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REVIEW

Wolverine in the slipstream: A systematic review of caribou-focused conservation benefits, gaps and uncertainties for wolverine in Canada

Rosemary Hohnen[1,2] | **Frances E. C. Stewart**[1,3] | **Matthew A. Scrafford**[4]

[1]Department of Biology, Wilfrid Laurier University, Waterloo, Ontario, Canada

[2]Research Institute for the Environment and Livelihoods, Ellengowan Drive, Charles Darwin University, Casurina, Northwest Territories, Australia

[3]School of Environmental Studies, University of Victoria, Victoria, British Columbia, Canada

[4]Ontario Northern Boreal Program, Wildlife Conservation Society Canada, Thunder Bay, Ontario, Canada

Correspondence
Rosemary Hohnen, Department of Biology, Wilfrid Laurier University, 75 University Avenue West, Waterloo, Ontario N2L 3C5, Canada.
Email: rhohnen@wlu.ca

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Abstract

With rates of biodiversity loss accelerating globally, debate exists regarding the most efficient ways of allocating resources to conserve species. Woodland caribou (*Rangifer tarandus caribou*, hereafter "caribou") are the focus of many Canadian conservation strategies. Here we examine the extent caribou-focused conservation can benefit wolverine (*Gulo gulo*), a Species at Risk that overlaps with caribou in distribution and ecological aspects. We conducted a systematic review of Canadian conservation documentation (51 caribou, 14 wolverine documents) and North American scientific literature (550 caribou, 167 wolverine papers) to quantify for wolverine and caribou: (i) variation in conservation documentation availability and age, (ii) overlap in commonly listed threats and recovery actions, and (iii) the extent threats have been researched across Canada. While we found differences in conservation and research focus, both key threats (including habitat loss, hunting and trapping, sensory disturbance, and linear features) and recovery actions (including management of important habitat, partnerships, and population monitoring) were listed in >50% of conservation documentation for both wolverine and caribou. We identify caribou-focused conservation actions that may support wolverine, and where gaps and uncertainties in wolverine management remain. Actions that effectively protect caribou critical habitat implicitly manage multiple threats relevant to wolverine.

KEYWORDS

conservation management, *Gulo gulo*, habitat loss, hunting, *Rangifer tarandus caribou*, species at risk, trapping, umbrella species

1 | INTRODUCTION

Biodiversity loss is accelerating at both local and global scales (Butchart et al. 2010; Waldron et al. 2017). Even in Canada, a country with some of the "wildest" places on

Frances E.C. Stewart and Matthew A. Scrafford shared last author position.

the planet (Hirsh-Pearson et al., 2022; Sanderson et al., 2002), one in five species are "At Risk" (critically imperiled, imperiled, or vulnerable) (Canadian Endangered Species Conservation Council, 2022). Canada's mountain and boreal forests are experiencing rapidly increasing impacts of climate change and industrial development (Brandt et al., 2013; Hansen et al., 2013; Potapov et al., 2017; Price et al., 2013). In response to these issues, Canada has committed to the Kunming-Montreal Global Biodiversity Framework (GBF), which includes targets to halt species extinctions and manage areas to reduce biodiversity loss (UN Convention on Biological Diversity, 2022). Given the accumulating number of Species at Risk, there is a distinct need for conservation planning to facilitate efficient and effective allocation of resources (Cabeza & Moilanen, 2001; Lindenmayer et al., 2000).

Debate exists regarding the most effective means of supporting biodiversity and ecosystem function at large scales (i.e., single large or several small Fahrig, 2020; Riva & Fahrig, 2022; Simberloff, 1998). Some conservation strategies focus on multiple species (Baptista et al., 2019; Schwenk & Donovan, 2011), or larger systems (Rosenberg & McLeod, 2005). Others focus on one or a few species, used as proxies or indicators in ecology and conservation biology (Lindenmayer & Westgate, 2020), sometimes referred to as umbrella or focal species (Caro, 2010). These species may be chosen based on past efforts, their importance in ecosystem functioning, their perceived value, or their ability to confer protection to sympatric species vulnerable to similar threats (Caro, 2010; Lindenmayer & Westgate, 2020; Verissimo et al., 2011). Such strategies can be useful ways to streamline conservation programs, where monitoring and management of one species can have benefits for broader systems (Caro, 2010; Fleishman et al., 2000).

In Canada, there is a strong conservation focus on woodland caribou (*Rangifer tarandus caribou*, hereafter "caribou"), a group which includes boreal and mountain caribou (including southern, central, and northern) ecotypes (COSEWIC, 2011; Drever et al., 2019; Labadie et al., 2024). All designatable units of boreal and mountain caribou (including southern, central, and northern) are assessed by COSEWIC as Threatened, Endangered, Endangered, and Special Concern, respectively (Environment and Climate Change Canada, 2025, provincial/territorial listings in Figure S1). Woodland caribou have disappeared from >24% of their historic distribution (Laliberte & Ripple, 2004), and only 27% of boreal caribou ranges are self-sustaining (Environment and Climate Change Canada, 2020). These declines have been driven by the cumulative impacts of landscape disturbance resulting in reductions in available critical caribou habitat, and higher rates of caribou predation (Environment and Climate Change Canada, 2020; Johnson et al., 2015; Maltman et al., 2024; Nagy-Reis et al., 2021). Both boreal and southern mountain caribou are included as priority species in federal conservation approaches (Environment and Climate Change Canada, 2018). Caribou distribution overlaps with 90% of all boreal mammals and birds (Drever et al., 2019), and some studies suggest that caribou conservation measures may have broader benefits for boreal biodiversity (Bichet et al., 2016; Johnson, Drever, et al., 2022; Labadie et al., 2024).

Wolverine (*Gulo gulo*) is a medium-sized carnivorous mustelid species found across similar regions as caribou: northern latitudes including the tundra, taiga, boreal, and selected mountain habitats of Eurasia and North America (Hall, 1981; IUCN, 2023). They are listed nationally in Canada as Special Concern under the Species at Risk Act (SARA, 2002, provincial/territorial listings in Figure S1). The species has experienced a 37% range reduction in Canada in the southern and eastern parts of its historical distribution, including south-eastern Alberta, southern parts of Saskatchewan, Manitoba, and Ontario, and likely extirpation from Vancouver Island, New Brunswick, and large parts of Quebec and Labrador (COSEWIC, 2014b; Dauphiné, 1989; Laliberte & Ripple, 2004). These declines are thought to be driven by impacts of settlement, including increased agriculture, forestry, mining, roadbuilding, unregulated trapping (Johnson, 1990; Newby & McDougal, 1964; Ruggiero et al., 2007; Slough, 2007), and potentially climate (Balkenhol et al., 2020; Copeland et al., 2010; Peacock, 2011).

In North America, both wolverine and caribou overlap considerably in their ecology, distribution, and range reductions (Laliberte & Ripple, 2004, Figure 1, Text S1). Both species have large home ranges (Banci & Harestad, 1990; Dawson et al., 2010; Wilson et al., 2019), slow reproductive rates (Anderson & Aune, 2008; Rettie & Messier, 1998), select for older forest ages (Apps et al., 2001; Hins et al., 2009; Hornocker & Hash, 1981; Lofroth, 2001; Wright & Ernst, 2004), and are negatively associated with industrial impacts (Bowman et al., 2010; Brown et al., 2003; Ray et al., 2018). While there is a strong conservation focus on Canadian caribou, including policies and guidelines introduced by multiple levels of government (Environment and Climate Change Canada, 2018), wolverine are largely managed through trapping regulations; no habitat-based conservation efforts exist for this species in any jurisdiction (COSEWIC, 2014b). In Ontario, allocation for wolverine habitat in forestry areas is considered captured by boreal caribou habitat management approaches, with the exception of protections for known active den sites (OMNRF 2010). Given the focus on caribou habitat conservation, a national-scale

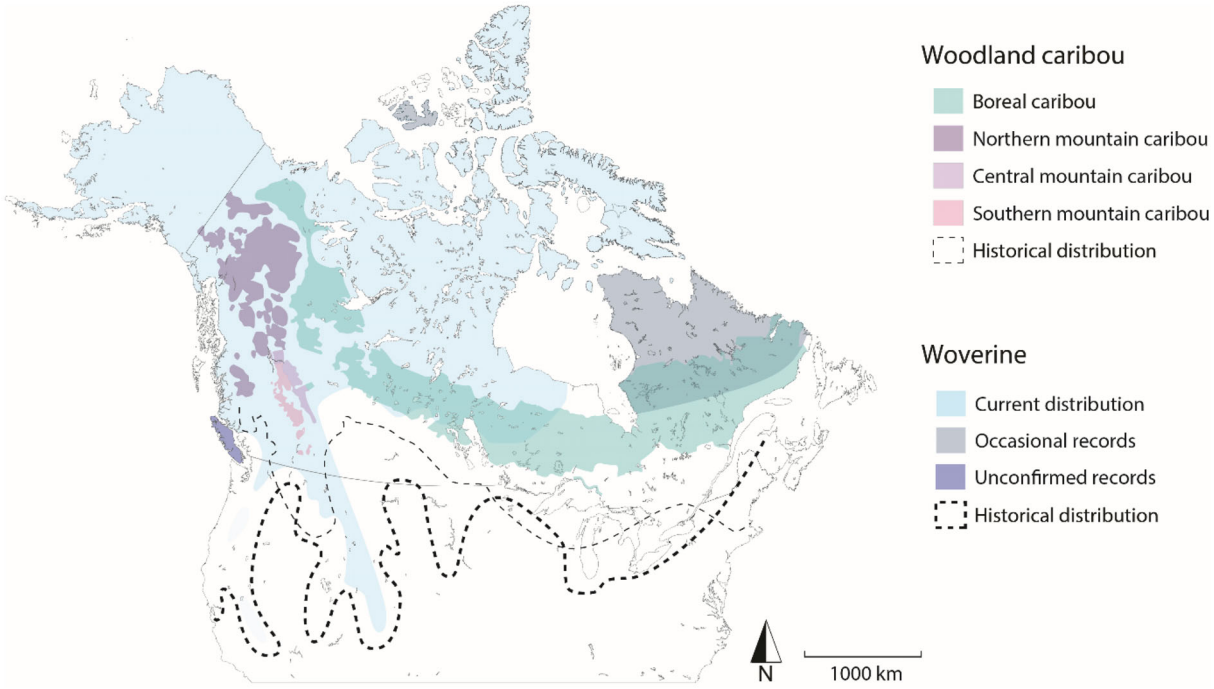

FIGURE 1 Current and historical distribution of woodland caribou (including boreal, northern mountain, central mountain, and southern mountain ecotypes), and wolverine in North America as adapted from (COSEWIC, 2003; Environment Canada, 2012; Kylie, 2018). Other caribou ecotypes not considered in this study have been excluded from this map.

investigation is required to examine the extent caribou-focused conservation can benefit wolverine.

We sought to assess the extent that wolverine might benefit from caribou-focused conservation in Canada. While many studies have quantified conservation overlap between species by examining shared habitat or distributions (Bichet et al., 2016; Johnson, Drever, et al., 2022; Labadie et al., 2024), we demonstrate that examining overlap in ecology, threats, and conservation priorities can provide insight into the strengths and limitations of coordinated management approaches between species. Specifically, we investigated for wolverine and caribou: (i) variation in conservation documentation availability and age, (ii) overlap in commonly listed threats and recovery actions, and (iii) the extent these key threats and recovery actions have been researched across Canada. We predicted that due to both the conservation and research focus on caribou and the ecological overlap between caribou and wolverine, there would be (i) a greater conservation focus on caribou, including more recently published and extensive conservation documentation, (ii) considerable overlap between caribou and wolverine in frequently listed threats and recovery actions, and (iii) more available caribou research into threats and recovery actions. We identify threats relevant to wolverine that may be managed through caribou-focused conservation, and where gaps in wolverine management and research remain.

2 | METHODS

2.1 | Systematic literature review

We conducted two separate systematic literature searches of conservation documentation and scientific literature to collate information on woodland caribou, specifically boreal and mountain caribou (northern, central, and southern), and wolverine management and ecology. Other Canadian caribou designatable units, despite overlapping in distribution with wolverine, were not included as we were most interested in looking at management overlap in boreal and mountainous areas where industrial, forestry, and human activity impacts have been highest (Brandt et al., 2013; Pattison et al., 2016; Venier et al., 2014). Additional considerations of this approach are outlined in Text S2. The study methods were designed to align with guidelines described in Pullin & Stewart, 2006, and following the PRISMA statement for reporting of systematic reviews (Liberati et al., 2009).

2.1.1 | Conservation documentation

We conducted a literature review of Canadian national and provincial/territorial conservation documentation (i.e., "gray literature") for woodland caribou and

wolverine, to build a conservation context for these species by (i) mapping spatial and temporal trends in publication date and (ii) investigating variation in commonly listed threats and recovery actions. National and provincial/territorial conservation documents represent the consolidated opinion of government representatives, Indigenous communities, and scientific experts from across Canada, and therefore these documents are a means of collating expert knowledge. Using both national and provincial/territorial documentation better reflects the conservation context of Canada, where responsibility to manage Species at Risk is primarily held by the provinces/territories, with the federal government only accountable on federal lands (national parks and military bases) or under specific circumstances outlined by (SARA, 2002).

We used species-specific search term sequences in Google that included (topic) = ((“wolverine,” or “boreal caribou,” or “woodland caribou” or “mountain caribou”) + (“national” or “the province/territory name”), + (“status assessment,” or “scientific assessment,” or “species information,” or “Species at Risk evaluation report,” or “recovery plan,” or “recovery strategy,” or “action plan,” or “implementation plan,” or “conservation agreement”)). Range plans were not included to avoid geographic bias in our search, as they were only available for some provinces/territories. Only official documents that were publicly available on government webpages were retained and collated. All documents were classified as reports, were open access and were published since 2000, as we were most interested in conservation management in the last three decades. French documents such as those from Quebec were translated to English using Google Translate. This search was conducted between December 1, 2023 and June 1, 2024.

Terminology used in many documents varied by jurisdiction. We considered status assessments to be documents that assessed the population trajectory of the species and generally included the document types “scientific assessment,” “assessment and status report,” “science update,” “Species at Risk evaluation report,” and “species information.” Recovery documents outlined the threats to the species and included the document types “recovery plan,” “recovery assessment,” and “recovery strategy.” Action documents were those that listed actions that could be undertaken to address threats and generally included “action plans,” “implementation plans,” and “agreement for conservation and recovery.” We classified documents by their title terminology, but in some circumstances, there was overlap between document type and purpose (e.g., some status assessments also listed threats and recovery actions), which were used in later analyses outlined below. We then mapped the availability and publication date of status, recovery, and action documents across Canada's provinces and territories.

We collated wolverine and caribou threats and recovery actions listed in national and provincial/territorial conservation documentation. We synthesized the threats section of all relevant documents, listing headings and key themes under 18 different threat categories (Table S1). Variation in terminology was collated under key categories; for example: “snow conditions,” “climate change,” “temperature extremes,” “freezing rainfall.” and “snow icing events” were all collated under the category of “weather and climate including climate change” (Table S2). We split habitat loss into two categories, including habitat loss (i.e., loss, degradation, or fragmentation) resulting from forestry, industrial, and development impacts, and habitat alteration as a result of forest fire (i.e., loss, degradation, or fragmentation). While there was overlap between threat categories (e.g., roads are a form of habitat alteration and may influence rates of human access and therefore hunting), the threat headings within documents were used to inform our analysis and terminology generally. We also synthesized the recovery actions from all relevant documents under 26 categories (Table S3). Finally, we compared the percentage of documents that list the threat or action between caribou and wolverine. One author collated and screened reports for inclusion and collected data used in the analysis.

2.1.2 | Scientific literature

We collated published North American caribou and wolverine peer-reviewed literature to examine variation in (i) geographic location of research occurrence (ii) key threats studied (identified in the analysis of conservation documentation outlined above), and (iii) species ecology relevant to key threats. We collated English language papers for this review by searching Google Scholar and Web of Science, and this search was conducted between December 1, 2023 and June 1, 2024. The search term sequence included (topic) = (“*Gulo gulo*,” or “wolverine,” or “woodland caribou,” or “mountain caribou,” or “boreal caribou” or “*Rangifer tarandus caribou*”). We included papers published since 2000 that utilized study sites within North America (including populations in the United States) because we were most interested in assessing research that had occurred over the same time period and investigated populations relevant to the conservation documentation collated in Section 2.1.1. We also included papers that met these criteria but did not specifically study caribou or wolverine. For example,

some investigated relevant ecological aspects (e.g., food availability or seismic line regeneration). We used titles, keywords, abstracts, and methods to classify papers by the country and province/territory. We mapped spatial variation in the total number of manuscripts that study wolverine and caribou in each Canadian province/territory to assess spatial bias in research focus. We classified papers by the key threats identified for both species during our first literature review of conservation documentation (Section 2.1.1). We then graphed the percentage of manuscripts that addressed these threats. We also quantified the total number of papers that addressed management action relevant to each species. One author collated and screened papers for inclusion and collected data used in the analysis.

3 | RESULTS

3.1 | Documented threats and recovery actions

For wolverine, 14 conservation documents were available; four national and 10 provincial/territorial. Of those, 10 were status documents, four were recovery documents, and none were action documents (though three documents also included recovery actions). We found almost four times the number of conservation documents available for caribou, 51 total; 12 national and 39 provincial/territorial. Of those, 13 were status documents, 18 were recovery documents, and 20 were action documents.

Wolverine conservation documentation was often older and available for fewer provinces/territories than caribou (Figure 2). Wolverine documentation was available from five of Canada's 13 provinces/territories (Figure 2), and most documents were published over a decade ago. A national status assessment was published for the western wolverine population in 2014 (COSEWIC, 2014b; Environment Canada, 2016), and a national recovery document for the extirpated eastern wolverine population in 2016 (since being delisted and merged with the western population). Alberta stood out with the longest time since publication of 1997 (nearly 30 years; Petersen, 1997). Exceptions were Northwest Territories and New Brunswick, with a status assessment published in 2022 (Grizzly Bear and Wolverine Biological and Management Feasibility Working Group, 2022; New Brunswick

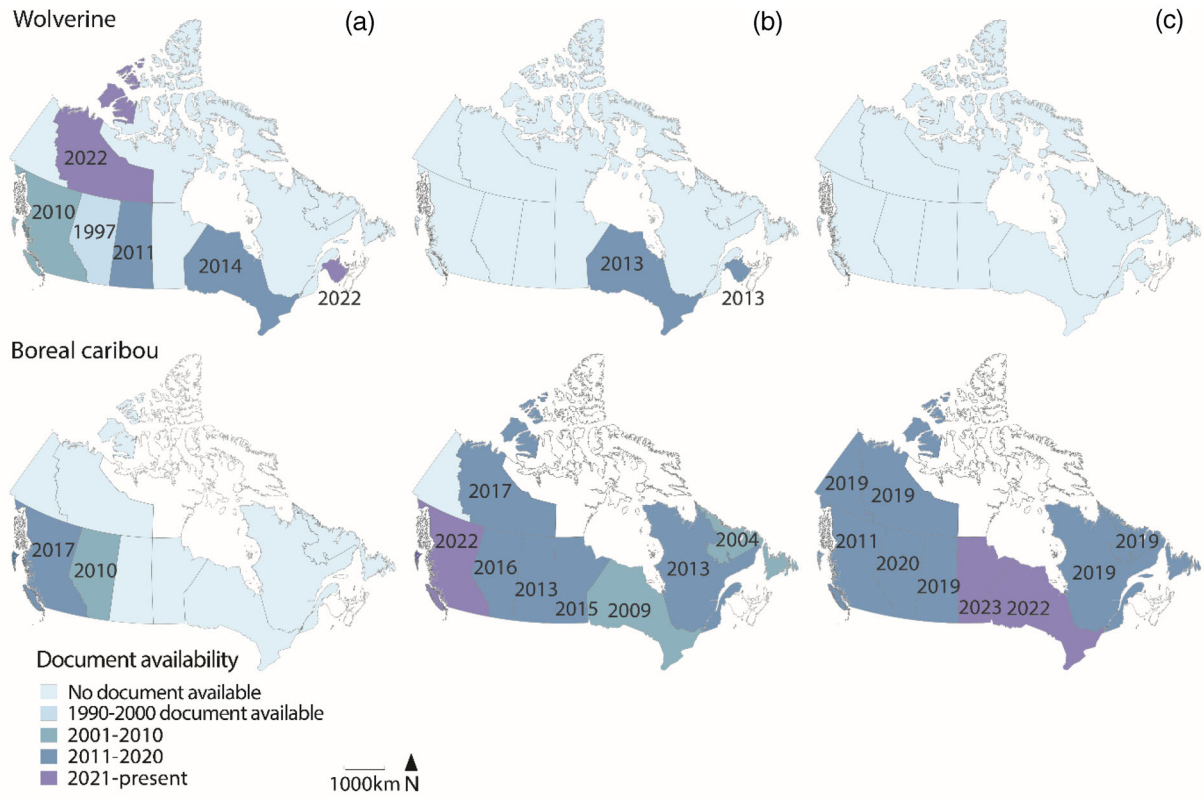

FIGURE 2 The distribution and most recent publishing date of (a) status documents, (b) recovery documents, and (c) action documents for both wolverine and boreal caribou. Mountain caribou documentation was not included for clarity, but is available in Table S6. More provincial/territorial boreal caribou conservation documentation was available, and published more recently, than wolverine documentation.

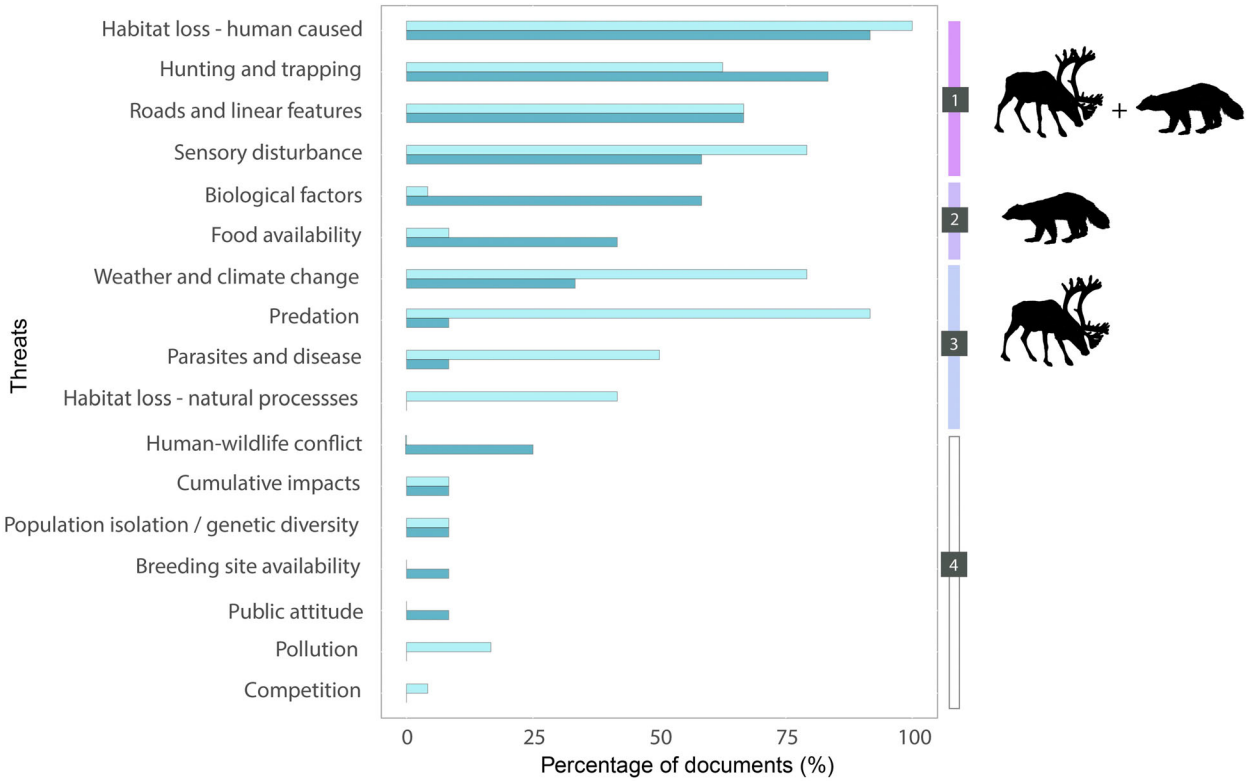

FIGURE 3 Percentage of conservation documents that list threats to wolverine (dark blue) and woodland caribou (light blue). Category 1 indicates threats listed in greater than 40% of both wolverine and caribou documents, Category 2 threats listed in >40% of wolverine documents but <40% of caribou documents, Category 3 threats listed in >40% of caribou documents but <40% of wolverine documents, and Category 4 threats listed in <40% of wolverine and woodland caribou documents. Human caused habitat loss was the most frequently listed threat for both species.

Department of Natural Resources and Energy Development, 2022). Ontario and New Brunswick were the only provinces that have published provincial/territorial recovery documents for wolverine (COSSARO, 2015), and no provinces had published action documents. In contrast, national documentation for boreal caribou was first published in 2012 (Environment Canada, 2012; Environment Canada, 2014) and was updated more recently in 2020 (Environment and Climate Change Canada, 2020). In 2014, a national status assessment was published for all three mountain caribou populations, and a recovery plan was published for southern mountain caribou (COSEWIC, 2014a; Environment Canada, 2014). Caribou recovery documents were available for all provinces/territories except for Yukon, and action documents published in the last five years were available for all provinces/territories.

Twelve conservation documents (4 national and 8 provincial/territorial) listed threats for wolverine and 24 (10 national and 14 provincial/territorial) for woodland caribou. There was overlap in frequently listed threats to wolverine and caribou found in available national, provincial, and territorial conservation documentation. For example, the top four most frequently listed threats for wolverine were within the top six most frequently listed for caribou (Figure 3). These included habitat loss (human-caused landcover change and fragmentation; $N = 12$ wolverine documents), hunting and trapping (11), sensory disturbance (human activity, recreation, noise, and light; 8), and roads and linear features (8). These threats are interrelated and are associated with industrial and recreational disturbance. For wolverine, biological factors (7) (such as reproductive rate) and food availability (5) were the only threats frequently listed for wolverine that were not listed for caribou. For caribou, weather and climate change (20), and predation (20) were more frequently listed than for wolverine (Figure 3).

Only four documents listed recovery actions for wolverine (two national and two provincial/territorial) compared to 32 for caribou (three national and 28 provincial/territorial), resulting in fewer recovery actions listed for wolverine. Management of habitat was mentioned as a recovery action for both species, as were increased awareness, partnerships, and data sharing, but actions such as scientific research were a higher priority for wolverine than for caribou (Figure 4). Threats—such as roads, linear features, and hunting and trapping—were infrequently mentioned as management actions in both wolverine and woodland caribou conservation

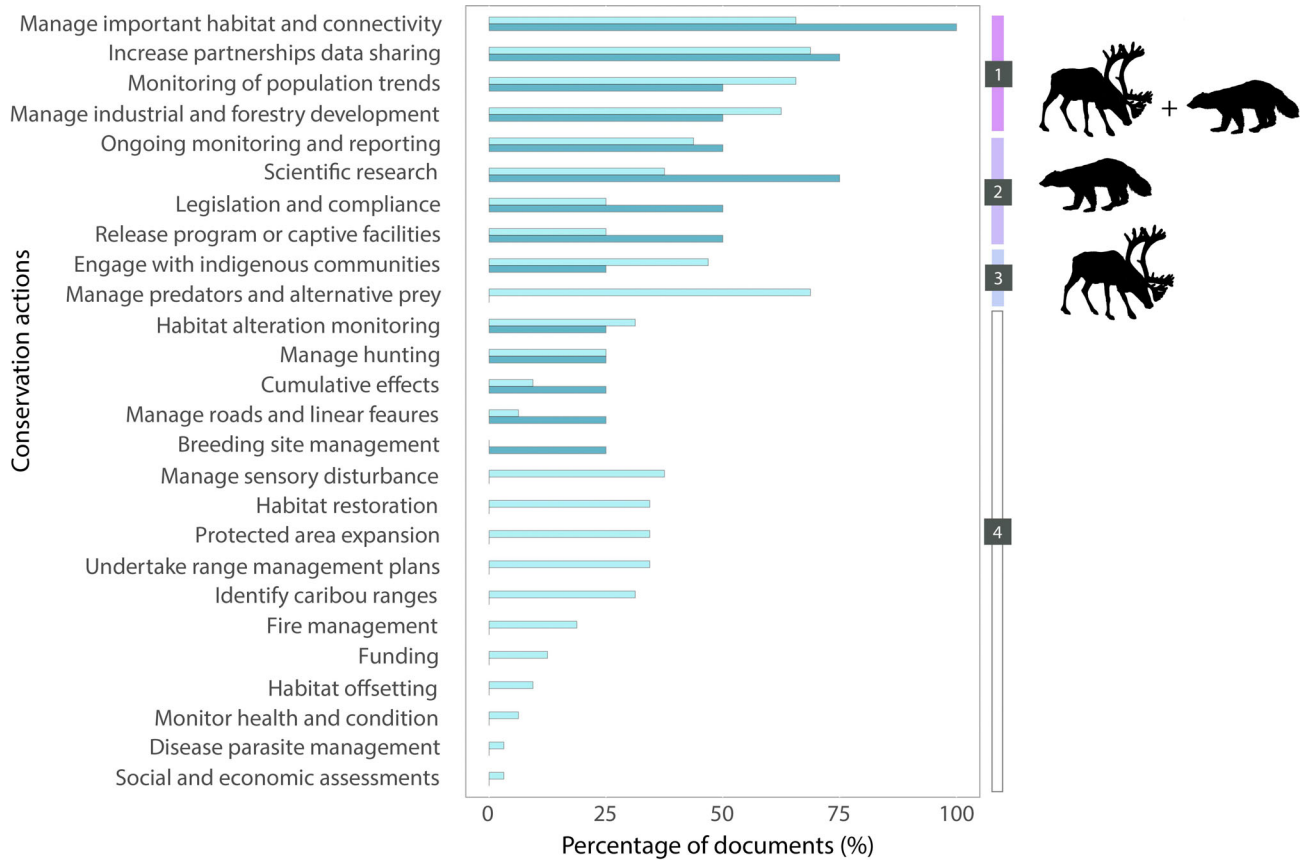

FIGURE 4 Percentage of conservation documents that list conservation actions for wolverine (dark blue) and woodland caribou (light blue). Category 1 indicates conservation actions listed in greater than 40% of both wolverine and caribou documents, Category 2 conservation actions listed in >40% of wolverine documents but <40% of caribou documents, Category 3 conservation actions listed in >40% of caribou documents but <40% of wolverine documents, and Category 4 conservation actions listed in <40% of wolverine and woodland caribou documents. Management of habitat and connectivity was the most frequently listed action for both species.

documentation, leaving a potential gap between identified threats and management practices for both species. Some threats frequently listed for caribou that were not frequently addressed by recovery actions in caribou documentation, including management of sensory disturbance (human activity, recreation, noise, and light) and the management of roads and linear features, may be captured by habitat management statements (Figure 4).

3.2 | Scientific literature

A total of 165 and 550 peer-reviewed wolverine and caribou research papers have been published in North America since 2000, respectively. Our initial search resulted in 270 papers for wolverine and 630 papers for caribou, but 105 wolverine papers were excluded due to either being published prior to 1990 or published on populations outside of North America. Wolverine papers focused both on populations in Canada and the USA (100 papers include populations in Canada and 80 USA; note that some papers included populations from both), whereas caribou papers were more focused on Canadian populations (542 papers include populations in Canada and 27 in the United States, again note that some papers included populations from both). Within Canada, boreal caribou were studied in 335 papers, followed by central mountain, northern mountain, and southern mountain (84, 78, and 56, respectively). Woodland caribou appear to be better studied across Canada, whereas wolverine have been primarily studied in the west (the spatial distribution of papers in Canada is outlined in Figure S2).

There were 80% fewer papers that investigated threats relevant to wolverine compared to caribou (84 and 430 papers, respectively). The impact of habitat loss was the most frequently researched threat for both wolverine and caribou (25 and 177 papers, respectively). The impact of roads and linear features was also relatively well studied for both species (22 and 59 papers, respectively), as was the impact of weather and climate (18 and 27 papers, respectively). The impact of sensory disturbance was not

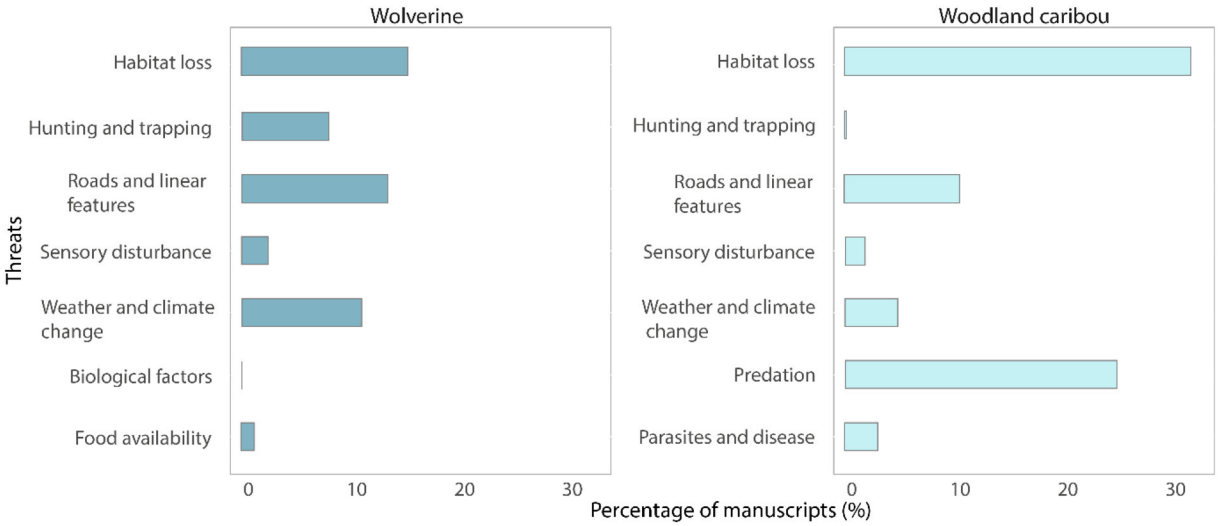

FIGURE 5 Percentage of wolverine and woodland caribou papers that investigate threats relevant to those species (identified by our review of conservation documentation). Caribou peer-reviewed literature outnumbered wolverine by more than fourfold. For both species' habitat loss, along with roads and linear feature impacts, were more frequently studied than hunting, trapping, and sensory disturbance.

well studied for either species (4 and 10 papers, respectively; Figure 5). Other frequently listed threats that were not well studied included food availability for wolverine (2 papers) and hunting of woodland caribou (1 paper), potentially representing research gaps for both species. There were almost 15 times more studies that examined the impacts of conservation management actions on caribou (104 papers) compared to wolverine (7 papers). All seven wolverine studies investigated hunting and trapping regulation impacts, whereas investigations into caribou conservation management actions were more varied.

4 | DISCUSSION

4.1 | Overview

Our review found strong commonalities in wolverine and caribou ecology, threats, and conservation actions, suggesting there is some scope for effective caribou-focused conservation to benefit wolverine, where the distributions of these species overlap. We found key threats, including human-caused habitat loss, hunting and trapping, sensory disturbance, and linear features, were listed in >50% of conservation documentation for both species. We also found overlap in recovery actions, with management of important habitat and connectivity, partnerships and data sharing, population monitoring, and management of industrial impacts also listed in >50% of conservation documentation for both species. However, additional threat management is required to support wolverine, particularly undertaking population monitoring, targeted research, and the regulation of hunting and trapping. There are also uncertainties regarding the impact of some caribou-focused conservation actions on wolverine populations, such as the impact of wolf control. More generally, the federal listing of caribou as threatened means conservation action documents exist that result from collaborations between federal and provincial/territorial teams. This contrasts with wolverine, where its lower national listing means wolverine management is largely under provincial jurisdiction, where it often does not have protected status, resulting in more variable management approaches. These results demonstrate the value of examining threat and conservation management overlap between species when assessing the potential efficacy of coordinated management approaches. We discuss threats and conservation actions shared by caribou and wolverine, informed by the terminology used in the conservation documentation, and highlight aspects of these species' ecology relevant to those threats, noting that full ecological reviews have been published elsewhere (Fisher et al., 2022; Scrafford et al., 2025; Stevenson et al., 2024; Webber et al., 2022). We use this information to determine the extent caribou-focused management of these threats would benefit wolverine and where management gaps remain.

4.2 | Threat overlap: Shared threats between caribou and wolverine

4.2.1 | Habitat loss–forest harvest

Our review found habitat loss—in this case, forest harvest without the effects of roads (i.e., polygonal habitat

loss)—was a frequently listed threat for both wolverine and caribou (91% and 100% of documents respectively). Over 61% of Canada's boreal forests suitable for forestry have been logged at least once (Venier et al., 2014). Forest harvest practices can change stand structure and age distributions at large scales (Shorohova et al., 2011), altering composition and abundance of wildlife assemblages, which in turn impacts food availability and predation risk (Venier et al., 2014). For example, in eastern Canada's boreal forests, large-scale forestry activities between 1930 and 2000 have inverted the stand age distribution, with availability of old forests (>100 years) decreasing from 75% to 15%, causing forests to be dominated by young and regenerating stands (Bouchard & Pothier, 2011; Boucher et al., 2009). Early seral stage deciduous forests support higher densities of moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), snowshoe hare (*Lepus americanus*), and grouse (*Tetraonini* spp.), which can also sustain larger populations of wolves (*Canis lupus*; Hebblewhite & Merrill, 2009; Venier et al., 2014). This has negative impacts on caribou that use habitats such as large continuous patches of late successional coniferous forests (Apps et al., 2001; Berglund et al., 2014; Brown et al., 2007; Ferguson & Elkie, 2004) or peatlands (Latham et al., 2011; Rettie & Messier, 2000) to avoid wolves (Gagné et al., 2016; James et al., 2004; Serrouya et al., 2017) and access food resources (Cichowski et al., 2022; Nobert et al., 2020). Caribou have been found to change their movement patterns in response to forest harvest, resulting in range shifts, contractions, or abandonment (Courtois et al., 2008; Smith et al., 2000; Stevenson et al., 2024), and display decreased survival linked to predation (Courtois et al., 2007; Stevenson et al., 2024). The influence of forest attributes such as stand type and age on wolverine habitat use and survival is less studied. In boreal and mountainous habitats, some studies suggest preferences for caribou-favored habitats including late successional stands (Hornocker & Hash, 1981; Wright & Ernst, 2004), conifer forests, bogs, and fens (Scrafford et al., 2017), and avoidance of deciduous forests (Bowman et al., 2010), with patterns of use sometimes varying between sexes (Krebs et al., 2007). Other studies show general preferences for forest cover but do not consider the influence of stand type (Krebs et al., 2007) or age (Copeland et al., 2007). The mechanisms that may drive habitat preferences are unclear, but proposed reasons include avoidance of wolves and ease of movement in stands with more overstory, which prevents snow accumulation (Bowman et al., 2010; Wright & Ernst, 2004). Wolverines have been found to avoid forest harvest features such as cut block interiors (Hornocker & Hash, 1981; Scrafford et al., 2017), but are also attracted to some features such as cut block edges (Scrafford et al., 2017). Managing forest harvest to increase the availability of undisturbed caribou habitat, at scales relevant to wolverine's large home ranges, may have positive impacts for the species, but further research into wolverine habitat preferences of different forest ages would help clarify these relationships.

4.2.2 | Roads and linear features

Our review found that linear features are a significant issue for wolverine and caribou, listed in 58% and 79% of conservation documents, respectively. These features increase rates of wildlife and vehicle collisions, access by trappers and hunters (Krebs et al., 2004; Plante et al., 2017; Vors et al., 2007), and stimulate new development that might not have otherwise occurred (Johnson et al., 2020). Wolves also use seismic lines and roads with low traffic volumes to move through the landscape (Dickie et al., 2017; Lesmerises et al., 2012; McKenzie et al., 2012); therefore, a higher density of these features increases encounter rates (Whittington et al., 2011) and landscape-scale predation risk for both species (Barrueto et al., 2022; McKay et al., 2021; Scrafford et al., 2024). Caribou have been found to avoid roads (Leblond et al., 2013) and have lower survival in areas with high road and linear feature density due to predation (Dussault et al., 2012; McKay et al., 2021). Wolverine occur less in areas where there are more roads (Barrueto et al., 2022; Copeland et al., 2007; Lofroth & Krebs, 2007; Rowland et al., 2003) and move quicker when they are closer to them, potentially to manage risk (Scrafford et al., 2018). At a landscape scale, higher road and linear feature densities are associated with lower occurrence of both caribou (Beguin et al., 2013; Fortin et al., 2008) and wolverine (Bowman et al., 2010; Ray et al., 2018). Notably, the management of roads (including restoration) was not often specifically stated as a caribou recovery action (6% of documents), though it may be captured by some habitat management statements, and particularly through the management of critical habitat.

4.2.3 | Sensory disturbance (human activity, recreation, noise, and light)

Sensory disturbance impacts are not lethal; however, they can indirectly influence survival through changes in habitat use and physiology (Dertien et al., 2021; Gill et al., 2024). This threat was listed in over 40% of conservation documents for both wolverine and caribou. Sensory disturbance impacts on wolverine and caribou have been most studied in the mountains of western Canada

(Barrueto et al., 2022; Gill et al., 2024; Heinemeyer et al., 2019), where the cessation of heliskiing operations for one winter season during COVID-19 lockdowns resulted in an 80%–120% increase in mountain caribou home range size (Gill et al., 2024). Wolverines have also been found to avoid human activity, with detection probability decreasing in areas with more human recreational activity, including backcountry skiing/helicopter use (Barrueto et al., 2022; Krebs et al., 2007) with a stronger avoidance by females than males (Heinemeyer et al., 2019). Government guidelines for recreation in British Columbia include recommendations regarding activities around wolverine den sites but do not consider habitat use more generally (British Columbia Ministry of Environment, 1996). Generally, management of sensory disturbance for caribou was not a commonly listed recovery action in Canada's national and provincial/territorial conservation documentation and was relatively infrequently studied for both caribou and wolverine relative to other threats. Potentially, this may reflect the varying importance of this threat across Canada. Alternatively, it may be because the impacts are difficult to manage, as they include use of public lands and may be unpopular.

4.2.4 | Hunting and trapping

Harvest of caribou and wolverine by hunting and trapping was identified in this review as a key threat. These are practices culturally important to communities across Canada, particularly Indigenous Peoples. Both species have been referred to as cultural keystone species (Garibaldi & Turner, 2004; Kanigan, 2018), important to the emotional wellness, identity, food security, financial security, and cultural continuity of Indigenous Peoples (Borish et al., 2021; Cunsolo et al., 2020). For First Nations, Inuit, and Métis peoples in Canada, harvesting rights fall under both Aboriginal and Treaty Rights (Sanders, 1990). For non-Indigenous people, wolverine trapping is permitted across a significant proportion of the western wolverine range including the Yukon, Northwest Territories, Nunavut, Alberta, Saskatchewan, and Manitoba, and hunting of woodland caribou is permitted in Newfoundland and Labrador. These practices are also a localized conservation issue for both species, with trapping of wolverines being the leading cause of mortality, both in areas where it is permitted and sometimes in areas where it is not, due to incidental trapping impacts (Bischof et al., 2020; Krebs et al., 2004; Scrafford et al., 2024). Available caribou mortality data also suggests hunting may be a localized issue in some ranges (Courtois et al., 2007; Nuna et al., 2004). Wolverine, like caribou, display a high demographic sensitivity to adult survival (Dalerum et al., 2008); therefore, decisions about wolverine trapping are critical regulators of extant populations (Barrueto et al., 2022; Dalerum et al., 2008). Wolverine trapping has been studied more than most other wolverine threats (Kukka et al., 2017; Kukka et al., 2022), with some indicating trapping rates may be unsustainable in some ecoregions with high human population density (Kukka et al., 2022; Mowat et al., 2020).

4.3 | Management overlap: Caribou-focused conservation actions that could benefit wolverine

4.3.1 | Management of habitat loss–forest harvest impacts

Commonalities in some habitat preferences between caribou and wolverine increase the likelihood that forest management focused on caribou may have co-benefits for wolverine. However, provincial/territorial forestry practices are complex and while there is often a focus on caribou habitat conservation, their efficacy can be unclear. We explore this idea using Ontario and British Columbia's complex forest management practices as case studies.

Forestry activities in Ontario are exempt from portions of the Endangered Species Act (2007), and wildlife habitat within Ontario's forestry areas is primarily managed under the Crown Forest Sustainability Act (CFSA) and the Forest Management Guide for Boreal Landscapes (the "Landscape Guide," Ontario Ministry of Natural Resources, 2014a). The area designated for forestry is split into 20 Forest Management Units (FMUs), and all but one of Ontario's boreal caribou ranges overlap with an FMU. The CFSA requires a Forest Management Plan (FMP) to be prepared for each of the FMUs using standards outlined in the Landscape Guide that aim to maintain or enhance habitat for caribou. To achieve this, Simulated Ranges of Natural Variation of disturbance are modeled, with the goal of ensuring harvested forest composition remains at historical levels (OMNRF, 2014b). The Caribou Conservation Plan (CCP) then includes requirements for harvest deferrals, road decommissioning strategies, and the Dynamic Caribou Habitat Schedule (DCHS). The DCHS is a tool that aggregates harvest blocks over 20-year time periods to encourage spatial separation of caribou from populations of deer and moose, and therefore their associated predators, wolves. Wolverine habitat is considered captured by boreal caribou habitat management approaches, with the exception of protections for known active den sites, which are very difficult to identify (OMNRF 2010). Neither the CFSA,

the Landscape Guide, nor the CCP consider cumulative disturbance effects within caribou ranges outlined in the Federal Recovery Plan for Boreal Caribou (Environment and Climate Change Canada 2020; Scrafford & Ray, 2020). The frequency and efficacy of forestry road decommissioning strategies remain unquantified, and the extent that harvest targets truly reflect historical disturbance patterns remains unclear (Environment and Climate Change Canada, 2024). This example illustrates the complexity of forest management for caribou in one province, with approaches varying across Canada. It also illustrates that caribou-centric management approaches may have unclear efficacy or fail to consider disturbance holistically, with uncertain benefits for both caribou and other co-occurring species.

In British Columbia's forestry practices, there is also a strong focus on caribou relative to other species like wolverine, but again the efficacy of these practices is unclear. Of the province's 54 herds, 7 (12%) are extirpated, 19 (35%) are declining, and 13 (24%) have an unknown trend (British Columbia Ministry of Environment, 2021). In British Columbia, Species at Risk are not managed under a standalone legislation, but instead are managed under multiple pieces of legislation including the Wildlife Act (1996), the Forest and Range Practices Act (1995, FRPA) (which also governs logging, related road building, reforestation, and grazing) and the Energy and Resource Activities Act (which also manages oil and gas exploration). The province is split into 38 timber supply areas, but unlike Ontario where typically the licence for a FMU is held by a single company, multiple licensees work in a given area. The FRPA provides statutory authority to the province's Identified Wildlife Management Strategy, which through the Government Action Regulation and the Environmental Protection and Management Regulation, allows the designation of Wildlife Habitat Areas (WHAs) and Ungulate Winter Range where forest practices are regulated to manage forest attributes used by an identified wildlife element. The strategy also enables the establishment of General Wildlife Measures, guidelines that can be put in place in certain areas to support Species at Risk that must be considered in stewardship and operational plans created by forest licensees. In 2024, the first WHAs were approved for wolverine, three areas in the Selkirk Range of the Rocky Mountains. The combined area of these WHAs is 12,837 ha (128.3 km^2), smaller than the home range of most wolverine (Government of British Columbia, 2025). In contrast, there are 224 WHAs designated for caribou, totaling 17,570 km^2, illustrating the strong focus on caribou (Government of British Columbia, 2025). Forestry activities in caribou ranges are also managed by Land Use Plans that aim to balance resource use with environmental protection. These can include the application of polygon-specific resource targets and connectivity objectives that must be incorporated into operational plans (termed Forest Stewardship Plans). Operational plans must adequately address the objectives outlined in the Land Use Plan, including caribou habitat provisions; however, a government review of provincial caribou habitat management indicates there is limited guidance regarding how much timber can be harvested and still reach caribou recovery targets (British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018). Caribou habitat targets can be aspatial, which means fragmented caribou habitat that is potentially unsuitable due to lack of continuity can count toward targets. There is no defined management of cumulative effects such as road building and mining, and no legislated requirements for the protection of federal critical caribou habitat or provincially defined caribou core and matrix habitat. On non-federal lands, 909 km^2 of critical caribou habitat was logged within five years of its legal identification under SARA (Palm et al., 2020). Therefore, like Ontario, the focus on caribou within the province's forest management system is evident, but efficacy is uncertain.

4.3.2 | Management of habitat loss-roads and linear features, and sensory disturbance

Habitat loss (human-caused), roads and linear feature impacts, and sensory disturbance impacts are threats relevant to both wolverine and caribou. We found that the management of habitat loss through conservation of important habitat was a common conservation action in the caribou conservation documentation; however, the management of roads, linear features, and sensory disturbance were infrequently listed actions. While this review considers these threats separately, they may be addressed concurrently through the management of caribou critical habitat. Critical habitat under SARA is defined as:

> "*the habitat that is necessary for the survival or recovery of a listed wildlife species*" (SARA, 2002), but specifically, boreal caribou critical habitat is identified as:
> *(i) the area within the boundary of each boreal caribou range that provides an overall ecological condition that will allow for an ongoing recruitment and retirement cycle of habitat, which maintains a perpetual state of a minimum of 65% of the area as undisturbed habitat in all ranges (other than one range in Saskatchewan); and (ii) biophysical attributes*

required by boreal caribou to carry out life processes (Environment and Climate Change Canada, 2020).

This definition is based on the quantified relationship between anthropogenic disturbance and both adult female survival and calf recruitment (Johnson et al., 2020). Once critical habitat is identified, SARA requires that it then be protected, although the majority of the responsibility for this lies on the provinces (Hebblewhite & Fortin, 2017). Caribou critical habitat protections require disturbance to be managed in adjoining caribou ranges resulting in conservation of habitat at landscape scales across the boreal forest, a scale relevant to the large distribution and home range size of wolverine. Disturbance causing the destruction of critical habitat includes forestry activities, mining, industrial, and infrastructure development, conversion of native forest to agriculture, as well as the development of roads, seismic lines, pipelines, and hydroelectric corridors (Environment and Climate Change Canada, 2021). Therefore, many threats relevant to caribou and wolverine (i.e., restoration of roads and linear features controlling trapping access and some sensory disturbances) could be directly addressed through the effective management of caribou critical habitat under the responsibility of provinces and territories. While federal and provincial/territorial governments have made investments and agreements regarding caribou conservation (Environment and Climate Change Canada, 2019), habitat loss and cumulative impacts of disturbance in woodland caribou ranges across Canada continues to increase (Environment and Climate Change Canada, 2020). Habitat loss in Alberta and British Columbia caribou ranges increased up to 262% between 2012 and 2018 (Nagy-Reis et al., 2021), shedding considerable doubt on the efficacy of current conservation measures.

4.4 | Gaps: Management of additional threats required for wolverine

4.4.1 | Hunting and trapping impacts

Trapping is a threat to wolverine that does not align well with caribou-focused conservation measures, requiring dedicated management of quotas and methods. Examples of wolverine-specific management include assessment of trapping sustainability at different scales, adjusting harvest regulations to ensure population sustainability, and managing trapping techniques to reduce incidental trapping (Kukka et al., 2022; Scrafford et al., 2024). The exception to this is the indirect management of trapping impacts through management of critical caribou habitat. The protection of such habitat requires management of cumulative disturbance, including the regulation of road building and intensification of road decommissioning, which, if prioritized, may limit trapper and hunter access and therefore impacts.

4.4.2 | Population monitoring

Monitoring of populations was a conservation action listed frequently for both wolverine and caribou (50% and 65% of conservation documents). Wolverines can persist at low densities, move over large areas, and are resource-intensive to trap and collar, making monitoring, particularly of reproductive success, difficult (COSEWIC, 2014b). Targeted wolverine monitoring efforts may require concerted resources, but there may be opportunities to include wolverine monitoring in multi-species aerial or camera-based surveys (Bowman et al., 2010; Chow-Fraser et al., 2022; Ray et al., 2018). Wolverines have often been monitored using trapping data (including mandatory pelt sealing, harvest reporting, and fur exports), but these data sources can be strongly impacted by factors such as trap effort and trapping methods (Imperio et al., 2010), leading to inaccurately derived population trends (DeVink et al., 2011). Attaining trap effort data from trappers, though potentially including other inherent biases, may facilitate better use of this data source. Modern population metrics such as occupancy or density estimation may provide more accurate insight into population trends, accounting for factors such as detectability and providing estimates of uncertainty (Fukasawa et al., 2020; Ranta et al., 2008) to inform provincial/territorial and national status listings. Woodland caribou are monitored across Canada at the scale of ranges (i.e., local population units; Environment Canada (2012)), and range plans for caribou assess and recommend conservation recovery actions that are locally important. In areas where there are conservation concerns for wolverine, a similar approach involving monitoring and management may be beneficial.

4.4.3 | Research, partnerships, and data sharing

As expected, the results of this study indicate wolverine are relatively less studied compared to caribou. Most wolverine research has occurred in western Canada, with less focus on wolverine in eastern and northern parts of Canada. More information on the similarities and differences in wolverine and woodland caribou habitat selection at different scales would be of benefit, particularly considering differences in the use of breeding and overwintering areas. More generally, reliable information on wolverine population trends is almost completely absent

(except Barrueto et al., 2022), and studies that monitor populations at large scales through time would be valuable. Our results indicate that trapping is one of the best-studied wolverine threats; however, few studies consider regional scales that include multiple provinces (excluding Mowat et al., 2020 and Scrafford et al., 2024) or track population changes through time using methods such as density or occupancy that include estimates of uncertainty. The impact of sensory disturbance (human activity, recreation, noise, and light) and impacts of wolf control on wolverine are also not well represented in the literature. Increasing partnerships and data sharing were also high priorities for both wolverine and caribou, emphasizing the importance of organizational relationships in managing species at large scales. This includes the engagement of Indigenous Peoples in both research, monitoring, and management of wildlife, which has been shown to have profound outcomes for biodiversity conservation, cultural continuity (Ens et al., 2016), and reconciliation (Wong et al., 2020).

4.4.4 | Identification of consensus wolverine conservation actions

Generally, the results of this study suggest current conservation objectives for wolverine are not well defined. There are only four national or provincial/territorial conservation documents that list recovery actions for wolverine, and the most recent national document (2014) does not list any. Some frequently listed threats are addressed with recovery actions either infrequently (e.g., hunting and trapping) or not at all (e.g., sensory disturbance), leading to a disconnect between identified problems and proposed solutions. Scientific literature does investigate and discuss wolverine threats, but research that assesses wolverine conservation action efficacy focuses on trapping. Production of a national management strategy is underway, which may address some of these issues (M. Scrafford pers. comm.). Overall, any future conservation approach for wolverine, coordinated or otherwise, would benefit from defined national objectives that address commonly listed threats.

4.5 | Uncertainties: Caribou-focused management actions with unknown impacts on wolverine

4.5.1 | Control predators and alternative prey

The impact of predator and alternative prey control (targeted at caribou conservation) on wolverine populations remains unknown. This was a frequently listed caribou recovery action, listed in over 68% of relevant conservation documentation (Hervieux et al., 2014; Proulx, 2017), but was not listed in wolverine documentation. Wolf kills, particularly of large ungulates, are a food source for wolverine (Rausch & Pearson, 1972; Van Dijk et al., 2008; Wallace et al., 2021); therefore, wolf control could negatively impact wolverine populations by decreasing food availability. Alternatively, as wolves kill wolverines (Krebs et al., 2004; White et al., 2002; Young et al., 2023), wolf control could result in less predation pressure on wolverines, positively impacting populations and resulting in a "mesopredator release" (Brashares et al., 2010; Ritchie & Johnson, 2009). Uncertainties related to wolf control impacts on wolverine are also compounded by possible effects on other competing mesopredators such as coyotes (Chow-Fraser et al., 2022). As the use of predator control as a caribou conservation measure is on the rise (Johnson, Ray, & St-Laurent, 2022), the need to address this conservation management knowledge gap is increasingly pressing.

4.5.2 | Impacts of wolverine on caribou populations

Wolverine have been found to prey on caribou adults (Magoun et al., 2018) and calves (Gustine et al., 2006), but wolverine predation is not considered a key threat to caribou in any national provincial/territorial conservation documentation (Environment and Climate Change Canada, 2020). The primary cause of caribou declines is the cumulative impacts of landscape disturbance resulting in reductions in available critical caribou habitat and higher rates of caribou predation by wolves (Environment and Climate Change Canada, 2020; Johnson et al., 2015; Maltman et al., 2024; Nagy-Reis et al., 2021). The efficacy of wolf control conservation measures in stabilizing small and declining caribou herds (Johnson, Ray, & St-Laurent, 2022) also demonstrates the relative importance of wolf predation. Wolverine is also negatively impacted by similar landscape disturbances, such as linear features, mining, and forestry (Bowman et al., 2010; Fisher et al., 2013; Heim et al., 2017; Scrafford et al., 2017; Barrueto et al., 2022, Sections 4.3.1 and 4.3.2). Wolverine predation, while not considered a cause of caribou population declines, may be an issue for small vulnerable caribou herds.

4.5.3 | Variation in caribou and wolverine distribution and scale of landscape use

Wolverine and caribou vary in both their distribution and population scale, which may limit the broadscale

efficacy of a coordinated management. There are parts of the wolverine distribution where caribou never occurred or are now extirpated (Figure 1), and therefore, caribou conservation actions may be less prevalent, with fewer benefits for wolverine (British Columbia Ministry of Environment, 2021). In these areas, wolverine would benefit from focused management on key wolverine threats. In areas where wolverine and caribou do overlap, we argue that variation in the geographic population scale between these species is not a significant barrier to coordinated management if caribou conservation management occurred at large regional scales. For example, caribou densities are on average 20–30 animals per 1000 km^2 (Environment Canada, 2011), but wolverine, in contrast, persist at lower densities, between 2 and 9.7 individuals/1000 km^2 (Awan & Boulanger, 2016; Barrueto et al., 2020; Lofroth & Krebs, 2007; Royle et al., 2011; Scrafford et al., 2024), and therefore require areas larger than single caribou ranges to support self-sustaining populations. This difference in population scale would not be an issue in areas where there are multiple abutting caribou ranges, as is the case across the boreal forest and large parts of the Rocky Mountains (Figure 1). Wolverine would benefit from caribou-focused conservation at a population level if caribou recovery actions were effective and shared across multiple caribou ranges.

4.6 | Conclusions and recommendations

Coordinated management approaches that include caribou and other Species at Risk such as wolverine may be attractive to governments, as they offer a way to increase the efficacy and impact of conservation programs through multi-species management. Wolverine and caribou overlap across a large part of their range (Figure 1) and respond to some threats in analogous ways due to similarities in their ecology. We conclude that wolverine would benefit from effective caribou-focused conservation, and a coordinated management approach has merit if gaps can be managed. We recommend:

- *Effectively manage critical caribou habitat for caribou to benefit wolverine*—Key wolverine threats including sensory disturbance, industrial disturbance including forestry, mining, roads, and linear features, and to some extent hunting and trapping, could be managed through conservation of critical boreal caribou habitat. This includes large-scale management of cumulative anthropogenic impacts associated with future industrial development, and remediation of past impacts including linear feature restoration to reduce access and impacts of predators and trappers. Conservation of caribou critical habitat must be effective with meaningful on-ground outcomes to be able to confer protection to co-occurring species.
- *Address management and knowledge gaps through wolverine-specific management actions*—Wolverine population monitoring, research, and management of wolverine trapping sit adjacent to a coordinated management framework with caribou. Continuing research relevant to wolverine conservation and wolverine-caribou coordinated management will elucidate regional trapping impacts and the response of wolverine populations to predator control. Monitoring populations using robust data sources is required to better inform status assessments and listings.
- *Prioritize partnerships and data sharing*—Encouragement of meaningful multi-organizational relationships, including engagement with Indigenous Peoples, will help to support ongoing species management and knowledge sharing (Wong et al., 2020).

Our study demonstrates the value of literature review approaches in identifying conservation management overlap between species, highlighting strengths and weaknesses that might be missed using standard habitat or range overlap approaches. Management of caribou may benefit wolverine, but relies on the efficacy of existing caribou conservation actions and the management of additional wolverine-specific threats.

AUTHOR CONTRIBUTIONS

RH led data collation, analysis, writing, and communication of concepts; FS funded the work and contributed to the analysis, writing, and communication of concepts; MS provided the manuscript concept and contributed to analysis and writing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

Data and code are available in a GitHub repository https://github.com/rhohnen/Wolverine_caribou_review and the Open Science Framework repository https://osf.io/m538k/.

ORCID

Rosemary Hohnen https://orcid.org/0000-0002-3638-6676
Frances E. C. Stewart https://orcid.org/0000-0001-9344-8346
Matthew A. Scrafford https://orcid.org/0000-0001-9971-6495

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SUPPORTING INFORMATION

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

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