and the scientific name, taxonomic group and the date that the literature search was conducted for each species. Taxonomic groups included amphibians, arthropods, birds, lichens, mammals, molluscs, mosses, reptiles and vascular plants (Naujokaitis-Lewis et al., 2022). In each article, the effect of each action on an individual species was considered one study (Table S2, Appendix B). Therefore, if an article examined multiple target species or multiple actions, it contained multiple studies, and data were extracted separately for each study. Actions were first categorized based on the action subcategories described by Salafsky et al. (2008). Subcategories "monitoring" and "research" were excluded due to the difficulty quantifying the positive effects these may have on the species, though we note that negative or neutral effects can also occur due to the effects of disturbance, handling and wildlife tracking equipment (e.g., tags, radiotransmitters, etc. (Kilpatrick et al., 2020; Raybuck et al., 2017). For the category "protection", evidence that some protection had been implemented had to be demonstrated, rather than simply the absence of a threat. For example, if a study found that areas with no logging benefitted caribou (e.g., Fryxell et al., 2020), we excluded it unless there was evidence that "protection" through legislation or other means resulted in a cessation of logging that then benefited caribou. We took this conservative approach because past research has shown that legal protection does not necessarily halt population declines. For example, the Core Area Policy in Wyoming was generally effective in halting the decline of Sage Grouse (*C. urophasianus*; Dinkins & Beck, 2019; Spence et al., 2017) but harvest restrictions may not meaningfully reduce harvest pressure for American Ginseng (*Panax cinquefolious*; (Mooney & McGraw, 2009). Additionally, threats will not necessarily affect a species in the absence of legal protection. If the efficacy of multiple actions were individually assessed, we created a new data extraction row, classifying each action as a unique study within an article.

To generalize actions across articles and species into comparable groups while generating more descriptive subcategories than those outlined by Salafsky et al. (2008), we further classified actions into secondary subcategories using an inductive approach (see Table S3 Appendix B for primary and secondary subcategories). These categories were also accompanied by action descriptions that provided more detail on what the action entailed. It is important to note that the action descriptions are not mutually exclusive. For example, we used "clearcut" or "shelterwood" rather than "even-aged management" if this information was available. If the action was implemented to combat a specific threat, this threat was recorded and categorized based on the level 1 categories outlined in Salafsky et al. (2008).

Conservation objectives fell into one of three categories: i) augment populations, ii) mitigate threats, and iii) slow or reverse declines. Outcomes of actions to address these objectives were then categorized as either effective, somewhat effective, no effect, harmful, or mixed effects. Effects were considered mixed if one metric was positive and another negative, or if different study sites or populations responded differently. For example, Pierluissi & King (2008) found that an increase in the number of irrigation canals was associated with an increased nest density for King Rail (*Rallus elegans*) but decreased nest survival, and Johnson et al. (2022) found that predator reduction successfully halted caribou declines in some contexts, but not others. Actions for which the objective was to augment populations were only considered effective if there was a measurable improvement in the response metric. If the objective was to mitigate a threat, the action was considered effective if the response metric was comparable to or better than either a control population or the study population prior to the occurrence of the threat. If the objective was to slow or reverse declines, the action was considered "somewhat" effective if the rate of decline was reduced, but only fully effective if it halted completely or reversed the declines. We recorded the ecological response metric that was used to assess efficacy, and the time period over which the study was conducted. Time periods were categorized into one-year bins: any studies where data collection took place for one year or less were binned as one year, between one to two years were binned as two, and so forth. All data extracted were reviewed by two co-authors to ensure quality and consistency. Finally, we synthesized the effects of each action on each species, based on all relevant studies from the extraction process (Table S4, Appendix B).

Results

Taxonomic Patterns and Research Gaps

We conducted literature searches for 208 terrestrial species listed as endangered in Canada. We screened 5786 articles and retained and extracted data from 510 of these. For 36 species (17.3%), we found no literature whatsoever. A further 38.9% of species had no literature investigating the efficacy of conservation actions, and for 2.9% of species, all conservation actions assessed were either ineffective, harmful, or had mixed outcomes. Thus, we only found literature with evidence of actions with positive outcomes for biodiversity for 40.9% of terrestrial endangered species in Canada (Figure 1).

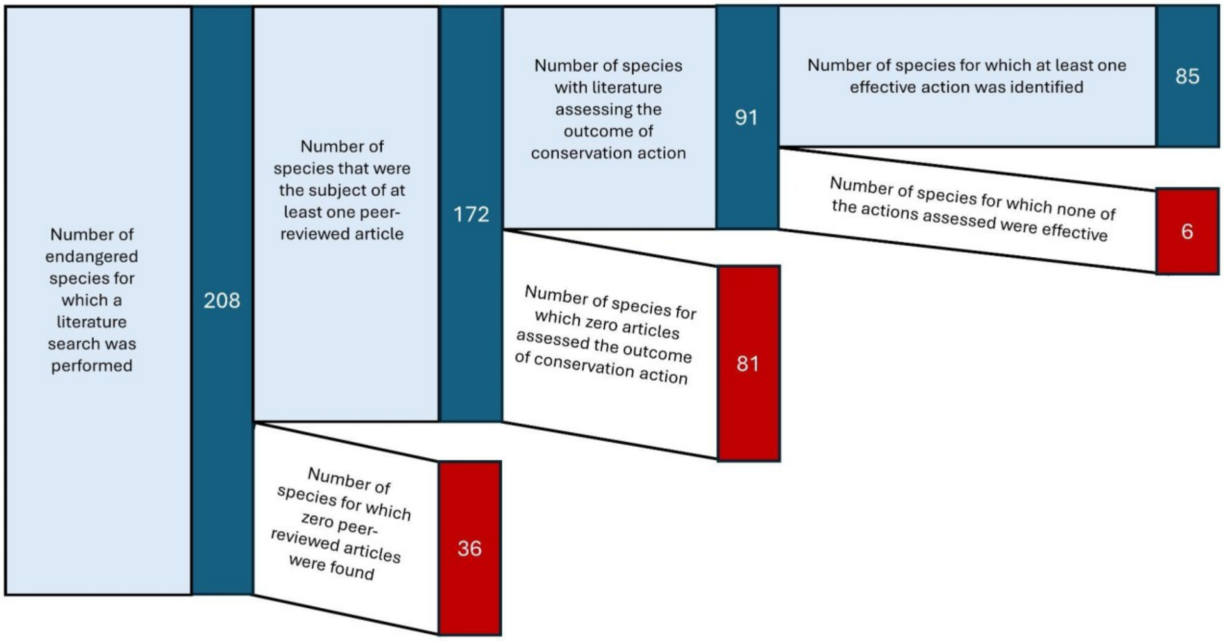

Figure 1. Summary of the available literature for 208 terrestrial Species at Risk (SAR) listed as endangered in Canada. The number of species in each category is noted in the rectangle to the right of each box.

Most research focused on birds, followed by vascular plants and mammals (Figure 2). Henslow's Sparrow (*Ammodramus henslowii*), Northern Bobwhite (*Colinus virginianus*), Greater Sage Grouse (*C. urophasianus*) and Caribou (*R. tarandus*) were the species with the greatest amount of action-oriented research. Of the top ten species with the most literature on conservation action, eight were birds (Figure 3). There were zero articles studying the efficacy of conservation action on mosses, lichens, or terrestrial molluscs. The number of articles examining the efficacy of any conservation action across all target species made up only 2.1% of all literature published on these species (Figure 2), ranging from 0.77% of articles on mammals to 3.6% of articles on birds (Table S5, Appendix C). The average proportion of articles that assessed the outcomes of actions across all target species was 7.1% (SE ±1.3%). The median time period over which data were collected to assess the efficacy of any given action was 3.0 (SE ±0.51) years.

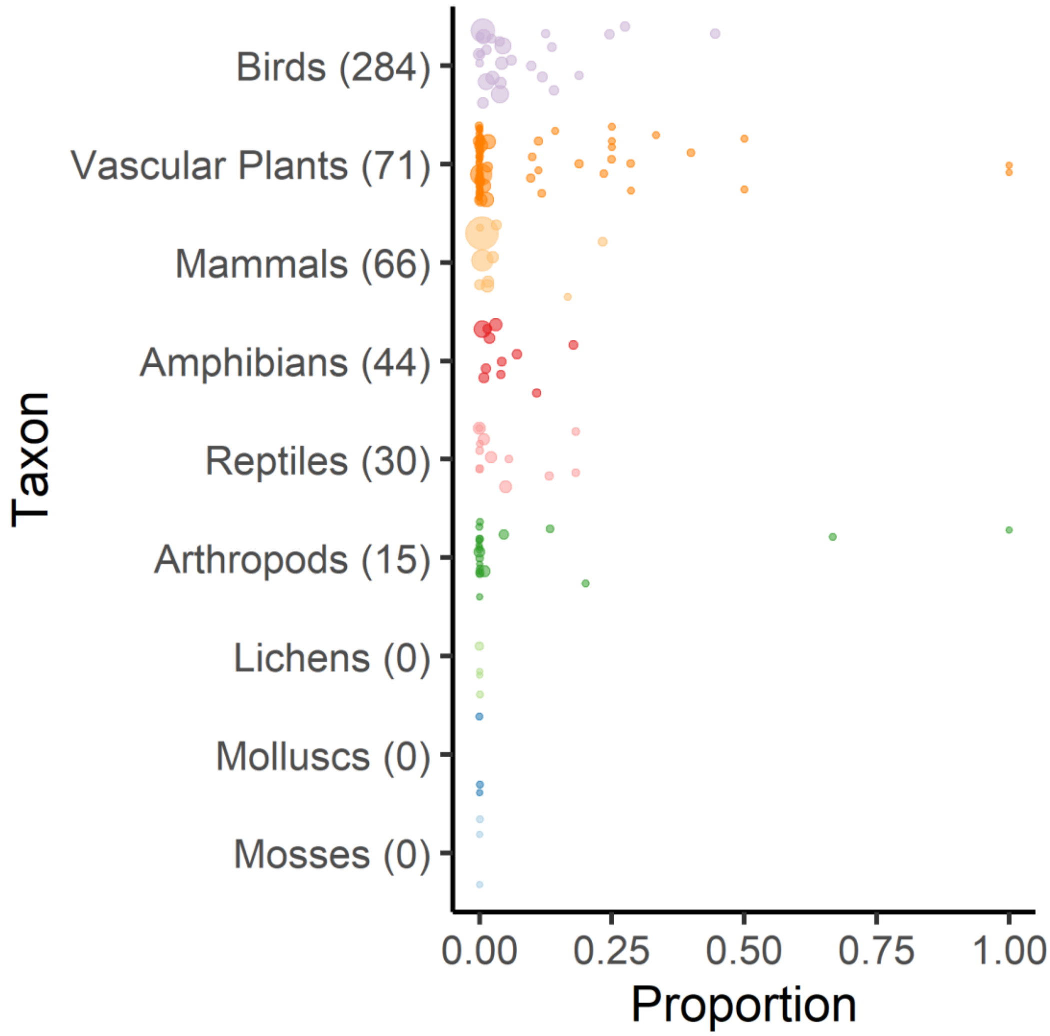

Figure 2. Proportion of articles for each taxonomic group that examined the efficacy of conservation actions. Each circle represents one species. Larger circles denote species for which there was more literature available overall. Proportion indicates the proportion of all articles for a given species that examined the efficacy of a conservation action (the number of such articles for each taxonomic group is denoted in brackets on the y axis). Species for which there were no articles found were excluded from this diagram.

Several understudied species, with fewer than 10 articles published about them in any subject, nevertheless had a high proportion (>50%) of studies focused on conservation action. For example, Perseus Duskywing (*Erynnis persius*), Streambank Lupine (*Lupinus rivularis*) and False Hop Sedge (*Carex Lupuliformis*) collectively had only four articles written about them, but all four assessed the efficacy of conservation actions. Conversely, many well-studied species (i.e., more than 1000 articles) had a very low proportion of research focused on conservation evidence. Our search for literature on Caribou (*Rangifer tarandus*), for example, yielded 6084 papers, only 0.51% of which were action-oriented. For mammals and birds, the literature was generally dominated by few species, yet for the majority of these species the proportion of research focused on conservation action was less than 25%. In contrast, for arthropods (and to a lesser extent, vascular plants), the research was more equally distributed among species, though there was still limited focus on conservation outcomes.

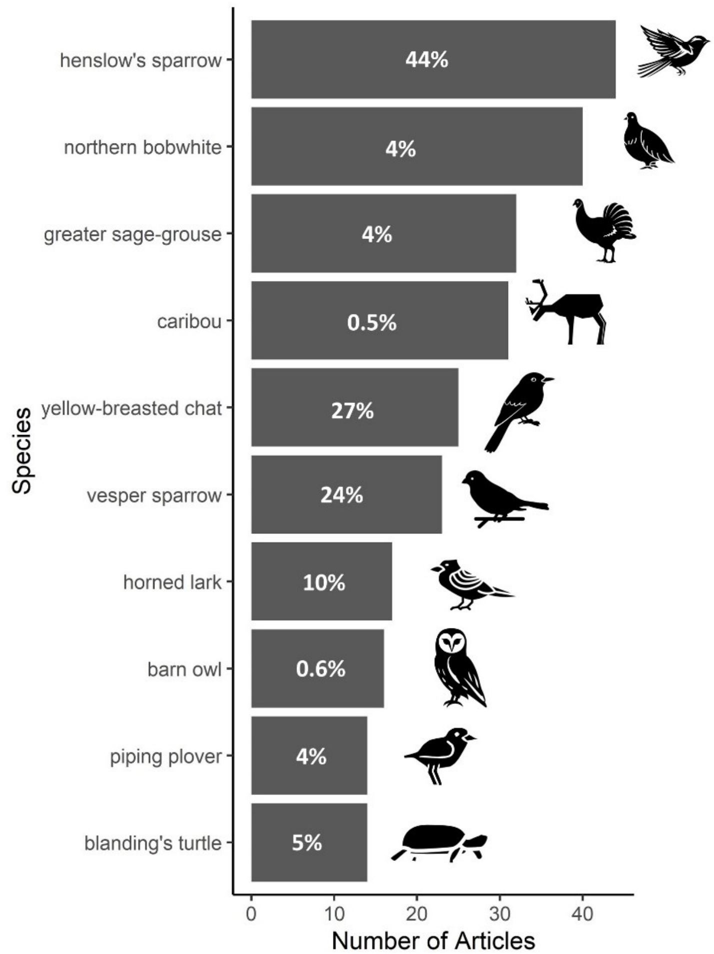

Figure 3. The ten species listed as Endangered in Canada with the highest number of research articles investigating the efficacy of conservation actions. Values on the bars denote the percentage of all literature on the species that assessed at least one conservation action.

<u>The Efficacy of Conservation Actions</u>

The greatest number of articles focused on habitat restoration actions (n=261), but these actions were harmful, ineffective, or had mixed results in approximately 38% of studies (Figure 4). Habitat restoration was the most commonly assessed action subcategory for all taxonomic groups except for vascular plants, for which captive breeding (i.e., growing plants in a nursery or laboratory) was more commonly assessed (Figure S1). Nearly 85% of studies (n=87) on captive breeding found it to be at least somewhat effective in augmenting populations of species at risk (Figure 4). By contrast, only seven studies investigated the effects of invasive species removal on an endangered species; four found that it was effective, but the other three found this action to be harmful to the focal species. The management of native species that were negatively impacting species at risk (e.g., managing predators using exclosures) was the focus of more articles (n=54) than invasive species removal, and was at least somewhat successful in 64% of studies. Only one study examined the effects of education on an endangered species, finding that education programs coincided with a decrease in the persecution and killing of Barn Owls over a decade in Spain (Fajardo, 2001).

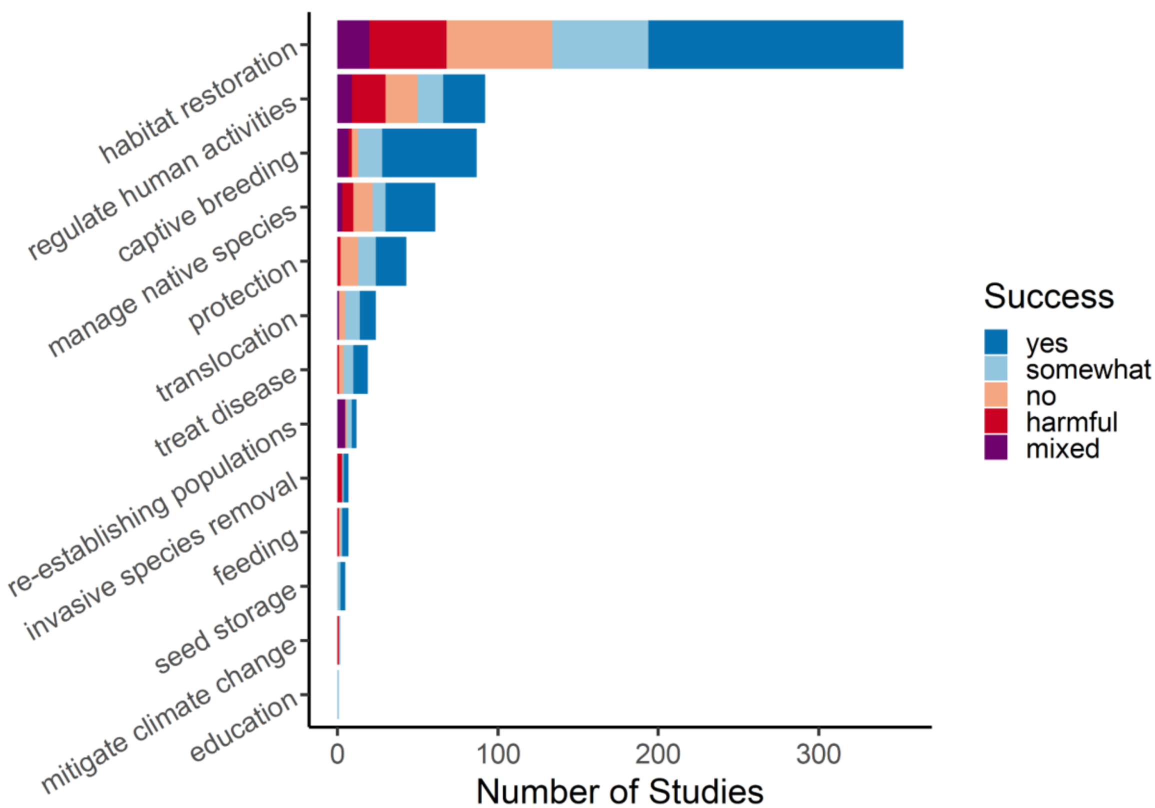

Figure 4. Number of articles examining the efficacy of a conservation action subcategory that were found to be effective (“yes”), somewhat effective (“somewhat”), ineffective (“no”), harmful (“harmful”), or demonstrated mixed results (“mixed”). A summary of these data by taxonomic group is depicted in Figure S1.

We were able to further refine the 13 action subcategories into 32 secondary subcategories, and examine how each species responded to them (Figure 5, Tables S3-S4 Appendix B). The efficacy of captive breeding was assessed across the broadest suite of species (40 species, 6 taxonomic groups), and demonstrated at least limited efficacy for 29 of them (Figure 5). The next three most commonly assessed actions across species were prescribed burns (29 species, 6 taxonomic groups), alternative timber harvest practices (27 species, 6 taxonomic groups), and vegetation control (22 species, 5 taxonomic groups). Although these actions had positive effects on many species, all three actions also had mixed or negative effects on a relatively high proportion of the target species (Figure 5). In particular, alternative timber harvest practices aimed at reducing harm to species at risk were either ineffective or harmful for 48% of species. The effects of prescribed burns differed by taxonomic group (Figure S2, Appendix C); with positive effects on most vascular plants (67%, n = 6 species), and reptiles (100%, n = 4 species) assessed, mixed effects on birds (positive for 50%, mixed or harmful for the rest, n = 14 species), and no effect or negative effects on arthropods and mammals (Figure S2, Appendix C). Conversely, protected areas, habitat creation, artificial shelter, alternative farming practices, reproductive material storage techniques, harvest or hunting restrictions, and supplemental feeding all had positive effects on the majority of species assessed (67-100%) and were harmful or had mixed impacts on few or no species (less than 10% of species assessed). For more details on each of these actions, and how they affect each species, see Table S4, Appendix B.

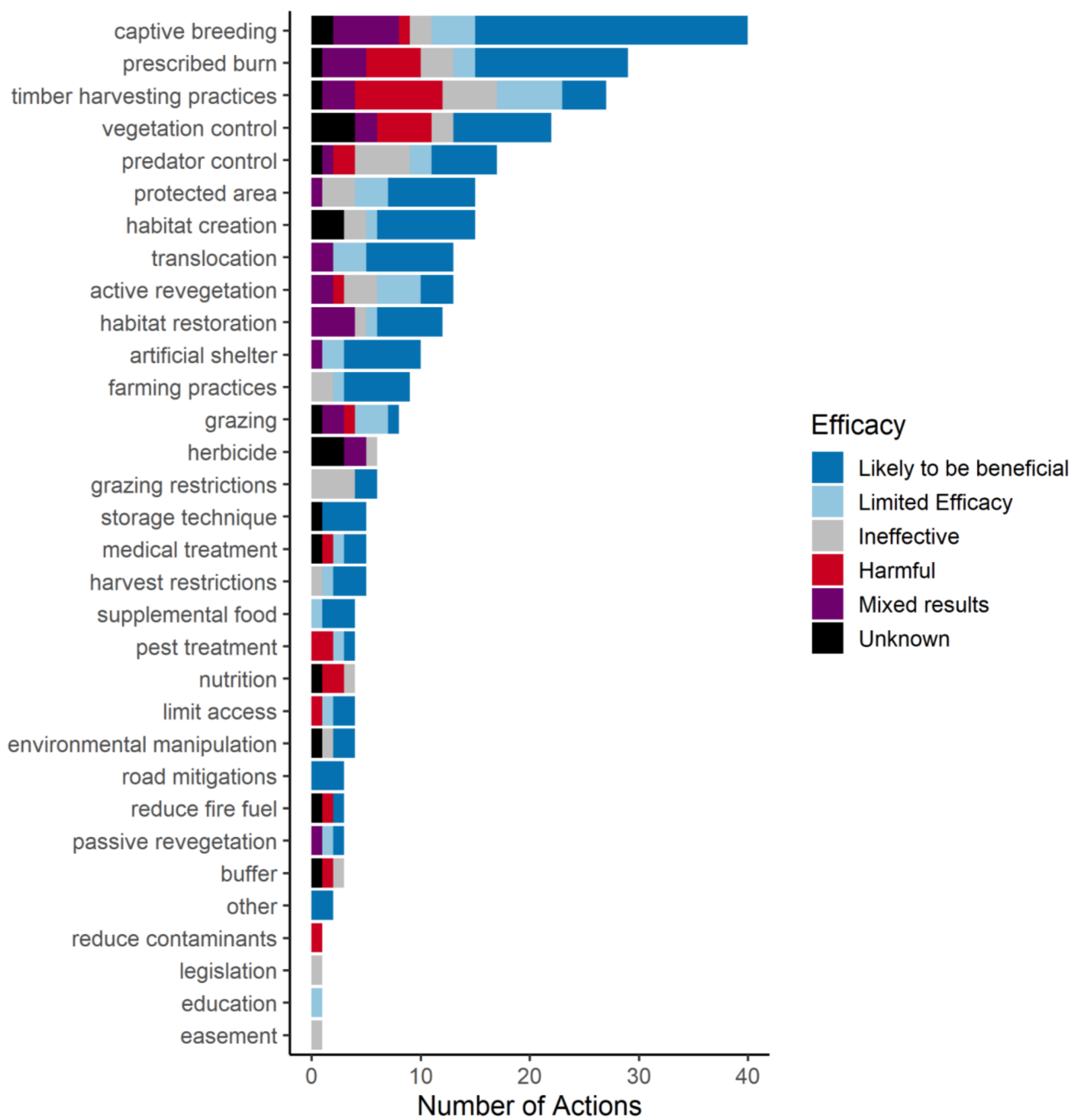

Figure 5. Responses of species at risk to conservation actions. “Number of Actions” on the x-axis represents the number of unique action-species combinations across studies evaluated for species listed as Endangered in Canada. Efficacy describes whether action objectives were met. Detailed descriptions of these actions and how they affect each species can be found in Table S3, Appendix B.

Discussion

Despite the growing need for evidence-based solutions to conservation problems, we found very little investigation into the efficacy of conservation action for many terrestrial species listed as endangered in Canada, even for those that were otherwise relatively well studied. While some broad patterns for the most effective actions may be discernible, the need for increased research effort in this area is apparent, particularly for understudied taxa such as invertebrates and nonvascular plants. Habitat restoration was the focus of the greatest amount of research effort, while other actions such as education were hardly examined at all. Captive breeding was found to be largely effective across species relative to other action categories, but typically does not address the initial drivers of population declines. Several actions demonstrated antagonistic effects (Silver et al., 2023), benefiting certain species at risk while harming others, but some, including creating or protecting habitat and sustainable agriculture, were broadly beneficial across all species examined.

Why is research that explores the effectiveness of conservation action apparently so limited? One hypothesis is that null results in early attempts may not be published, and could even lead conservation to stagnate. For example, early efforts to reintroduce American Chestnut had limited success, resulting in widespread inaction (Newhouse & Powell, 2021). Another hypothesis is that researchers are exploring limited approaches, perhaps also out of an abundance of caution (Meek et al., 2015). For example, captive breeding and translocation programs made up the majority of actions for vascular plants, demonstrating broad benefits and limited negative impacts. However, while these approaches may be relatively well established, they are also often focused on augmenting populations without addressing the initial causes of declines (e.g., Leech et al., 2017; Martin et al., 2012). Researchers may therefore need to broaden their scope if they are to increase our capacity to mitigate threats and prevent declines in the long term. Moreover, for endangered species in particular, research can be limited in part by the rarity of the species, and limited access to remaining individuals (Rathwell et al., 2016). For those species that are the focus of many research articles, but relatively few on conservation action, researchers are likely well positioned to start exploring potential conservation approaches supported by evidence of their habitat requirements and known responses to threats.

Often the adequate implementation and assessment of conservation action can span decades, which may limit our capacity to understand what is ultimately effective. In our study, the median period of data collection was 3 years, which may be an insufficient time scale to assess outcomes. For example, a study published in 1997 showed inconclusive results about the effects of the Conservation Reserve Program on Henslow's sparrow over 21 years (Herkert, 1997). However, a follow up study (Herkert, 2007) demonstrated that enrollment in this program was associated with the reversal of population declines for this species in Illinois after almost 30 years. The reversal of declines for imperiled species may take decades, demonstrating the importance of periodic assessment of the efficacy of actions. Similarly, actions implemented for different durations, or assessed over different temporal scales, may have different effects. For example, Henslow's sparrow responds negatively to burning regimes in the short term (Applegate et al., 2002), but positively after two to three years (Powell, 2008).

Among actions that were assessed in the literature, we discovered several alarming patterns. Habitat restoration was the action subcategory that received the greatest amount of research focus, yet had mixed, negligible or harmful effects in almost half of the articles where these actions were assessed. Several global biodiversity targets (Convention on Biological Diversity, 2022; https://www.bonnchallenge.org/) emphasize the restoration of degraded habitats, but our results demonstrate the breadth of uncertainty surrounding the efficacy of these interventions. There was only one study that explored the outcomes of education for species at risk (Fajardo, 2001). However, education and outreach is the most common action in species at risk action plans in Canada (Buxton et al., 2020). Surprisingly, the effect of invasive species removal on endangered species was not well studied, and in some contexts we found this action had a negative impact on the target species. For example, the removal of woody vegetation at reclaimed mine sites resulted in lower densities of Yellow-breasted Chat (*Icteria virens*; Lautenbach et al., 2019), and a herbicide used to reduce the growth of leafy spurge (*Euphorbia Esula*) had negative effects on growth and reproduction in Western Prairie Fringed Orchid (*Platanthera praeclara*; Erickson et al., 2006). The unintended negative consequences of these actions on Endangered species reinforce the need to assess the outcomes of conservation actions that have been implemented. Furthermore, given established publication biases against null or negative results (Wood, 2020), we have likely understated the potential for these actions to have negligible or harmful effects on species at risk.

Almost all action categories had some mixed results, and many actions were found to be ineffective or even harmful to some species in certain contexts (e.g., prescribed burns, alternative timber harvesting approaches). For example, mowing vegetation to benefit Sage Grouse was harmful to the similarly imperiled Sage Thrasher that occupies the same habitat (Carlisle et al., 2018). However, actions that are antagonistic between species may still be useful, if they are part of a suite of actions that together provide net benefit across species (Bylo et al., 2014). Furthermore, actions that benefit one species but harm another may still be worth implementing if the species do not overlap in time and space. Conversely, while some actions are simply ineffective and do not result in direct harm, they can act as resource sinks that divert time and effort from more cost-effective actions. This can be true even for effective actions. For example, implementing captive breeding and translocation programs was rarely detrimental to the targeted species, but is very costly (Leech et al., 2017; Serrouya et al., 2019), and may divert resources from other conservation actions.

Several assumptions were made which could influence how our database is used and interpreted. As noted above, we only specified literature searches and actions to the species level, rather than lower levels such as subspecies. We believe this is justified due to the lack of literature on many of the subspecies. However, all evidence should be carefully examined to ensure it is in fact relevant to the subspecies in question (Irwin et al., 2015). Similarly, we did not collect information on the geographic region where the data were collected. However, regional differences can play an important role in the efficacy of conservation action (Doherty et al., 2016). Moreover, costs are almost never accounted for in the comparison between methods, but may have a significant influence on which action yields the best results. For example, Dunwiddie et al. (2016) found that Golden Paintbrush plugs had higher survival than seeds, but seeds were more cost effective. It is important to note that our database does not represent a comprehensive picture of all actions and their efficacy for all species. Further evidence of conservation successes that are not well documented in the peer-reviewed literature almost certainly exist, and may hold information critical for conservation (Khorozyan, 2022). Publication biases may also be present, leading to an underrepresentation of actions that were ineffective (Josefsson et al., 2020; Wood, 2020). Finally, the individual actions we have characterized here are often part of more holistic schemes. For example, the successful combination of predator removal and maternal penning in one subpopulation of caribou recorded in Serrouya et al. (2019) can be largely attributed more generally to the conservation efforts and management of the West Moberly First Nations and Saulteau First Nations (Lamb et al., 2022). Despite these limitations, our study identified clear and concerning patterns in conservation research on endangered terrestrial species in Canada.

Conclusions

Many countries have committed to the ongoing conservation and recovery of global biodiversity, through the development of ambitious biodiversity targets (Convention on Biological Diversity, 2022). However, as our analysis shows, we may still lack the evidence required to meet them. Despite half of conservation funding being spent on research and monitoring (Buxton et al., 2020), we found evidence describing the effectiveness of conservation action for less than half of terrestrial endangered species in Canada. There was a strong research bias against less charismatic taxonomic groups, resulting in no literature whatsoever for endangered mosses, lichens, or terrestrial molluscs. Concerningly, several of the most well-studied actions, including timber harvesting prescriptions and habitat restoration practices, were found to be ineffective or even harmful in many cases. This reinforces a dire need for adaptive management frameworks, prioritizing quick action where it is urgently required, but also monitoring and assessing the efficacy of the chosen approach. These results also highlight the necessity of open research and the publication of null or negative results. Our database provides a starting point for scientists to understand the current knowledge gaps in the species-at-risk literature, and for practitioners to begin mobilizing the information we already have. The need for more evidence is apparent, but should not limit our capacity to act on the information currently available. If countries are to meet their goals of conserving biodiversity (Convention on Biological Diversity, 2022), they must prioritize implementing effective, evidence-based action and conducting research that can adequately address this gap.

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